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PERFORMANCE OF A TWO-STAGE CONSTRUCTED WETLAND IN THE ALPINE REGION OF AUSTRIA UNDER PEAK LOADS

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by

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Abstract

Constructed Wetlands (CWs) are a well-established means of wastewater treatment around the world. The engineered systems are low cost, easy in operation and maintenance and offer the possibility to use local materials and manpower. This master thesis investigated the performance of a two-stage vertical flow (VF) CW with intermittent loading. The examined CW of the inn *Bärenkogelhaus* is the first non-experimental full-scale system with such a two-stage design. The inn is situated on top of the Bärenkogel at an altitude of 1168 m in an alpine cold climate. The system was dimensioned for 40 person equivalent (PE) with an organic load of 32.4 g COD m^{-2} d^{-1} (corresponding to 2.47 m^2 of CW per PE). This study focused on the period of July 2011 until September 2012. During this period the inn was only opened on demand for events. Therefore the CW received fluctuating and peak loads. Out of the seventeen events that took place, five were sampled, in order to examine the system's performance under these peak loads. Additionally, two tracer tests with potassium chloride were conducted, with the aim to measure the residence time of wastewater and pollutants in the system. The average hydraulic load was 13% of the design load. The average organic load was 2.2 g COD m^{-2} d^{-1} (i.e. only 7% of the design load). Also during periods with high hydraulic loads of around 100% of the design load, the organic load was only about 14 g COD m^{-2} d^{-1} (i.e. only around 50% of the design load). The CW was therefore over-dimensioned for the current operation. The treatment performance was high and stable, with removal rates of 98, 96 and 99.9% for BOD_5, COD and NH_4-N, respectively. Furthermore, the CW had a TN removal of around 70%. Effluent concentrations were constantly below legally required thresholds, also during very cold periods and hydraulically fluctuating or peak loads due to events. The tracer tests showed how the two-stage design enabled the CW to receive higher hydraulic loads, due to the coarser grain size in the first filter bed, as well as the effect of the impoundment of the first filter bed's drainage layer on ensuring a minimal mean residence time.

Kurzfassung

Bepflanzte Bodenfilter sind weltweit eine etablierte Methode zur Abwasserreinigung. Die Anlagen sind kostengünstig, einfach in Bedienung und Wartung, und bieten die Möglichkeit lokale Materialien und A rbeitskräfte zu nützen. Diese Masterarbeit untersucht die Leistungsfähigkeit einer 2-stufig aufgebauten, intermittierend beschickten, vertikal durchströmten Bodenfilteranlage. Der bepflanzte Bodenfilter des Bärenkogelhauses ist die Erste, nicht experimentelle Anlage mit diesem 2-stufigen Aufbau. Das Gasthaus befindet sich am Bärenkogel auf einer Seehöhe von 1168 m, in einem alpinen, kalten Klima. Die Anlage war für 40 Einwohnerwerte (EW) und einer organischen Belastung von 32.4 g CSB m^{-2} d^{-1} (i.e. 2.47 m²/EW_{CSB}) dimensioniert worden. Diese Masterarbeit konzentriert sich auf den Zeitraum von Juli 2011 bi s September 2012. Während dieser Periode war das Bärenkogelhaus nur auf Vorbestellung für Veranstaltungen geöffnet. Daher traten beim Abwasseranfall und folglich der Belastung der Anlage Fluktuationen und Spitzen auf. Von den 17 Veranstaltungen in diesem Zeitraum wurden fünf beprobt, um die Leistung des Systems unter diesen Spitzenbelastungen zu untersuchen. Zusätzlich wurden zwei Tracerversuche mit Kaliumchlorid durchgeführt, mit dem Ziel die Aufenthaltszeit von Abwasser und Schadstoffen im Bodenfilter zu messen. Die durchschnittliche hydraulische Belastung in der untersuchten Periode entsprach 13% des Dimensionierungswertes. Die durchschnittliche organische Belastung betrug 2.2 g CSB m^{-2} d^{-1}, was nur 7% des Dimensionierungswertes entsprach. Auch während Perioden mit einer hohen hydraulischen Belastung um 100% des Dimensionierungswertes, erreichte die organische Belastung lediglich ungefähr 14 g CSB m^{-2} d^{-1}, was nur ca. 50% des Dimensionierungswertes entspricht. Der Bodenfilter war demzufolge für den de rzeitigen Betrieb des Bärenkogelhauses überdimensioniert. Die Reinigungsleistungen für BSB_5, CSB und NH_4-N waren mit 98%, 96% und 99.9% sehr hoch und s tabil. Des Weiteren wurde eine Reinigungsleistung für N_{ges} von ungefähr 70% erreicht. Die Ablaufkonzentrationen haben konstant die geforderten Ablaufgrenzwerte auch während sehr kalten Perioden sowie eventbedingten hydraulischen Belastungsschwankungen und -spitzen deutlich unterschritten. Die Tracerversuche haben gezeigt, wie der 2-stufige Aufbau es ermöglicht, dass die erste Stufe, aufgrund ihrer größeren Körnung, hydraulisch höher belastet werden kann und wie der Einstau der Drainageschicht der ersten Stufe eine minimale Verweilzeit gewährleistet.

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Abbreviations

BOD_5	Biochemical Oxygen Demand in 5 days
BOD_7	Biochemical Oxygen Demand in 7 days
BOKU	University of Natural Resources and Applied Life Sciences Vienna, Austria
COD	Chemical Oxygen Demand
CW	Constructed Wetland
DIN	Deutsches Institut für Normung (German Institute for Standardization)
EC	Electrical Conductivity
EIB	Effluent Infiltration Bed
EN	Europäische Norm (European standard)
FB	Filter Bed
FWS	Free Water Surface
HF	Horizontal Flow
KCl	Potassium Chloride
LU	Lincoln University, New Zealand
MID	Magneto-Inductive flow meter
MO	Microorganism
MRT	Mean Residence Time
N	Nitrogen
NH_4-N	Ammonium-Nitrogen
NO_2-N	Nitrite-Nitrogen
NO_3-N	Nitrate-Nitrogen
N_{org}	Nitrogen in organic form = (TKN - NH_4-N)
P	Phosphor
PE	Person Equivalent
RR	Recovery Rate
SS	Suspended Solids
SSF	Subsurface Flow
TKN	Kjehldal-Nitrogen = (N_{org} + NH_4-N)
TN	Total Nitrogen = (NO_2-N + NO_3-N + N_{org} + NH_4-N)
TOC	Total Organic Carbon
TP	Total Phosphorus
TSS	Total Suspended Solids
VF	Vertical Flow
WWTP	Wastewater Treatment Plant

1. Introduction and Objectives

Only 63% of the global population had access to improved sanitation in 2012. Even though this is a gain of around 1.8 billion people since 1990, the millennium development goals (MDGs) target of 75% for 2015 will not be reached until 2026, unless the pace of change can be accelerated (WHO and Unicef, 2012).

Constructed wetlands (CWs) are engineered systems for water and wastewater treatment, modelled after treatment processes in natural wetlands (Vymazal, 2011). They have a strong potential for application in emerging countries due to their comparative low cost, easy operation and maintenance as well as the possibility to use local materials and manpower (Kivaisi, 2001). Hence, CW systems could contribute to raise the worldwide access to improved sanitation in a sustainable way.

Austria's public sanitation services on the other hand are very advanced in terms of conventional wastewater treatment. In 2008, 93% of Austrians were connected to sewers (BMfLFUW, 2010). In 2012 probably 95% were already connected, whereas centralized wastewater treatment plants (WWTPs) treated the majority of the collected wastewater (Haberl et al., 2012). Of course, also the remaining 5% have to be at least biologically treated, as required by the Austrian wastewater treatment act (WRG 1959, as amended). Austria has stringent effluent standards for removal of organic matter and additionally for nitrification. Austrian regulation requires a maximum ammonia nitrogen effluent concentration of 10 mg/L (if effluent water temperatures are higher than 12 °C), for WWTPs with less than 500 person equivalent (PE). Organic matter effluent concentrations have to be below 90 mg COD/L and 25 mg BOD_5/L throughout the whole year. WWTPs with capacities less than 500 PE have no requirements regarding nutrient removal but in case of sensitive receiving waters the authorities can set additional requirements (1.AEVkA, 1996; Langergraber et al., 2011).

In rural areas with a low population density as well as remote alpine huts and inns, a connection to the sewer is often not reasonable in terms of ecological, economical or technical aspects. If this wastewater is treated at all, decentralized systems can be implemented to meet treatment requirements. Decentralized systems include intensive systems (activated sludge plant, sequencing batch reactor, membrane bioreactor, trickling filter, submerged rotary body) as well as extensive systems like lagoons and of course CWs. The above mentioned remaining 5% represent a proportionally small amount of the nationwide wastewater but appropriate treatment is of high importance for the environment and human health. Not only because local receiving waters, if available, are often small and especially sensitive to imissions but also because groundwater resources might be in danger due to inappropriate disposal.

There are various different CW configurations, whereas subsurface flow (SSF) CWs are most common in Europe. The vertical flow (VF) CW with intermittent loading is a widely used SSF system and meets Austrian effluent standards, including nitrification. VF CW with intermittent loading are - according to the Austrian design standard (ÖNORM B 2505, 2009) - dimensioned with 4 m² per PE (equals an organic load of 20 g COD m^{-2} d^{-1}). In order to increase complete nitrogen removal, a two-stage VF system has been developed and further on tested under controlled experimental conditions at the WWTP Ernsthofen. The system showed a stable total nitrogen removal higher than 60%, without the need of recirculation. Even though a higher effluent quality could be reached than with a comparative single-stage CWs, only half the specific surface area (i.e. 2 m² per PE) was required. Therefore the two-stage VF CW system could be designed and operated with an organic load of 40 COD m^{-2} d^{-1}, while still reaching stable nitrogen removal rates during the whole operation period. Additionally the investment costs amounted only around 60% of those for a single-stage system (Langergraber et al., 2008; Langergraber et al., 2011).

This master thesis investigates the performance of the CW *Bärenkogelhaus*, which is the first full-scale system with the above described two-stage setup. The goal is to develop a design standard for the two-stage system, which would raise its practical acceptance. The performance investigation, described in this thesis, is only one step towards this final goal.

The *Bärenkogelhaus* is situated on top of the Bärenkogel at an altitude of 1168 m above sea level in subalpine cold climate with high precipitation. Due to an operation change of the inn - from full time to event operation - the CW additionally had to deal with long periods of low or no load at all, interrupted by short periods with peak loads when events took place. This resulted in highly fluctuating peak hydraulic and organic loads. The master thesis deals mainly with the period from July 2011 until September 2012 when special investigations were conducted. The special investigations encompassed five event samplings and two tracer tests, with the aim to examine the system's performance in general and under these difficult conditions. This research is further based on routine investigations at the CW and a literature research.

Similar studies on CWs, which treat wastewater from tourism facilities with peak and fluctuating loads, have been conducted in different regions of Italy (including cold climates) by Foladori et al. (2012), Canepel and Romagnolli (2010), Masi et al. (2007) and in the course of a project co-financed by the European Community called SWAMP (2002). Those studies are outlined in section 2.6. The investigation on the Bärenkogel provides references for performance and design considerations (e.g. specific area requirement) for the two-stage VF design under peak loads in a cold climate.

The objective of this master thesis was to examine the performance of the two-stage CW with intermittent loading of the inn *Bärenkogelhaus*. The investigation also focused on the influence of peak loads and cold climate on the CW's treatment performance.

2. Fundamentals

2.1 Short history of natural and constructed wetlands

Wetlands are transitional environments between terrestrial and aquatic ecosystems. Natural wetland environments exist in a wide range of landscapes and on every continent of the earth except Antarctica. Natural wetlands are estimated to cover 5 to 8% of the world's land surface area and provide important ecosystem services for humankind due to their extreme diversity and particular characteristics (Mitsch et al., 2009; Vymazal, 2011). Generally, wetland ecosystems depend on constant or recurrent, shallow inundation or saturation at or near the surface of the substrate (Haberl et al., 2003). The wetland's soil, substrate and biota are adapted to prolonged flooding, waterlogging and similar conditions of restricted aeration (European Commission, 2000).

Natural wetlands have been used for wastewater treatment since centuries ago (Vymazal, 2011) and the use of natural wetlands as wastewater discharge sites probably goes back to the start of sewage collection, which is proven to have already been implemented in ancient human settlements some thousand years ago (Rodda and Ubertini, 2004). There are more recent examples of wetland sites in the United Kingdom and the United States of America, which are still used for sewage discharge and have been used for this purpose since more than a century (Cooper and Boon, 1987; Kadlec and Knight, 1996; Kadlec and Wallace 2009). Often the reason for utilizing a wetland was the absence of receiving water, rather than the intention to treat the sewage, often leading to a degradation of the ecosystem (Haberl et al., 2003). Nowadays CWs are used to utilize these natural processes in controlled environments. CWs are engineered systems for water or wastewater treatment and are simple in construction, operation and maintenance. Furthermore, they have a high buffer capacity and treatment efficiency. Therefore, CWs are especially suitable for wastewater treatment of small villages and single households (Langergraber et al., 2011).

The first experiments on the controlled use of wetlands for wastewater treatment were carried out in 1952 at the Max Planck institute in West Germany by Dr. Kaethe Seidel, followed by the first full-scale implementations in the 1960s (Seidel, 1965). Since then, SSF systems are more common in Europe, while free water surface (FWS) systems are more popular in North America, Australia and New Zealand (Haberl et al., 1995; Tanner et al., 2000; Kadlec and Wallace, 2009; Vymazal, 2011). CWs widely spread in the mid-1980s, not only due to their mechanical properties but also due to intensified international information exchange amongst scientists through conferences and expert groups. Today CWs are recognized as a reliable technology to treat different kinds of wastewater. Thousands of CWs are implemented worldwide on all inhabited continents (Vymazal, 2011).

2.2 Types of constructed wetlands

2.2.1 General distinction

CWs can be distinguished and categorized by a multitude of different design parameters. The most important categorizations are based on hydrology, macrophytic growth and flow path (see Figure 3-1).

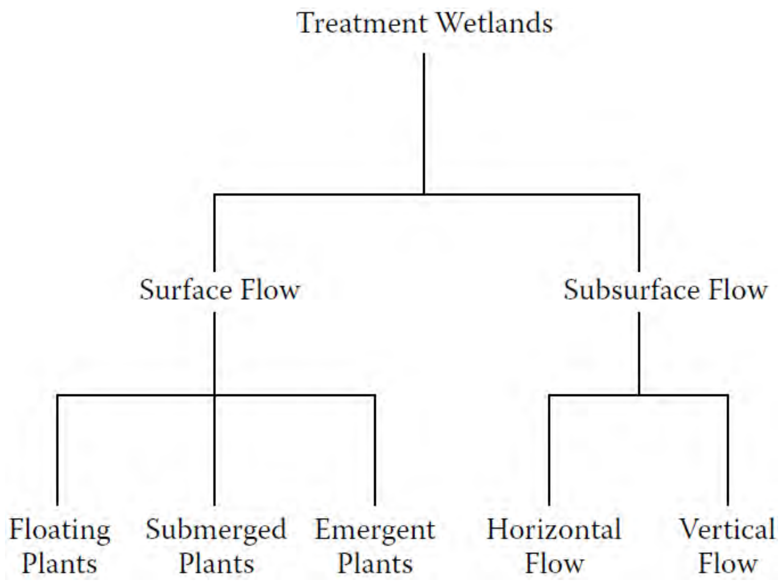

Figure 3-1 Treatment wetland types (Kadlec and Wallace, 2009)

Hydrology divides CWs into FWS and SSF flow systems. FWS systems can be further distinguished, according to Brix and Schierup (1989), after their type of macrophytic growth into:

- emergent aquatic macrophytes,
- submerged aquatic macrophytes, and
- floating aquatic macrophytes.

SSF flow systems can be classified according to the flow path through the filter bed into:

- horizontal flow (HF) systems, and
- vertical flow (VF) systems.

Different systems and setups can be combined in series, parallel or other ways to multi-stage systems (see section 2.2.5). This way it is possible to utilize different characteristics of wetland environments for different purposes and requirements.

2.2.2 Aquatic macrophytes

2.2.2.1 General remarks

Kadlec and Wallace (2009) stated that many studies have concluded that CWs show a higher performance when macrophytes are present. Initially, researchers thought that plants are the major cause of treatment, due to their direct uptake and sequestration of pollutants. That is only true for some pollutants (like heavy metals and special organic compounds) and in low-loaded systems. Many other pollutants are mainly transformed by microbial and physical processes (Haberl et al., 2003; Kadlec and Wallace, 2009). The most important effects of aquatic macrophytes in relation to wastewater treatment processes are (Brix, 1994; Haberl et al., 2003):

- physical effects of plant tissue;
    - erosion control;
    - filtration effect;
    - roots provide surface area for attached microorganisms (MOs);
    - root growth maintains hydraulic properties of the substrate;
    - vegetation cover protects bed surfaces from erosion;
    - shading of vegetation prevents algae growth; and
    - litter provides an insulation layer on the bed’s surface (important for winter operation);
- metabolism of macrophytes depending on the design, whereas the nutrient uptake by plants is only of quantitative importance in low-loaded systems, thus in FWS CWs.

Other advantages of macrophytes in CWs include ancillary benefits like the provision of habitat for wildlife and a more aesthetic appearance of systems. To find an appropriate plant for a given application, the plant’s pollutant removal efficiency and productivity have to be considered. Contaminants incorporated in macrophytes will only leave the system if they are harvested, otherwise they return into the system during decomposition (Haberl et al., 2003).

In the following subsections the different types of aquatic macrophytic plants are described.

2.2.2.2 Emergent aquatic macrophytes

Emergent aquatic macrophytes (see Figure 3-2) extend out of the water and are rooted in the substrate until up to a water depth of 150 cm, whereas wetlands may support a standing water table which is either temporary or permanent shallow, and generally lower than 2 meters (Brix and Schierup, 1989; Vymazal, 2011). Emergent aquatic macrophytes are used to grow in waterlogged and submerged substrate and use internal air spaces to transport oxygen to the extensive roots and rhizome systems. Therefore they stimulate decomposition of organic matter and nitrification by possibly creating oxidized conditions in otherwise anoxic environments. Examples for emergent aquatic macrophytes are common reed (*Phragmites australis*), bulrushes (*Scirpus* spp.) and cattails (*Typha* spp.), whereas each is adapted to different water depths and shows different depth penetration of roots and rhizomes (Brix and Schierup, 1989).

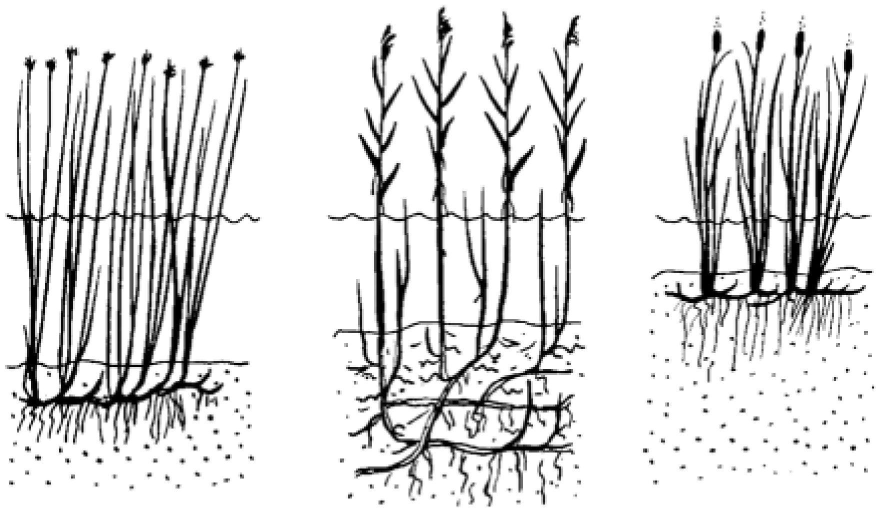

Figure 3-2 Sketches of emergent aquatic macrophytes, showing *Scirpus (Schoenoplectus) lacustris* (left), *Phragmites australis* (middle) and *Typha latifolia* (right) (From Brix and Schierup, 1989)

Emergent aquatic macrophytes are the only type that may be used in SSF CWs, whereas FWS may accommodate all three types.

2.2.2.3 Submerged aquatic macrophytes

The photosynthetic tissue of submerged aquatic macrophytes is entirely submerged in the water column but the flowers are usually exposed to the atmosphere (Brix and Schierup, 1989). Examples are curly-leaved pondweed (*Potamogeton crispus*) and shoreweed (*Littorella uniflora*) (see Figure 3-3).

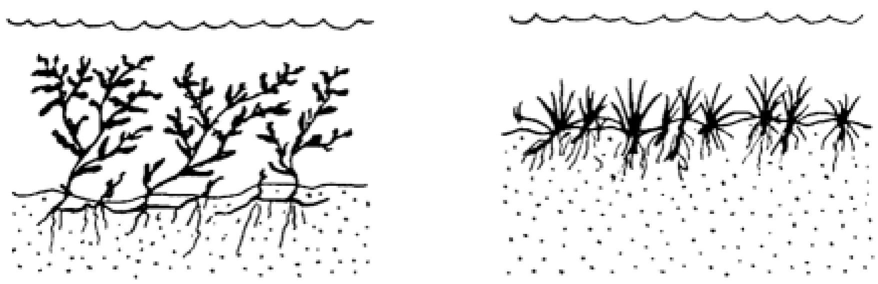

Figure 3-3 Sketches of submerged aquatic macrophytes, showing *Potamogeton crispus* (left) and *Littorella uniflora* (right) (From Brix and Schierup, 1989)

Submerged aquatic macrophytes may be present in FWS CWs together with other types of aquatic macrophytes.

2.2.2.4 Floating aquatic macrophytes

Floating aquatic macrophytes have photosynthetic tissue that floats on the water surface and the flowers are exposed to the atmosphere as well.

Figure 3-4 Sketches of floating macrophytes rooted in the substrate, showing *Nymphaea alba* (left), *Potamogeton gramineus* (middle) and *Hydrocotyle vulgaris* (right) (From Brix and Schierup, 1989)

They are very diverse in form and habit and can be further subdivided into species which are rooted in the substrate, e.g. water lilies - *Nymphaea* spp. (see Figure 3-4) and species which are completely free floating, e.g. common water hyacinth - *Eichhornia crassipes* (see Figure 3-5) (Brix and Schierup, 1989).

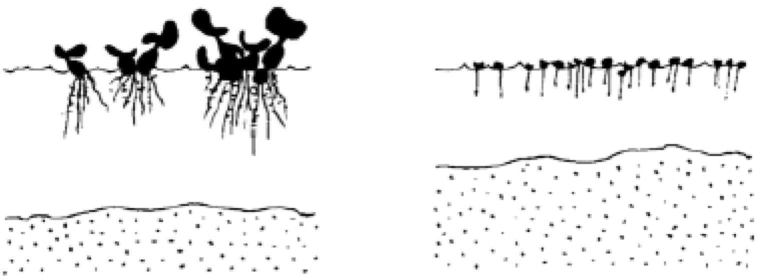

Figure 3-5 Sketches of completely free floating macrophytes, showing *Eichhornia crassipes* (left) and *Lemna minor* (right) (From Brix and Schierup, 1989)

Floating aquatic macrophytes may be present in FWS CWs together with other types of aquatic macrophytes.

2.2.3 Free water surface wetlands

FWS wetlands are very similar to natural wetlands, with areas of open water and mixed types of aquatic macrophytes (emergent, submerged and floating), attracting a wide range of wildlife (Kadlec and Knight, 1996). FWS wetlands have an inlet and outlet and the wastewater flows over the wetland, where it spreads and slows down (see Figure 3-6). This way particulate matter settles and dissolved pollutants are absorbed by plants, soil and MOs (Langergraber and Haberl, 2001). Water flow is regulated by low flow velocity, shallow water depth and plant parts (Vymazal, 2011).

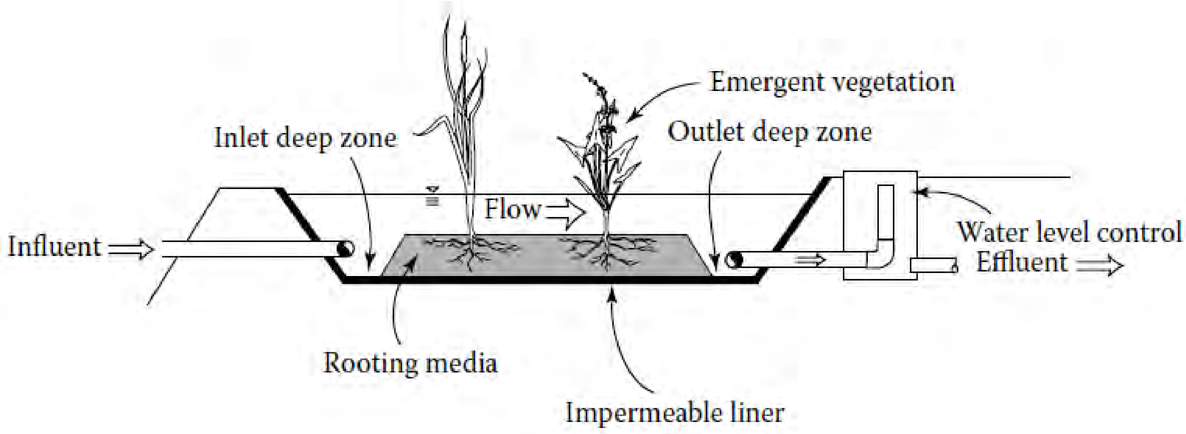

Figure 3-6 Basic scheme of a FWS CW (From Kadlec and Wallace, 2009)

This type of wetland is most commonly used for storm water treatment as well as treatment of mine waters, groundwater remediation, leachate treatment or advanced treatment of effluents from secondary and tertiary treatment processes, such as lagoons, trickling filters or activated sludge (Kadlec and Wallace, 2009).

2.2.4 Subsurface flow constructed wetlands

2.2.4.1 General description

SSF CWs are designed to receive pre-treated wastewater with low contents of particulate matter. Therefore SSF systems in practice are mainly used as a secondary or tertiary treatment step. The filter bed's substrate consists of soil or gravel as substrate and is commonly planted with emergent wetland plants, such as common reed (*Phragmites australis*). Pre-treated wastewater flows horizontally or vertically through the filter bed and is mainly treated by MOs living in association with the substrate and plant roots (Haberl et al., 2003). According to Langergraber and Haberl (2001), the contact area with bacteria and substrate in SSF systems is much higher than in FWS wetlands, what enhances the system's process rates resulting in a decreased area requirement. According to Kadlec and Wallace (2009), SSF wetlands have only limited ancillary benefits compared to FWS systems. Ancillary benefits are benefits not related to the actual water treatment process, e.g. for human recreational uses or wildlife habitat. Langergraber and Haberl (2001) emphasized the importance of a good pre-treatment for SSF CWs in order to prevent clogging.

2.2.4.2 Horizontal subsurface flow constructed wetlands

In horizontal flow (HF) CWs the wastewater is fed through an inlet, flows belowground through the porous media and is collected and discharged from the bed through an outlet (see Figure 3-7). Therefore wastewater is not exposed to the atmosphere, thus lowering the risk of contact by humans or wildlife with pathogens contained in the wastewater (Kadlec and Wallace, 2009). The water flows around roots, rhizomes and plants and is exposed to a network of aerobic zones in the upper parts of water table, as well as anoxic and anaerobic zones in the bottom of the wetland. Since the oxygen transport of roots is too weak to facilitate aerobic processes in the lower realms of the wetland, anoxic and aerobic processes play a major role in treatment processes. Organic matter can be decomposed in aerobic and anaerobic conditions but only incomplete nitrification can take place (Langergraber and Haberl, 2001). Phosphorus removal is limited due to the low sorption capacity of filter material (gravel, crushed rock) (Vymazal, 2005).

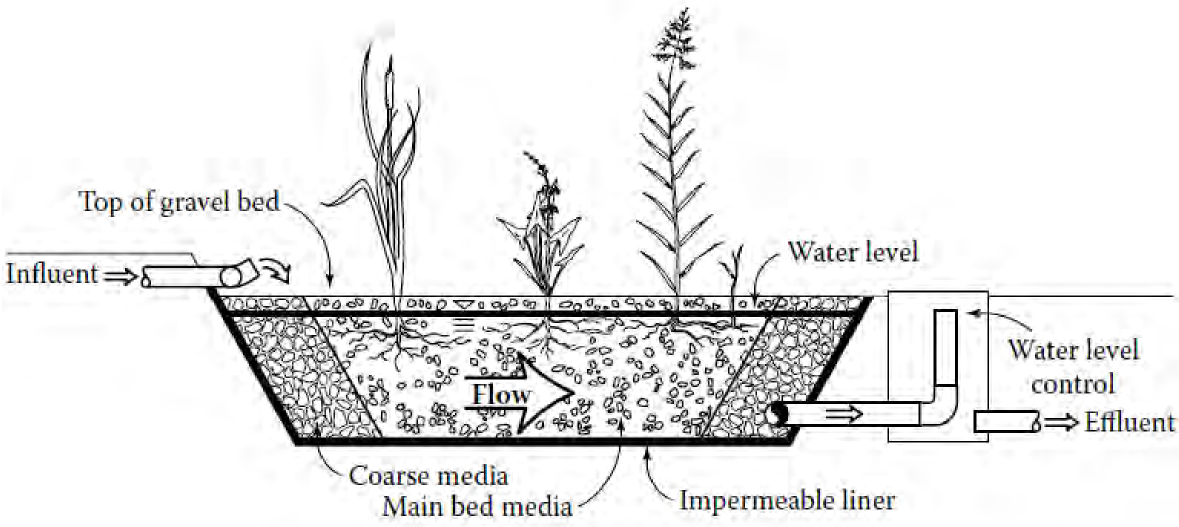

Figure 3-7 Basic scheme of a HF CW (From Wallace and Knight, 2006)

HF systems are commonly used for secondary treatment of wastewater from single-family homes or small cluster systems (Wallace and Knight, 2006) or small communities (Cooper et al., 1996). Vymazal (2005) suggested the use of HF systems for small sources of pollution, especially if the target is treatment of organics (BOD_5 and COD) and suspended solids. However, Kadlec and Wallace (2009) stated that there are many other applications, whereas Laber et al. (1998) found that the appropriate gravel size used in the main layer of the HF filter bed is determined by the application. If used for primary wastewater treatment a coarse substrate (e.g. gravel 4/8 mm) should be used, whereas for tertiary treatment a finer substrate (e.g. sand 0/4 mm) is more suitable.

2.2.4.3 Vertical flow constructed wetlands

In VF systems, wastewater is fed through an inlet, distributed by above- or belowground perforated pipes over the whole bed surface area, infiltrated vertically into filter bed, drained at the bottom and finally leaves the bed through an outlet at the end of the bed (see Figure 3-8).

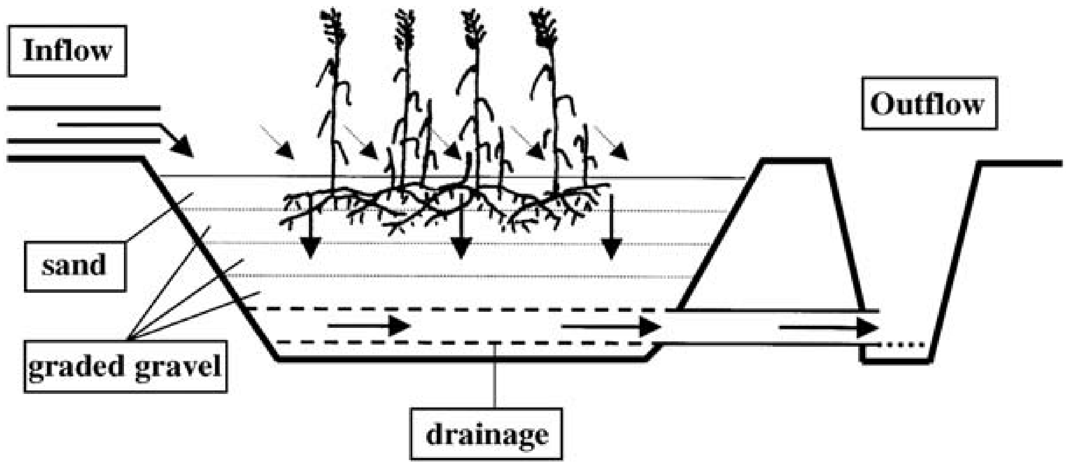

Figure 3-8 Basic scheme of a VF CW (From Vymazal, 2011)

Varieties of VF CWs include:

1. *unsaturated downflow with intermittent loading* (also called intermittent downflow). This is the most common mode of VF CWs and employs a single-pass configuration. This type of VF CW is used in a two-staged setup in the system investigated in this master thesis. For a detailed system description see section 3.2. Due to HF system's limited capacity to oxidize ammonia, because of limited oxygen supply, the intermittent VF system was developed to meet the stringent effluent standards regarding nitrification in many European countries (Langergraber and Haberl, 2001; Kadlec and Wallace, 2009). The ability of VF systems to nitrify high amounts of ammonia led to the utilization of this type of wetland for wastewaters with very high ammonia concentrations such as food processing wastewaters (Burgoon et al., 1999);
2. *unsaturated downflow with continuous loading.* In this mode water is distributed aboveground, or belowground in cold climates, on to the surface of granular media. The water trickles downwards through the media in unsaturated flow either in a single pass mode or recirculation (Crites and Tchobanoglous, 1998; Crites et al., 2006). A number of such systems are used in North America, called vegetated recirculating gravel filters (Lemon et al., 1996). These vegetated recirculating gravel filters are mainly used in cold climate applications because surface flooding or spray irrigation creates problems during winter operation. Otherwise, surface flooding is simpler and can be used when thermal considerations allow to;
3. *saturated up- or downflow*. This mode makes use of a continuous saturated flow of water through the plant root zone. Examples are upflow systems for treatment of groundwater contaminated by chlorinated solvents (Kassenga et al., 2004) or downflow configurations used for mine water treatment by immobilizing metals in anaerobic conditions (Younger et al., 2002); and

4. *fill-and-drain (tidal flow)*. These systems make use of filling and draining cycle in a granular bed in order to create cyclic redox conditions (Maciolek and Austin, 2006). They are for example used to treat high-strength wastes (Austin and Lohan, 2005).

Further on, VF systems can treat very concentrated wastewaters like raw sewage (Molle et al., 2005) or dewater activated sewage sludge in sludge reed bed facilities (Nielsen, 2004). Biosolids (sludge) dewatering wetlands trap organic solids on the wetland's surface and water percolates, mainly through unsaturated flow, vertically down through the bed's alternating filter layers. Since biosolids dewatering wetlands are simple in use and require low operation and maintenance, they are increasingly supported by operators of traditional wastewater treatment plants.

2.2.5 Multi-stage systems

Any type of CW system can be combined to meet different goals. One common goal is higher removal efficiency of certain nutrients or pollutants. These so called multi-stage systems (also called hybrid or combined systems) were already built by Seidel at the Max Planck Institute in Germany (Seidel, 1965). Like Seidel's configuration, most multi-stage systems are a staged combination of HF and VF wetland beds, whereas the most common configuration is a VF stage followed by a HF stage (see Figure 3-9).

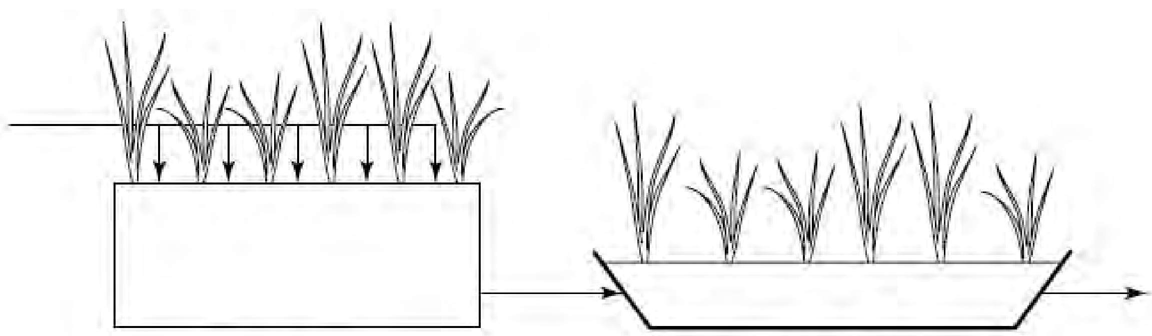

Figure 3-9 Sketch of a multi-stage CW (From Kadlec and Wallace, 2009)

The VF stage provides aerobic conditions, removes organic matter and suspended solids and allows nitrification. The following HF stage partly provides anoxic/anaerobic conditions and therefore denitrifies as well as further eliminates organic matter and suspended solids. Many of these systems have been built in European countries because of the stringent requirements for ammonia removal.

Another possible configuration lines the systems up the other way around, starting with a large HF stage which removes organic matter, suspended solids and provides denitrification. As a second stage, an intermittently loaded VF bed further removes organic matter, suspended solids and provides nitrification. The nitrified effluent is then partly pumped either to the sedimentation tank prior to or directly to the HF bed inlet in order to recycle Nitrate (NO_3^-) and maximize denitrification in the HF stage. A disadvantage of this system is that the recycling increases the hydraulic loading, which could negatively affect the system's nitrification capacity. The area use by this system is 5 m^2 per PE (Brix et al., 2003). The system described in this work can be classified as a multi-stage system, due to the two VF stages used in series.

2.3 Treatment processes

The purpose of a CW is to treat water or wastewater in order to reduce or completely remove pollutants as well as trace metals, pathogens, viruses and other pollutants. The removal efficiency depends on the CW design, biological and chemical reactions as well as physicochemical environmental parameters like temperature, pH or dissolved oxygen. The performance of a CW is as well influenced by the hydraulic load, which is the quantity of wastewater led into the CW, which also affects the retention time in the system (Naja and Volesky, 2011). According to Kadlec and Wallace (2009), the most important wetland treatment processes are:

- **microbially mediated processes** by bacteria and MOs;
- **chemical networks** involving more than one reaction and chemical species;
- **volatilization** of compounds, creating gases that are released into the atmosphere (e.g. ammonia or methane);
- **sedimentation** removing suspended solids;
- **sorption** of contaminants by the CW's filter substrate;
- **photodegradation** by sunlight can degrade or convert many waterborne substances and kill MOs, including pathogenic bacteria and viruses by UV radiation;
- **plant uptake** of nutrients and trace metals in the root zone or stems and leaves in the water column. Contaminants in aboveground plant parts may be r emoved through harvesting;
- **vertical diffusion in soils and sediments** is only the dominant process if there is no infiltration. It carries dissolved contaminants to sorption and r eaction sites and roots, either by hydraulic head or plant transpiration;
- **transpirational flux** driven by plant water uptake;
- **seasonal cycles** governing plant uptake and decomposition; and
- **accretion** formed by dead plant material which does not undergo decomposition.

Kadlec and Wallace (2009) stated that accretion, the creation of new soils and sediments, is one of the least studied pollutant transfer processes in CWs. Thereby, small portions of aboveground and belowground plant material resist decay and form stable new accretions, which are assumed to be resistant to decomposition.

2.4 Field of application

CWs are applied to treat wastewater from a wide range of sources, such as (Langergraber and Haberl, 2001; Molle et al., 2005):

- **domestic wastewater** is generally treated by CWs in the secondary or tertiary treatment stage, whereas a g ood pre-treatment is necessary to reduce the suspended solids load;
- **stormwater and runoff management** is important since urban stormwater runoff is a major contributor to non-point source pollution of surface waters. Besides dry and wet detention ponds, stormwater CWs can be applied to treat stormwater;
- **surface water**, even if heavily polluted, can be treated by CWs and further on used for groundwater recharge or restoration of contaminated surface waters;
- **agricultural wastewater** as well as crop runoff can be treated by CWs;
- **food wastes** from food processing industries usually contain high organic loads, which can be biodegraded by CWs;
- **industrial wastewater** e.g. from coal and metal mining, refinery effluents, oil sand processing water, and pulp and paper industry can be treated by CWs;
- **hospital wastewater** can be successfully treated by CWs;
- **landfill leachate** is highly polluted due t o anaerobically decomposition over many years. CWs provide a long-term sustainable treatment with low operation and maintenance needs;
- **sludge consolidation** creates excess water from sludge, which can be treated by CWs. This is an important step during disposal of municipal wastewater sludge; and
- **raw sewage** treatment by two-stage VF systems (common in France).

2.5 Constructed wetlands in cold climates

2.5.1 General remarks

CWs in cold (subfreezing) climate environments face several challenges. Climate influences operation and performance of a CW, because water and bed temperatures as well as biological, physical and chemical processes are amongst other factors dependent on weather phenomena like temperature, precipitation or wind. For example, wind in combination with low temperatures can play a major role in cooling or even freezing of wetland surfaces. Since, there are few control mechanisms in CW systems, it is very important to consider cold climate operation in the design and operation of a system (Beran, 2011; Kadlec and Wallace 2009). Another difficulty when operating CWs is to ensure sufficient oxygen supply in order to prevent plant stress and preserve sufficient removal efficiencies, especially for ammonia nitrogen (Langergraber and Haberl, 2001). In cold climates this can be problematic when having a snow cover that does not allow gas exchange.

There are various strategies how to keep bed and wastewater temperatures on a level that allows sufficient operation and treatment performance and as a result keep a system from freezing and resulting hydraulic failure (Wallace et al., 2001). Some of these strategies are described in the following chapters, whereas the emphasis lays on solutions which do not require additional energy input or complex mechanical systems. In this way CWs preserve their advantage of being simple in operation and maintenance as well as an energy efficient alternative (ideally independent from anthropogenic energy sources) compared to energy intensive traditional wastewater treatment systems.

2.5.2 Aquatic macrophytes in cold climate constructed wetlands

Climatic conditions and genotypical habitat govern the rates and seasonality of transformation processes by plants, such as growth, death, litterfall, and decomposition (Kadlec and Wallace, 2009). Whigham et al. (1978) stated that even in cold climates the total annual plant growth is about 20% larger than the plant's biomass at the end of the season.

The selection of wetland plants is amongst other factors (degree of rhizome spread, root biomass and depth) dependent on climate. Further on, if a mulch layer is used for insulation, the competitive advantage shifts from obligate towards facultative wetland plants, due to the created permanent unsaturated zone. In cold climates vegetation might need a grow-in period of around two growing seasons, depending on plant density and vegetation propagation rate (Kadlec and Wallace, 2009). Grazing pressure by animals in winter and early spring might be a significant concern during the establishment of the plantation. In case of high grazing pressure, replanting and/or exclusion measures should be anticipated (Wallace et al., 2001).

Further on, Stein and Hook (2005) believed that oxygen transport to the rhizosphere by plants is varying dependent on interactions between species and seasonal temperature variation. This interaction and other factors may influence the treatment performance of CWs but better understanding of seasonal variation of treatment processes would be needed to infer design and management improvements.

2.5.3 Different systems in cold climates

2.5.3.1 Free water surface constructed wetlands in cold climates

In general FWS CWs are suitable for all climates but ice formation can have negative effects on hydraulics and oxygen-dependent removal processes. For example, when ice formation occurs in a FWS wetland due to cold or freezing temperatures, the depth of the water column and therefore the detention time of wastewater are reduced. This can be taken into account by an additional freeboard when designing a FWS system in cold climates, whereas ice thickness varies from year to year due to various influences like temperature or snowfall (insulation effect). Also the height of a snow layer on top of an ice layer depends on different influences. For example, surface areas with emergent wetland vegetation trap snow more effectively than unvegetated areas. Different management options may be used for FWS systems in cold climates (Kadlec and Wallace, 2009):

- full year-round discharge, allowing for ice formation;
- restricted winter discharge accompanied by partial pond storage and accelerated discharge through FWS systems during the unfrozen season; and
- storing water in ponds over the frozen season and discharge through FWS treatment wetlands during the unfrozen season.

In cold climates frost protection of FWS systems must be considered for inlet water distribution and associated plumbing, which must be kept below the ice layer. Dead plant biomass can provide an additional insulation in FWS systems (as well as for HF systems). The plant parts protect wetlands soil or water surface from direct wind exposure and additionally hold up s now, creating a zone of air spaces between plant biomass and captured snow. These effects contribute to thermal insulation and may prevent freezing in FWS systems (Kadlec and Wallace, 2009).

Langergraber and Haberl (2001) mentioned the possible freezing of FWS wetlands in addition to the requirement of large areas as the reason why these are not used for wastewater treatment in Europe as commonly. However, Kadlec and Wallace (2009) mentioned several existing FWS systems in Europe (e.g. Norway, Sweden, Denmark, Poland, Estonia and Belgium) and pointed out that VF systems are not so popular in North America because they accumulate biosolids on t he bed s urface which might not be compatible with regulatory standards.

2.5.3.2 Subsurface flow constructed wetlands in cold climates

In cold climate environments it is necessary to keep SSF systems from freezing and resulting hydraulic failure. Several measures can keep bed or wastewater temperatures on a sufficient level and therefore maintain the performance of SSF systems in cold climate environments:

- **added insulations** on top of the CW's bed surface. Layers may be combined and result together with potential snow in an overall thermal conductivity and resistance of a filter bed (e.g. gravel layer, mulch and snow; see Table 2-1).

  Table 2-1 Example of the Cumulative Effect of Insulation Layers (from Kadlec and Wallace, 2009)

	Thickness (cm)	**Thermal conductivity** (MJ/m·d·°C)	**Resistance** (MJ/m·d·°C^{-1})
Air above/in canopy (*U = 0.3*)	-	-	3
Snow	25	0.010	25
Peat mulch	10	0.005	20
Dry gravel	5	0.026	2
Total	**-**	**-**	**50**

  A snow cover alone is not reliable enough and does not provide sufficient insulation in periods with limited snow cover (Wallace and Kadlec, 2005). Added insulation layers affect transfer rates of oxygen and other gases of a system's bed and the atmosphere and therefore the system's treatment performance, this has to be considered in their design (Beran, 2011; Wallace et al., 2001). Possible insulation techniques include:

  - **mulch layer** (ASTM, 1969; Malterer et al., 1991; Steiner and Watson, 1993; Wallace et al., 2001; Wallace and Knight, 2006): Insulation by mulch is a possibility to prevent a SSF system from freezing. A wide variety of materials might be used, such as bark, pine straw, wood chips, reed-sedge peat or high quality yard waste compost. Disadvantages of mulch may include negative effects on atmospheric exchange rates (including oxygen), pollutant removal performance, and plant establishment. Only well decomposed organic materials should be used in order to minimize a decrease in treatment efficiency. The used vegetation is affected by the mulch layer and should tolerate the presence of the consequent unsaturated root zone. Further on, mulch can affect the nitrogen cycle of a system. Mulch is a common design feature of HF systems in Canada and northern regions of the United States. Application of mulch can enhance nitrate reduction, presumably due to leaching of organic carbon but adversely affect BOD removal;
  - **gravel layer** (Langergraber et al., 2009; Beran, 2011): As an adaption to cold climate environments a gravel layer balances temperature peaks by insulation. Further on, it prevents the filter bed from desiccating, covers puddles when slow infiltration occurs and prevents direct contact of humans or animals with wastewater on the bed surface. Disadvantages are initial cold storage in the gravel layer at the start of the vegetation period as well as the prevention of reed stalks from moving in the wind and thereby decreasing the beds oxygenation capacity. Oxygen exchange capacity might

be adversely affected as well by possible compression and/or compaction of the filter bed surface by the gravel layer. This could be enhanced by a potential snow cover and lead to decreased treatment performance of the system;

  - **blankets** (Kadlec and Wallace, 2009): Blankets might be used for small systems. These can be supported by standing dead plant litter as well;
  - **snow cover** (weather dependent) (Beran, 2011): A snow cover of freshly fallen and permeable snow acts insulating and is gas-permeable at the same time, which is important for a sufficient oxygen supply. However, a thick snow cover of wet snow prevents oxygen exchange between the filter bed surface and atmosphere, resulting in a decreased treatment performance;
  - **leave vegetation on the bed after vegetation period** (dependent on vegetation) (Beran, 2011): Leaving vegetation over winter results in number of advantages; the leftovers act as an insulation layer to balance temperature fluctuations and protect the bed surface from wind exposure. The reed stalks lead oxygen into the filter bed also in winter. Reed stalks sway in the wind and loosen the uppermost layer of the filter bed and possible snow cover. The vegetation acts as snow guard, therefore an insulating closed snow cover builds up faster. In case of VF systems, possible disadvantages include dead plant remains on the filter bed surface which may enhance colmatation processes as well as potential deformation of distribution pipes by plants due to high snow pressure (in case of plastic pipes); and
  - **straw** (Kadlec and Wallace, 2009): Straw can be used as a supplement for leftover dead vegetation (see above).

- **water level control:**
  - **lowered water levels** (Jenssen et al., 1994): Lowering of the system's water table in order to create a layer of dry media in the uppermost area of the bed; and
  - **create ice layer on top of dry media** (weather dependent) (Jenssen et al., 1994; Mæhlum, 1999): An ice layer is created by raising water levels slightly above the bed surface at the time of freeze-up. Afterwards the water level is lowered below the bed surface in order to create a dry media gap sealed by the beforehand created ice layer.
- **use deep beds** (Jenssen et al., 1996): Design of deep beds allows for ice formation while the hydraulic capacity should still be big enough to pass water under the ice;
- **control of wastewater temperature** (Beran, 2011): The higher the wastewater temperature is when applied to the filter bed; the lower is the danger of ice formation. Prerequisite is a quick infiltration of the wastewater. A short detention time of wastewater in the pre-treatment (e.g. 3-chamber-pit, septic tank etc.) prevents excess cooling of wastewater but leads to a higher load of suspended solids (SS). In case of a VF system with an aboveground distribution system SS are held back on the filter surface and may cause colmatation;
- **design, operation and maintenance** (Reed et al., 1988, Kadlec and Wallace, 2009): For example, it has to be taken into account that due to diurnal fluctuating water use patterns, the wastewater flow of very small systems at night might be zero. This poses design challenges in general and can as well cause freezing of pipes in very cold climates. Distribution pipes should be prevented from freezing in order to keep the system operable. In HF system pipes are therefore usually buried belowground. In VF CW ice formation may cause operational problems in case the

inflow distribution device is aboveground and must be designed to self-drain between loading events. In very cold climates the intermittently fed system common in Europe might have to be altered or changed to a system with buried distribution pipes. Controversially, freezing is beneficial for biosolids (sludge) dewatering systems because it lyses the cell walls within the sludge material, aiding in dewatering; and

- **other energy intensive solutions** (Wallace et al., 2001; Brix et al., 2003): Possible, but energy intensive solutions to reach a sufficient treatment performance in cold climates include re-circulation (pumping needed), forced aeration or heating.

2.5.3.3 Multi-stage systems in cold climates

In Norway the applicability of CW for wastewater treatment was initially questioned due to the cold climate of the country located between 58° and 71° northern latitude. However, the first CW was built in 1991 and since then numerous systems followed. The developed system of a vertical down-flow aerobic biofilter as pre-treatment, followed by a HF porous media filter (majority using lightweight aggregate as media and vegetated with common reed) is a widely spread method for wastewater treatment in Norwegian rural areas, due to high performance and low maintenance requirements despite the cold climate. The recommended surface area of such a system is 7 to 9 m^2 per PE for domestic sewage and 2 to 3 m^2 per PE for greywater. In general the treatment performance of these systems exceeds 80% for BOD_7, 90% for TP and varies between 40 and 60% for removal of TN. (Jenssen et al., 2005)

Browne and Jenssen (2005) showed that it is possible to treat wastewater of a whole community with a pond and reed bed system in a cold climate environment (Vidaråsen, Norway), including wastewater from 160 people, a dairy, a food processing workshop, a bakery and a laundry. The system consists of a sludge settlement bed, pre-treatment surface VF CWs, a facultative pond, three stabilization ponds, a planted sand filter and two HF CWs filled with lightweight aggregate. Jenssen et al. (2005) also considered it necessary in Norwegian conditions to aerobically treat wastewater before leading it into CWs in order to provide the required oxygen levels to efficiently remove phosphorus and nitrogen. This way, despite harsh winter conditions with -10° C and a 50 cm ice layer on the ponds, the system showed effective treatment, meeting the high Norwegian effluent standards regarding nitrogen as well as phosphorus by additionally using a filter media with high adsorption capacity in the HF stage which can be recycled resulting in a reuse of nutrients (Jenssen and Krogstad, 2002). The system average reduction of TOC, N and P was 94, 92 and 96 %, respectively. The area requirement of the system is relatively high with 10 m^2 per PE but year-round treatment performance is high, even for P. Effluent quality meets WHO drinking water requirements and European requirements for swimming water while the system only requires low-skilled maintenance and shows a high buffering capacity as well as enhanced pathogen removal (Browne and Jenssen, 2005).

Tanner et al. (2012) compared a HF CW with different multi-stage CW systems which were combined with denitrifying bioreactor elements (also known as reactive filters and denitrification beds or walls) in a multi-component pilot-scale testing facility in Hamilton, New Zealand, including:

- a HF CW with gravel media (HG);
- two single-pass VF wetlands with either gravel (VG+C) or sand media (VS+C) followed by carbonaceous bioreactors;
- a recirculating system including HF beds followed by VF wetlands (R(HG+VS)); and

- a recirculating system including VF wetlands preceded by a submerged attached growth bioreactor (R(A+VS)) with optional supplementary carbonaceous bioreactors (R(A+VS)[+C]) for efficacy investigation at the end of a recirculating system.

The bioreactor elements incorporate a source of organic C (e.g. wood chips), which enhance organic carbon supply to sufficient levels in order to attain full denitrification. The multi-stage systems were capable of achieving advanced effluent quality with low energy input and generally required only half or less of the HF wetland's area requirement.

For specific area requirement per PE and TN reduction for different systems see Table 2-2.

Table 2-2 Comparison of specific area requirement and TN reductions of different treatment systems (Tanner et al., 2012)

	HG	VG+C	VS+C	R(HG+VS)	R(A+VS)	R(A+VS)[+C]
Specific area (m^2/PE)	6.5	2.9	2.8	2.7	1.6	3.6
TN reduction (%)	49	83	63	73	58	95

Overall treatment efficiencies were as follows:

- BOD_5 and TSS average removal of 94% in all systems;
- NH_4-N average reduction from 98 to 99.8% in multi-stage and bioreactor systems;
- TN average reduction from 58 to 95% in the multi-stage system;
- TP average removal from 36 to 65%; and
- Faecal indicator bacteria reduction from 2.5 to 4.7 log units.

The removal of TN varied between 30 to 50% in the HF wetland stage, depending on temperature. Since the black plastic covered bioreactors were situated aboveground, solar heating during summer resulted in warming of up to 6% above influent temperatures but slightly reduced temperature and denitrification rates during winter (Tanner et al., 2012).

In cold climates, CWs are often over-dimensioned to compensate for possible decreased treatment efficiencies as a result of low temperatures in cold climates (Werker et al., 2002). In order to avoid over-dimensioning, Põldvere et al. (2009) investigated the possibility of re-circulation of wastewater and compared continuous-flow and batch-operated systems (VF followed by HF bed) in order to determine optimal management of this CW system in cold climates for secondary treatment of domestic wastewater. The result of the pilot-scale plant in in Nõo, Estonia showed that re-circulation rate must be from 100% to 300% of the inflow wastewater in order to achieve effective BOD_5, COD, TSS and TP removal as well as denitrification.

2.6 Tourism facilities with peak wastewater loads

Hydraulic and organic wastewater loads of tourism facilities, such as restaurants, inns, hotels, campsites and others, are likely to have peaks or fluctuations due to seasonal, weekly, daily or other usage patterns, which makes it necessary to plan wastewater treatment accordingly. Appropriate CW systems may offer sufficient wastewater treatment with low sensitivity to such peaks and fluctuations and the possibility to be rested. Further on, CWs are a possible solution for remote sites where conventional wastewater collection is not available (SWAMP, 2002).

A demonstration project co-financed by the European Community called “Sustainable water management and wastewater purification in tourism facilities” (SWAMP) describes CWs as very well suitable for demands of tourism facilities in remote areas, due to (SWAMP, 2002):

- high treatment efficiency,
- simplicity in construction (possible use of local materials) operation and maintenance,
- low operation and maintenance costs,
- high ability to tolerate fluctuations in flow and insensitivity to peaks, as well as
- appealing aesthetic appearance.

A research in the frame of SWAMP by Masi et al. (2007) on the tolerance of CWs in regards to hydraulic and organic load fluctuations investigated the following four systems in central Italy, which treated effluents from tourism facilities:

1. a single-stage CW for secondary treatment of domestic wastewater at a holiday farm site;
2. a two-stage CW with a HF system followed by a VF system for secondary treatment of a tourist resort;
3. a single-stage VF CW for a mountain shelter; and
4. a pair of single-stage HF CWs for secondary treatment of segregated grey and black water produced by a camping site.

All of them are located in remote areas with no sewer connection and most of them discharge into sensitive environments. The four different systems show a high variability of water consumption and wastewater loads, depending on season, weather and weekly patterns. Larger number of tourists during warmer months and fixed NH_4-N limits for discharge in open water bodies are recurrent conditions for tourism facilities in remote areas of Italy. Table 2-3 shows main features and removal rates for each system.

Table 2-3 Main features and removal rates of four different CWs in central Italy (from Masi et al., 2007)

System	(1) Holiday farm	(2) Tourist resort	(3) Mountain Shelter	(4) Camping site	
				Blackwater	Greywater
Load (PE)	30	140	100	80	
Specific organic load (g COD m^{-2} d^{-1})	Mean 4.2 Min 0.14 Max 23.2	HF: mean 17.5 Min 1.5 max 50.3 VF: mean 2.0 Min 0.5 max 5.9	Mean 2.9 Min 0.4 max 3.2	Mean 11	Mean 36
Specific hydraulic load (L m^{-2} d^{-1})	Mean 19 Min 4 Max 62	HF: mean 150 Min 110 max 230	Mean 18 Min 10 Max 23	Mean 15	Mean 73
Influent flow rate (L/d)	400 - 7,000	17,000 - 33,000	2,000 - 8,000	900 - 2,400	3,000 - 10,000
COD removal rate	85.4%	93.9%	83.4%	88.1%	89.4%
NH_4-N removal rate	78.4%	85.3%	98.5%	54.9%	92.4%

The facilities had a high variability in hydraulic load. The tourist resort and the black- and greywater of the camping site showed very good COD removal rates with 93.9, 88.1 and 89.4%, respectively. The holiday farm and mountain shelter had good COD removal rates with 85.5 and 83.4%, respectively.

Concerning NH_4-N removal, the holiday farm, tourist resort and greywater of the camping site showed good results with 78.4, 85.3 and 92.4%, respectively. However, the blackwater of the camping site showed a lower removal rate with 54.9% removal of NH_4-N.

Outlet concentrations were stable at low levels throughout the entire monitoring period despite drastic flow variations, which were experienced in all four systems. Furthermore, high hydraulic volumes and retention times minimised problems regarding peak and fluctuating flow. Also bacterial communities indicated fast adaption to higher hydraulic loading rates. Especially the tourist resort's multi-stage system showed very good results, considering the relatively small specific surface area of 2 m^2 per PE (Masi et al., 2007).

Canepel and Romagnolli (2010) investigated on a multi-stage CW in the Italian Alps, with fluctuating hydraulic and organic loads as well as snow covering the filter beds most of the year. The system was designed for a load of 66 PE and consisted of a HF bed (216 m^2) planted with *Phragmites australis* followed by a FWS wetland (225 m^2). The systems organic load was 60 g COD m^{-2} d^{-1}. Despite fluctuating loads and cold climate the CW's removal rates were very good with more than 99% NH_4-N and 96% COD removal.

Foladori et al. (2012) investigated on another multi-stage CW treating wastewater of a community in the Italian Alps, with peak loads during the tourist period in summer. The system consisted of a VF bed (2.25 m^2) followed by a HF bed (4.5 m^2). Aim of the research was to find out whether the system, designed only on basis of the resident population, would be able to treat the additional load due to summer tourism without drastic loss of treatment efficiency or clogging problems. The resulting advantage would be a smaller land area requirement, which is a limiting factor especially in mountain regions. Two operational periods were considered; the first low-load period based on literature indications and the second high-load period with higher hydraulic and organic loads. For main parameters and removal rates during the two periods see Table 2-4.

Table 2-4 Main parameters and removal rates of a multi-stage CW in the Italian Alps (from Foladori et al., 2012)

Parameter	First low-load period (May-June 2010)	Second high-load period (July-August 2010)
Specific area (m^2/PE)	3.2	1.3
Specific organic load (g COD m^{-2} d^{-1})	37	87
Specific hydraulic load (L m^{-2} d^{-1})	55	123
Influent flow rate (L/d)	124	276
COD removal rate	93.7%	88.2%
NH_4-N removal rate	80.2%	68.8%.

The inflow rate and therefore the specific organic and hydraulic load were more than doubled during the high-load period, leading to a reduction in removal rates of 5.5% and 11.4% for COD and NH_4-N, respectively. These results suggest that it is possible to periodically apply higher peak loads on a multi-stage CW without a significant loss of treatment efficiency. One reason is that the HF stage helps the VF to remove COD, nitrogen and phosphorus during peak periods. There were no problems of clogging or plant growth observed (Foladori et al., 2012).

3. Material and Methods

3.1 General remarks

Parts of the section material and methods are based on the final report of "*Begleitende Untersuchungen zur praktischen Anwendung eines 2-stufigen bepflanzten Bodenfilters beim Gasthaus Bärenkogel*" by Langergraber et al. (2013). The status report describes the scientific research at the CW *Bärenkogelhaus* by the Institute of Sanitary Engineering and Water Pollution Control of the University of Natural Resources and Life Sciences, Vienna (BOKU). This master thesis is about this particular CW and therefore partly using the same material and methods. Hence, the research papers are partly overlapping and complement each other.

The operator of the inn *Bärenkogelhaus* built the two-stage VF CW in 2009. Since the two-stage design is not yet state of the art it only got a 3 year permit under the Water Act. In these 3 years the authority requested an extended treatment performance evaluation in order to gain a definite permit under the Water Act (WRG 1959, as amended).

In the course of the performance evaluations, the Institute of Sanitary Engineering conducted scientific researches on the CW of the *Bärenkogelhaus*, to gain fundamentals for the definite permit under the Water Act. Subsequently one could refer to the *precedent* to get a permit under the Water Act for a longer period of time. Therefore the project goals of the institute were set as follows:

1. sampling and analysis of influent and effluent concentrations over a period of 3 years;
2. raising the acceptance of the two-stage system and therefore making it easier to get a permit under the Water Act through scientific researches on a real-life system in the first years of operation; and
3. transfer the experiences into an acknowledged design standard to make the two-stage system state of the art.

The project started on 1 April 2010 and ended on 30 June 2013 with the following schedule:

1. April 2010 - June 2010: commissioning and start-up (3 months);
2. July 2010 - June 2013: routine operation with routine investigation (36 months);
3. **May 2011 - June 2013: special investigations as well as routine investigation (26 months);** and
4. April 2011, April 2012 and July and August 2013: status reports are written.

The master thesis mainly covers the special investigations phase, in particular the special investigations carried out from February until September 2012. During this time the inn was only open on demand for events. This so called "event operation" started in July 2011 after the tenant cancelled his contract at the end of 2010 (which ended the "full-time operation" with open days from Wednesday until Sunday). The mode of event operation resulted in long periods with low or no loads at all, interrupted by peak loads. The effect of the peak loads on the CW's performance was as well investigated during the special investigation period, by sampling five out of the total 17 events.

3.2 System description

3.2.1 General design

The CW is treating wastewater of the inn *Bärenkogelhaus* (Lechen 26, A-8682 Langenwang). The inn is situated about 116 km southwest from Vienna at an altitude of 1168 m above sea level in subalpine climate with high amounts of precipitation, many rainfall days, cold winters and warm summers (ZAMG, 2013).

The 70 seats and 16 beds of the inn were taken as design parameters for the dimensioning of the CW. The expected number of overnight stays was assumed to be quite few. At peak days, for example on Sundays and public holidays, it was expected that 70 hot meals would be sold. The water supply is provided by a house well. The daily average water demand was estimated to be around 2.500 L per day, based on the expected number of weekly served meals and the guest frequency. Based on this data and the dimensioning experience of the contractor (*Ökologisches Projekt*) the CW was designed for 40 PE with a surface area of 98.7 m² (each bed 49.35 m²), resulting in a specific surface area of 2.47 m² per PE (Ökologisches Projekt, 2009). Therefore, the CW is dimensioned for a specific organic load of 32.4 g COD m^{-2} d^{-1}.

The wastewater is first mechanically treated by a grease separator and a modified 3-chamber pit. The subsequent biological treatment is accomplished by a two-stage VF intermittently loaded CW (see Figure 3-1).

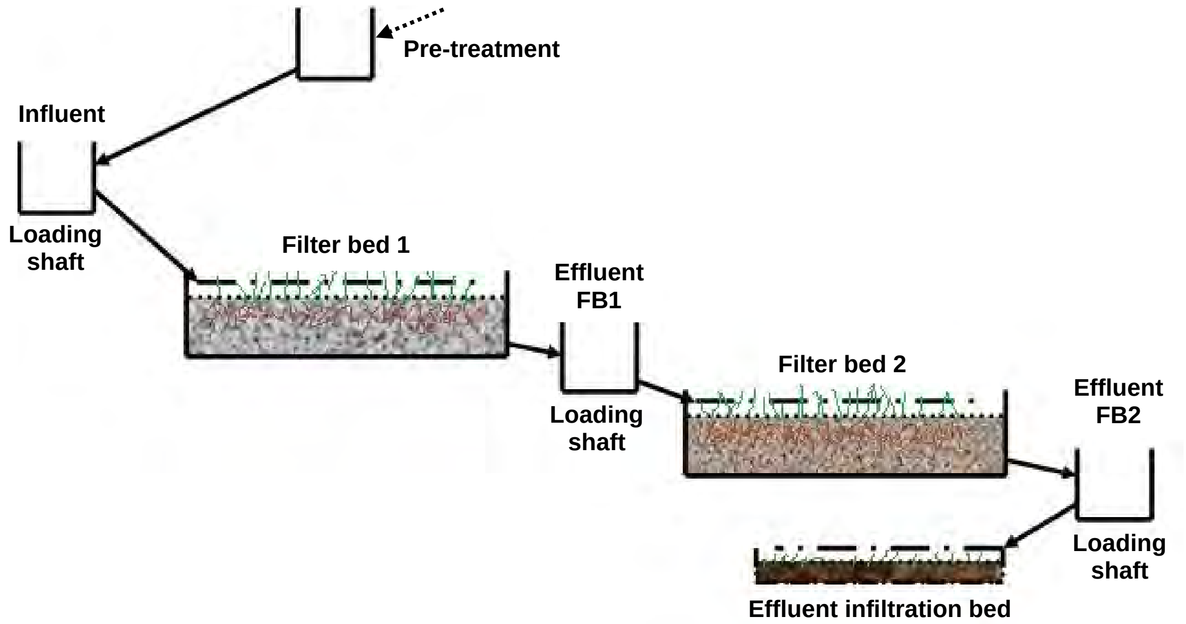

Figure 3-1 Scheme of the CW

The two stages, filter bed 1 (FB1) and filter bed 2 (FB2), are operated in series. For plans of the two filter beds and the location of the CW system and the inn see Appendix I. Both beds are planted with common reed (*Phragmites australis*). The biologically treated wastewater is then lead to an effluent infiltration bed (EIB). The treatment steps are described more thoroughly in the following subsections 3.2.2 and 3.2.3.

3.2.2 Mechanical pre-treatment

Mechanical pre-treatment reduces suspended and solid matter in the wastewater and is a necessary premise for biological treatment. Further on, kitchen wastewater is collected in a grease separator. The degreased wastewater is then led to the first pre-treatment chamber (corresponds to the "first chamber" of a 3-chamber-pit), which also receives greywater from other sources such as sinks or showers as well as blackwater from toilets. Downstream, a commercial 3-chamber-pit was refitted to a buffer for temporary weekend peaks (see Figure 3-2).

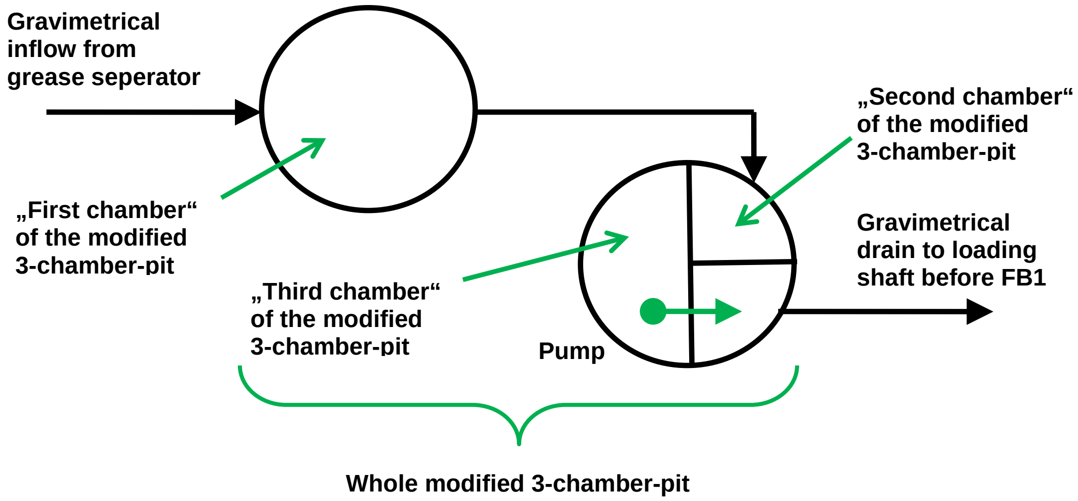

Figure 3-2 Scheme of the modified 3-chamber pit (after Langergraber et al., 2013)

The second chamber of the 3-chamber-pit (corresponds to the "third chamber") is equipped with a submersible sewage pump which is controlled by a floating device and a relay in such a way that it lifts a defined amount of wastewater (around 100 L) into the third chamber of the 3-chamber-pit. The relay enables the pump to work only for around two minutes per hour and only if the installed floating device is lifted up by collected wastewater. If these conditions (two minute period and floating device up) are fulfilled, the pump starts and lifts wastewater into the third chamber of the 3-chamber pit (Ökologisches Projekt, 2009). In this way the floating device keeps the pump from dry running and the time-controlled relay allows mixing of the wastewater before it is pumped into the last chamber, from where it flows gravimetrically to the loading shaft before FB1.

3.2.3 Biological secondary treatment

The wastewater from the pre-treatment is collected in the loading shaft before FB1 until it is intermittently loaded onto FB1. Aboveground perforated pipes (DN 50 with 8 mm holes) distribute the wastewater over the whole bed surface from where it evenly floods the bed and infiltrates vertically through the substrate. The perforated pipes are mounted on concrete blocks to keep them from clogging and to provide an air layer between the pipes and the bed surface for better oxygen supply (Ökologisches Projekt, 2009).

After passing through FB1 the partly biologically treated wastewater is drained and collected in the loading shaft between FB1 and FB2 before it is likewise intermittently loaded to FB2 (see Figure 3-3).

Figure 3-3 FB2 in the foreground and parts of the EIB on the right (May 2012)

After passing through FB2 the biologically treated wastewater is again drained and collected in a smaller loading shaft which intermittently loads to the EIB. The EIB is opened down slope and protected by a damn on the remaining three sides. There is no receiving water nearby, the EIB is not situated in a water protection or conservation area and there are no water supply facilities within a radius of 300 m. Therefore, the CW got a permit to infiltrate the treated wastewater into the subsoil below the EIB (Ökologisches Projekt, 2009).

The ground below FB1 and FB2 is flattened with fine sand and covered with an unwelded waterproofing sheet (1.5 mm PE-HD DB I) (Ökologisches Projekt, 2009). The compositions of the filter beds and the EIB are summarized in Table 3-1:

Table 3-1 Composition of filter beds and effluent infiltration bed

	FB1	**FB2**	**EIB**
Top layer	10 cm gravel 4-8 mm	10 cm gravel 4-8 mm	3 cm gravel 4-8 mm
Main layer	50 cm sand 2-4 mm	50 cm sand 0-4 mm	50 cm sand 0-4 mm
Drainage layer	20 cm gravel 8-16 mm	20 cm gravel 8-16 mm	-

The height of impoundment of the drainage layers of FB1 and FB2 can be adjusted (Ökologisches Projekt, 2009). The benefits from these particular compositions of the filter beds and t he impoundment as well as the special role of the intermittent loading are explained in the following subsections.

Filter bed 1

The main layer of FB1 has a coarser grain size than FB2 or a single-stage VF CW according to ÖNORM B 2505 (2009). This has several benefits in connection to the two-stage design. Due to the coarser grain size, FB1 is able to receive higher hydraulic loads, and organic matter is only partly removed, sparing some organic matter for denitrification later on. However, some nitrification is taking place anyway already in the main layer of FB1. Another important feature of the two-stage VF CW is the impounded drainage layer in FB1, which is set to a height of 25 to 30 cm. The impoundment provides an anoxic environment, which is needed for denitrification. Altogether the needed requirements for denitrification in FB1 are provided:

- Organic matter not completely degraded due to coarser grain sizes in the main layer;
- nitrate through nitrification in the main layer;
- anoxic conditions through impoundment of the drainage layer; and
- high retention time due to impounded drainage layer.

Filter bed 2

The main layer of FB2 has the same grain size as used for single stage CWs according to ÖNORM B 2505 (2009). The purpose of FB2 is full nitrification and removal of remaining organic matter. It also serves as a safety stage in case there are problems with FB1. The drainage layer of FB2 is not impounded.

Intermittent loading

A load from the loading shafts onto the filter beds occurs when the water level in the shaft reaches a defined height and is able to flow into a flexible pipe. Due to the weight of the entering wastewater, the flexible pipe bends down like an arm until a chain takes hold of it, enabling a certain amount of wastewater (around 541 L) to rapidly flow down to the distribution pipes of FB1 or FB2, respectively.

It is important to notice that the intermittent loading contributes greatly to the oxygen supply of the FBs and therefore the system's treatment performance. Aerobe MOs need oxygen for their metabolism as well as for decomposition of OM and nitrification of NH_4-N.

An intermittent loading rapidly floods the entire FB surface and infiltrates through the pores vertically downwards in a more or less even layer until it is collected in the bottom drainage layer. After a loading occurs a time gap of at least 5 hours allows atmospheric oxygen to enter the FB's pores before it is tapped by the next loading (Langergraber and Haberl, 2001). In intermittently loaded VF CWs with loading rates as low as at the *Bärenkogelhaus,* the dominant oxygen renewal process within the FB media is diffusion, mainly in the upper parts of the FB. Therefore the main bacterial activity is observed in the first few centimetres of the VF FBs (Petitjean et al., 2011).

3.3 Investigation program and sampling

3.3.1 Routine investigations

3.3.1.1 Routine sampling

Samples were taken throughout the project from July 2010 until June 2013 (36 months) from three sampling points:

1. influent = loading shaft before FB1;
2. effluent FB1 = loading shaft between FB1 and FB2; and
3. effluent FB2 = loading shaft after FB2.

Samples were taken alternately every second week by the operator and staff from the Institute of Sanitary Engineering. At the beginning of the investigation in 2010, the inn had closing days on Mondays and Tuesdays. Therefore sampling days where planned on Mondays, right after the expected peak load on weekends, in order to investigate the CW's performance under highest possible loads.

Further on, a checklist was developed to document the sampling by the operator and the institute. This checklist was updated in 2012 (see Appendix II). The checklist was filled in by the operator or staff while sampling, and afterwards collected by the institute.

3.3.1.2 On-line measurement

The following parameters were measured on-line and recorded by loggers:

- water consumption and wastewater volume (influent flow);
- temperature in influent and effluent FB2;
- air temperature; and
- bed temperatures in FB1, FB2 and EIB.

The data was read from the loggers by the institute's staff when visiting the CW. During special investigations further parameters were measured on-line.

3.3.2 Special investigations

3.3.2.1 Event sampling

The aim was to investigate the CW's performance under peak loads. Therefore event samplings were conducted during some of the events (sampled events) on the Bärenkogel, as shown in Table 3-2.

Table 3-2 Sampled events

Date	Sampled event #	Event
19.02.2012	1	Banquet
16.06.2012	2	Concert
23.06.2012	3	Wedding
28.07.2012	4	Wedding
09.09.2012	5	Traditional fair

During event samplings, influent and effluent samples were taken with automatic samplers (ISCO 6700) over a pe riod of six days. The automatic sampler contained 24 one-litre sample bottles and was programmed to take a sample every three hours for six days.

For the first event sampling of event 1 in February 2012, thermally insulated boxes were constructed for the automatic samplers (see Figure 3-4) and equipped with heating cables, in order to prevent samples, hoses or wetted parts of the automatic samplers from freezing. During event 1 only the influent of FB1 and effluent of FB2 were sampled. Starting from event 2, samples were taken from the influent and effluent of FB1 as well as the effluent of FB2. Starting from 27 July 2012 (before event 4) effluent FB1 samples for event sampling are taken from a bucket which was fitted onto the effluent hose of FB1 instead of taking the samples from the loading shaft after FB1 (see Figure 3-5).

Figure 3-4 Thermally insulated box for automatic sampler sampling effluent FB2

Figure 3-5 Sampling of effluent FB1 from a bucket (white suction hose belongs to automatic sampler)

This way, the recent effluent from FB1 mixes with less water before it gets sampled, since the buckets volume (ca. 10 L) is much smaller than the loading shaft's.

3.3.2.2 Tracer tests

Two tracer tests were conducted in May and June 2012, in order to simulate the movement and retention of wastewater and pollutants through the CW system. The tracer substance used was potassium chloride (KCl) dissolved in water. The tracer concentration in the CW system was measured with electrical conductivity (EC) measurement devices in influent and effluent shafts of FB1 (see Figure 3-7) and FB2. EC is a material's ability to conduct an electric current. KCl is very conductive and therefore qualified as a tracing substance for the tracer tests. Flow was measured through magneto-inductive flow meters (MIDs) in effluent FB1 (see Figure 3-7) and FB2. EC and flow measurements had an interval of 90 seconds. Each tracer test lasted over a period of around eight days. From these measurements, the mean residence time (MRT) and recovery rate (RR) of the tracers could be calculated.

For each test, KCl was mixed with 580 L of water in a tank (1 m^3 volume), which was set up around four meters uphill from the loading shaft before FB1. The tracer solution was mixed in a way that it reached an EC of 5 mS/cm or 10.1 mS/cm for the first and second test, respectively (see Table 3-3). A pipe was laid from the tank directly into the flexible pipe of the loading shaft before FB1 (see Figure 3-6), in order to simulate a rapid loading of 580 L, similarly to a normally occurring loading.

Figure 3-6 Pipe loading the tracer from the tank rapidly into the flexible pipe before FB1

Figure 3-7 Measurement devices for flow (MID underneath black protective plastic cover) and EC (in U-shaped pipe) of effluent FB1

During the tracer tests a constant flow was ensured by feeding the system with a constant controlled tap water flow of 1.0 L/min or 1.5 L/min during the first and second test, respectively (see Table 3-3). This way a loading should be triggered every five to ten hours, in order to push the tracer through the system.

Table 3-3 Parameters for both tracer tests in May 2012

	Initial rapid load (L)	Constant controlled tap flow (L/min)	EC tracer pulse (mS/cm)	background EC in water at start of experiment (mS/cm)
First tracer test	580	1.0	5.0	0.040
Second tracer test	580	1.5	10.1	0.044

As shown in Table 3-3, it was decided after the first tracer test to alter the EC in the initial rapid load, in order to get more distinct variances from the measurements. The constant controlled tap water flow was adjusted due to the observed loading frequency during the first tracer test.

The analysis of the recorded data was done with Microsoft Excel 2010. Both measured parameters (EC and flow) had to be adj usted and smoothened. The EC data was quite noisy because the wetland acts as an electrical conductor. The transmitters in the devices interfered with each other, due to the application of EC measurement devices in the same medium.

In order to calculate the additional EC due t o the applied tracer, a background EC was needed for comparison. Therefore, for each tracer test a straight base line was fitted as a background EC for the measured EC, as seen in Figure 3-8 for the second tracer test.

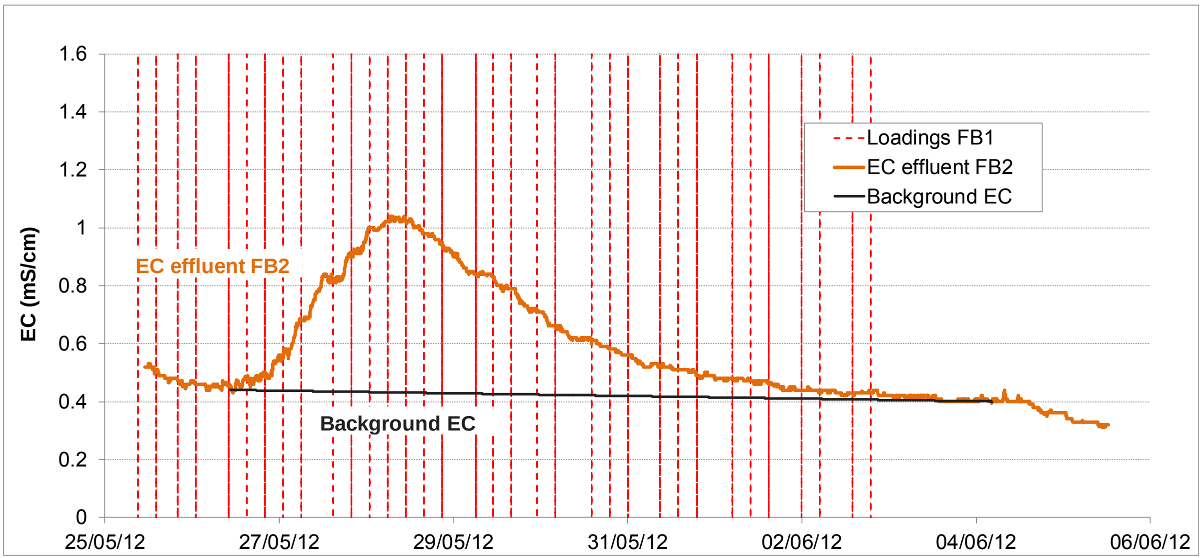

Figure 3-8 EC of effluent FB2 with fitted background EC during the second tracer test

The straight base lines were created from the beginning until the end of each tracer test, in order to determine the additional EC in consequence of the tracer. The tracer's (MRT) and (RR) could be calculated from the adjusted data (sum graph of additional EC times outflow quantity) for FB1 alone and the whole system.

The MRT is the time between the tracer's application and when 50% of the tracer (i.e. half of additional EC times outflow quantity) reached effluent FB1 (for FB1 alone) or effluent FB2 (for the whole system), respectively. Therefore, the 50% refer to the totally measured tracer at the effluent (additional EC times outflow quantity) as 100%, not to the initially applied tracer.

The RR is the percentage of the tracer mass that is detected at the outflow of the system at the end of the tracer test (i.e. additional EC times outflow quantity) at effluent FB1 and FB2, respectively, compared to how much initially entered the system (i.e. tank of 580 L times 5 or 10.1 mS/cm, for first and second tracer, respectively).

3.4 Sample analysis

The following parameters were analysed for routine samples:

- Suspended solids (SS)
- Biochemical oxygen demand in 5 days (BOD_5)
- Chemical oxygen demand (COD)
- Ammonium-Nitrogen (NH_4-N)
- Nitrate-Nitrogen (NO_3-N)
- Nitrite-Nitrogen (NO_2-N)
- Total nitrogen (TN)

Only COD and NH_4-N influent and e ffluent concentrations were analyzed during event samplings. These two parameters are most significant in order to investigate the system's treatment performance under peak loads, and Austria has stringent effluent thresholds regarding nitrification as well as organic matter concentrations (see Table 3-4). Also, the high number of samples, taken by the automatic samplers, required a reduction of analyzed parameters.

Table 3-4 Effluent concentration thresholds in Austria for WWTPs with capacities between 50 - 500 PE (from 1.AEVkA, 1996)

Parameter	**Maximum effluent concentration** (mg/L)
BOD_5	25
COD	90
NH_4-N	10

The used analysis methods are summarized in Table 3-5:

Table 3-5 Analysis methods (Langergraber et al., 2013)

Parameter	**Analysis method**
Suspended solids (SS)	DIN 38409 H2
Biochemical oxygen demand in 5 days (BOD_5)	DIN H51 / EN 1899-1
Chemical oxygen demand (COD) *	DIN 38409 H41
Ammonium-Nitrogen (NH_4-N)	DIN 38406 E5-1
Nitrite-Nitrogen (NO_2-N)	EN 26777 D10
Nitrate-Nitrogen (NO_3-N)	DIN D19/EN ISO 10304
Kjehldal-Nitrogen (TKN)	DIN EN 25663
Organic nitrogen (N_{org})	Difference between TKN and NH_4-N
Total nitrogen (TN)	Sum of NH_4-N, NO_2-N, NO_3-N & N_{org}

* Limit of determination 20 mg/L (until June 2011) resp. 10 mg/l (from July 2011).

During each routine investigation, on-site measurements were conducted. Samples from each sample point (influent, effluent FB1 and effluent FB2) were immediately analysed on-site, in order to minimise environmental influences (e.g. temperature change, oxygenation). The following on-site parameters were measured:

- pH
- redox potential
- EC
- oxygen content
- water temperature

All taken samples were analysed in the laboratory of the Institute of Sanitary Engineering and Water Pollution Control at BOKU, Vienna.

3.5 Data analysis and evaluation

The respective median was taken to compare the influent and effluent concentrations. The median (50%-value) is the numerical value, which is exactly in the middle of a statistical series, separating the higher and the lower half of a sample.

For measured concentrations which are below the limit of determination, the limit itself is assumed as calculation value for statistical parameters.

The analysis of the recorded data was done with Microsoft Excel 2010.

The hydraulic load in per cent of the design load and in mm/d was calculated using Equations (1) and (2), respectively, while Equation (3) was used for the organic load:

$$hydraulic\ load = \frac{(n_{loading} - 1) * V_{loading}}{(t_{loading}[n] - t_{loading}[1]) * V_{consumption}}\ (\%) \tag{1}$$

with

$n_{loading}$	number of loadings in the period of evaluation
$t_{loading}$	time and date when a loading occurred
$V_{loading}$	volume of water per loading in L; median Volume from all recorded loadings, calculated from the data of the water level logger (541 L)
$V_{consumption}$	volume of water consumption per day in L; estimated for the dimensioning of the CW (design load of 2500 L/d)

$$hydraulic\ load = \frac{(n_{loading} - 1) * V_{loading}}{(t_{loading}[n] - t_{loading}[1]) * A_{area}}\ (mm/d) \tag{2}$$

with

A_{area}	Area of the CW's filter beds; each bed has 49.35 m², resulting in a total area of 98.7 m² (Ökologisches Projekt, 2009)

$$organic\ load = \frac{(n_{loading} - 1) * COD * V_{loading}}{1000 * (t_{loading}[n] - t_{loading}[1]) * A_{area}}\ (COD \cdot m^{-2} \cdot d^{-1}) \tag{3}$$

with

COD	COD concentration

In all formulas the number of loadings ($n_{loading}$) is subtracted by one, because the timespan ($t_{end} – t_{start}$; time difference between last and first loading) does not take into account the time period before the first recorded loading. Therefore the first loading must not be taken into account for the number of loadings either, when calculating hydraulic or organic load.

The time and date when a loading occurred ($t_{loading}$) was derived from an on-line influent flow measurement device in the loading shaft before FB1, installed by the Institute of Sanitary Engineering. The building contractor measured the effluent water volume with a tipping bucket, whereas the number of impulses triggered has been recorded. Due to bouncing of the tipping bucket the recorded number of loadings was not accurate and had to be corrected manually. Therefore, a set of rules was developed in order to identify the real loadings in the contractor's data as far as possible. This was done by comparing loading records during times when both, the institute's and the contractor's measurement devices, were working. The following rules for using data of the contractor were elaborated from the comparison:

- If the time difference between two successive loading records is equal or higher than five hours, both loadings are classified as real loadings.
- If the time difference between two successive loading records is smaller than five hours, only the first loading is classified as a real loading and the second one is not.
- If another loading occurs less than five hours after the ignored loading record, this loading record might be classified as a real loading, provided that the time difference to the previously classified real loading is equal or higher than five hours. Therefore the time difference to the last loading which is classified as a real loading counts.

The time interval of five hours was chosen due to the sewage pump configuration in the second chamber of the 3-chamber-pit (corresponds to the "third chamber"). Every hour around 100 L of wastewater can be pumped at most into the third chamber from where it gravimetrically flows into the loading shaft before FB1. Therefore it takes at least five hours with five times of pumping until enough wastewater is collected to trigger a loading onto FB1 of the CW.

The applied rules were initially tested on months where reliable data of the institute's and contractor's measurement devices exist (January until middle of June 2012). The number of loadings per month classified as real loadings from the contractor's data matched in a range of plus minus 10% with the real loadings from BOKU data. Only one out of six months was overestimated by 29%.

However, this method cannot identify false loadings which originate from the contractor's measurements due to a bouncing of the tipping bucket that occurred more than five hours late.

4. Results

4.1 General remarks

4.1.1 Data gaps of on-line measurements

During a storm at the end of April 2011, a lightning strike the wetland and destroyed the data logger for measuring the influent flow. Therefore, there are no on-line influent flow measurements between 28 April and 07 June 2011. Only after starting up the measurements again in June 2011 it became apparent that the lightning strike also damaged the electronics of the temperature measurement and destroyed some temperature sensors. On-line temperature measurements were available again from October 2011. The temperature sensors in the EIB were taken out of operation in March 2012, in order to replace the defect temperature sensors in FB1 and FB2. Due to another strike of lightning in June 2012 the measurement electronic was destroyed a second time. After that it was decided to only leave the on-line influent flow measurement in operation (starting from 22 October 2012). The temperature logger was not replaced anymore.

During the outage of the on-line influent flow measurement, the loadings onto FB1 - during the period of event operation from July 2011 until September 2012 - were reconstructed from other sources (see Table 4-1).

Table 4-1 Sources of loadings times during event operation

Source	Number of loadings
Influent flow measurement (institute)	235
Tipping bucket (contractor)	120
Interpreted from MID's water volume data	6
Observed during samplings	2
Total	**363**

Out of a total of 363 loadings during event operation, 120 loadings had to be interpreted (as described in section 3.5) from data of the contractor's tipping bucket effluent flow measurements. Six loadings were interpreted from the wastewater flow recorded by the MIDs. Two loadings were proven to be real due to direct observations. Therefore, 235 loadings were derived from the institute's on-line influent flow measurement device while it was operative.

4.1.2 Impact of disturbed periods on hydraulic and organic load

The following incidents during event operation led to "disturbed periods" (i.e. too many loadings and/or too low influent concentrations) at the CW Bärenkogel:

- water boiler installation (August 2011);
- exchange of second water tank (September 2011);
- cleansing of grease separator and collector shaft (November and December 2011);
- running water tap (February 2012); and
- first and second tracer test (May and June 2012).

Sample concentrations and inflow measurements (i.e. loading times), which were needed for the calculation of hydraulic and organic loads, were altered (i.e. additional loadings, lower concentrations) through these incidents and therefore had to be considered in the analysis; hydraulic loads were calculated with and without loadings during disturbed periods, respectively and organic loads were based on sampled COD concentrations with and without disturbed periods, respectively. The organic load is also dependent on the hydraulic load and different COD samplings (i.e. routine samplings alone or combined with event samplings). The hydraulically and organically disturbed periods differ slightly because hydraulic measurements (i.e. loading times and influent flow) were affected more directly because the additional volume more or less just pushed the amount of wastewater through the pre-treatment, leading to an immediate effect. The COD concentrations and therefore the organic load on the other hand were affected after a short delay but for longer periods, since the wastewater has to move through the pre-treatment chambers and gets mixed and buffered.

4.2 Routine investigation

4.2.1 Loadings, hydraulic load and loading intervals

Table 4-2 shows loadings in undisturbed and disturbed periods, influent flow and hydraulic load (in mm/d and % of the design load) during event operation from July 2011 until September 2012. Values which include loadings in disturbed periods are shown in brackets. A loading volume of 541 L was used for the calculation of influent flow and hydraulic load. This volume is derived from the geometry of the loading shaft and analysis of measured water levels in the loading shaft.

Table 4-2 Number of loadings, influent flow and hydraulic load per month with and without loadings in disturbed periods from July 2011 until September 2012 (values including loadings in disturbed periods are in brackets)

Year	Month	**Loadings** (#)	**Influent flow** (L)	**Hydraulic load** (mm/d)	**Hydraulic load** (%)
2011	July	11	5 950	1.9	8
	August	53 (57)	28 668 (30 832)	9.4 (10.1)	37 (40)
	September	9 (11)	4 868 (5 950)	1.6 (2.0)	6 (8)
	October	6	3 245	1.1	4
	November	4	2 164	0.7	3
	December	14	7 573	2.5	10
2012	January	13	7 032	2.3	9
	February	10 (30)	5 409 (16 227)	1.9 (5.7)	7 (22)
	March	14	7 573	2.5	10
	April	14	7 573	2.6	10
	May	11 (57)	5 950 (30 832)	1.9 (10.1)	8 (40)
	June	28 (35)	15 146 (18 932)	5.1 (6.4)	20 (25)
	July	28	15 146	5.0	20
	August	37	20 014	6.5	26
	September	32	17 309	5.8	23
Whole period		**284** (363)	**153 620** (196 352)	**3.4** (4.3)	**13** (17)

The average hydraulic load with and without loadings in disturbed periods was 4.3 mm/d (i.e. 17% of the design load) and 3.4 mm/d (i.e. 13% of the design load). The lowest monthly average hydraulic load of 0.7 mm/d (i.e. 3% of the design load) was measured in November 2011. The highest undisturbed monthly average hydraulic load of 9.4 mm/d (i.e. 37% of the design load) was measured in August 2011.

Disturbed periods were caused by the first and second tracer test in May and June 2012, which lead to around 20 and 30 additional loadings, respectively. Another 20, 4 and 2 loadings occurred due to a running water tap in February 2012, a boiler exchange in September 2011 and a tank exchange in August 2011, respectively.

Figure 4-1 shows the distribution of loading intervals during event operation (without loadings in disturbed periods); separately for loadings during periods of sampled events, other events and no events. Measured loading intervals were assigned to the closest group of intervals in the figure. For example, the group with a 5 h interval includes loading intervals from 4.5 up to 5.5 hours and the group with a 48 hour interval includes loading intervals from 42 up to 54 hours. As an exception, the group >96 h includes loading intervals from 96.5 h upwards.

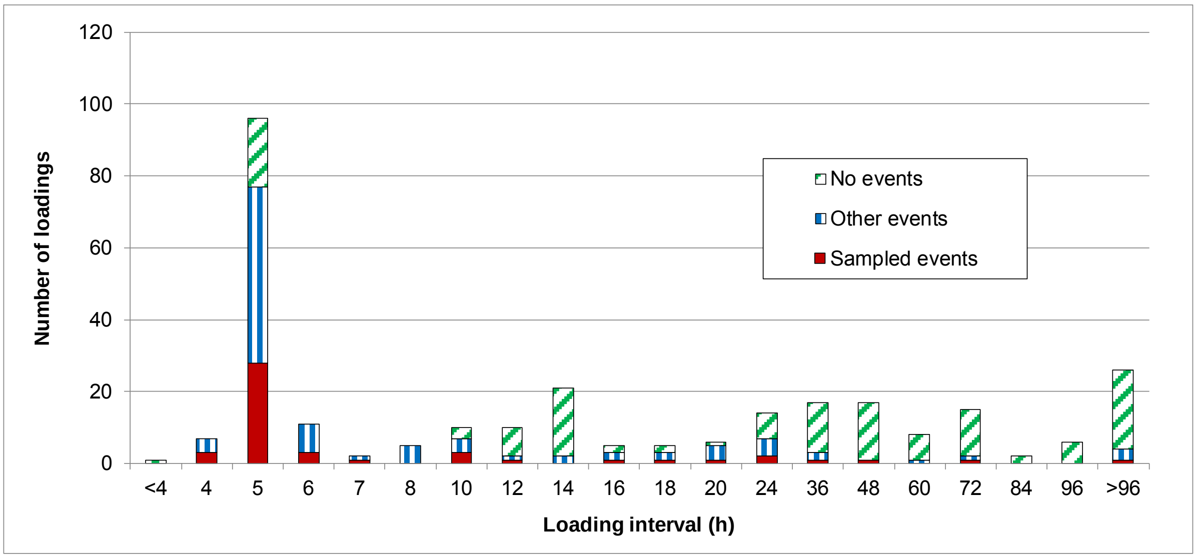

Figure 4-1 Distribution of loading intervals (without loadings in disturbed periods), separated into loadings during sampled events, other events and no events (July 2011 until September 2012)

During periods with no events, a loading interval of bigger than 96 h (4 days) was the most common, with 22 out of 142 loadings. The 5 h interval is the most common during sampled events and other events with 28 out of 48 and 49 out of 94 loadings, respectively. The 5 h interval is most common due to the setup of the sewage pump in the mechanical treatment and the flexible loading arm in the loading shaft before FB1. The second most common number of loadings during sampled events amounted only 3 times, for intervals of 4, 6 and 10 h, respectively.

The 8 loadings with an interval smaller than 5 hours may be triggered by hand, due to maintenance work or were wrongly interpreted from recorded data.

4.2.2 Routine sampling

4.2.2.1 Influent concentrations and measured organic loads

Table 4-3 shows influent concentrations only from the 21 routine samplings during event operation from July 2011 until September 2012. Therefore results from event samplings are not included. Results from event and routine samplings combined are separately presented in Table 4-8.

Table 4-3 Influent concentrations (mg/L) from routine samplings

Parameter	TSS	BOD_5	COD	NH_4-N	NO_2-N	NO_3-N	N_{org}	TN
Number of samples	21	21	21	21	21 (2*)	21 (19*)	21	21
Median	**60**	**143**	**294**	**38.5**	**0.005**	**<0.1**	**6.3**	**46.7**
Mean	66	144	301	39.0	0.009	<0.1	11.5	50.6
Standard deviation	40	95	174	22.6	0.013	<0.1	15.8	25.9
95% Confidence int.	17	41	75	9.7	0.000	<0.1	6.7	11.1
Maximum	162	352	720	84.8	0.062	0.1	66.3	103.6
Minimum	15	17	71	12.8	0.003	<0.1	1.1	16.2

* Number of analysis below detection limit (0.003 mg NO_2-N/L and 0.1 mg NO_3-N/L, respectively)

The median COD influent concentration of 294 mg/L is based on measured COD concentrations from routine samplings during event operation. Together with a hydraulic load of 3.4 mm/d (without disturbed periods, see section 4.1) or 4.3 mm/d (with disturbed periods) the specific organic load results in 1.0 g COD m^{-2} d^{-1} or 1.3 g COD m^{-2} d^{-1}, respectively (see also Table 4-10).

4.2.2.2 Effluent concentrations and treatment performance

Figure 4-2 to Figure 4-8 show influent and effluent concentrations of BOD_5, COD, NH_4-N and TN from the 21 routine samplings during event operation from July 2011 until September 2012. BOD_5, COD and NH_4-N concentrations are also shown in a logarithmic scale of the vertical axis in order to better express the low effluent concentrations.

The effluent concentration thresholds according to Austrian law for WWTPs with capacities between 50 - 500 PE (1.AEVkA, 1996) of 25 mg BOD_5/L, 90 mg COD/L and 10 mg NH_4-N/L are shown as red horizontal lines in the Figure 4-2 to Figure 4-7. The maximum ammonia N effluent concentration of 10 mg NH_4-N/L has to be met when wastewater temperatures are above 12°C, therefore Figure 4-6 shows also effluent water temperatures on the secondary vertical axis. Figure 4-6 and Figure 4-7 show periods with effluent water temperatures above 12°C shaded.

Figure 4-2 shows BOD_5 influent and effluent concentrations from July 2011 until September 2012, Figure 4-3 shows the same in a logarithmic scale. All measured BOD_5 effluent FB2 concentrations were below the detection limit of 3 mg BOD_5/L during event operation, and thereby below the threshold of 25 mg BOD_5/L.

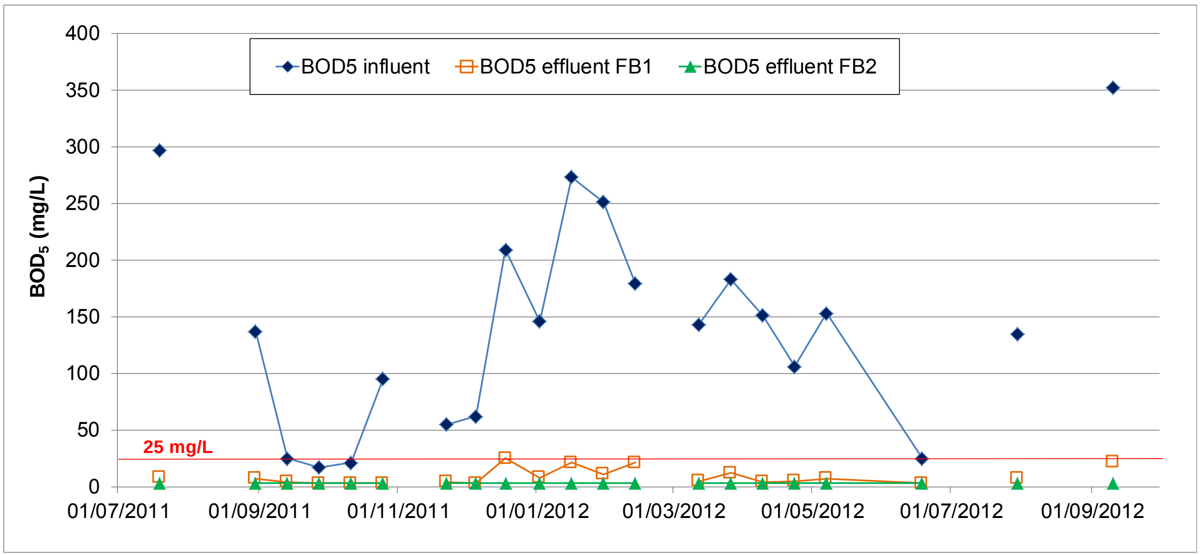

Figure 4-2 BOD_5 influent and effluent concentrations

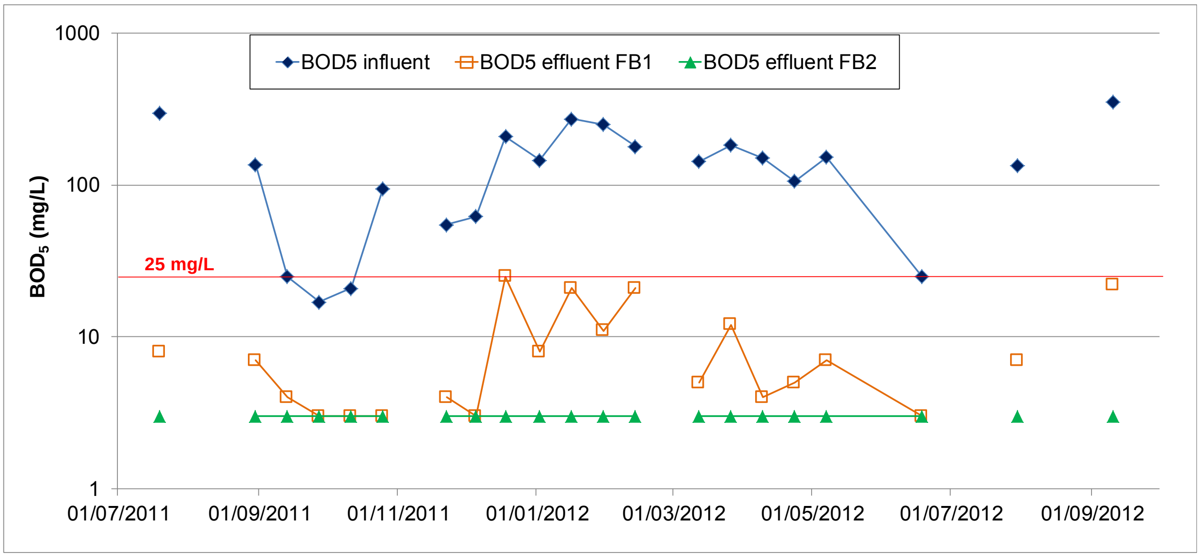

Figure 4-3 BOD_5 influent and effluent concentrations (logarithmic scale)

Figure 4-4 shows COD influent and effluent concentrations from July 2011 until September 2012, Figure 4-5 shows the same in a logarithmic scale. COD effluent FB2 concentrations were not higher than 24 mg COD/L and thereby below the threshold of 90 mg COD/L.

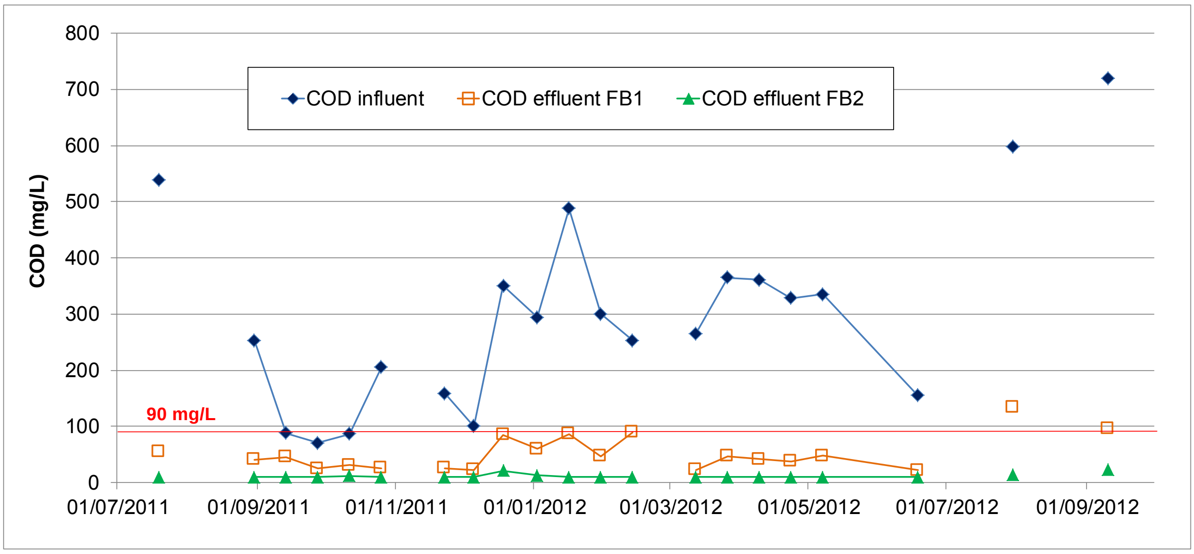

Figure 4-4 COD influent and effluent concentrations

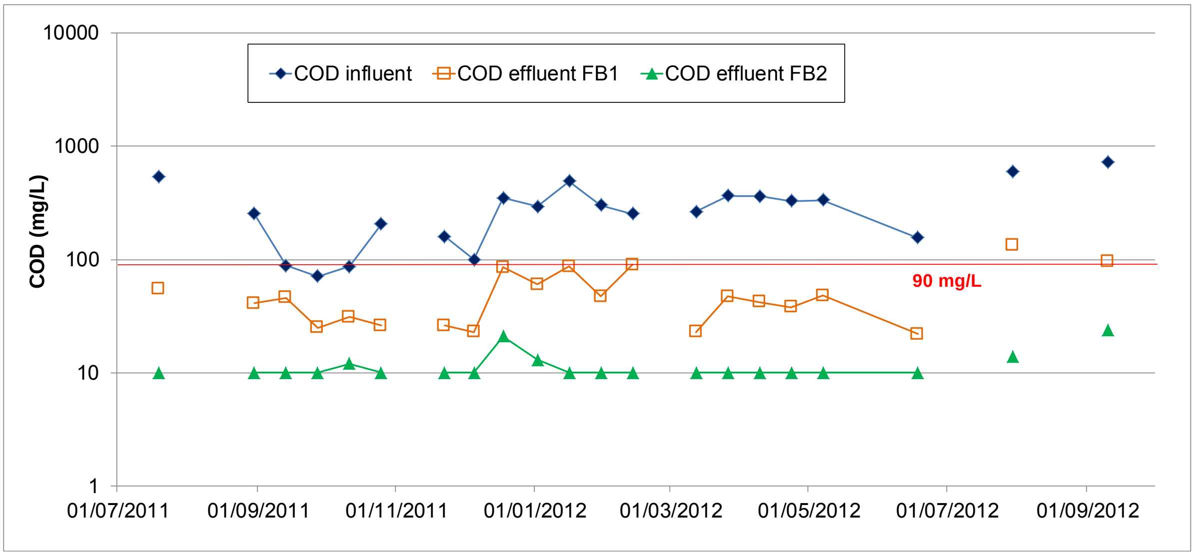

Figure 4-5 COD influent and effluent concentrations (logarithmic scale)

Figure 4-6 shows NH_4-N influent and e ffluent concentrations from July 2011 until September 2012, Figure 4-7 shows the same in a logarithmic scale. Effluent water temperatures below 12°C were measured between 22 November 2011 and 23 April 2012 during event operation. All NH_4-N effluent FB2 concentrations were below the threshold of 10 mg NH_4-N/L.

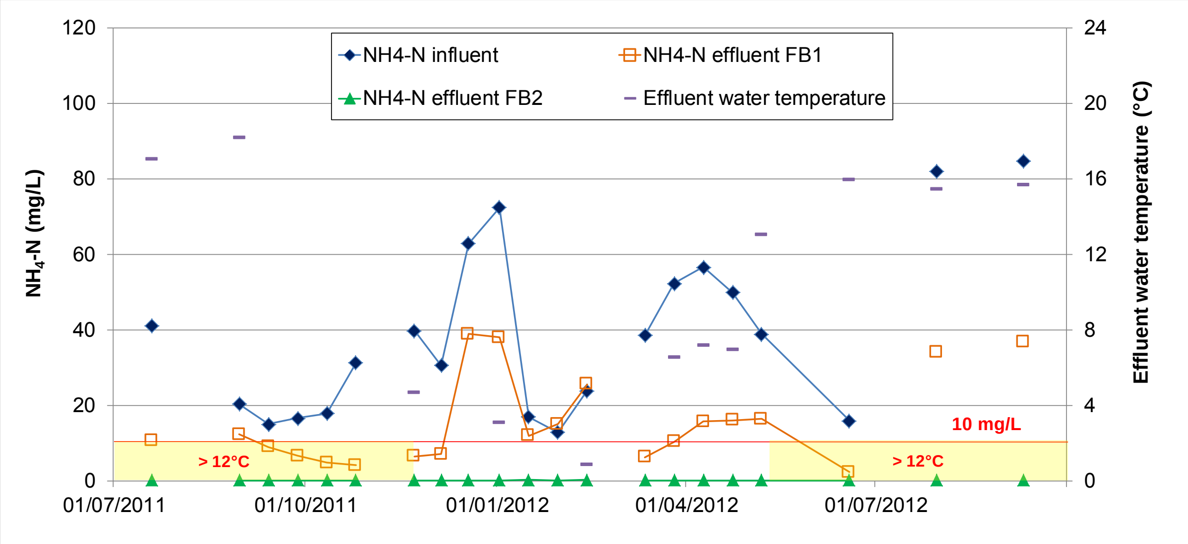

Figure 4-6 NH_4-N influent and effluent concentrations

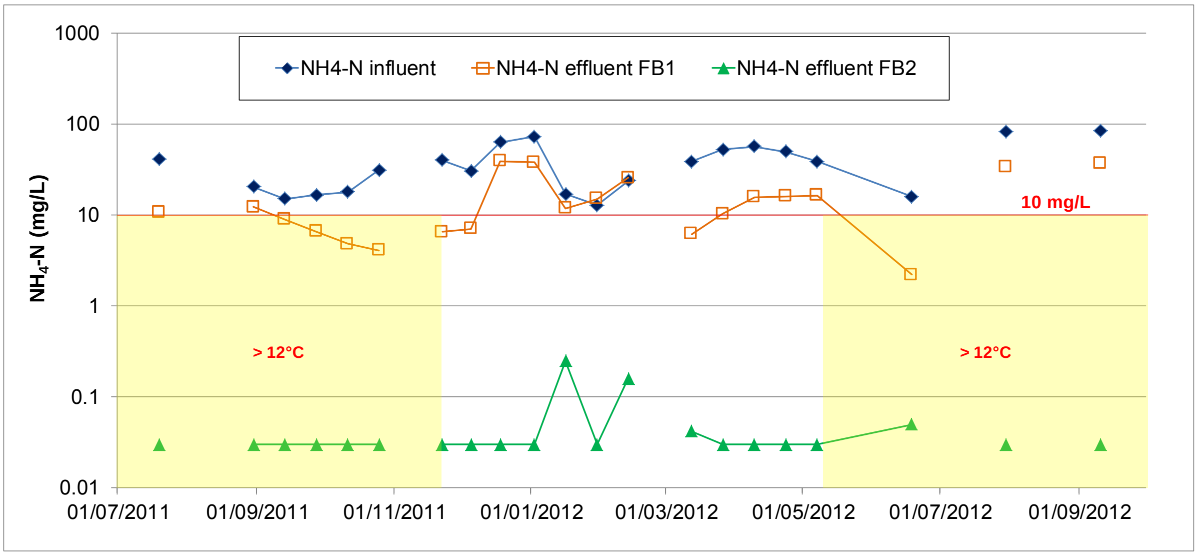

Figure 4-7 NH_4-N influent and effluent concentrations (logarithmic scale)

Figure 4-8 shows TN influent and effluent concentrations from July 2011 until September 2012.

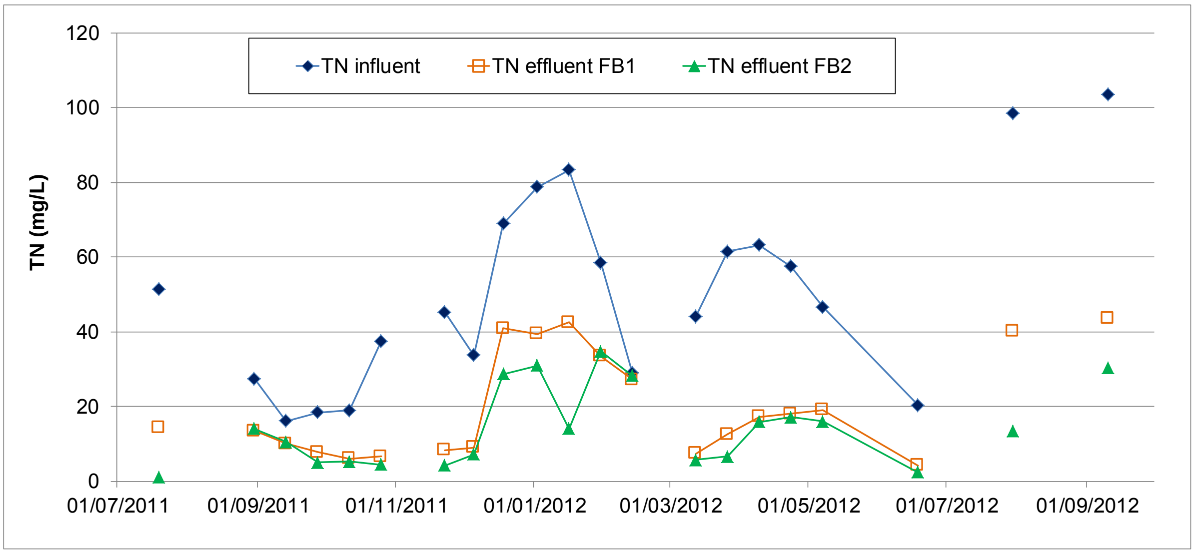

Figure 4-8 TN influent and effluent concentrations

Table 4-4 and Table 4-5 show effluent FB1 and FB2 concentrations, respectively, from routine samplings during event operation from July 2011 until September 2012. Table 4-6 shows the treatment performance of FB1 and the whole system based on routine samplings.

Table 4-4 Effluent FB1 concentrations (mg/L) from routine sampling

Parameter	**TSS**	**BOD_5**	**COD**	**NH_4-N**	**NO_2-N**	**NO_3-N**	**N_{org}**	**TN**
Number of samples	21	21 (3*)	21	21	21	21 (5*)	21 (5*)	21
Median	**10**	**7**	**46**	**11.9**	**0.056**	**0.2**	**1.4**	**14.4**
Mean	28	9	52	15.6	0.080	0.4	4.1	20.1
Standard deviation	36	7	30	11.8	0.070	0.3	7.2	14.0
95% Confidence int.	15	3	13	5.1	0.030	<0.1	3.1	6.0
Maximum	103	25	134	38.9	0.270	1.2	30.5	43.7
Minimum	2	3	22	2.2	0.004	<0.1	1.0	4.2

* Number of analysis below detection limit (3 mg BOD_5/L, 0.1 mg NO_3-N/L and 0.1 mg N_{org}/L, respectively)

Table 4-5 Effluent FB2 concentrations (mg/L) from routine sampling

Parameter	**TSS**	**BOD_5**	**COD**	**NH_4-N**	**NO_2-N**	**NO_3-N**	**N_{org}**	**TN**
Number of samples	21 (6*)	21**	21 (14*)	21 (13*)	21 (10*)	21 (1*)	21 (8*)	21
Median	**2**	**<3**	**10**	**0.03**	**0.004**	**11.6**	**1.0**	**13.5**
Mean	9	<3	12	0.05	0.024	12.8	1.3	14.2
Standard deviation	11	-	4	0.05	0.047	10.3	0.6	10.6
95% Confidence int.	5	-	2	0.02	0.020	4.4	0.3	4.5
Maximum	43	<3	24	0.25	0.200	33.8	3.6	34.8
Minimum	1	<3	10	0.03	0.003	0.1	1.0	1.1

* Number of analysis below detection limit (1 mg TSS/L, 10 mg COD/L, 0.03 mg NH_4-N/L, 0.003 mg NO_2-N/L, 0.1 mg NO_3-N/L and 0.1 mg N_{org}/L, respectively)

** All analysis are below detection limit (3 mg BOD_5/L)

Table 4-6 Treatment performance of FB1 and the whole system in % from routine sampling

Parameter	**FB1**				**Whole system**			
	BOD_5	**COD**	**NH_4-N**	**TN**	**BOD_5**	**COD**	**NH_4-N**	**TN**
Number of samples	21	21	21	21	21	21	21	21
Median	**94.5%**	**83.8%**	**60.2%**	**59.2%**	**97.9%**	**96.0%**	**99.90%**	**72.1%**
Mean	92.5%	79.8%	56.6%	60.4%	95.5%	94.6%	99.80%	67.6%
Standard deviation	4.5%	11.0%	28.7%	19.1%	5.0%	3.7%	0.33%	24.6%
95% Confidence int.	1.9%	4.7%	12.3%	8.1%	2.1%	1.6%	0.14%	10.5%
Maximum	97.4%	91.3%	86.9%	83.1%	99.1%	98.1%	99.96%	97.8%
Minimum	82.4%	47.7%	-17.2%	5.9%	82.4%	85.9%	98.52%	2.0%

4.2.2.3 On-site parameters

Table 4-7 shows on-site measurements of pH, EC and redox potential during routine investigations from July 2011 until September 2012

Table 4-7 On-site measurements during routine sampling

	Influent			Effluent FB1			Effluent FB2		
Parameter	**pH** (-)	**EC** (µS/cm)	**Redox** (mV)	**pH** (-)	**EC** (µS/cm)	**Redox** (mV)	**pH** (-)	**EC** (µS/cm)	**Redox** (mV)
Number of samples	10	10	10	10	10	10	10	10	10
Median	**7.3**	**897**	**-267**	**7.8**	**719**	**171**	**7.4**	**543**	**215**
Mean	7.4	924	-275	7.8	748	141	7.5	554	217
Standard deviation	0.3	342	75	0.2	234	94	0.3	185	52
95% Confidence int.	0.2	212	47	0.1	145	58	0.2	115	32
Maximum	7.9	1398	-150	8.1	1068	230	8.1	788	280
Minimum	7.0	416	-373	7.6	385	-90	7.1	325	130

4.2.3 Temperature

Since the temperature measurement was not reactivated anymore after the second lightning strike, the results are shown for the period of July 2010 until June 2012. Figure 4-9 shows air temperature as well as influent and effluent FB2 wastewater temperatures. Also the times of the two strikes of lightning and the times of repairs of devices are noted.

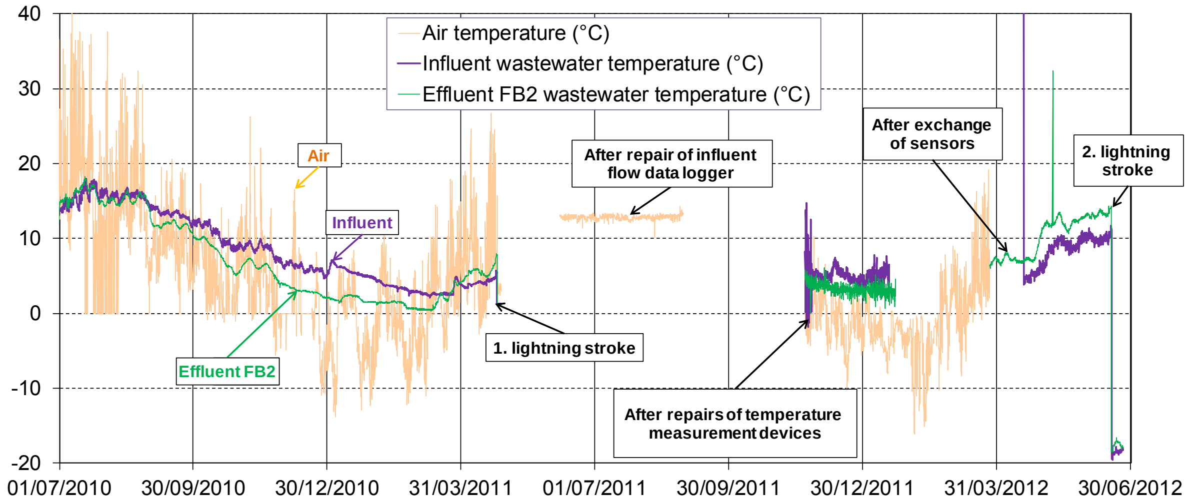

Figure 4-9 Air temperature as well as influent and effluent wastewater temperatures

The air temperature sensor was not shaded during the first few months of installation. This resulted in high peaks during sunny days. After the first strike of lightning at the end of April 2011 the air temperature measurement did not work until November 2011 and the measurement of influent and effluent temperatures did not work until spring 2012. At the end of March 2012 the temperature sensors of the EIB replaced the defective influent and effluent FB2 temperature sensors and worked until the second strike of lightning on 17 June 2012.

Figure 4-10 shows bed temperatures in the main layer of FB1 in depths of 0, 10 and 40 cm.

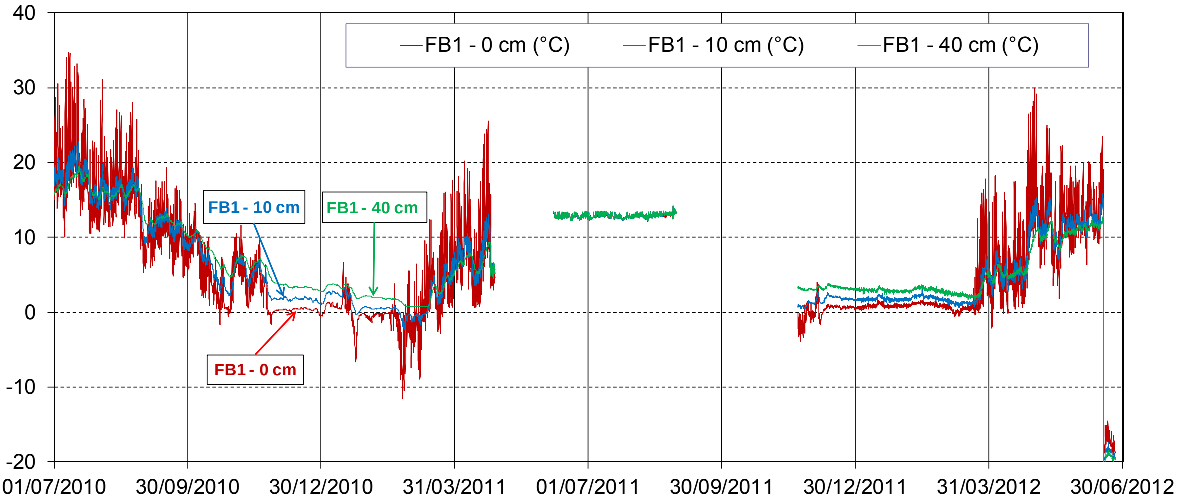

Figure 4-10 Bed temperatures in main layer of FB1 in depths of 0, 10 and 40 cm

The temperature at 0 cm of FB1 is measured at the border of main and top layer. Daily temperature fluctuations are still clearly visible in this depth. Also the insulating effect of the snow cover is clearly visible because there are no daily fluctuations anymore at 0 cm depth. The long lasting snow cover during winter 2012 (middle of December 2011 until middle of March 2012) led to very even bed temperatures.

Figure 4-11 shows bed temperatures in the main layer of FB2 in depths of 10 and 40 cm as well as the wastewater temperature of effluent FB2.

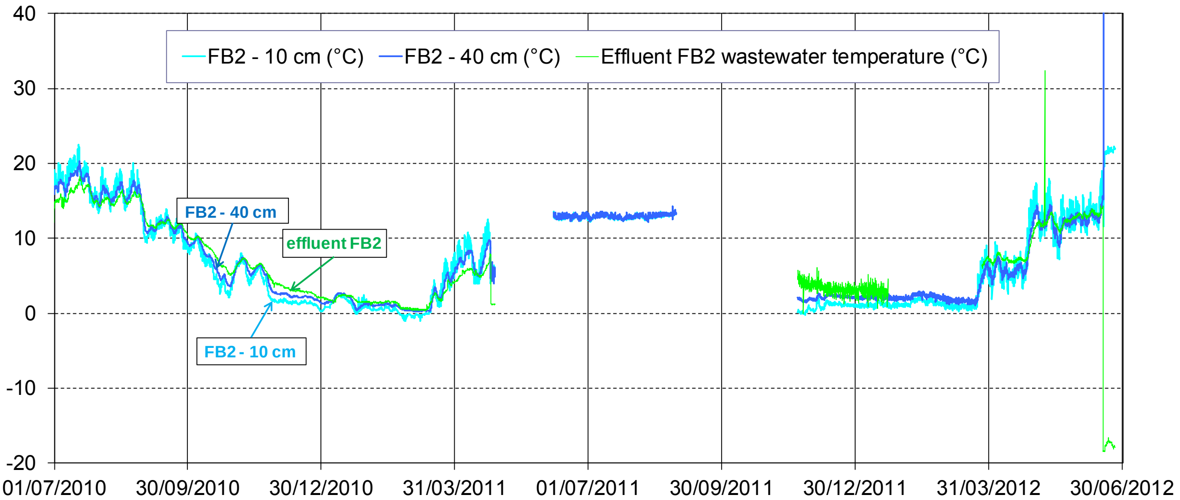

Figure 4-11 Temperatures in main layer of FB2 in depths of 10 and 40 cm and wastewater of effluent FB2

The insulating effect of the snow cover in winter 2012 is clearly visible also in FB2.

Figure 4-12 shows bed temperatures of the EIB in depths of 10 and 40 cm as well as wastewater temperatures of effluent FB2.

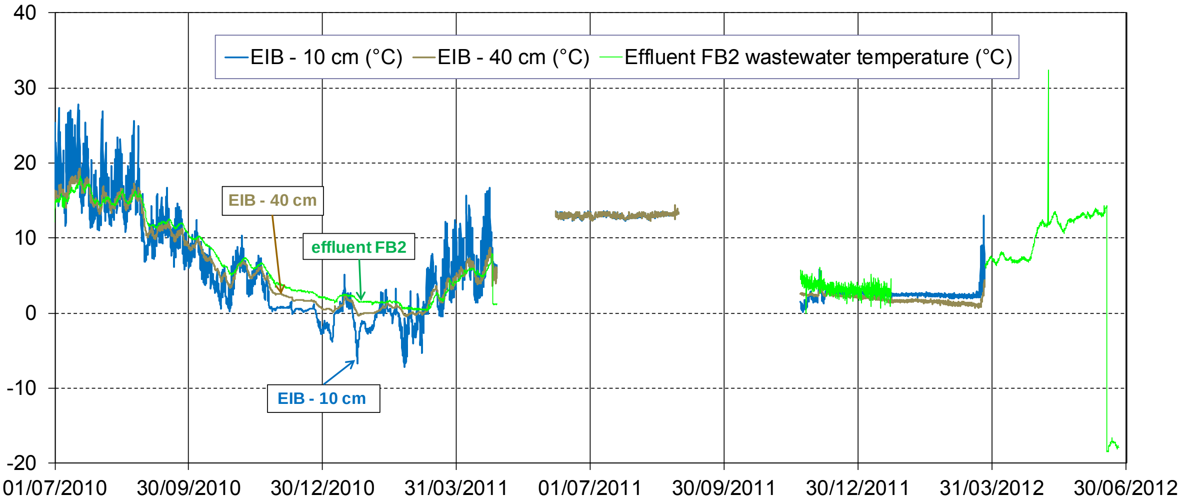

Figure 4-12 Temperatures of EIB in depths of 10 and 40 cm and wastewater of effluent FB2

The effects of sunlight are still visible at 10 cm depth of the main layer, since the EIB only has a thin top layer with around 3 cm depth.

4.3 Special investigations

4.3.1 Event sampling

4.3.1.1 Event 1 - Banquet

Event 1 took place on Sunday 19 February 2012 during a v ery cold period, with temperatures dropping beneath -15°C (see Figure 4-13).

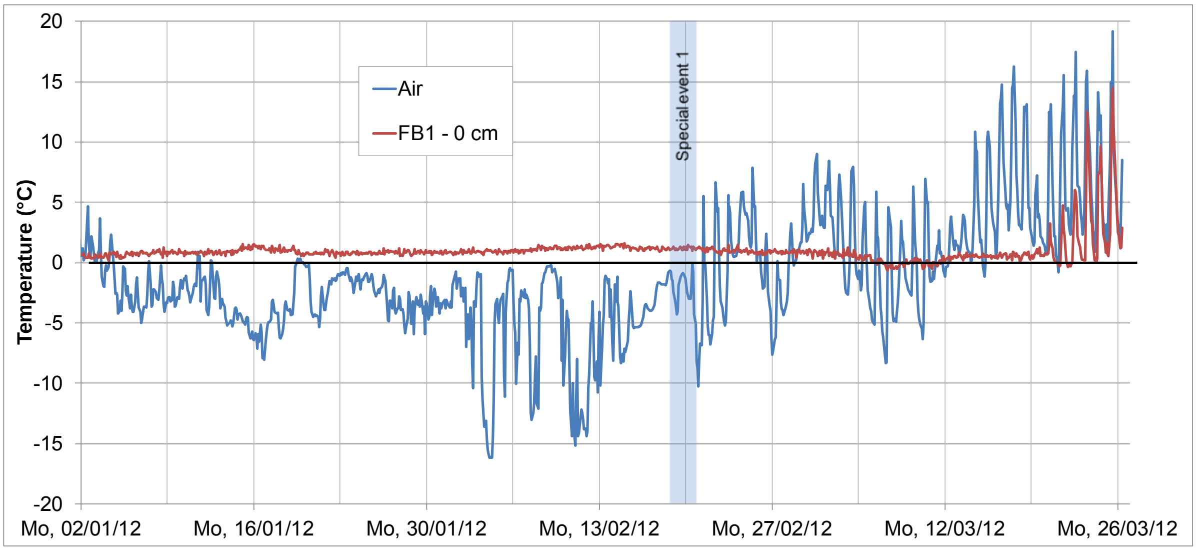

Figure 4-13 Air temperature and bed temperature in the main layer of FB1 at 0 cm (21 November 2011 until 26 March 2012)

Two automatic samplers in thermally insulated boxes were installed at the influent of FB1 and the effluent of FB2, respectively and s ampled from Friday 17 unt il Thursday 23 February 2012. The event had 90 v isitors and 4 people staying overnight on 18 February. Six event loadings were recorded between Saturday 18 February 17:59 and Monday 20 February 17:51, resulting in a hydraulic load of 13.7 mm/d (i.e. 54% of the design load, see also Table 4-9).

Figure 4-14 shows measured NH_4-N influent and effluent FB2 concentrations as well as loading times for event 1. The loading times are only related to the x-axis (timeline) but not related to the y-axis in any of the following event related figures. A volume of 541 L for each loading was used for calculations.

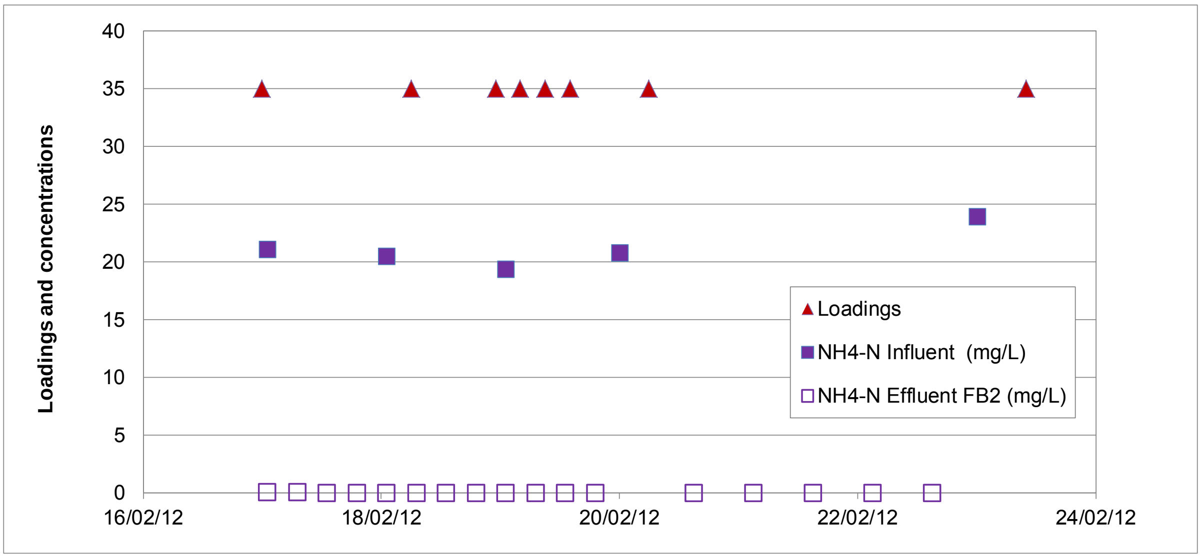

Figure 4-14 Loading times and NH_4-N influent and effluent concentrations measured during the event sampling for event 1 from 17 until 23 February 2012

The measured NH_4-N concentrations resulted in an influent mean value of 21.2 ±1.7 mg NH_4-N/L (N=5) and an effluent FB2 mean value of 0.03 ±0.01 mg NH_4-N/L (N=17, whereas 11 measurements were below the detection limit of 0.03 mg NH_4-N/L).

Figure 4-15 shows COD concentrations for the influent of FB1 and effluent of FB2 as well as loading times for event 1.

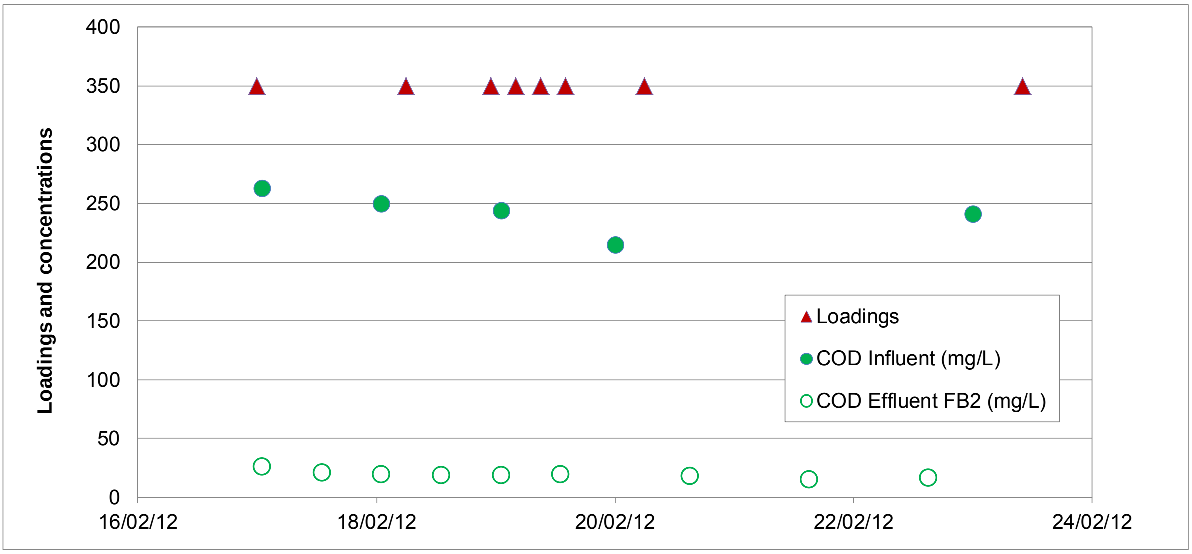

Figure 4-15 Loading times and COD influent and effluent concentrations measured during the event sampling for event 1 from 17 until 23 February 2012

The measured COD concentrations resulted in mean values of 243 ±18 mg COD/L (N=5) and 19 ±3 mg COD/L (N=9) for influent and effluent FB2, respectively. Unfortunately the measured COD and NH_4-N concentrations were not informative concerning the treatment performance during the event because a running water tap lead to the heavy dilution in the pre-treatment chambers already before the event.

The specific organic load of event 1 has been 3.4 g COD m^{-2} d^{-1} (see Table 4-9), based on the event's median influent COD value of 244 mg/L (number of samples 5; 95% confidence interval = 15 mg/L) and the above described hydraulic load of 13.7 mm/d.

4.3.1.2 Event 2 - Concert

Starting from event 2, three automatic samplers were used, sampling the influent of FB1 as well as the effluent of FB1 and FB2. Event sampling lasted from Friday 15 until Thursday 21 June 2012. The event had 100 visitors and no overnight stays. Six event loadings were recorded between Friday 16 June 17:02 and Sunday 17 June 11:02, resulting in a hydraulic load of 15.7 mm/d (i.e. 62% of the design load, see also Table 4-9).

Figure 4-16 shows NH_4-N concentrations for the influent of FB1, effluent of FB1 and FB2 as well as loading times for event 2.

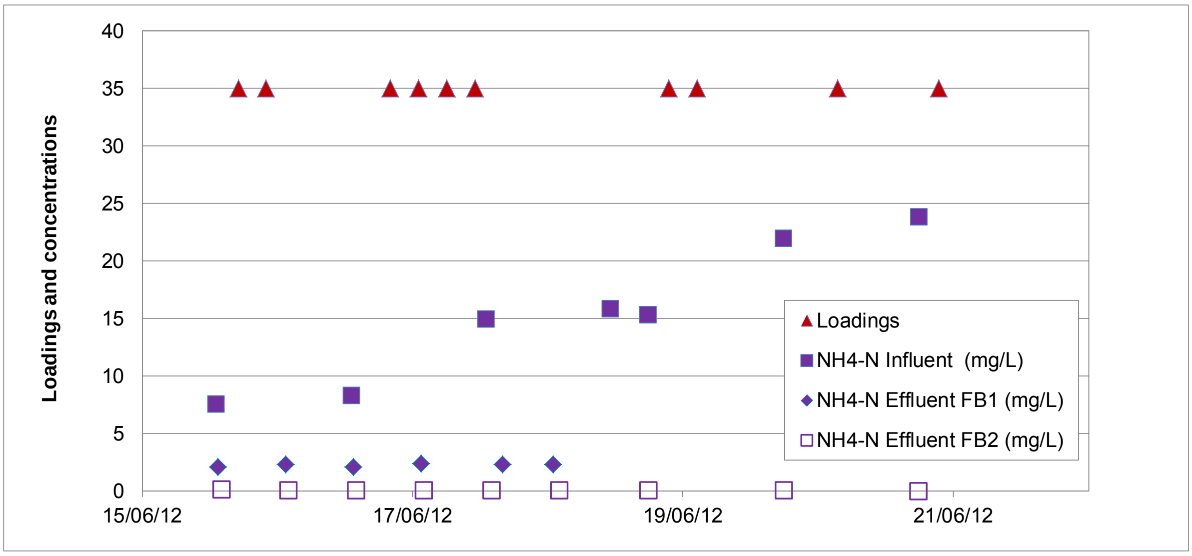

Figure 4-16 Loading times and NH_4-N influent and effluent concentrations measured during the event sampling for event 2 from 15 until 21 June 2012

The measured NH_4-N concentrations resulted in mean values of 15.5 ±6.1 mg NH_4-N/L (N=7), 2.3 ±0.1 mg NH_4-N/L (N=6) and 0.06 ±0.03 mg NH_4-N/L (N=9) for influent, effluent FB1 and effluent FB2, respectively.

Figure 4-17 shows COD concentrations for influent of FB1, effluent of FB1 and FB2 as well as loading times for event 2.

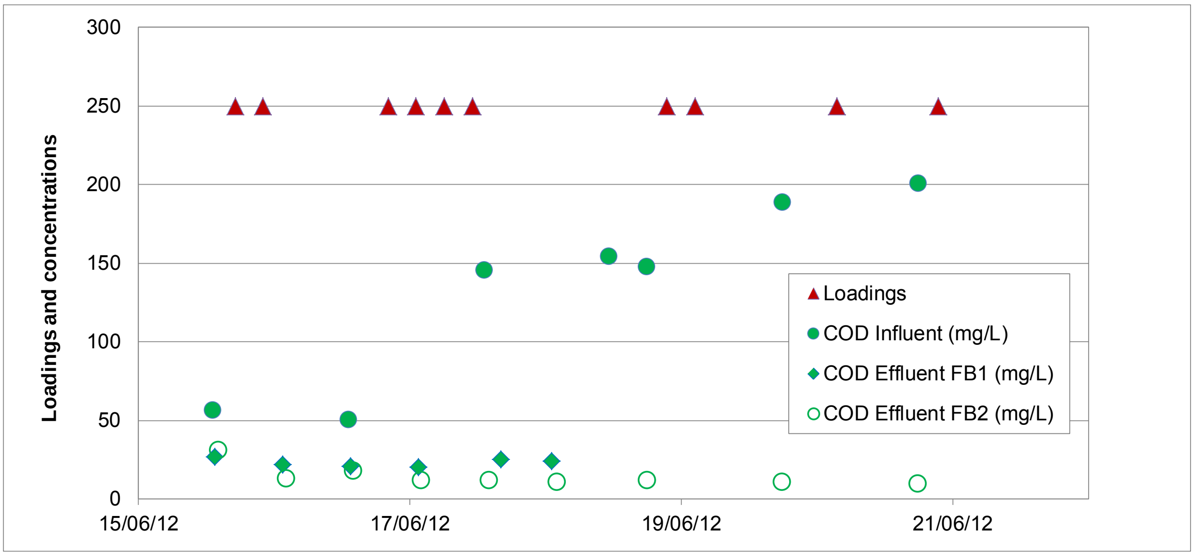

Figure 4-17 Loading times and COD influent and effluent concentrations measured during the event sampling for event 2 from 15 until 21 June 2012

The measured COD concentrations resulted in mean values of 135 ±59 mg COD/L (N=7), 23 ±3 mg COD/L (N=6) and 14 ±7 mg COD/L (N=9) for influent, effluent FB1 and effluent FB2, respectively.

The specific organic load of event 2 has been 2.3 g COD m^{-2} d^{-1} (see Table 4-9), based on the event's median influent COD value of 148 mg/L (number of samples 7; 95% confidence interval = 43 mg/L) and the above described hydraulic load of 15.7 mm/d.

4.3.1.3 Event 3 - Wedding

Event 3 took place on 23 June 2012. Samples were taken from Friday 22 until Thursday 28 June 2012. The event had 150 visitors and 25 people staying overnight in the inn's guest rooms as well as 40 campers on 23 June. The campers partly used the sanitary facilities in the inn as well. Thirteen event loadings were recorded between Friday 22 June 18:28 and Tuesday 26 June 11:02, resulting in a hydraulic load of 20.0 mm/d (i.e. 79% of the design load, see also Table 4-9).

Figure 4-18 shows NH_4-N concentrations for the influent of FB1, effluent of FB1 and FB2 as well as loading times for Event 3.

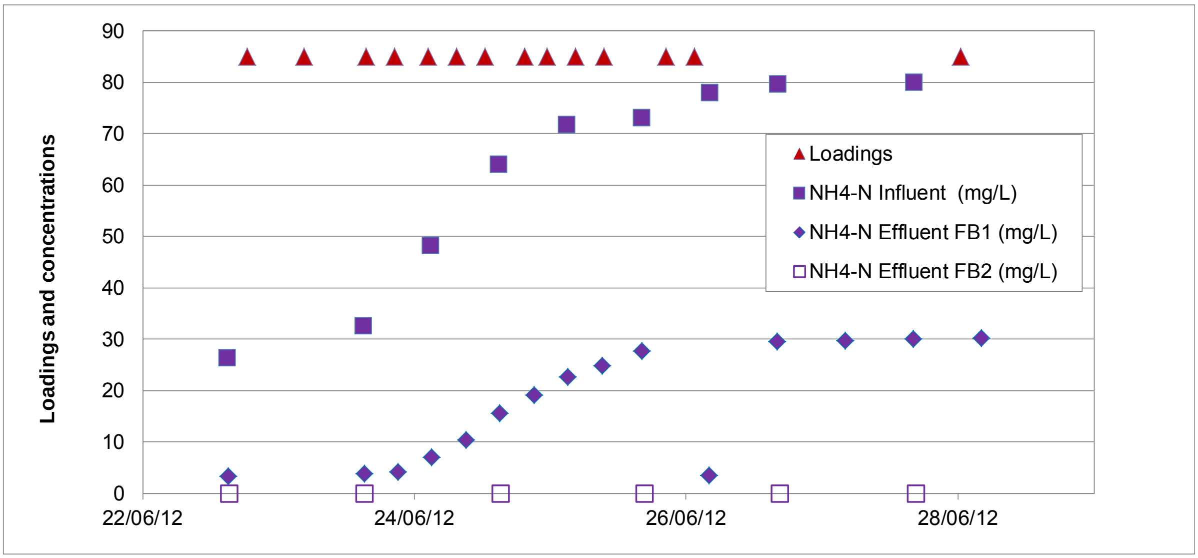

Figure 4-18 Loading times and NH_4-N influent and effluent concentrations measured during the event sampling for event 3 from 22 until 28 June 2012

The measured NH_4-N concentrations resulted in mean values of 61.7 ±20.7 mg NH_4-N/L (N=9), 17.5 ±11.1 mg NH_4-N/L (N=15) and 0 .04 ±0.01 mg NH_4-N/L (N=6) for influent, effluent FB1 and effluent FB2, respectively.

Figure 4-19 shows COD concentrations for the influent of FB1, effluent of FB1 and FB2 as well as loading times for event 3.

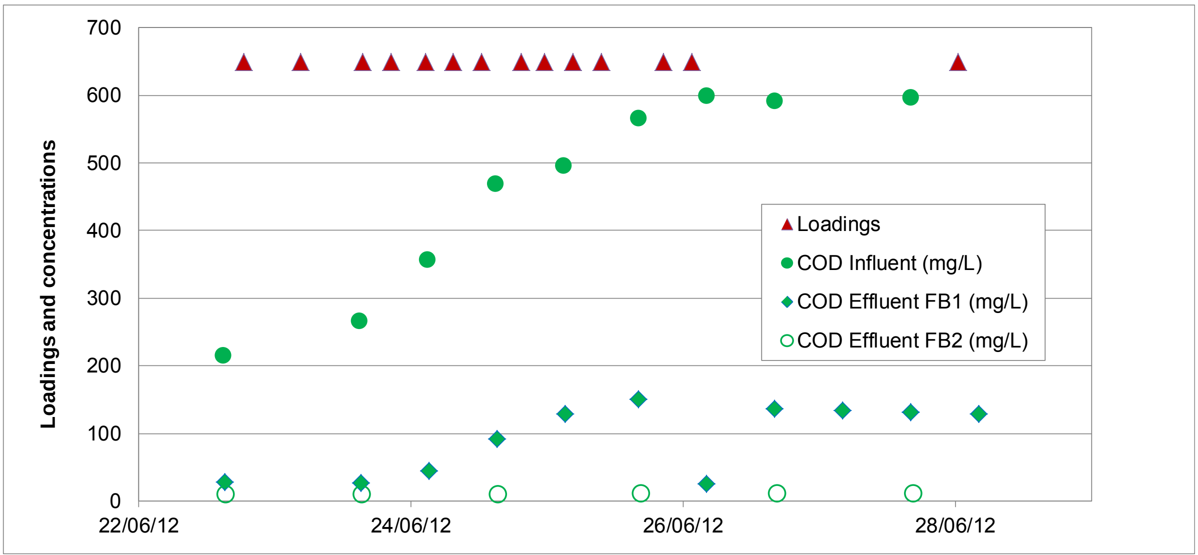

Figure 4-19 Loading times and COD influent and effluent concentrations measured during the event sampling for event 3 from 22 until 28 June 2012

The measured COD concentrations resulted in mean values of 462 ±148 mg COD/L (N=9), 93 ±51 mg COD/L (N=11) and 11 ±1 mg COD/L (N=6) for influent, effluent FB1 and effluent FB2, respectively.

The specific organic load of event 3 has been 9.9 g COD m^{-2} d^{-1} (see Table 4-9), based on the event's median influent COD value of 567 mg/L (number of samples 9; 95% confidence interval = 97 mg/L) and the above described hydraulic load of 20.0 mm/d.

4.3.1.4 Event 4 - Wedding

Event 4 took place on 28 July 2012. Samples were taken from Friday 27 June until Thursday 5 July 2012. The event had 90 visitors and 20 people staying overnight on 28 July. Fourteen event loadings were recorded between Friday 27 July 21:03 and Monday 30 July 19:03, resulting in a hydraulic load of 24.4 mm/d (i.e. 96% of the design load, see also Table 4-9).

Figure 4-20 shows NH_4-N concentrations for the influent of FB1, effluent of FB1 and FB2 as well as loading times for event 4.

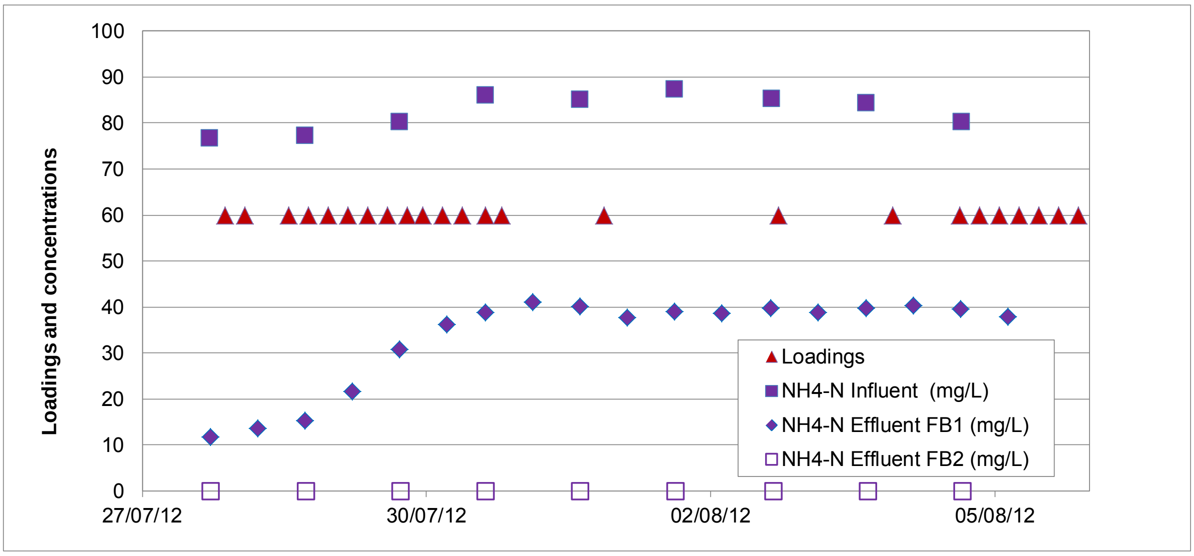

Figure 4-20 Loading times and NH_4-N influent and effluent concentrations measured during the event sampling for event 4 from 27June until 4 July 2012

The measured NH_4-N concentrations resulted in mean values of 82.7 ±3.9 mg NH_4-N/L (N=9), 33.4 ±10.2 mg NH_4-N/L (N=18) and 0 .05 ±0.01 mg NH_4-N/L (N=9, whereas 1 measurement was below the detection limit of 0.03 mg NH_4-N/L) for influent, effluent FB1 and effluent FB2, respectively.

Figure 4-21 shows COD concentrations for the influent of FB1, effluent of FB1 and FB2 as well as loading times for event 4.

Figure 4-21 Loading times and COD influent and effluent concentrations measured during the event sampling for event 4 from 27 June until 4 July 2012

The measured COD concentrations resulted in mean values of 582 ±40 mg COD/L (N=9), 111 ±25 mg COD/L (N=18) and 17 ± 3 mg COD/L (N=9) for influent, effluent FB1 and effluent FB2, respectively.

The specific organic load of event 4 has been 13.9 g COD m^{-2} d^{-1} (see Table 4-9), based on the event's median influent COD value of 567 mg/L (number of samples 9; 95% confidence interval = 26 mg/L) and the above described hydraulic load of 24.4 mm/d.

4.3.1.5 Event 5 - Traditional fair

Event 5 took place on 9 September 2012. Samples were taken from Friday 7 until Thursday 13 September 2012. The event had 500 visitors and no overnight stays. There were four portable toilets set up in addition to the toilets in the inn, which were not connected to the CW system. Nine event loadings were recorded between Saturday 8 September 11:03 and Monday 10 September 11:02, resulting in a hydraulic load of 18.1 mm/d (i.e. 72% of the design load, see also Table 4-9).

Figure 4-22 shows NH_4-N concentrations for the influent of FB1, effluent of FB1 and FB2 as well as loading times for event 5.

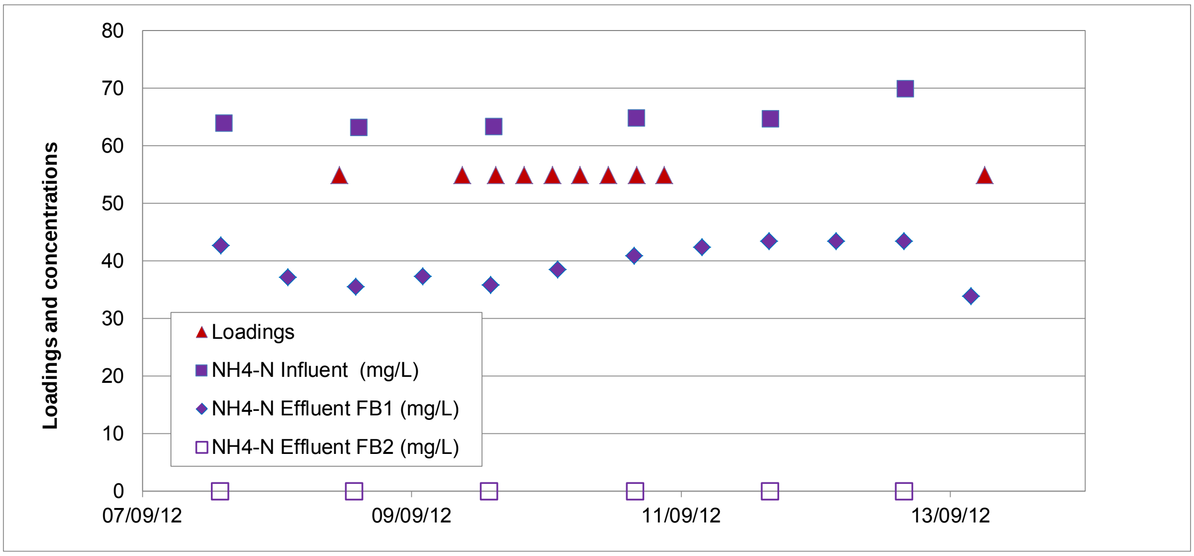

Figure 4-22 Loading times and NH_4-N influent and effluent concentrations measured during the event sampling for event 5 from 7 until 13 September 2012

The measured NH_4-N concentrations resulted in mean values of 65.1 ±2.5 mg NH_4-N/L (N=6), 39.6 ±3.5 mg NH_4-N/L (N=12) and 0. 05 ±0.02 mg NH_4-N/L (N=6) for influent, effluent FB1 and effluent FB2, respectively.

Figure 4-23 shows COD concentrations for the influent of FB1, effluent of FB1 and FB2 as well as loading times for event 5.

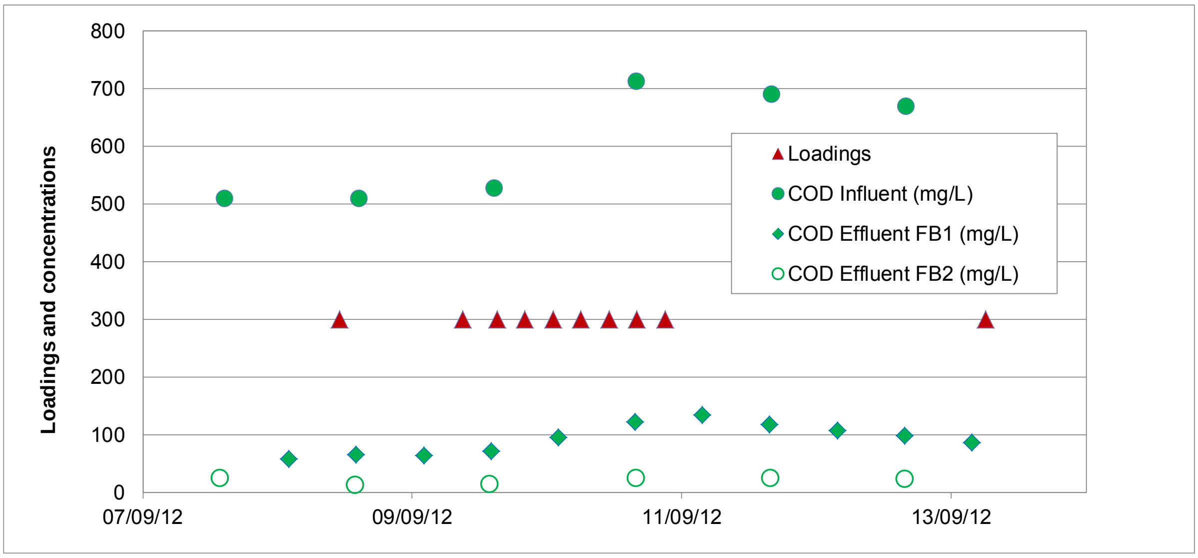

Figure 4-23 Loading times and COD influent and effluent concentrations measured during the event sampling for event 5 from 7 until 13 September 2012

The measured COD concentrations resulted in mean values of 604 ±97 mg COD/L (N=6), 93 ±26 mg COD/L (N=11) and 22 ±6 mg COD/L (N=6) for influent, effluent FB1 and effluent FB2, respectively.

The specific organic load of event 5 has been 10.9 g COD m^{-2} d^{-1} (see Table 4-9), based on the event's median influent COD value of 600 mg/L (number of samples 6; 95% confidence interval = 77 mg/L) and the above described hydraulic load of 18.1 mm/d.

4.3.2 Routine and event sampling combined

4.3.2.1 Measured influent and effluent COD and NH4-N concentrations

Table 4-8 shows all measured COD and NH4-N concentrations, from routine and event samplings combined, during the period of event operation. During event samplings only COD and NH_4-N concentrations were analysed, whereas during routine sampling also TSS, BOD_5, NO_3-N, NO_2-N and TN were analysed (for routine sampling results see section 4.2.2). Therefore, Table 4-8 includes the above shown COD and NH_4-N samples together with samples from event samplings.

Table 4-8 Influent and effluent COD and NH4-N concentrations from routine and event samplings during event operation (July 2011 until September 2012)

Parameter	**Influent**		**Effluent FB1**		**Effluent FB2**	
	COD	**NH_4-N**	**COD**	**NH_4-N**	**COD**	**NH_4-N**
Number of samples	56	56	67	70	59 (18*)	68 (26*)
Median	**354**	**49.2**	**85**	**24.1**	**13**	**0.03**
Mean	381	48.4	79	23.0	15	0.04
Standard deviation	200	27.0	42	15.0	18	0.03
95% Confidence int.	52	7.1	10	3.5	5	0.01
Maximum	720	87.5	150	43.4	31	0.25
Minimum	51	7.6	20	2.1	10	0.03

* Number of analysis below detection limit (10 mg COD/L and 0.03 mg NH_4-N/L, respectively)

The median COD influent concentration of 354 mg/L is based on measured COD concentrations from routine and event samplings. Together with a hydraulic load of 3.4 mm/d (without disturbed periods, see section 4.1) or 4.3 mm/d (with disturbed periods) the specific organic load results in 1.2 g COD m^{-2} d^{-1} or 1.6 g COD m^{-2} d^{-1}, respectively (see also Table 4-10).

4.3.2.2 Calculated organic and hydraulic loads

Due to the disturbances, the measured COD influent concentrations during some sampled events were very low and did not reflect the events actual organic loads. Figure 4-24 shows COD influent concentrations from routine and event samplings, whereas samples taken during disturbed periods are shaded.

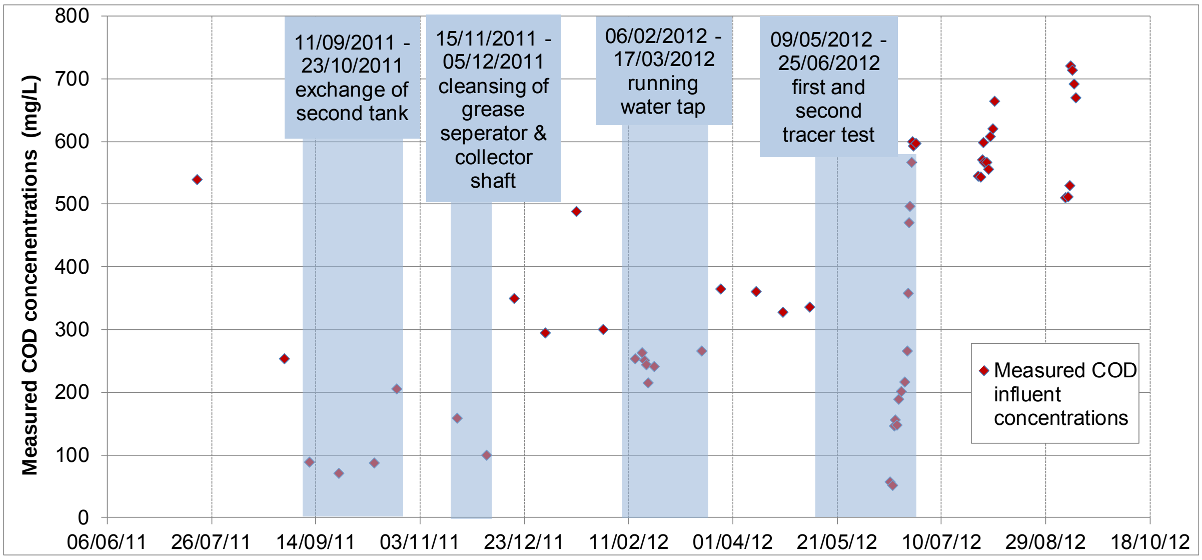

Figure 4-24 Measured COD influent concentrations from routine and event samplings, with disturbed periods shaded in grey

The calculated median COD influent concentration without these disturbed periods was 556 mg/L (number of samples 31; 95% confidence interval = 46.6 mg/L). As a r esult, sampled events have two different organic loads; (1) a measured organic load, based on the actual sampling during the event (see also section 4.3.1) and (2) a calculated organic load, based on the above described median COD concentration of 556 mg/L.

Table 4-9 summarizes all events, including sampled events and other events, during event operation. Each event has information regarding visitors attending, overnight stays, number of loadings, duration, hydraulic load in mm/d and per cent of the design load as well as measured (only for sampled events) and calculated organic load.

Table 4-9 Sampled events and other events during event operation from July 2011 until September 2012

From	To	Event	Sampled event (yes/no)	Visitors (#)	Overnight stays (#)	Duration (d)	Loadings (#)	Hydraulic load (mm/d)	Hydraulic load (%)	Measured organic load (g COD·m^{-2}·d^{-1})	Calculated organic load (g COD·m^{-2}·d^{-1})
13.08.2011	15.08.2012	Lodgers	no	40	40	2.42	10	24.2	80%	-	11.3
15.09.2011	18.09.2011	Lodgers	no	6	6	2.09	3	5.3	21%	-	2.9
22.10.2011		Birthday party	no	60	-	0.21	2	26.3	104%	-	14.6
14.01.2012		Birthday party	no	85	21	2.09	8	18.4	73%	-	10.2
19.02.2012		**Event 1 - Banquet**	**yes**	90	4	1.99	6	13.7	54%	3.4	7.6
24.03.2012	25.03.2012	Birthday party	no	30	-	2.54	8	15.1	60%	-	8.4
05.05.2012		Banquet	no	65	5	2.71	7	12.1	48%		6.8
30.05.2012		Christening	no	40	-	-	-	-	-	-	-
16.06.2012		**Event 2 - Concert**	**yes**	100		1.75	6	15.7	62%	2.3	8.7
23.06.2012		**Event 3 - Wedding**	**yes**	150	25	3.29	13	20.0	79%	9.9	11.1
28.07.2012		**Event 4 - Wedding**	**yes**	90	20	2.92	14	24.4	96%	13.9	13.6
04.08.2012		Wedding	no	80	20	4.00	13	16.4	65%	-	9.1
25.08.2012		Wedding	no	80	25	3.08	12	19.6	77%	-	10.9
31.08.2012	01.09.2012	Banquet & Bicycle race	no	48	-	1.67	6	16.4	65%	-	9.1
09.09.2012		**Event 5 - Traditional fair**	**yes**	500		2.42	9	18.1	72%	10.9	10.1
15.09.2012		Birthday party	no	85	9	2.42	10	20.4	81%	-	11.3
21.09.2012		Concert	no	80	-	0.50	3	21.9	87%	-	12.2

The calculated organic load for the entire period of event sampling is based on the median COD influent concentration of 556 mg/L. Together with a hydraulic load of 3.4 mm/d (without disturbed periods) or 4.3 mm/d (with disturbed periods) the specific organic load results in 2.2 g COD m^{-2} d^{-1} or 2.4 g COD m^{-2} d^{-1}, respectively (see also Table 4-10).

Figure 4-25 shows the calculated organic and hydraulic loads per day over the whole event period.

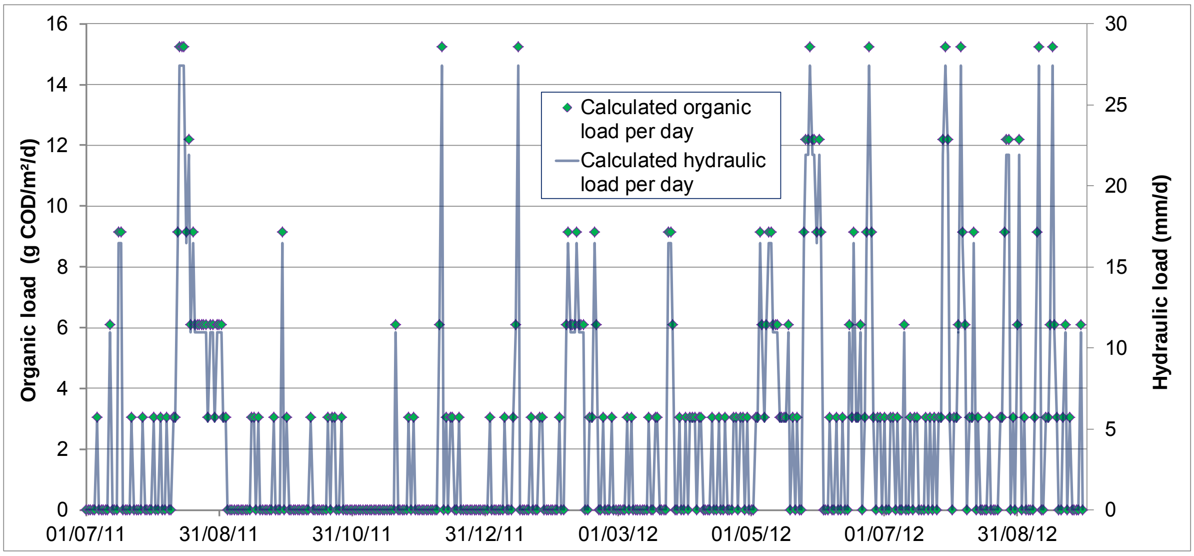

Figure 4-25 Calculated organic and hydraulic load per day (July 2011 until September 2012)

The maximum calculated hydraulic load per day was 27.4 mm/d (108% of the design load) and the maximum calculated organic load per day was 15.2 g COD m^{-2} d^{-1}. This maximum was reached on 11 days during event operation. The minimum hydraulic and organic load per day was 0 mm/d and 0 g COD m^{-2} d^{-1}, respectively. Coherently, the average of the calculated organic loads per day equals the above calculated organic load of 2.4 g COD m^{-2} d^{-1}. The calculated organic and hydraulic load per day are proportional to each other, because both are dependent on the variable loading times per day and otherwise calculated with constant values. In case of the calculated organic load, these constant values are the median influent COD concentration of 556 mg COD/L and the filter bed area of 98.7 m². In case of the hydraulic load per day, the constant value used for calculation is the design load of 2500 L.

4.3.2.3 Summary of organic loads

Due to the above described disturbances and different samplings, the organic load can be calculated using different median COD concentrations and hydraulic loads. The COD concentrations differ from each other due to the considered samplings (only routine or routine and event samplings combined) and whether disturbed COD concentrations are considered or not. The hydraulic load can be based on loadings with and without disturbed periods. Table 4-10 shows an overview of the different organic loads which were already individually presented in previous chapters.

Table 4-10 Overview of organic loads (g COD m^{-2} d^{-1}) based on different median COD concentrations and hydraulic loads

Median COD concentration		**Hydraulic load** (see section 4.2.1)	
		without loadings in disturbed periods 3.4 mm/d	**with loadings in disturbed periods** 4.3 mm/d
With samples during disturbed periods			
from routine sampling (see section 4.2.2.1)	294 mg/L	1.0	1.3
from routine and event sampling (see section 4.3.2.1)	354 mg/L	1.2	1.6
Without samples during disturbed periods			
from routine and event sampling (see section 4.3.2.2)	556 mg/L	2.2	2.4

The lowest organic load of 1.0 g COD m^{-2} d^{-1} resulted from the combination of a hydraulic load without loadings in disturbed periods and a median COD concentration with disturbed samples from routine sampling. The highest organic load of 2.4 g COD m^{-2} d^{-1} resulted from the combination of the hydraulic load with loadings in disturbed periods and a median COD concentration without disturbed samples from routine and event sampling.

4.3.3 Tracer tests

4.3.3.1 First tracer test

The first tracer test started on 8 May and ended on 18 May 2012. The tracer (580 L with 5 mS/cm EC) was loaded from the tank directly into the loading pipe and onto FB1 at 16:11. The loading lasted for around 2.5 minutes. During the test, 18 loadings were recorded between Tuesday 8 May 16:11 and Friday 18 May 22:56, resulting in a hydraulic load of 10.1 mm/d (i.e. 40% of the design load).

Figure 4-26 shows MID flow measurements of effluent FB1 and FB2. Each loading on FB1 amounts around 541 L.

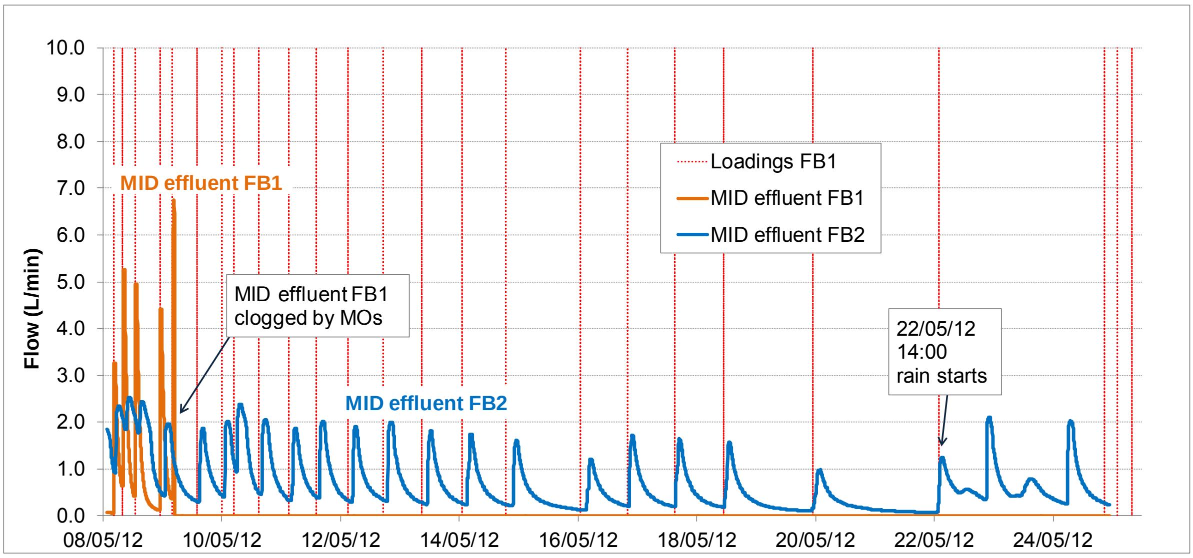

Figure 4-26 Effluent flow measured by MIDs after FB1 and FB2 during the first tracer test

The MID effluent FB1 in the loading shaft after FB1 clogged with a thick slime after one day and therefore stopped measuring the flow. This probably happened due to the tracer's high concentration of KCl in the filter bed, which rapidly changed the ecological environment in FB1. This way, a thick slime of MOs was released through the effluent of FB1, clogging the MID effluent FB1. Therefore, the EC effluent FB1 measurement device, which was placed at the outlet of the MID effluent FB1, could not measure EC neither (see Figure 4-27).

Figure 4-27 shows influent and effluent EC measurements during the first tracer test.

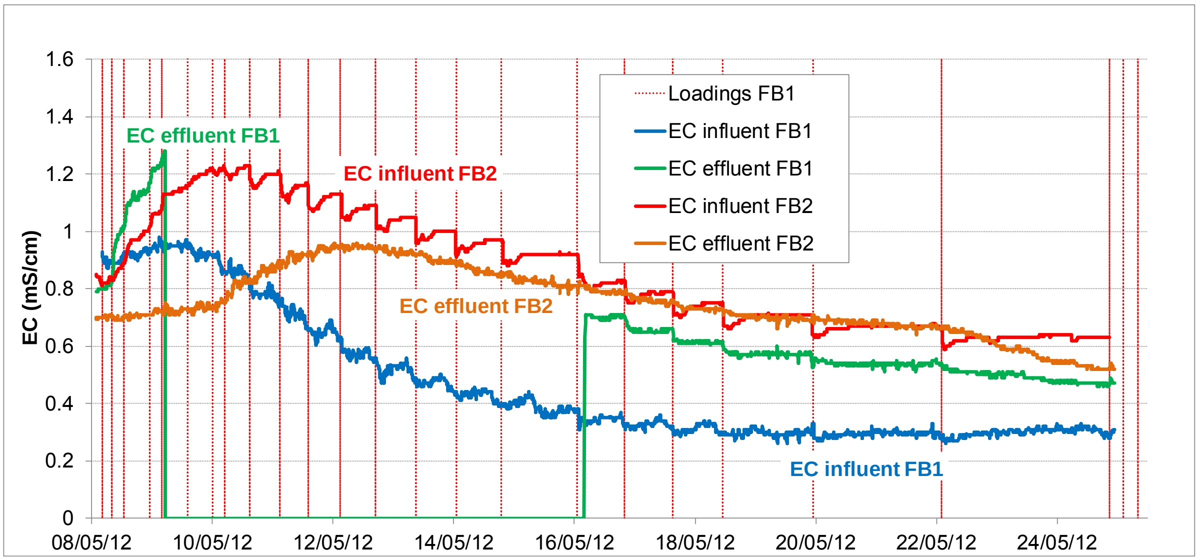

Figure 4-27 EC measured in influents and effluents of FB1 and FB2 during the first tracer test

However, weather conditions were perfect, with hardly any precipitation during the days after the start. Rain could have affected the tracer tests seriously, as can be seen by the change of flow at MID effluent FB2 on 22 May 2012 after the flow from the water tap was already stopped and it started to rain (see Figure 4-26). Rain naturally affects the ECs measured at influents and effluents, since wastewater gets diluted by it, which has a very low EC. Of course, rain also would have affected flow measurements.

Due to the missing data for flow and EC in the effluent of FB1, the MRT and RR could not be calculated for FB1 alone but only for the whole system, including FB1 and FB 2 (see Figure 4-28).

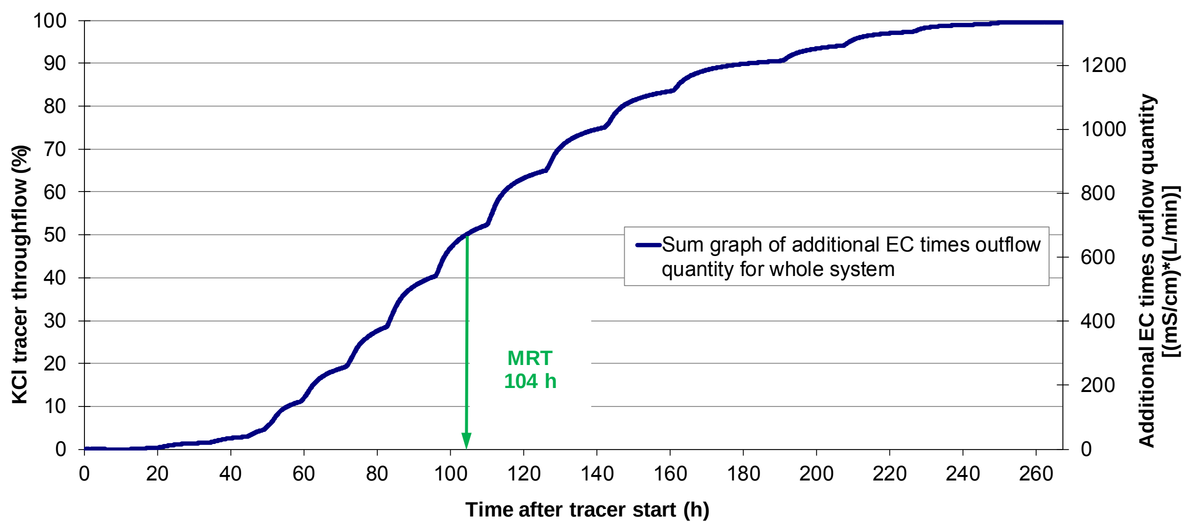

Figure 4-28 Sum graph of additional conductivity times outflow quantity for the whole system showing the resulting MRT of the first tracer test

At the end of the first tracer test, a total load of 1335 [(mS/cm)*(L/min)] reached effluent FB2. The MRT of 104 h was reached after half of the load, i.e. 667.5 [(mS/cm)*(L/min)], flowed through the whole system. In Figure 4-28, the MRT can be seen where the sum graph of additional EC times outflow quantity crosses the 50% line of the KCl tracer throughflow. At this time half of the tracer passed through the system.

Table 4-11 shows the resulting MRT and RR for the whole system for tracer 1.

Table 4-11 First tracer test mean residence time and recovery rate for the whole system

	Mean residence time (h)	**Recovery rate** (%)
Whole System	104	46

The tracer test resulted in a MRT of 104 h (4 d 8 h) and a RR of 46% for the whole system. This means that, during the first tracer test, 46% of the initial tracer's load reached the effluent of FB2, whereas the remaining 54% were still in the system.

4.3.3.2 Second tracer test

The second tracer test started on 25 May and ended on 2 June 2012. During the test 33 loadings were recorded between Tuesday 8 May 14:06 and Friday 18 May 22:56, resulting in a hydraulic load of 20.8 mm/d (i.e. 82% of the design load).

The EC applied in the tracer's initial rapid load was roughly doubled from 5.0 to 10.1 mS/cm and the constant controlled tap water flow was raised by 50% from 1.0 L to 1.5 L, compared to the first tracer test. The ECs after FB1 and FB2 were situated before the MIDs to ensure their function independently from the MIDs. No excess MO slime appeared or caused problems. Figure 4-29 shows the MID flow measurements after FB1 and FB2 during the second tracer test as well as loading times.

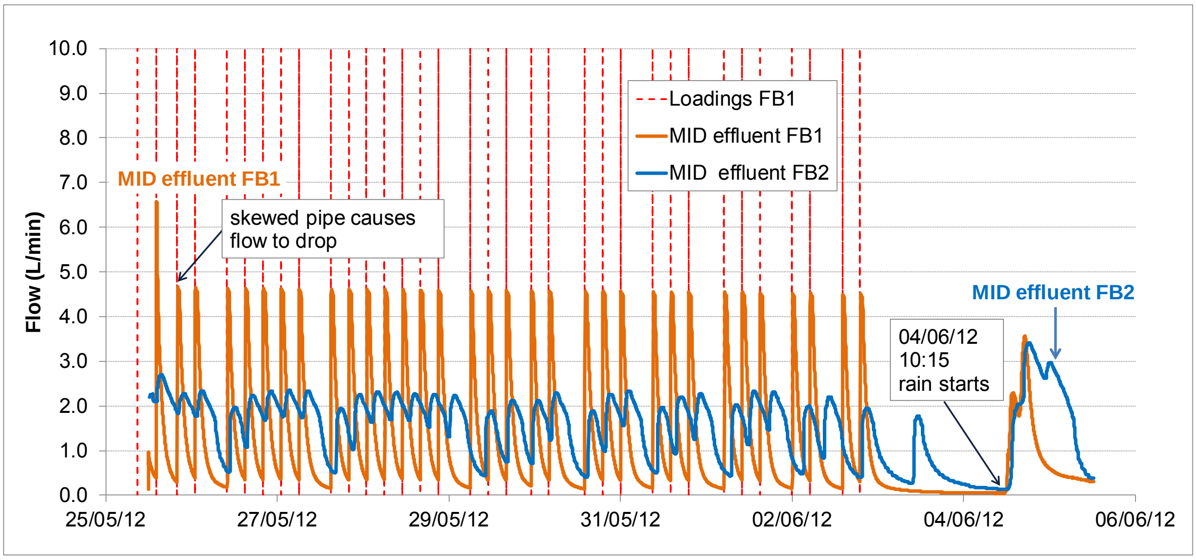

Figure 4-29 Effluent flow measured by MIDs after FB1 and FB2 during the second tracer test

Figure 4-29 shows very well how the flow at MID effluent FB1 increases rapidly some minutes after each loading but decreases quickly again. Also the delay until the impact of the loading reaches the effluent of FB2 is visible. Due to the retention capacity of the filter beds, the flow increase at MID effluent FB2 is lower but phases out longer than at MID effluent FB1.

Unfortunately, this time the U-formed pipe in front of MID1 skewed due to the weight of the entering water (see Figure 3-7), causing the initial maximum feed of 7 L/s to decrease down to 4.5 L/s.

Figure 4-30 shows the influent and effluent EC measurements of FB1 and FB2 as well as loading times.

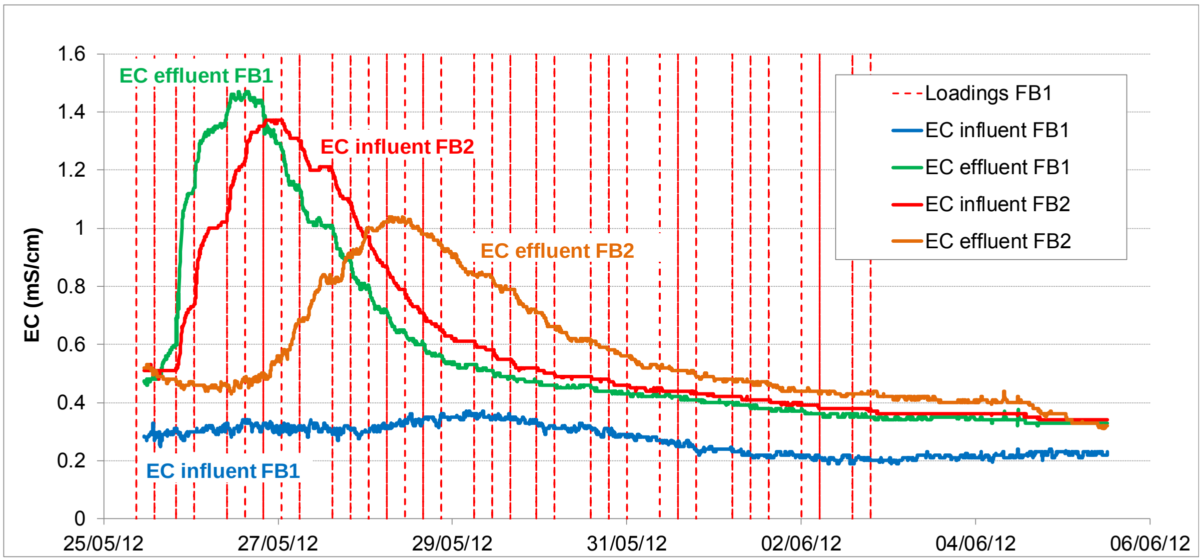

Figure 4-30 EC measured in the influents and effluents of FB1 and FB2 during the second tracer test

EC influent FB1, which was situated in the loading shaft before FB1, was not influenced by the KCl tracer, because the tracer was directly led into the shafts loading pipe to FB1. The other EC measurements show how the tracer impacted the EC throughout the system. Again, due to the retention capacity of the CW system, the tracer's impact was most distinct at the beginning at EC effluent FB1 and continues to be weaker and weaker but longer lasting towards EC effluent FB2. The difference between EC effluent FB1 and EC influent FB2 shows the impact of the mixing of the effluent from FB1 with wastewater stored in the loading shaft after FB1. The weather conditions were again perfect, with hardly any precipitation during the days after the start. This way the EC in influents and effluents of FB1 and FB2 could be measured without any major disturbances.

This time MRT and RR could be calculated for FB1 alone as well as for the whole system. The MRT for FB1 alone is shown in Figure 4-31.

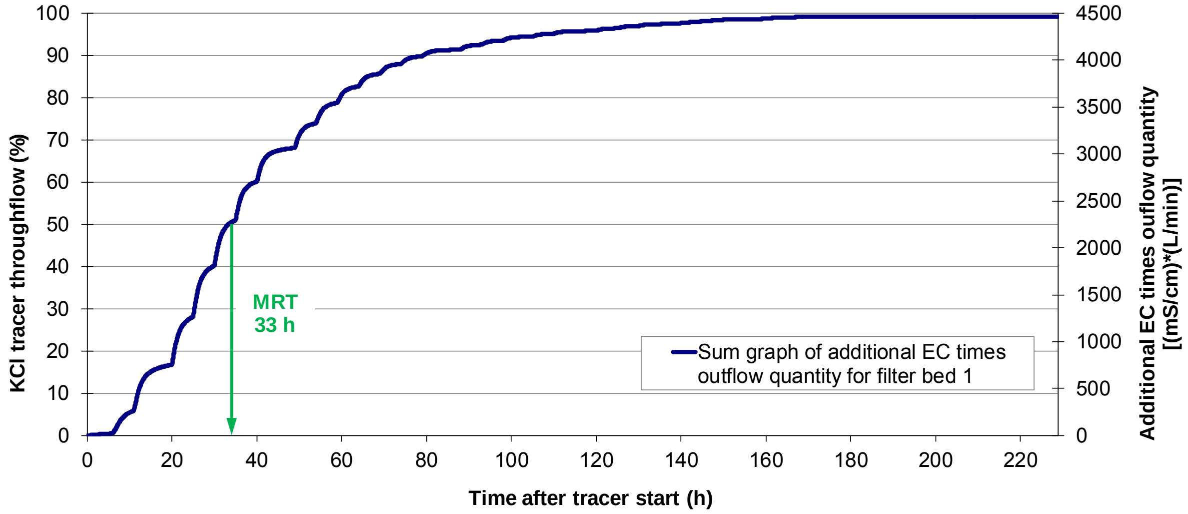

Figure 4-31 Sum graph of additional conductivity times outflow quantity for FB1 and resulting mean residence time of the second tracer test

At the end of the second tracer test, a total load of 4465 [(mS/cm)*(L/min)] reached effluent FB1. The MRT FB1 of 33 h w as reached after half of the load, i.e. 2232.5 [(mS/cm)*(L/min)], flowed through the FB1.

Figure 4-32 shows the MRT for the whole system, including FB1 and FB2.

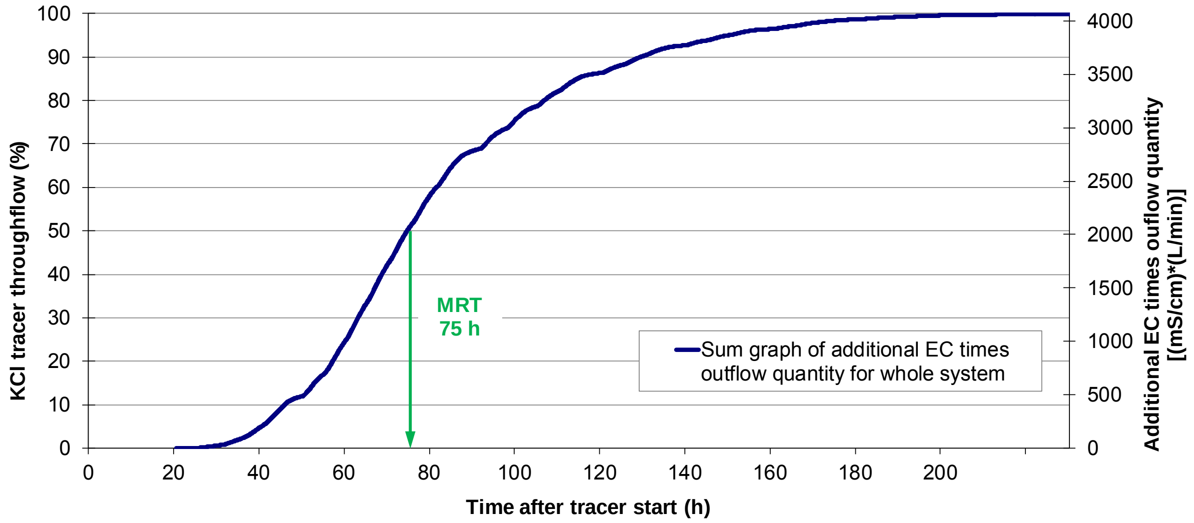

Figure 4-32 Sum graph of additional conductivity times outflow quantity for the whole system and resulting mean residence time of the second tracer test

At the end of the second tracer test, a total load of 4063 [(mS/cm)*(L/min)] reached effluent FB2. The MRT of the whole system of 75 h was reached after half of the load, i.e. 2031.5 [(mS/cm)*(L/min)], flowed through FB1 and FB2.

Figure 4-33 compares the sum graphs and MRTs of FB1 and the whole system.

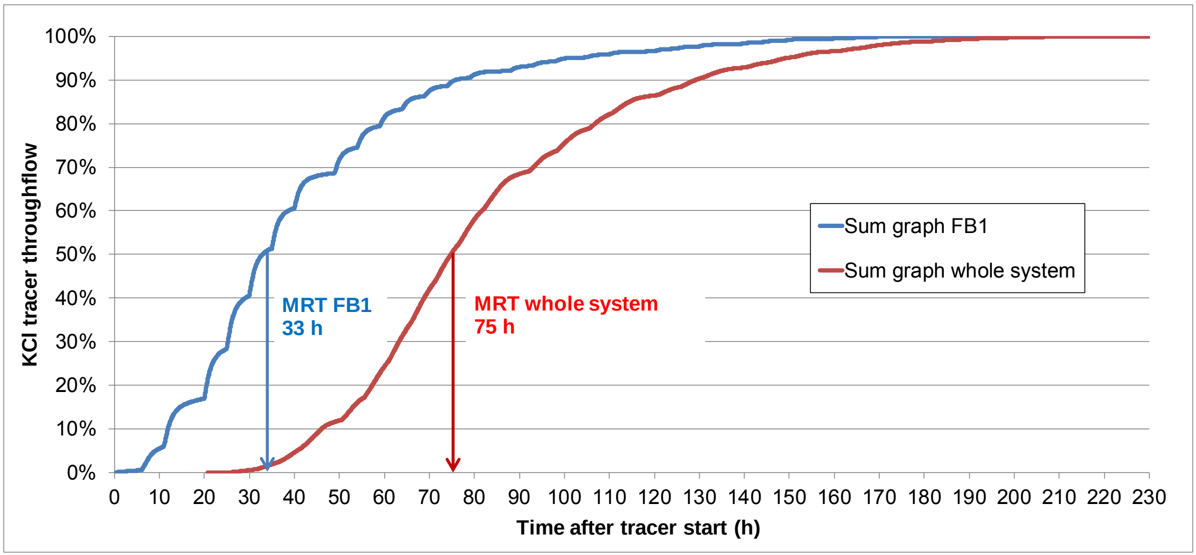

Figure 4-33 Comparison of sum graphs and MRTs of FB1 and whole system

It took around 21 h until the KCl tracer reached effluent FB2, which can be seen by the delayed increase of sum graph whole system compared to sum graph FB1.

Table 4-12 shows the results for MRT and RR of the second tracer test, for FB1 alone and for the whole system.

Table 4-12 Second tracer test mean residence time and recovery rate for FB1 and the whole system

	Mean residence time (h)	**Recovery rate** (%)
FB1	33	76
Whole System	75	69

The MRTs during the second tracer test were 33 h (1 d 9 h) and 75 h (3 d 3 h) in FB1 and the whole system, respectively. The RRs for FB1 and the whole system were 76 and 69%, respectively.

5. Interpretation and Discussion of Results

5.1 Loading times and hydraulic load leading to peak and fluctuating loads

During the whole period of event operation - from July 2011 and September 2012 - a total of 284 loadings during undisturbed periods were recorded. From these, 37 % had a loading interval of 24 h or longer. During undisturbed periods with no events, the most common loading interval was longer than 94 h, with a proportion of 15%. Further on, a majority of 61% of loadings during no events had a loading interval of 24 h and longer. During sampled events and other events on the other side, 58 and 52% and therefore the biggest proportion of loadings in undisturbed periods had a loading interval of 5 h, respectively. Five hours is the minimum time between two successive loadings given by the design of the pump in the 3rd chamber of the 3-chamber-pit. This illustrates the CW's fluctuating hydraulic load, with short loading intervals and peaks during events and long periods of no or low flow in between. However, in general the hydraulic load was low during the period of event operation; the average hydraulic load without and with loadings in disturbed periods was 13 and 17%, respectively.

5.2 COD and NH_4-N influent concentrations

The measured median influent COD concentrations were rather low during event operation. Only in the end of event 3 (end of June 2012), influent COD concentrations reached levels which were in line with expectations (ca. 600 mg COD/L). The low COD concentrations occurred partly due to disturbed periods, which were caused by several incidents (e.g. running water tap and tracer tests). Another important reason was the change of the inn's operational mode, from full-time (5 days a week open) to event operation (operated for events and on order), which started in July 2011. Compared to the preceding full-time operation, the organic influent concentrations BOD_5 and COD were nearly three times lower in event operation. The reason for the low BOD_5 and COD influent concentrations can be affiliated to decreased input of kitchen wastewater during event operation (Langergraber et al., 2013). Also median NH_4-N influent concentrations during event operation were lower compared to full-time operation (July until December 2010), with 38.4 and 50.8 mg NH_4-N/L, respectively (Langergraber et al., 2013). Here, the disturbed periods were the main reason for the difference.

5.3 Organic load

The overall measured and calculated organic load during event operation depended on whether disturbed periods were considered and which samplings were used. The obtained organic loads ranged from 1.0 up to 2.4 COD m^{-2} d^{-1}. The organic load of 2.2 COD m^{-2} d^{-1}, resulting from the combination of a hydraulic load without loadings in disturbed periods and a median COD concentration without disturbed samples from routine and event sampling, was considered most realistic, because these conditions resemble an operation without disturbances by the scientific investigations.

According to that, the system was loaded with only 7% of the organic design load during event operation, since the CW *Bärenkogelhaus* was dimensioned for full-time operation with 40 PE and an organic load of 32.4 g COD m^{-2} d^{-1} (i.e. 2.47 m^2 per PE). On 11 days during event operation, the daily maximum hydraulic load of 108% of the design load was reached. However, even during these periods with high hydraulic loads, the organic load was only about 50% of the organic design load with values around 14.0 g COD m^{-2} d^{-1}. This upper limit of daily organic load arises from the hydraulic limitation through the number of possible intermittent loadings per day.

5.4 Effluent concentrations and treatment performance

All measured BOD_5 effluent FB2 concentrations were below the detection limit of 3 mg BOD_5/L during event operation and thereby far below the threshold of 25 mg BOD_5/L. Already effluent FB1 concentrations were so low that only one measurement was not below but exactly on the threshold of 25 mg BOD_5/L. COD effluent FB2 concentrations were not higher than 24 mg COD/L throughout event operation, and thereby far below the threshold of 90 mg COD/L.

NH_4-N effluent FB2 concentrations were below 1 mg NH_4-N /L during the whole period of event operation and thereby far below the threshold of 10 mg NH_4-N/L. Also during periods with effluent water temperatures below 12°C, the maximum measured effluent FB2 concentration was only 0.25 mg NH_4-N /L. N treatment is generally believed to be temperature dependent and therefore strongly influenced by cold climate environments. However, dependent on factors like aeration, nitrification may still be achieved at temperatures as low as 2 to 5 °C (Lemon et al., 1996).

The median NH_4-N reduction from routine sampling resulted in 99.9%, which was very high, also compared to other CW's rates with fluctuating and peak loads (see also section 2.6):

- Masi et al. (2007) measured 85% NH_4-N reduction for a multi-stage system (HF followed by a VF) with a specific surface area of only 2 m^2 per PE;
- Foladori et al. (2012) measured 80 and 69% NH_4-N reduction for a multi-stage system (VF followed by HF) during a low (3.2 m^2 per PE) and high-load (1.3 m^2 per PE) period, respectively; and
- Canepel and Romagnolli (2010) measured 99% NH_4-N reduction for a multi-stage CW, which was as well situated in a cold climate (6.7 m^2 per PE).

The median TN treatment efficiency from routine sampling of 72% was comparable to other multi-stage systems in cold climates (see also section 2.5.3.3):

- Jenssen et al. (2005) measured 40-60% TN reduction for a vertical down-flow aerobic biofilter followed by a HF bed in Norway (7 - 9 m^2 per PE for domestic wastewater); and
- Tanner et al. (2012) measured 58-95% TN reduction for different multi-stage systems in New Zealand (3.6 - 6.5 m^2 per PE).

5.5 On-site parameters

The pH value in CWs generally decreases through nitrification and increases through denitrification (Gerardi, 2002). The median pH value at the Bärenkogel CW differs only slightly between influent, effluent FB1 and effluent FB2. This is because nitrification and denitrification took place in the two-stage system, thereby balancing the pH value. In a one-stage system - according to the Austrian design standard (ÖNORM B 2505, 2009) - pH usually would decrease from influent to effluent, due to nitrification being the dominant process.

EC indicates total ionized constituents of water. It is directly related to the sum of cations and anions as well as the total salt content in the water (Pescod, 1992). The median EC values at the Bärenkogel CW successively decreased from influent to effluent FB1 and effluent FB2, indicating a loss of total ionized constituents and therefore a treatment of the wastewater.

The redox potential is the potential of the wastewater to permit oxidation-reduction reactions (van Loon and Duffy, 2011). The median value of redox potential measurements at the Bärenkogel CW successively increased throughout the system. The measured potentials were still negative (reducing potential) in the influent and turned positive (oxidizing potential) in effluent FB1 and effluent FB2, which is an indicator for aerobic treatment of the wastewater.

5.6 Cold climate operation

In cold climates it is crucial to keep bed and wastewater temperatures on a level that allows sufficient operation and treatment performance and as a result keeps the system from freezing and resulting hydraulic failure. When designing insulation for cold climate CWs, two key issues have to be considered: (1) sufficient oxygen transfer rate and (2) sufficient insulation (heat transfer rate) in order maintain the system's treatment performance at an acceptable level (Wallace et al., 2001; Kadlec and Wallace, 2009; Langergraber et al., 2009). Different insulation materials (e.g. gravel, mulch or blankets) have individual advantages, disadvantages and characteristics which have to be considered in regards to the respective context of the CW system. Wallace and Kadlec (2005) stated that snow cover alone is not reliable enough and does not provide sufficient insulation in periods with limited snow cover.

The Bärenkogel system was insulated with a 10 cm gravel top layer (grain size 4-8 mm), which was added on top of the FBs main layers. The top layer was not designed deeper, because at the experimental two-stage CW at the WWTP Ernsthofen, a top layer with 15 cm depth (grain size 4-8 mm) caused a very unstable performance, assumable due to reduced oxygen transfer. As a result organic matter could not be degraded anymore in between loadings, leading to a clogged filter (Langergraber et al., 2009).

However, the Bärenkogel system generally performed very well in the cold climate, also when air temperatures dropped beneath minus 15°C and stayed below zero throughout event 1 (see Figure 4-13). The measured air temperatures during event 1 were warmer than on preceding days but only because the sensor was covered with snowdrift due to heavy snow fall. Therefore it is safe to assume that actual temperatures were similar to the period before the event. Despite these freezing temperatures, bed temperatures at 0 cm depth (border of top to main layer) remained quite constant at around plus 2°C, due to the insulation effect of the snow cover. Only after the layer of snow melted in March 2012, the bed temperatures started to follow the air temperatures again.

Unfortunately, event 1 had no influence on the measured COD and NH4-N concentrations, due to a running water tap that massively diluted the pre-treatment chamber. Therefore the CW's performance could not be investigated under such extremely cold conditions in combination with a peak load from an event.

The selection of plants is amongst other factors dependent on climate. In cold climates vegetation might need a grow-in period of around two growing seasons, depending on plant density and vegetation propagation rate (Kadlec and Wallace, 2009). The CW on the Bärenkogel is vegetated with common reed (*Phragmites australis*) and was able to gain full treatment efficiencies already shortly after start of operation although the vegetation cover was low (Langergraber et al., 2013).

5.7 Tracer tests

Table 5-1 compares MRT measurements of the second tracer test with tracer tests on one- and two-staged systems in the technical laboratory of the Institute of Sanitary Engineering, Vienna.

Table 5-1 Comparison of measured MRTs of one and two-stage CWs (from Langergraber et al., 2013)

System	**Main layer grain size** (mm)	**Hydraulic load** (mm/d)	**MRT** (h)
Two-stage system *Bärenkogelhaus*	**2-4 (FB1) 0.06-4 (FB2)**	**20.8**	**33 (FB1) 75 (whole system)**
Two-stage system in the technical laboratory of the Institute of Sanitary Engineering (BOKU)	1-4 (FB1) 0.06-4 (FB2)	120	24 (FB1) 51 (whole system)
One-stage system in the technical laboratory of the Institute of Sanitary Engineering (BOKU)	0.06-4	40	68
	0.06-4	60	44

Due to the small hydraulic load at the Bärenkogel system, its MRT is higher compared to the laboratory's two-stage system. Even though the hydraulic load in the laboratory's two-stage system is nearly six times bigger, the MRT did not go beneath a m inimal limit, because of the impoundment of the drainage layer in FB1.

Both two-stage systems have a c oarser grain size in the main layer of FB1 than the laboratory's one-stage system. Despite high hydraulic loads, the MRTs of the one-stage system are much higher than the MRTs for FB1 of the two-stage systems. This is because of the finer grain size in the one-stage system and shows how the coarse grain size in FB1 of the two-stage design allows the CW to receive higher hydraulic loads.

6. Summary and Conclusion

The aim of this master thesis was to examine the performance of the intermittently loaded, two-stage CW of the inn *Bärenkogelhaus*. The system is located in a cold climate, in the subalpine region of Austria. Due to the inn's event operation the CW received fluctuating and peak loads. The investigation focused on the time period of event operation - from July 2011 until September 2012 - when special investigations, including event samplings and tracer tests, took place.

The treatment performance of the CW was very high throughout the whole time, with median removal rates of 98, 96, 99.9 and 72% for BOD_5, COD, NH_4-N and TN, respectively. The measured effluent concentrations were below the legally required thresholds of 25 mg BOD_5/L, 90 mg COD/L and 10 mg NH_4-N/L throughout the whole period of event operation. Several incidents (i.e. running water tap and tracer tests) during event operation lead to hydraulically and organically disturbed periods. Therefore, results had to be considered with and without these disturbed periods. Otherwise, there were no technical problems concerning the CW system during the whole period.

During event operation, a total of 284 loadings (in undisturbed periods) were measured, resulting in an average hydraulic load of 13%. The most realistic organic load could be calculated without consideration of loadings in disturbed periods and without consideration of samplings from periods with too low influent concentrations, thus resulting in 2.2 g COD m^{-2} d^{-1}, which is 7% of the design load. During some events a hydraulic load of around 100% of the design load was reached, whereby the organic load was still less than 50% of the design load.

Out of the 17 events that took place during event operation, 5 were sampled, in order to examine the system's performance under the occurring peak loads. Throughout these event samplings the effluent concentrations were barely above the limit of detection and therefore far below the legally required thresholds.

The tracer tests showed that the coarser grain size in the first bed of the two-stage design allows for a higher hydraulic load on the system. The tests also showed how the impoundment of the drainage layer of FB1 ensures a minimal MRT in the CW system.

In conclusion, the investigations on the performance of the CW Bärenkogel showed:

- despite the cold climate, the two-stage design ensured a stable treatment performance and effluent concentrations were far below legal thresholds throughout the whole period of investigation;
- despite peak and fluctuating loads, caused by long periods with low flow followed by peaks due to an event, the two-stage design showed a high treatment performance;
- with the two-stage design, legal requirements concerning effluent concentrations can be met throughout the whole year;
- the CW was planned for full-time operation of the inn and was therefore over-dimensioned for event operation;
- the two-stage design enables a TN removal of around 70% without recirculation, which is very high, also compared to other systems in similar circumstances;
- the impoundment of the drainage layer in FB1 ensures a minimal MRT; and
- the two-stage design allows higher hydraulic loads, due to the coarser grain size in FB1.

The first non-experimental full-scale two-stage VF CW system at the Bärenkogel performed very well. Therefore, I recommend onward research on two-stage VF CWs, in order to further raise their practical acceptance and eventually develop a design standard.

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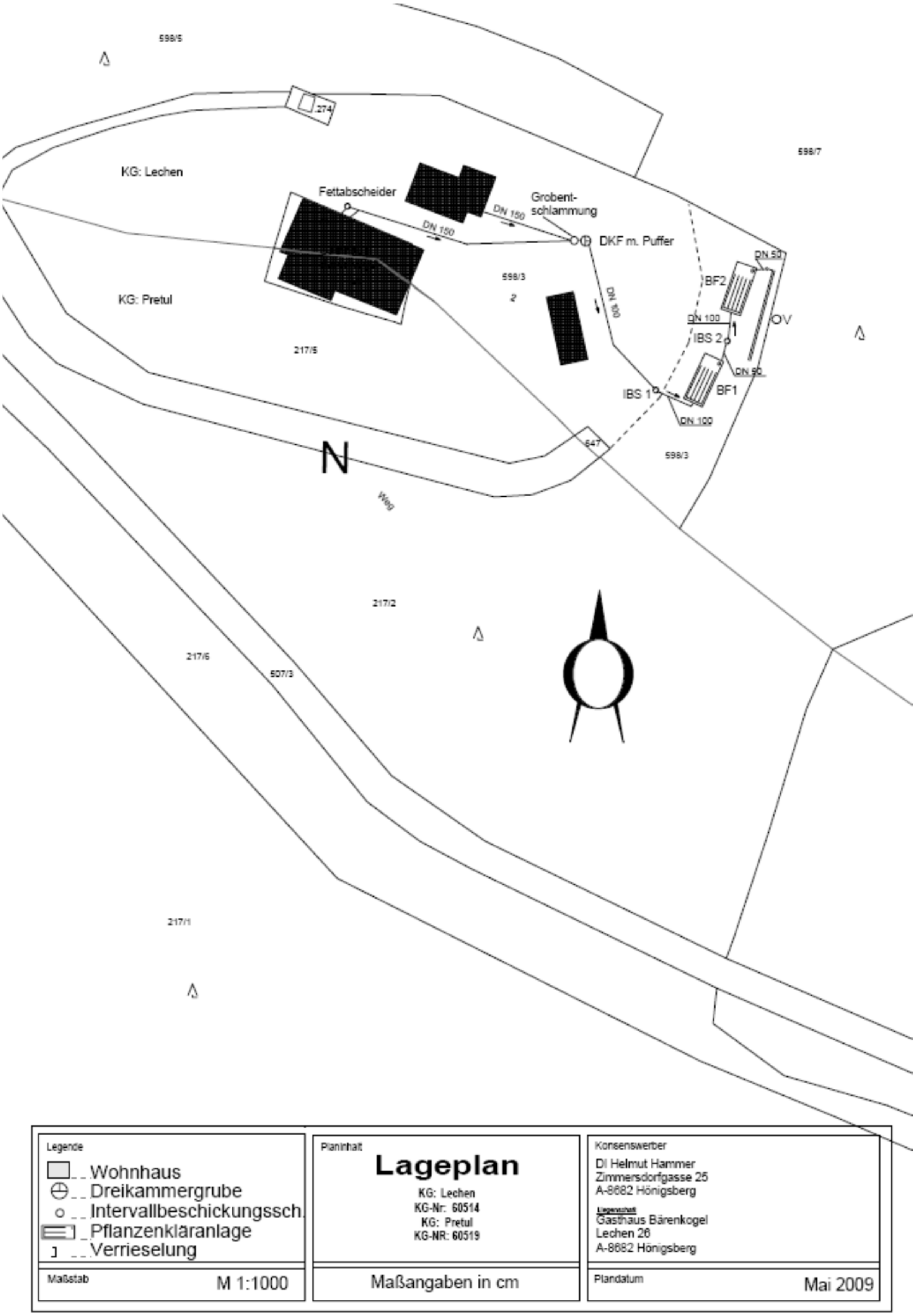
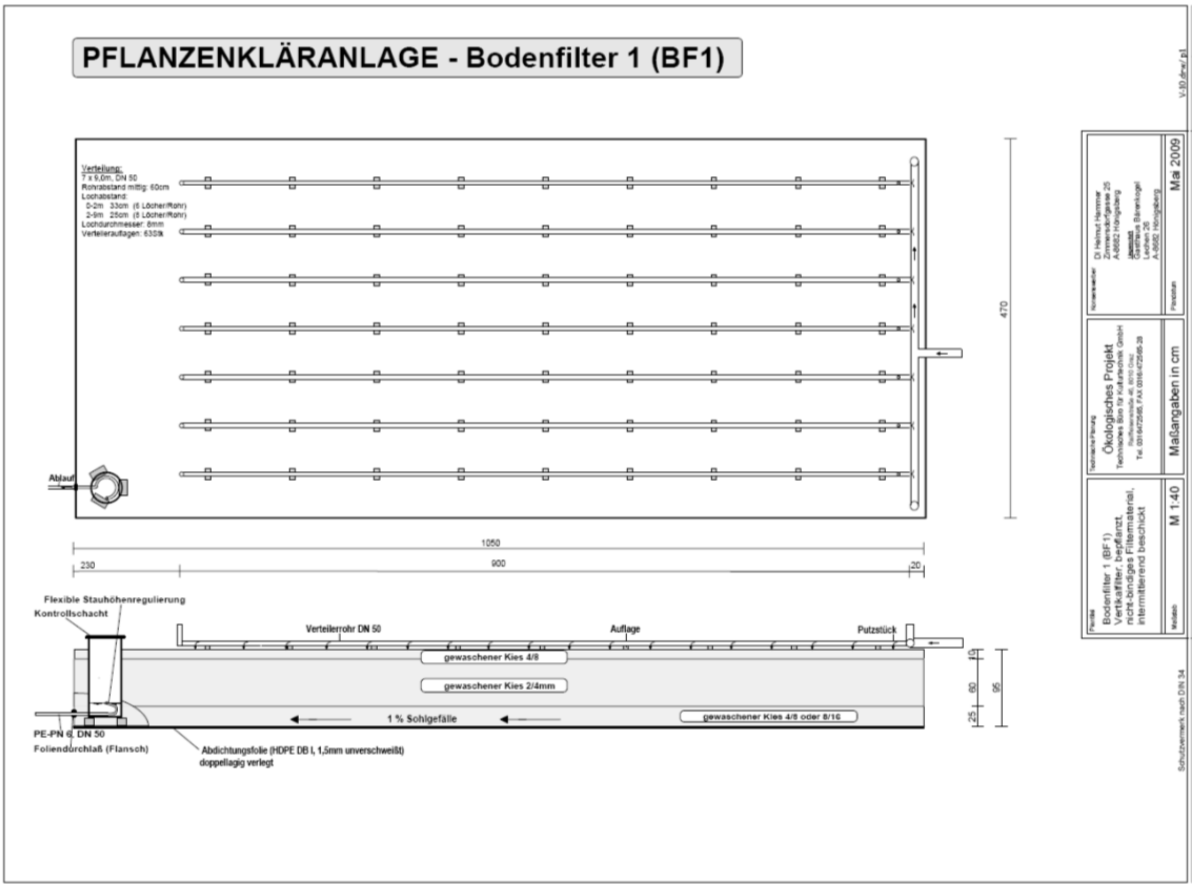
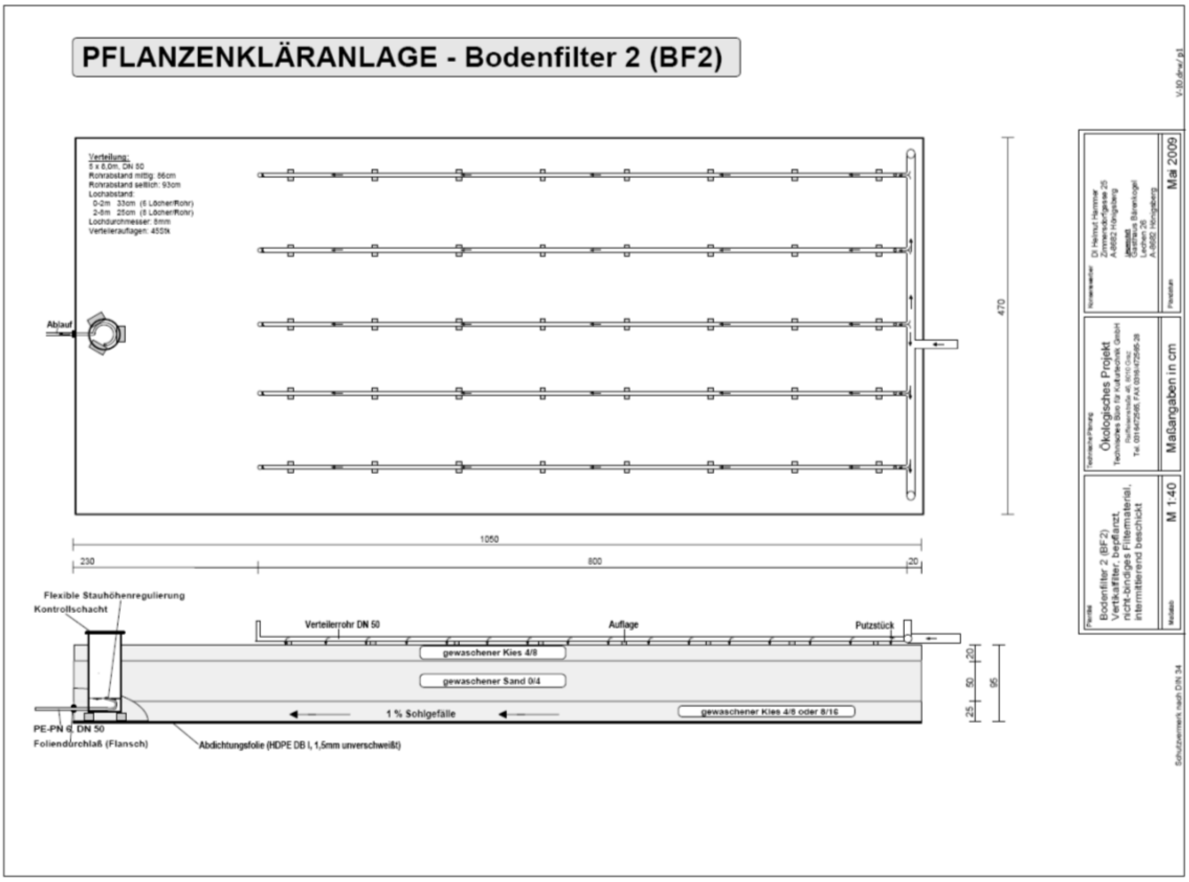
Appendix I: Plans

Appendix I: Plans, page 1 of 2 (in German):



Appendix I: Plans, page 2 of 2 (in German):





Appendix II: Routine investigation checklist

Appendix II: Routine investigation checklist, page 1 of 2 (in German):

Checkliste 2012 Nr. .... Datum:

(für die Betreuung der Bodenfilter am Gelände des Bärenkogelhauses)

Generell: Die Checkliste ist während der Probenahme zu führen und weiterzuleiten an:

- **BOKU (z.Hd. Langergraber/Pressl)**
- **Fax.: 01 / 47654 5803 (neue FAX Nummer!)**
- **email: guenter.langergraber@boku.ac.at und alexander.pressl@boku.ac.at**

Checkbox

☐ 1. Beginn der Probenahme: *Uhrzeit:* ....

Wetter der letzten 12 Stunden [Regen(pfützen), Schneefall, sonnig, bewölkt, Dauerfrost, etc.]:

....

☐ 2. Trinkwasserverbrauch: Bei der Wasseruhr manuell abzulesen.

Uhrzeit: .... *Zählerstand:* .... Liter

☐ 3. 3-Kammeranlage:

(Nach Bemerken des Ausfalls oder Verstopfung der Förderpumpe sind verantwortliche Personen sofort telefonisch zu verständigen!)

- *Ordentliche Funktion* erfüllt / nicht erfüllt
- *Schwimmschlamm in 2. Kammer* vorhanden / nicht vorhanden

☐ 4. Ablaufschacht 2: Betonschacht **nach** dem zweiten Pflanzenbeet.

Ordentliche Funktion erfüllt / nicht erfüllt

☐ 5. Ablaufschacht 1: Betonschacht **nach** dem ersten Pflanzenbeet.

Ordentliche Funktion erfüllt / nicht erfüllt

☐ 6. Beschickungsschacht: Betonschacht **vor** dem ersten Pflanzenbeet.

- *Ordentliche Funktion* erfüllt / nicht erfüllt
- *Förderleistung der Pumpe in Ordnung* (Falls möglich - nach Augenschein) erfüllt / nicht erfüllt

Checkliste_Baerenkogel_2012_NEW.doc BOKU Wien

Appendix II: Routine investigation checklist, page 2 of 2 (in German):

Checkbox

☐ 7. Abwasserverteilungssystem:

- *Keine Verstopfung der Beschickungsöffnungen* (Nach Augenschein) — erfüllt / nicht erfüllt
- *Keine Vereisung der Beschickungsöffnungen* (Nach Augenschein) — erfüllt / nicht erfüllt
- *Waagrechte Lage der Beschickungsstränge* (Nach Augenschein) — erfüllt / nicht erfüllt

☐ 8. Bepflanzte Bodenfilter:

- *Wasser versickert unmittelbar nach Beschickung* — erfüllt / nicht erfüllt

  (Falls es zu Verstopfungserscheinungen/Oberflächenstau kommt, sind verantwortliche Personen sofort telefonisch zu verständigen!)
- *Zustand der Beetoberflächen*:

  Auftritt von schlammigem Belag (Wenn „ja", auf welchem Beet.........................) — ja / nein

  Auftritt von Fremdbewuchs (Moos, Unkraut, Gras, etc. ....) (Auftretender Fremdbewuchs ist umgehend zu entfernen!) — ja / nein
- *Bepflanzung (Schilf)*:

  Nach äußerem Anschein gesund — ja / nein

  Kein Ungezieferbefall — erfüllt / nicht erfüllt

  Ausfälle von Pflanzen (Wenn „ja", auf welchem Beet: ....) — ja / nein

  Schneedecke (Wenn „ja" – ungefähre Höhe = ... cm) — ja / nein

☐ 9. Ausfall der Anlage: Angabe der Ursache, falls bekannt.

- aufgrund Stromausfall am / von / bis ....
- aufgrund Störung der Beschickung am ....
- aufgrund ....

☐ 10. Gästefrequenz (Art des Events bzw. Anzahl Gäste/Übernachtungen)

Datum	Event	Gäste/Übernachtungen	Anmerkungen
....	....	....	....
....	....	....	....
....	....	....	....
....	....	....	....

☐ 11. Sonstiges (besondere Vorkommnisse, Beobachtungen, Reinigungen, Reparaturen)

....

....

Probenehmer: .... (Name) .... (Unterschrift)

CV

Personal details

Name	Marco Hartl
Date of Birth	7th of June 1987
Place of Birth	Schladming, Austria
Address	Graumanngasse 39/40 1150 Wien, Austria
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Contact number	+43 650 877 2 388
E-Mail	hartlmarco@gmail.com

Educational qualifications

10/2011 – 01/2014 (expected end)	**University of Natural Resources and Life Sciences, Vienna** (BOKU) International Joint Master: Natural Resources Management and Ecological Engineering (NARMEE) Master thesis: „Performance of a t wo-stage constructed wetland in the alpine region of Austria under peak loads" Supervisor: Dipl.-Ing. Dr. Günter Langergraber Co-Supervisors: PhD Magdy Mohssen Dipl.-Ing. Alexander Pressl
02/2013 – 06/2013	**Lincoln University** (LU), New Zealand Exchange semester in the course of NARMEE program
10/2007 – 06/2011	**University of Natural Resources and Life Sciences, Vienna** BSc: Environment and Bio-Resources Management
01/2010 – 06/2010	**Norwegian University of Life Sciences** (UMB) Exchange semester during Bachelor
2001-2006	**HTBLA Kaindorf** (federal higher technical institute) Department IT and Organisation

Work experience

08/2012 – 09/2012	**Kommunalkredit Public Consulting** Department Climate and Environment, Internship, Environmental funding
04/2011 – 06/2011	**GLOBAL 2000** – Friends of the Earth Austria Internship, Campaigning Team Resources, Climate and Energy
08/2010 – 09/2010	**via donau** – Österreichische Wasserstraßen-GesmbH Internship, Team Development and Infrastructure, paper on „Effects of extreme weather events on inland navigation"
08/2009 – 09/2009	**via donau** – Österreichische Wasserstraßen-GesmbH Internship, Team Basics and S tratgey, paper on „Effects of extreme weather events on inland navigation"
04/2007	**VERBUND -** Austrian Power Vertriebs GmbH (APC) Data management
07/2006 – 03/2007	**Deaconesses-Hospital Schladming** Alternative service (instead of military service)
08/2005	**Land Government Styria** Internship, Department 1A, Organisation Process modelling (ARIS)
2002, 03 und 04 1 month each	**Planai- und Hochwurzen Ski Area** Internship, Secretarial work

Skills

Languages	German	–	first language
	English	–	business fluent
	Spanish	–	basic knowledge
IT skills	User-level knowledge in MS Office, ArcGIS, R (statistics) and several database systems. Basic programming knowledge in SQL, C# and Java.		