REVIEW OF SUBSURFACE FLOW TREATMENT WETLAND FEASIBILITY IN FINLAND

Gábor Horváth

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ABSTRACT

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Constructed wetlands are engineered systems for treating wastewater. They have normally been used only as secondary treatment systems. However, over the last five decades, they have started to be utilized more extensively, as problems with operation and maintenance are gradually being solved. In Finland, treatment wetland is still ignored as a way to replace expensive chemicals for wastewater treatment purposes. The wetland system is rejected partly because the biological and chemical processes are temperature dependent, and secondly, there are concerns about ice formation and its effect on hydraulic flow, hydrology and hydraulics. Thermal consequences for biologically or microbiologically mediated treatment processes are the main constraints. Constructed wetland systems in Finland have commonly failed because the temperature coefficient has not been designed carefully, and clogging by organic matter has occurred in the inlet of the pool. Therefore, energy and water balance calculations as well as thermal modeling are useful tools to prevent design, operation and maintenance failure.

Studies of constructed wetlands have shown less sensitivity to temperature swings in full-scale experiments than laboratory-scale ones. The lab-scale results should not prevent a full-scale trial because biological living beings in the nature interact with and affect the environment in ways which cannot be predicted in laboratory-scale testing. The wetland treatment method relies on anaerobic and partly aerobic conditions, which are essential for the transformation of nutrients and organic pollution to take place.

A common problem with treating wastewater with an SSF wetland system is clogging failure. Also, oxygen transfer is reduced significantly by the need to use an insulating mulch layer, compared with situations where a mulch layer is unnecessary. Nitrogen removal is low due to the lack of oxygen availability, but this can be increased by artificial aeration.

Key words: cold climate, temperature, horizontal subsurface, clogging, aeration

CONTENTS

GLOSSARY

BAT	Best Available Technology
BOD	Biological Oxygen Demand
CBOD	Carbonaceous Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
Cold climate	“cold climate” means annual average temperatures lower than 10°C, as well at least one month snow cover and natural vegetation equals to boreal species
CW	Constructed Wetland
CW-TW	to avoid confusion, Constructed Wetland and Treatment Wetland used by turns but it refers to the same meaning in the context
FWS	Free Water Surface
H_2O_2	Hydrogen Peroxide
HF	Horizontal Flow
HSSF	Horizontal Subsurface Flow
HSSF TW	Horizontal Subsurface Flow Treatment Wetland
N	Nitrogen
SS	Suspended Solid
SSF	Subsurface Flow
SYKE	Finnish Environmental Institute
TAMK	Tampere University of Applied Sciences
TW	Treatment Wetland
VSSF	Vertical Subsurface Flow
VF	Vertical Flow

1 INTRODUCTION

As the human population grows, there are corresponding increases in the amount of anthropogenic waste generated. Conventional wastewater treatment development projects cannot keep up with the continuously increasing amount of waste created in the inbound side by urban and industrial developments, and inevitably partly or completely untreated waste must be released to the nature. The discharged solid and liquid waste is highly concentrated in nutrition and harmful substance to the nature, and must be assimilated by the ecosystems of the environment.

The release of the effluent contamination into the environment without appropriate treatment may overwhelm receiving water bodies and widen the effects of pollution, endangering ecosystems health (Gray 2008). Our social, economic and environmental coherence is sought in the management to ease these rising dangers. One of the major problems which need to be solved is the protection of water resources, especially surface and ground waters. Wetlands are one of the many possible ways to treat our water resources. Swamp or marsh areas where the water table is at/near the surface at least part of the year and is generally characterized by the presence of specially adapted vegetation types and soil characteristics that developed a response to the wet and saturated conditions (Kadlec et al. 2009).

1.1 Objective

The overall goal of this thesis is to revision the feasibility of constructed wetlands for wastewater treatment under cold climate. The thesis intends to be a summarized work to present up-to-date methods about horizontal subsurface flow constructed treatment wetlands (also named constructed wetlands in this thesis) and their removal effectiveness in cold climate. The objective of this study is to analyze the criteria steps for a successfully operating HSSF wetland. The thesis also shortly discusses the current wastewater treatment and management legislation permits.

1.2 Existing Legislation in Finland

In Finland, about one million residents and over one million vacationers are located outside the municipal sewer systems. There are about 350 000 onsite wastewater systems serving permanent dwellings. The estimated amount of untreated discharge of phosphorus to waterbodies is 50% higher than in urban areas (Ruokojärvi A. 2007). Therefore, rural wastewater treatment is tightly connected to eutrophication and needs to be considered in planning further water management and restoration.

1.2.1 Treating Wastewater in Areas Outside Sewer Network

The Decree, also called Onsite Wastewater (542/2003) System Decree (Wastewater treatment at...2012), came into force on 1.1.2004. The Decree sets minimum standards concerning wastewater treatment for planning, construction, use and maintenance of treatment systems. The relevant information to thesis is the building act which states that new building after 1.1.2004 should fulfil the required treatment obligation immediately. The same obligation stands for old buildings built before 1.1.2004, and must reach the standard treatment releasing treated water to the nature, before 1.1.2014. The Decree redrafted the permit to ease the public stress due to community demand of strict due date as well tight nutrient restriction.

The Decree states primary criteria to analyse the removable organic matter, and the amount of processed phosphorus and nitrogen in wastewater treatment systems before allows being available as a treatment technology for the public. In table one, the minimum criteria limits can be seen for passing the standard for dwellings at a discharged load of 50 g/d for BOD, 2.2 g/d for total P and 14 g/d for total N.

TABLE 1 Old reduction limits for treating wastewater in areas outside sewer network (Santala and Jorma from Finnish regulations...)

BOD7	90%
Total P	85%
Total N	50%

The updated version of Onsite Wastewater Treating (209/2011) law entered into force on March 15th, 2011, and gave time for premises to install proper treatment system on those building sites which were completed before the entry came into force from 1.1.2014 to 15.3.2016.

The Decree (209/2011) announces minimum treatment requirements for onsite wastewater systems (see table 2) and give guidance for existing systems whom must have a specified wastewater system report to apply for a new building permit which will include a wastewater system plan for the premises. The wastewater system must be built according to the Plan and Maintenance instruction, and it is necessary to provide help to implement the manual according to the regulation by municipality.

TABLE 2 Requirements for the reduction of wastewater loads as specified by treating wastewater in areas outside sewer network degree (Wastewater management at..., 2012)

BOD_7	80%
Total P	70%
Total N	30%

The Decree emphasise that “no treatment method or device is automatically better than another.” The natural preservation is important and very strict in terms of talking about tight reduction demands, which do not take area differences into account. The list which specifies all the best available up-to-date sources for treating wastewater in rural areas does not include many biological treatment methods, which e.g. would be suitable for small waste water uptake in dwellings. The author´s only concern that Finnish Environmental Institution (SYKE) does not favour CW (also named “root zoned”) method as an ideal treatment due to Finland located CW method experiments failures because of inadequate fundamental design errors. In this thesis, the basic failures will be discussed to prevent fault and to make CW methods preferable to treat wastewater in rural areas in Finland.

The nature and water resources protection in rural municipalities with low population densities do not have the financial capital for conventional treatment plant, even if the community has the money, it is still difficult to attract qualified technical expert for overseeing large conventional treatment facilities. In such rural areas, alternative treatment methods are available with high removal capacity. Subsidies are available for those residents whom have financial difficulties in a form as governmental funds on social grounds (max 35% of costs); tax claim deductions for the work done etc.

By 2014, 95% of all properties outside sewerage networks should be equipped with facilities corresponding to best available wastewater treatment techniques; and by 2018 all properties should be duly equipped. In the year 2000 the phosphorus loads entering watercourses totalled some 350 - 400 tonnes annually, and this figure should be reduced by 2015 to 100 - 150 tonnes.

2 Constructed Wetlands

Constructed wetlands are engineered systems which provide secondary treatment and designed to cleanse and detoxify surface water by mimicking many of procedures and/or process that naturally-occur (Knowles P. et al 2011). They are designed to take advantages of many unique conditions such as sedimentation, filtration, chemical precipitation, microbial interaction, plant assimilation and adsorption to soil particles.

The several simple beneficial attributes in constructed wetlands are the capacity to operate on energy provided by the sun, fix itself up and create productive treatment capacity over time, provide natural space for animals, increase oxygen levels in subjected water bodies and decrease levels of carbon dioxide, and reach high levels of treatment with small levels of maintenance (Wallace, 2000, Vymazal et al. 2008) give wetlands the ability to remove several substances like nitrogen, carbon, sulphur, potassium, and phosphorus, what result in an increase in water quality (Gray 2008).

Treatment wetlands employ these processes in order to provide effective environmental and sustainable systems for wastewater purification improvement in small and rural communities which ensure researchers to expand the applicability territories of such systems (Gray 2008).

Apart from this great opportunity, the ability of treatment wetlands to maintain sufficient removal levels under boreal climate has been questioned. Wetlands are avoided to treat wastewater due to questions of effectiveness, understanding and sufficient reference studies in the Nordic regions. The biological and chemical processes are temperature depended which requires careful design and maintenance and some energy input for good level of removal efficiency in such climate. Systems mostly not succeed because of the temperature coefficient not designed carefully and systems get clogged by organic matter (Kunihiko Kato 2012). One of the necessary implementation, when designing subsurface flow wetland to overcame the above mentioned problems, is the mulch (blanket) layer which prevents the system from dropping below 0 ºC.

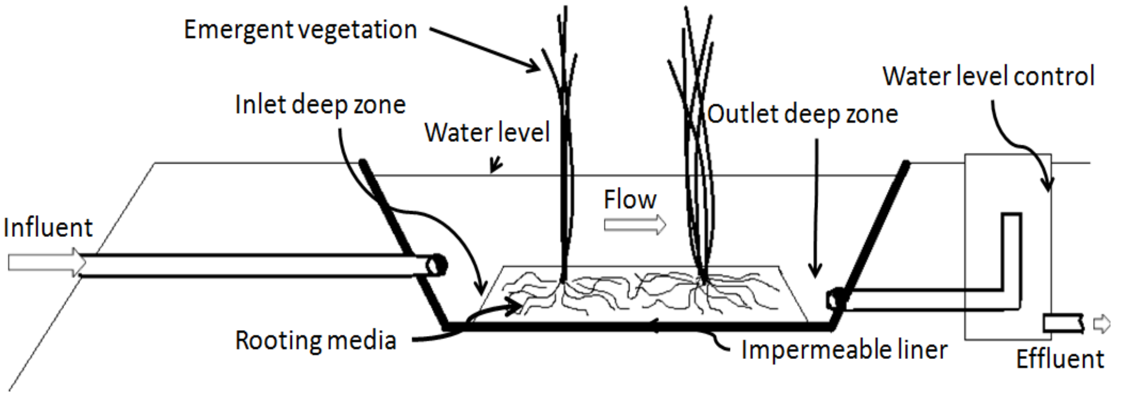
Studies showed that the blanket cover will have a positive effect on rates of oxygen transfer, plant establishment and performance level with which pollutants are removed negatively therefore new ways of wetland method must be employed for good results.

This study aims to investigate this subject because constructed wetlands remain one of the least expensive treatment systems based on their low annual costs with minor energy and chemical consumption (Kadlec et al. 2009, Wallace et al. 2000).

Subsurface flow wetland has the primary benefit to not be exposed to the atmosphere which secures its homogenized environment during the treatment procedure and minimize the energy loss through evaporation and convection. It was first introduced in Germany (Wallace, 2000). The two most efficient applicable solutions for winter conditions are horizontal subsurface flow (HSSF) and vertical flow (VF). However vertical flow requires more attention in installation as well during maintenance. Therefore it is not advised for small application areas.

2.1 Free Water Surface Constructed Wetlands

Surface or horizontal flow wetland is fed in an inlet where the fluid slowly run through the soil or another medium which able to sustain rooted vegetation (if present) in a shallow unit. One of their primary design purposes during the passage is that the wastewater will come into contact with a network of aerobic, anoxic and anaerobic zones. Aerobic process occurs in the roots and rhizomes of the wetland vegetation that leak oxygen into the substrate (Vymazal 2000). Wastewater purifies by microbiological degradation and by physical and chemical processes through the rhizomes transfer. FWS effectively remove organic compounds (TSS BOD and COD) from the water.



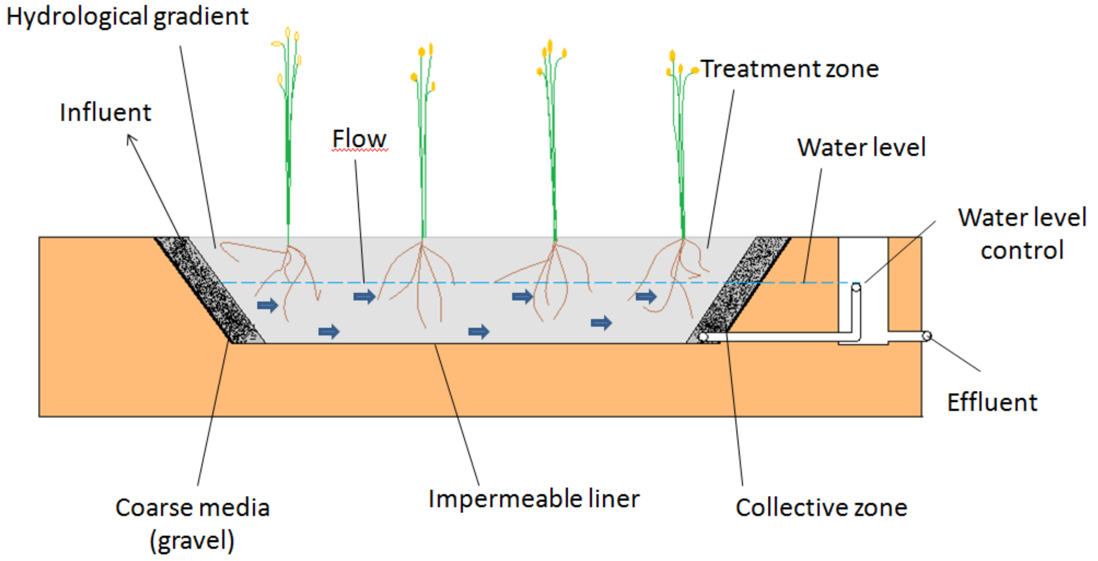
PICTURE 1 Basic draft of a Horizontal Flow Wetland (adapted from Kadlec and Wallace(2009) Treatment Wetlands Second edition.

2.2 Horizontal Subsurface Flow Treatment Wetlands

Horizontal subsurface flow treatment wetlands are planted with gravel filters which means subsurface flow wetland designs have no natural wetland analog (Kadlec et al. 2009). This system has promising treatment solution for territories such as Finland where innovative answer have to been found as a response to cold climate. The concept was developed in the 1960s in Germany (Vymazal et al 2008).

Yet, Denmark is a word-pioneer in promoting root-zone method for cold climate zones. Therefore the most reliable data comes from their projects. According to studies, the nitrogen removal and filtering of pre-treated wastewater are the major goals in the most of the cases. If the winter extreme cold, it is a common procedure to store the discharged wastewater in a tank during extreme winter and reflow it again during spring time onto the site.

The HSSF reed bed is the most widely used concept of TW. Typically rectangular in design, the subject water flows into the pool from the inlet pipe and it slowly passes through the media below the surface in a horizontal path before discharging at the outflow pipe. Over time, the subsurface will become clogged as a result of the physical, biological, and chemical processes that occur through wastewater treatment (Ouellet-Plamondon et al 2006, Kato K et al 2011). The hydraulic performance of the subsurface will eventually deteriorate to the point where the TW will no longer function as required. Remediating clogged TWs is the major cost associated with utilizing this technology, and therefore it is desirable to obtain a greater understanding of the clogging process so the longevity may be improved (Wallace et al 2000, Ouellet-Plamondon et al 2006, Kadlec et al 2009, Vymazal et al 2008).

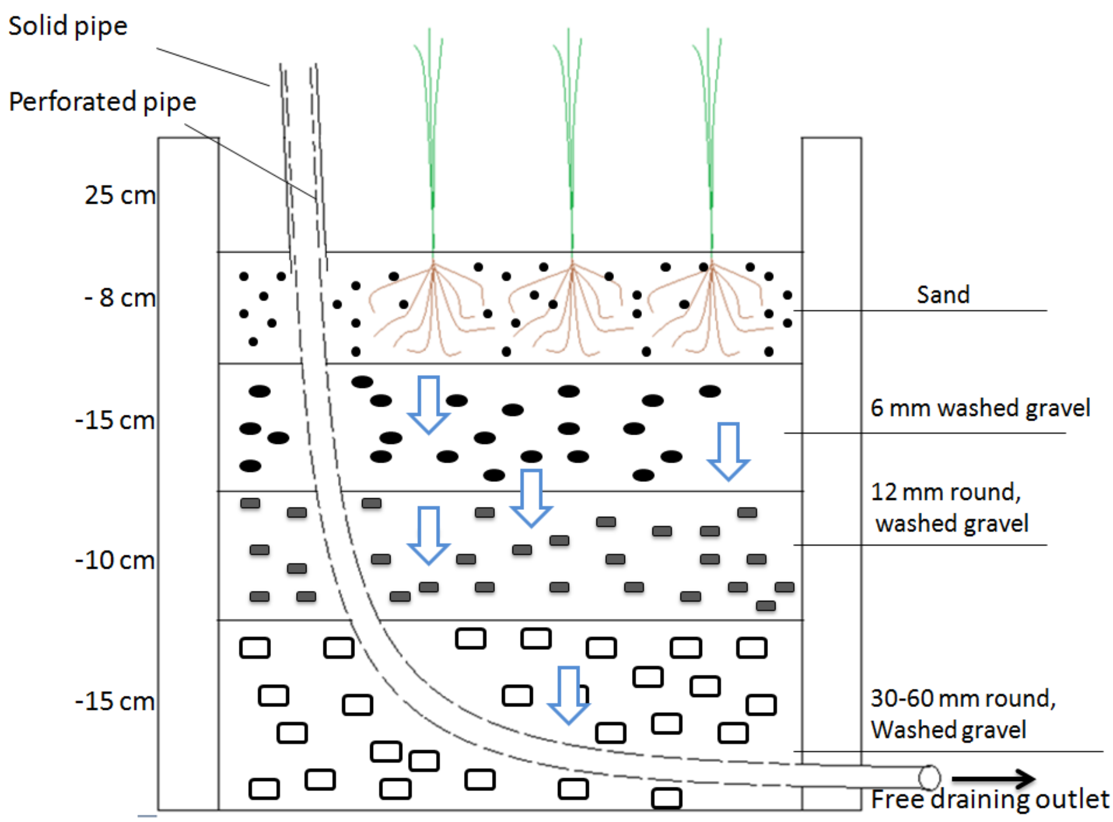


PICTURE 2 HSSF wetland schematic. (adapted from Wallace and Knight (2009) Small-scale constructed wetland treatment systems)

2.3 Vertical Subsurface Flow Treatment Wetlands

The earliest vertical-downflow systems were used in Germany in the 1970s; similar systems were used in the Netherlands as well. HF beds have low ability to oxidize ammonia to nitrate mainly due to insufficient amount of oxygen transferred by macrophytes to the rhizosphere (Vymazal et al 2008).

VF wetlands consist of a bed of sand topped with sand/gravel and vegetation. Wastewater is led from the top and gradually penetrates downward through the media and collected by drainage at the bottom. The size fraction distribution of gravel is larger in the bottom layer (e.g., 30-60 cm) and smaller in the top layer (e.g., 6 mm). Wastewater gradually infiltrates down through the bed and is collected by a drainage network at the base. The bed drains completely free and it allows air to refill the bed. This leads to good oxygen transfer and hence the ability to nitrify. The main purpose of macrophytes presence in VF CWs is to help maintain the hydraulic conductivity of the bed. It has a much greater oxygen transfer capacity resulting in good nitrification, and effectively removes BOD5, COD and pathogens but it is difficult to maintain such systems in small communities. It has also the advantage in sizing because it requires a considerably smaller area than a HF system.

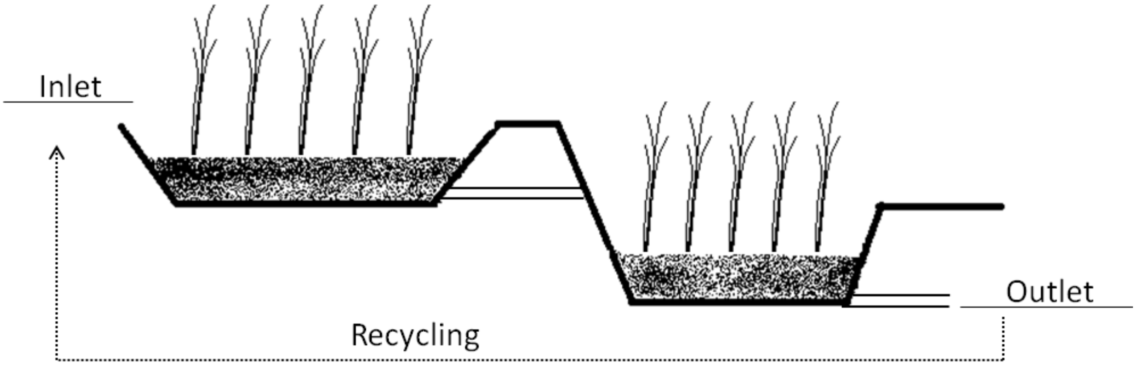


PICTURE 3 Typical arrangement of a downflow vertical-flow constructed wetland (adapted from Vymazal et al. 2008)

2.4 Hybrids

Various types of constructed wetlands may be combined in order to achieve higher treatment effect, especially the nitrogen removal is surpassing. There has been growing demand to achieve full-nitrification effluents but secondary treatment HF systems cannot do this because of their limited oxygen transfer capacity (Vymazal et al 2008). VF systems have a much greater oxygen transport capacity and therefore provide a better condition for nitrification. The problem that very limited or no denitrification occurs in VF systems. Therefore, there has been a growing interest in hybrid systems.

Hybrid systems most often a combination of VF and HF systems and this way the engineers gain the individual systems advantages to eliminate the other systems disadvantages. Depending on the purpose, hybrid wetlands could be either HF which followed by VF or VF followed by HF wetland (UN-HABITAT, Vymazal et al. 2008).

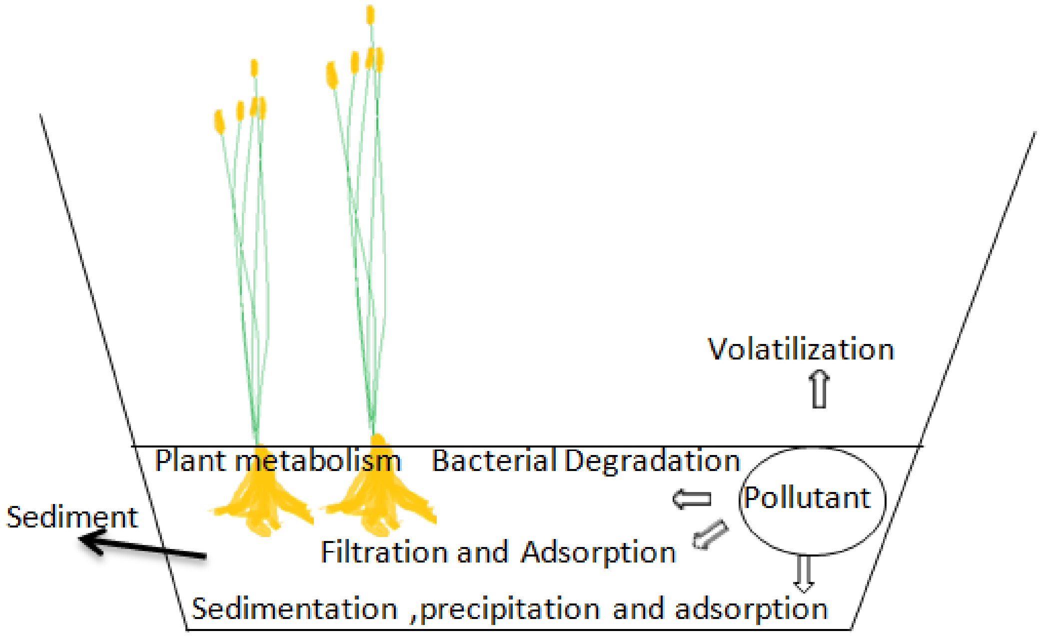


PICTURE 4 Two-stage Horizontal and Vertical flow hybrid wetland system (adapted from Vymazal et al. 2008)

2.5 Water Purification Processes in Treatment Wetlands

Wetlands, general are considered as a negative agent in the combating the climate change because of their emission of greenhouse gasses e. g. methane and their low albedo which is supposed to result in temperature increase in the surroundings (Brom et al, 2008) yet constructed wetland (CW) system gain wider practice thanks to their treatment and buffering of effluent and runoff water.

In Picture five, the general removal mechanism can be seen. The different kinds of removal mechanism effectiveness differ from one to another; depend on the wetland type applied in practise (e.g. HF has efficient volatilization removal while HSF has very limited or negligible).



PICTURE 5 Pollutant removal mechanism (adapted Kadlec et al. 2009)

Treatment wetlands are complex collection of wastewater, substrate, vegetation and microorganisms systems (reed zoned method is the most used in Europe), designed to achieve a specific water treatment function, and have a specific, different and more accurate meaning than the wider term of "Constructed Wetlands" which often applied to wetlands created for water quality improvement purposes (Fonder et al). The system purifies water by organic matter (BOD, oxidizing ammonia, reducing nitrogen and phosphorus quantity) (Vymazal et al. 2008, Kadlec et al. 2009).

TABLE 3 Formulated pollutant removal mechanism of Picture 5 (adapted from Constructed wetlands manual…2008)

Wastewater component	Removal process
Suspended solids	Sedimentation, Filtration
Soluble Organic	Aerobic& anaerobic microbial degradation
Phosphorus	Matrix sorption, Plant uptake
Nitrogen	Ammonification followed by microbial nitrification, denitrification, plant uptake, matrix adsorption

2.5.1 Sedimentation

Primary sedimentation is used to reduce the high concentration of total suspended solids (TSS). The operation is accomplished with a constant flow within a deep (typically 3 to 5m) pond or septic tank. Settled solids are removed and can be further treated or disposed. SS also removed by bacterial metabolism and physical processes and may also be removed by particulate nitrogen from the water, either as a structural component or as sorbed ammonia.(Vymazal et al 2008, Wittgren et al 1997)

In SSF wetlands, the main concern is the method of the sedimentation and there is no evidence that inlet zone clogging can be avoided, as the process is a cumulative practice and the majority of the particulate matter is settled in the inlet area (Kadlec et al 2009). This can be explained by physical processes as sedimentation and decantation which are important in particulate organic matter removal are unaffected during colder season. Studies (e.g. Jenssen et al 2008, Wallace et al. 2000) suggest a ten years maintenance circle to avoid overflow problems occurs by clogged in the inflow.

2.5.2 Phosphorus sorption

Sorption is important for phosphorous retention during the start-up period; for ammonia and nitrogen removal. The bed material represents a potential adsorption for removal of phosphorus if the soil has the capacity to bond phosphorus substances. The amount which will be stored it depends on the volume of the inflow wastewater and the soil retention capacity.If the soil and sediment reach equilibrium with the surrounding water the substance will be released to the water and will be flow into the water body untreated. Consequently, it is important to solve constant uptake by plant of phosphorus or other chemical and biological reaction.

There are certain equations to be used to calculate bed media total sorption capacity. Phosphorus retention also influenced by the amount of iron, aluminium, calcium and organic matter present in the soil. As phosphorus retention is endothermic, colder water temperature will decrease the sorption capacity if the bed aggregate (Kadlec et al 2008).

2.5.3 Plant uptake

Plant takes nutrient to sustain their metabolism. They might also capture chemicals found in the root zone, which stored or transferred into gases. The uptake occurs in the root, which locates in the wetlands soil.

Nutrient uptake by plants and microbial transformations of wastewater components and plant litter in wetlands are both directly and indirectly affected by climatic conditions. Directly in the sense that plant physiology is governed by solar radiation and temperature, and microbial processes by temperature alone. Indirect influences include the dependence of biological and biochemical processes on physical conditions, which in turn are affected by the climatic conditions (Wallace et al. 2000).

The annual plant uptake of nutrients, and the potential for harvest of nutrients, varies with the affect of the climatic coefficient. This is illustrated with nitrogen and phosphorus uptake in treatment wetland plants from different climatic regions (Wittgren H. et al 1997).

In table four, Wittgren (1997) and his colleagues collected years of data from different locations, mostly from Nordic countries, and calculated the nitrogen and phosphorus uptake by plants species. It is extremely useful at wetland design when plant species choose is in question. In order to let continuous nutrient uptake by plant requires several harvests per year. Without harvesting, the plants reach saturated level in nutrient load where plants cannot uptake anymore. Harvesting is not used in dormant time, and usually plants are not harvested before winter period so the dead litters may provide insulation for the system which might protects it from freeze (Wittgren et al 1997, Jenssen et al 2008).

TABLE 4 Annual nutrient uptake for selected plants in wastewater treatment wetlands (examples from Wittgren H. et al 1997)

*Plant species(*location)	Nitrogen (*kg ha*$^{-1}$ *yr*$^{-1}$)	Phosphorus (*kg ha*$^{-1}$ *yr*$^{-1}$)
Cold temperature		
Cladophora glomerata+ Elodea canadensis (Sweden)	160-228	19-28
Glyceria maxima (Sweden)	198-321	30-48
Phalaris arundinacea (Alberta, Canada)	200-434	
Salix spp- stems (Sweden)	107-199	23-30
Salix spp- stems+leaves (Sweden)	251-367	48-66

Oxidation of organic matter and nitrogen transformation are the most important microbiogically treatment processes affected directly by temperature. These processes are also sensitive to the level of available oxygen. Phosphorus removal, being largely a physical (sedimentation) and chemical (adsorption) process, is less directly sensitive to temperature, but may be influenced by the oxygen availability due to the sometimes large role played by redox sensitive adsorption to ferrous/ferric oxides. Oxygen presence or lack of presence plays a major role in the efficiency during the treatment procedure. As a result, supplement oxygen must be available to the system either naturally or artificially for the best removal capacity in winter conditions (Kadlec et al 2008, Wallace et al 2000, Grey 2008).

2.5.4 Nitrogen processes

Nitrogen (N) exists in various forms and compounds, and is continuously involved in chemical processes that change it from one for to another through reversible reactions (Grey 2008). There are several chemical processes which transform N such as nitrificitation, denitrification, ammonification, N fixation and N assimilation. These transformations create a complex nitrogen cycle in wetland systems (Grey 2008, Jenssen et al 2008).

Ammonia can be picked up by plant uptake. This means that nitrification is the dominant mechanism for ammonia reduction in HSSF wetlands. But some cases this method is not so effective. Because all mechanism of ammonia reduction require oxygen, it is useful to speculate that the amount consumed in the HSSF wetland has other chemical contribution as well.

3 CRITERIA OF HSSF TW INSTALLATION IN COLD CLIMATE

In this paragraph tries a clear overview about the important factors implementing a successful system is given. The best practice to implement a successful treatment wetland should be in warmer regions due to effectiveness and additional attention on maintenance, however numerous studies suggest the effective applicability such systems in colder climate (Wittgren et al. 1997).

The two most important aspects when designing HSSF TW are the avoidance of clogging and hydraulic failure (Kato K et al. 2011). If the system design based on inadequate background knowledge, it most probably will lead to flood on the surface, especially wetlands that used soil for bed medium. Therefore, studies suggest the use of FWS wetland for small summer dwellings, permanent dwellings with low contaminant impact (e.g. dry toilet deployed) which is not recommended all year maintenance in Finland. In other cases subsurface flow wetland is the reasonable answer to residents.

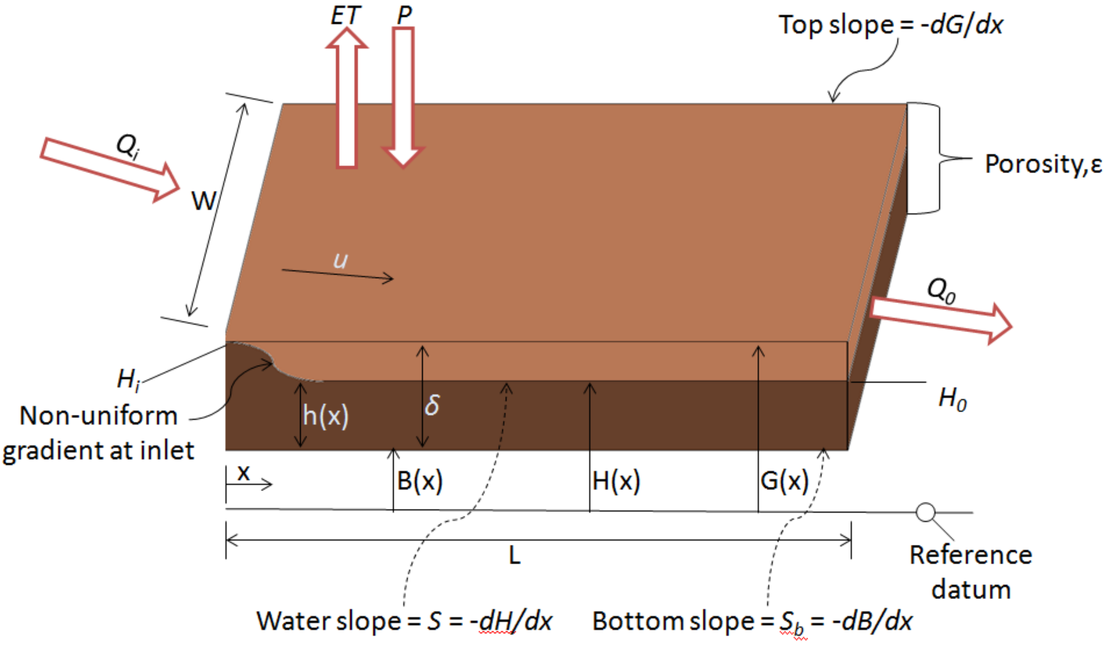
In cold climate, biological processes are more sensitive to temperature fluctuations, especially at low temperature conditions. Lower winter temperature coupled with low oxygen accessibility, although there is more soluble oxygen still the gas exchange may be reduced by the reason of dormant plants and insulation layer or accumulated dead litter (depends on the used method). Low soluble oxygen results in low aerobic organic matter decomposition. Consequently, it is important to pay attention on the maintenance during winter time to ensure the system continuous optimal procedure (Gray 2008).

The nitrification process considered the main limitation factor when wetlands considered secondary treatment method in cold climate. Some studies suggest oxygen enhance in the system through macrophytes but the exact contribution remains a debate (Ouellet-Plamondon et al. 2006, Wittgren et al. 1997). There are some alternative solutions to improve different ways the oxygen presence in HSSF e.g. injection of compressed air in the bed matrix (Wallace et al. 2000) which favor nitrification and improve total N removal (approx 22-24%). Artificial aeration demands extra energy input which comes with additional cost, but some instances, it may be still profitable in long term.

One of the great feasibility of HSSF is that it can be easily adapted to cold climate environment. Experience suggests that most of the removal occurs within the first few meters of a HSSF reed bed length. As a result, the distance between the inlet and the outlet is usually between 11-15m. Studies have also showed that horizontal excess in length has minimal impact on the overall treatment efficiency. The width recommendation has increased over time as more practical projects were published. Solids drop out in the first few meters of reed bed, resulting in clogging and can thus compromise even distribution of flow. Spreading the distribution over a wider flow path helps minimize the extent of clogging and increase the longevity of the wetland (Ouellet-Plamondon et al. 2006). Additional protection to prevent freezing can be elevated by specific design such as larger and deeper bed or applying a natural/artificial insulation on the structure (Kadlec et al. 2009, Wittgren et al.1997, Wallace et al. 2000).

3.1 Horizontal Subsurface Flow Wetlands Hydraulics

Hydraulics of HSSF can be described simple as water flows through in a planted bed of porous medium. The design is not that simple, and there are numerous problems arise in practise. Problems may trace back to design failure or wetland characteristic changes in the bed structure. Hydraulic design is crucial if the failure wants to be avoided e.g. clogging. Most of the SSF wetlands are rectangular as can be seen in Picture six. The picture includes all the physical factors which alter the hydraulic flow. A good meteorological, topographic and physics background needed to design a HFFS wetland.



PICTURE 6 Notation for HSSF bed hydraulic calculation for the simplest case. The actual velocity of water is v=u/ε. The subscripts i and o stand for inlet and outlet, respectively. (adapted from Kadlec and Wallace (2009) Treatments Wetlands 2nd edition)

Note for the figure:

B(x) =elevation of bed bottom, m
G(x) =elevation of bed surface, m
H(x) =elevation of water surface, m
P = precipitation, m/d
x = distance from inlet, m
ET = evapotranspiration, m/d
h(x) = water depth, m
L = bed length, m
Q = volumetric flow rate, m^3/d
б = bed depth, m

3.1.1 Cold Climate Effects on Hydrological and Hydraulic Conditions

Cold winter climate with snow will influence the wetland water balance as a result of dry winter periods with snow accumulation and little run-off, followed by snow melt and flooding during spring. The magnitude of the influence will largely depend on the wetland-to-catchment ratio. Hydraulic residence time may decrease significantly during snow melt. If this is the case, it is advised to provide storage for the melting water avoiding flooding in the system (Wittgren et al 1997). Many households in rural areas have shallow piping, and these systems need constant flow (bleeding) in the pipes to prevent freezing of the water supply during cold periods. This will decrease the effluent water temperature and decrease the hydraulic residence time in on-site natural treatment systems. The hydraulic loading will be several times higher than design values and may lead to surface flow in SSF systems, with freezing and hydraulic failure as a consequence. Therefore proper modelling is the key for successful long term operation if minimum maintenance care is aimed.

The Hydraulic loading rate (q) depends on flow and wetland area as follow:

$$q = \frac{Q}{A}$$

where

q = hydraulic loading rate (HLR), m/d

A = wetland area (wetted land area), m^2

Q = water flow rate, m^3/d

Hydraulic loading rate can be extremely useful in a well deigned constructed wetland if common risk of problems need to be lowered e.g. clogging, oxygen, freeze.

3.2 Ice Formation

The formation of ice greatly determines the feasibility of wetlands. Studies have shown that ice will begin to form on a water surface when the water temperature reaches as low as 3°C, because of density differences and convective losses. The insulation layer of snow and the dead vegetation acts as an effective way to prevent freezing in the system. If snow accumulates before a significant ice layer happens to form, subsequent freezing is strongly inhibited (Wittgren B et al. 1997).

The presence of ice layer might be beneficial if the ice layer provide insulation and decline the cooling of the underlying water but if the flow beneath ice fall shorts it leads to subsequent flooding, freezing and hydraulic failure. It might be beneficial to operate the HF wetland with a higher water level at the time of freezing and thus create space for both water and air beneath the ice. In SSF wetlands, it is suggested to dig a deeper hole to avoid; or applying a mulch layer to prevent the system from freezing. The prediction of ice formation and thickness requires calculation of energy balances and water temperatures in treatment wetlands. Major factors for the calculation are wetland temperature, wind speed, wetland dimension, and loading rate of wastewater, the ambient air temperature depth and thermal conductivity of different layers (snow, ice, water, plant litter and another porous media)

3.3 Temperature Dependence of Treatment Performance

The temperature dependence of reaction rate constants is commonly expressed from van´t Hoff-Arrheniusas equation:

$$k_{T1} = k_{T2} * \theta^{(T1-T2)}$$

where

k_{T1} and k_{T2} are first-order rate constants at temperatures T1 and T2, respectively, and θ is the temperature coefficient.

Small-scale, well controlled experiments often show clear temperature dependence for microbiologically mediated process, such as BOD removal and nitrogen transformation. In full-scale treatment wetlands the temperature dependence is not as strongly correlated as in small-scale. Studies showed rare correlation between BOD removal and temperature in full scale. The same connection was noticed in COD as well. Phosphorus usually not affected by temperature; however Nitrogen shows significant temperature dependence with temperature coefficient. Ammonium removal occurs by cation exchange in SSF wetlands during fall and winter. Nitrification and plant uptake might than “strip” the soil media of ammonium during the warm season renewing the bed for the next cool season (Jenssen D et al. 2008).

Studies suggest temperature adoption of the microbial community to the climatic conditions and might explain the tendency of cold climate wetlands to show less temperature dependence than in laboratory circumstances. The developments presume that the wetland is in a steady state, but it is rarely the case. The aim is to achieve good performance results for long-term. It is presumed that the porous medium is isotopic. This is probably not true, due to the presence of plan roots and other introduced particulates (Jenssen D. et al. 2008, Wittgren et al. 1997).

3.3.1 Thermal Conductivity of Various Materials and Insulation (Mulch)

Good insulation design for wetland treatment in cold climate eliminates hydraulic failure e.g. due to freezing. It is a good plan to discover what effects of mulch and plant species will have on constructed wetlands to eliminate heat transfer issues (Wallace et al, 2000). A proper insulation is necessary because cooling water flow in the soil will reduce the temperature in the system and could lead to malfunctioning e.g. clogged, freeze (Kadlec et al. 2008). In general for HF wetland, the increased depth, an ice cap and an average of 10 cm water level under the surface equally elevates the frost mitigation (Kato K et al 2011).

Conductive studies suggested using e.g. wood chips, pine straw for mulch material. After a variety of mulch types have been tested Wallace is (2000) listed various kind of insulation material for colder climate. The material must be well processed and decomposed, therefore it will not let additional nutrient intake on the system, and must have a good moisture retention capacity so seeding are not threatened to drought stress. The nutrient composition of the layer needs to be homogenised, and the structure of the fibre have to be soft enough to provide a good thermal conductivity, and the mulch formation must have a good contact between the seeding layer and insulation to not be an obstacle for fertilization (Kadlec et al. 2009).

Table five represents the different kind of mulch materials nutrient effluent excess on the wetland system in the first two years. Wallace (2000, 2005) calculated (using carbonaceous biochemical oxygen demand (CBOD)) the nutrient soaking by physical, biological processes.

TABLE 5 CBOD5 Values for Different Blanket covers Calculated Emissions (examples from Wallace et al., 2000)

Material	Year 1	Year 2
Wood Chips	40 mg/L	20 mg/L
Poplar Bark(“hog fuel”)	60 mg/L	20 mg/L
Wood Chips buried under Sand	120 mg/L	80 mg/L
Reed-Sedge Peat	5 mg/L	3 mg/L
High Quality Yard Waste Compost	5 mg/L	5 mg/L

Choosing the right mulch material is very important at the establishment process. It not only maintains the process but also helps to prevent additional nutrition intake from the mulch into the system. Applying the wrong insulation material will highly affect the constructed wetlands operability and most likely will appear in the maintenance expenses.

In table six, another example can be found where the author lists different kind of materials used as mulch and their parameters according to physical conditions e.g. thermal conductivity. The point of reference material was the Styrofoam in the study of Jenssen (2008). This is a good reference data which helps what kind of physical conditions needs analysing to find the best available insulation layer.

TABLE 6 Thermal properties of various materials and insulation equivalent to the insulation provided by 10 cm of Styrofoam (data used from Jenssen et al. 2008)

Material	Thermal conducti-vity (W/mK)	Specific heat (J/m^3°C)	Density (kg/m^3)	Eq. thickness to 10cm Styrofoam (cm)
Styrofoam	0,030			10
Air	0,025	0,003		8,3
Water	0,57	1,0	1000	190
Ice	2,2	0,45	920	733
Snow	0,049-0,190		100-700	16
Peat dry	0,06	0,35	100-300	20
Peat saturated	0,5-1,25	0,7	900-1200	166
Straw dry	0,09			30
Sand Haug-stein	1,77		1710	590
Leca (0-4mm) sat	0,56		340	183
Leca(0-4 mm) unsatruated	0,07		340	23

3.4 Wetland Energy Flows

Water temperatures in treatment wetlands are driven by energy flows (gains and losses) that act on the system. During warm conditions, the largest energy gain is solar radiation, and the largest energy loss is evapotranspiration (Kadlec et al., 2009).

Because temperature exerts a strong influence in some chemical and biological processes, it is important to wetland design. In cold climates, freezing of the wetland may be an operational concern. It is important to understand the energy flows within treatment wetlands to ensure systems will remain functional in subfreezing conditions.

3.4.1 Modified Energy Balance Term for Cold Climate

When the water surface is below ground, a key assumption in the energy balance approach is no longer valid: the transfers of water vapour and sensible heat are no longer similar. Water vapour must first diffuse through the dry layer of gravel, and than be transferred by swirls and eddies up through the vegetation to the air above the ecosystem. Energy balance equation can be simplified for winter (Wallace et al, 2000, Kadlec et al 2009) by the energy lost to the atmosphere equals to the conductive transfer from ground, plus the difference from the energy entering and leaving from the water.

$$E_{loss} = G + (U_i - U_o)$$

$$MJ/m^2/d = MJ/m^2/d + (MJ/m^2/d - MJ/m^2/d)$$

A constructed wetland which was designed for cold climate requires that *energy* loss be "throttled down" so the energy inputs, *G + (Ui –Uo)* can equal to what was lost. Do not design a system to depend only on ice layer and snow cower if the system was planned to operate successfully by minimising open heat loss through evapotranspiration. Studies (Wallace et al 2005, Jenssen et al 2008) showed that ice cannot be expected to work as an efficient insulator due to high thermal conductivity (e.g. 0.19 MJ/m/d/ºC) which is about four fold to that of water in liquid state (e.g. 0.05 MJ/m/d/ºC). However, ice can be used to minimize evapotranspiration. It is usable together with air interstice or blanket (mulch) to increase the thermal resistance.

Wallace (2000) study analyzed 28 systems with a hydraulic loading rate of 2cm/day with 15cm of blanket cover filling showed that hydraulic consummation of subjected treatment wetlands could not be compromised. Mulch insulation provides an adequate layer when there is severely cold, even extreme temperature such as 20-30º C below freezing point, but no adequate snow cover. Wallace study showed that mulch insulation provides a good thermal loss of 0.31 MJ/m2/d compare to a 5cm ice cap and

5 cm air gap would result 1.22 MJ/m2/d, almost 4 times greater (Wallace et al., 2000, 2005).

The temperature of the influent flow does not affect the heat linearly of the constructed wetland system due to the dissipation thermal gradient. According to field monitoring the heat scatters within the first 25% of the bed length (Wallace, 2000). The aim is to find a balance point temperature to keep up the system from freeze, and the effluent temperature considered heavily in the equation. If the system is economic and properly designed than the energy loss ($E_{loss} \leq G$) in the atmosphere must be equal or lower than what the ground conductively transfers from the system.

3.5 Cold Climate Solutions

The author felt important to mention FWS wetland because of the rather cheap overall deploy cost which makes it attractable for small dwelling house owners whom have little effluent impact on the nature.

In the cold climates, the limited oxygen-transfer capability of conventional subsurface-flow treatment wetlands has lead to the development of alternative design configuration that improves subsurface oxygen availability. Subsurface-flow (SSF) wetlands equipped with mechanical aeration have been widely used in North America to increase oxygen transfer rates and sustain aerobic conditions in the substratum (Kadlec et al 2008, Jenssen et al 2008).

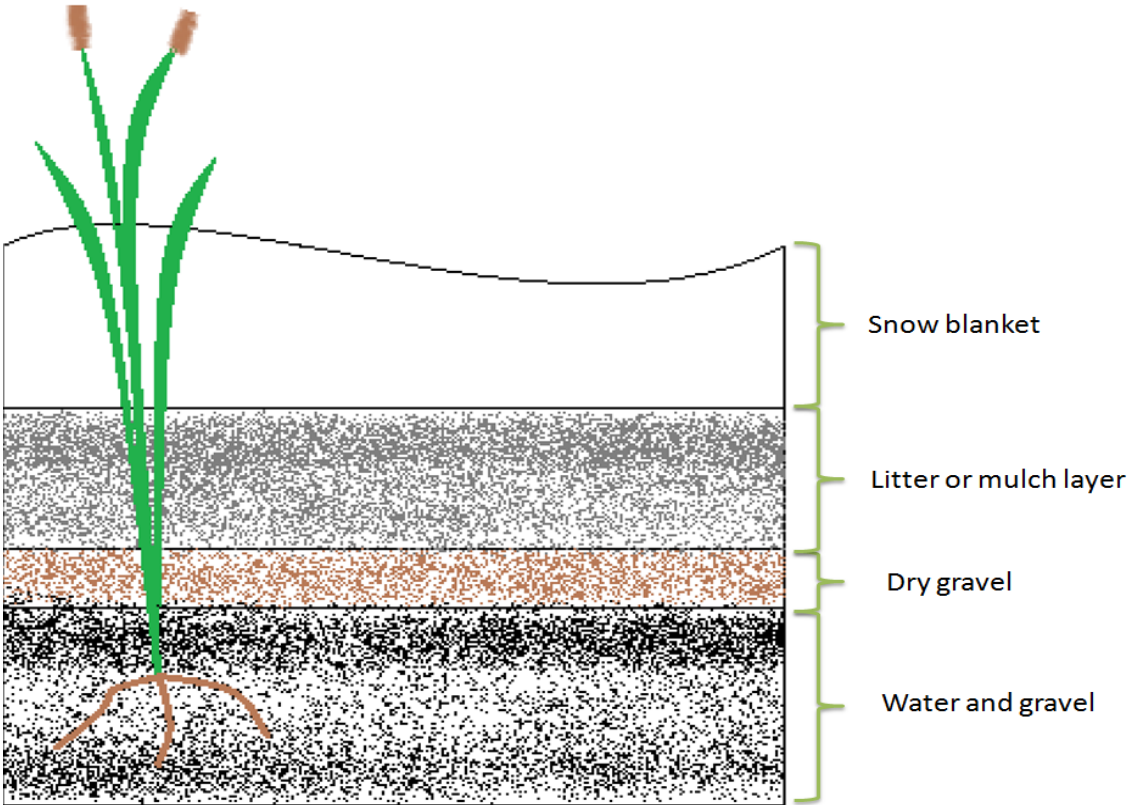
3.5.1 Free Water Surface Treatment Wetland

FWS treatment wetlands may be the perfect option to replace other existing methods offered from the database in Finland. A full year operational wetland system allows ice formation, and by raising the amount of inflow water an ice-air-water layers gap can be modelled. This is accomplished by raising water levels slightly above the media at the time of freeze-up. After the surface water freezes, the water level is dropped below the media surface, creating a dry media gap sealed by ice. Seasonally operated FWS offers the solution to keep discharged water in a pond or tank during winter time, and reflow it in the system in good weather conditions. This might be a good solution to cottages which is accommodated rarely during winter times and preferably dry toilet is installed on the premise.

Treatment wetlands that operate in cold (subfreezing) environment face several unique design challenges. During periods below freezing, the water temperature can no longer be approximated by air temperatures once an ice layer forms on the wetland. Effluent water temperatures will be in 1 to 2ºC, and the thickness of the ice layer becomes a design consideration. The formation of an ice layer will reduce the depth of the water column, reducing detention times, unless the water level is increased in the fall to accommodate the anticipated thickness of the ice layer. Energy balance calculations are required to determine the extent of ice formation (Kadlec at al. 2009).

3.5.2 Insulation of Horizontal Subsurface Flow Wetlands

Because HSSF systems can be insulated by the addition of dry gravel and mulch layers, the balance condition energy fluxes can be modified to prevent ice formation. These layers add heat flow resistance over and above that which occurs naturally in the wetland (standing dead, litter, and the snow trapped in the senesced vegetation). These natural insulation effects can be very important, and may in fact be one of the most important thermal functions of the vegetation during the winter months.



PICTURE 7 Cross section of a SSF wetland in winter (adapted from Kadlec and Wallace 2009 Treatment Wetlands, 2nd edition)

The ice thickness can vary significantly from year to year due to variations in snowfall and temperature. The principal factor is the insulation provided by the snow layer. Areas of emergent wetland vegetation are much more effective in trapping snow than non vegetated areas.

In a HSSF wetland, the added insulation provides a better support with an ice layer on the top of dry media if the bed soil or standing dead plants kept dry which means lowering water level in the system during winter times (Jenssen et al 2008) or using specific mulch which keeps the area wetness (Wallace et al., 2000). Often blankets, supported by standing dead litter are the most effective solution (Kadlec et al., 2009).

3.6 Wetland Plant Species Selection

Selection of the plants for TWs is important (Wallace et al, 2000, Vymazal et al 2008). Therefore previous knowledge of geography and wildlife are necessary for successfully choice of plant species and for ensuring them to be well propagated rapidly spread, and resistant to grazing pressure. One step is to prevent graze time by deploying fences around the TWs area but that cause additional costs which might not be affordable for areas where people have low-budget. The other step would be finding plants which are less favoured by animals.

TABLE 7 Recommended Wetland Plant Species (data used from Wallace et al 2000)

Common name	Scientific Name
Duck Potato	*Sagittaria latifolia*
Green Bulrush	*Scirpus atrovirens*
Blue Flag Iris	*Iris versicolor*
Cup Plant	*Silphium perfoliatum*
Stiff Goldenrod	*Solidago rigida*
Swamp Milkweed	*Asclepias incarnata*
Sandbar Willow	*Salix exigua*

Mulch layer establishment is strongly influenced by the material used. Systems will have poor seed germination and place large drought stresses on seedling if the mulch layer is implemented poorly or non-existent in cold climate. Consequently, only sprouts plants can be established due to boreal climate. It needs to be counted to the implementation plan and species must be purchased minimum three growing seasons before the planting. Better mulch design results a more hospitable conditions to plant seedlings and allows for seed germination. Studies have showed that as little as one growing season plants can be established under these circumstances (Wallace et al, 2000). In the first growing season, blanket cover should be irrigated by water because it helps the seed growing by dissolving nutrients from the mulch layer and ensuring that the layer will be more homogenous with the system.

3.7 Treatment Performance

Kadlec and Wallace demonstrated (2009) that there are still flow related problems (e.g. clogging) in the treatment systems and there is not a good existing design for constructed wetland to predict accurate performance outcome yet.

3.7.1 Clogging

Sedimentation of suspended solids within SSF systems can cause potential clogging of the system, especially near the inlet (Kato K 2011). Degradation products from the volatile portion of the TSS can accumulate within the filter together with the mineral fraction of TSS. These deposits can block the pores and decrease the hydraulic conductivity (Wittgren et al 1997).

The suggested procedure is to remove the clogged bed media in question, and replace it with new soil. This might raise greatly the maintenance cost if the bed clogged and signs of flood appear on the surface. If additional cost is a problem or difficult to implement Kedlec(2009) mentions a washing process after the clogged bed soil was removed from the system. If none of the above mentioned options can be carried out than a hydrogen peroxide (H_2O_2) chemical oxidising may help in situ to eliminate the clogging problem.

Bed clogging comes from the hydraulic failure of full-scale systems (often at a high price) because clogging phenomena takes longer to develop than a typical graduate student would work on it. The consequence is the long term viability, and maintenance requirements, of HSSF wetlands is still unknown, despite the fact that thousands of systems have been constructed worldwide (Kadlec et al. 2009)

A new method was developed to describe how the hydrological behaviour of a HSSF CW changes over its lifetime. The model validates measurements of permeability, hydraulic gradient and total solids accumulation. The governing equation for the movement of water through this system is the Groundwater Flow Equation (GFE),

$$Sy\frac{\partial h}{\partial t} = \nabla(K(\theta)h\nabla h) + R$$

where h is the hydraulic head, equal to the elevation *(D)* plus the metric pressure head *(Hp)*, *K* is the hydraulic conductivity, a function of the water content *(θ)*, *R* is the vertical recharge, and *Sy* is the specific yield, a property of the porous material describing its ability to retain water for a change of *h*.

In boreal area, applied constructed wetland is a sensitive setup and requires meticulous implementing in order to achieve good efficiency, avoid failure and minimize error potentiality so it is crucial to take the clogged effect into consideration as well during establishment process.

3.7.2 Aeration

Previous project works revealed that aerated subsurface-flow TWs are a viable technology selection for effective removal of ammonia-nitrogen of landfill leachate, especially under boreal conditions. Saturated wetlands with mechanical aeration are extremely efficient in removal of ammonia-nitrogen (Jenssen et al 2008, Kato K et al. 2011, Kadlec et al. 2009).

Nitrogen is a temperature sensitive substance or it was believed until research results of studies (Wallace et al, 2000, Jenssen et al. 2008) presented that nitrification can be still removed from the system lower than 4ºC. The same studies showed that ammonia at temperatures as low as 2.8 to 4.4ºC can oxidize in HSSF treatment wetlands. A VF constructed wetland reached nitrification at temperature of 2 - 5ºC in Northern America (Wallace et al., 2000). The reason why these studies achieved such a significant results is because biological processes are more oxygen than temperature sensitive. Therefore artificially aerated constructed wetlands are the answer for achieving good removal results.

A Forced Bed Aeration™ which is a patent-pending design from Wallace (2000) has shown great results helping nitrogen removal but any other kind of manufacture designed aeration method will have the same positive effect on the wetland removal efficiency. A pilot treatment wetland was carried out at the Jones Country, Iowa landfill to show feasibility of an aeration system. After the initial time an overall CBOD removal was in excess of 93 % and ammonia reduction was in excess of 90 % at very low temperatures (3ºC inlet and 0ºC outlet). A family home conducted study resulted in 89 % or greater Total Nitrogen removal by nitrification and denitrification in cold climate condition (Wallace et al., 2000). Aeration within the system also showed positive correlation of redox potential in the root morphology of wetland vegetation.

3.7.3 Monitoring

The monitor process must meet the municipality operating permits to avoid confliction. Monitoring requirements are generally quarterly or monthly, depending on the permit. Data collected from influent and effluent sources.

3.7.4 Carbonaceous Biochemical Oxygen Demand

Carbonaceous biochemical oxygen demand measures the depletion of dissolved oxygen by biological organisms in a body of water in which the contribution from nitrogenous bacteria has been suppressed. CBOD method is widely used as an indication of the pollutant removal from wastewater in US (Nivala et al 2007).

Biochemical Oxygen demand (BOD) is the amount of oxygen required by microbes or microorganisms to break down the organic material and oxidize the inorganic matter present in the water sample. It is essential that BOD is reduced before release to the waterbody to prevent harm to aquatic life. Too high BOD indicates the risk that, microorganisms will consume the oxygen present in the water column as they degrade organic matter, thus creating an anoxic environment and altering the aquatic ecosystem (Gray 2008).

The five days carbonaceous biochemical oxygen demand ($CBOD_5$) is linked to a developed age, stable population of microbes in constructed wetland. According to Wallace (2000) the subjected wetland should be timed to start operating at full wastewater load in late fall “cold start” because vegetation and media of the system needs adjustment time and winter is perfect to do that due to plants are dormant.

Constructed wetlands projects show that systems with good blanket layer under cold climate, achieve a level of 75% reduction in $CBOD_5$ values in the first year, and a treatment resulting in 90 % in the following year (Wallace, 2000). The systems revealed a better insulation layer with reed-sedge versus wood chips which suggest reed-sedge mulch use in Finland. Reed-sedge peat insulation may offer a low-cost thanks to domestic peat production in Finland.

3.7.5 Total Nitrogen

Nitrogen removal in a subsurface flow TW is very sensitive of oxygen absence. In the oxygen absence, ammonia is not well converted to nitrate. The limited nitrogen removal has been observed in many studies apart that the hydraulic loading rate should allow nitrification to occur. (Wallace et al, 2000).

4 EVALUATION OF COST-EFFICIENCY OF HSSF APPROACH

The economics of treatment wetlands consists of two major factors: capital costs and operation costs. The capital cost for free water surface and subsurface flow wetlands are more or less the same, the cost of difference comes from the gravel which used for HSSF wetland (Kadlec et al. 2008). It is not possible to tell exact figures when planning to estimate average cost of a wetland system, because conductors use local material and labour during construction. The price is also determined by the place where the manufactured parts are being made and shipped. Residents are advised to compare the capital cost for the different best available systems (BAT) before implementation. There is a tendency that alternative technologies replace wetland offered solutions due to high land value in urban areas, however in rural areas it is still competitive solution by reason of operation cost significantly lower than e.g. chemically treated. Alternative solutions also have the disadvantage that requires energy input while constructed wetlands require minimal or none.

4.1 Capital Cost

Treatment wetland systems could provide significant savings when installation costs are conclusive. The sustainable nature of these systems requires little or no energy inputs, and also makes them a green investment. Estimated cost savings could encourage smaller communities and households to install such systems (Gray, 2008).

The sampling of the soil composition and the raw water characteristic is important to study to reduce the problems which may cause additional greenfield investment. The costs which need investing to prevent groundwater contamination are land area, soil construction, and constructed wetland bed liners. The bed media selection is crucial for good hydraulic flow and plants grow. Site investigation is the first step before designing the wetland and piping system. It is advised to find the most resistant plant against extreme winter conditions to keep some level of removal by plant uptake during winter times. Additional cost are site work (e.g. fencing, access roads etc.), and human use facilities.

The construction site must be evaluated and soil characteristics need well understanding, including soil composition, groundwater elevations, and site topography.

Soil identification on the site is done carefully to avoid additional cost e.g. transfer soil from other region. Small scale soil transformation may be done by (0.05ha) human power. Greater soil transformation needs to be involved with machine power. Constructed wetland bed liners means additional cost if the soil topography and characteristic of the ground permeability (e.g. threaten of contamination of ground basin water) are too high.

Media means the main cost because meanwhile HF wetland use only 30-40 cm soil, the HSSF wetland needs 50-80 cm of soil which needs to be shipped to the construction if the soils structure is not adequate on site. It is important to pick the right media due to high risk of clogging. The better the composition of the soil the longer the system will operate without human interfere.

In cold climate region, insulation might be necessary for HSSF systems if natural processes are not sufficient e.g. snow cover, dead litter. It might be done with straw, or some blanket cover for cottages. Peat may be the best economic solution in a reason of constant availability in Finland. Hydraulic control of wetlands must provide a fluent piping and water level distribution, especially in Finland where cold weather means a constant threat for HSSF wetlands failure.

4.2 Operation and Maintenance Costs

Wetland systems have very low Operation and Maintenance costs e.g. energy input by pumping, compliance monitoring, maintenance of access roads, mechanical repair. One primary operating cost of a dwelling HSSF system is the cost associated with pumping the septic tank. Another cost may arise from piping system does not run deep enough in the ground at dwelling houses, and it requires constant circulation in the piping to avoid freeze (Kadlec et al. 2009). Other costs are determined by the local market. In an example, a constructed wetland development providing wastewater treatment for 46-home residential was calculated an annual operational cost of a 25 085 USD (from 2006 inflation) in Minnesota. It costs approximately 545 USD for a single home annually (Kadlec et al 2009).

5 CONCLUSIONS AND RECOMMENDATIONS

Sub-surface flow treatment wetlands provide with unsaturated surface layer provides a better thermal protection than surface-flow constructed wetland in cold regions. Therefore such systems enjoy greater use in colder climate zones. Aerobic pre-treatment (e.g. sandfilter, aerated pond or tank) is an important key design if the system has to meet a strict regulation limit. Energy loss prior to discharge to the wetland can be minimized if the supply piping system and the pre-treatment units are also insulated. If the plant material remains intact for winter period, it may provide some insulation. It is still advised to not harvest the plant in the first growing semester due to dead litter is thin and may not provide enough protection against cold if mulch layer is not used.

It is recommended to apply mulch layer instead of dead litter with litter harvest which helps greater nutrients removal from the plant site. SSF surface can be covered with a porous media with low thermal conductivity which is to be kept unsaturated during the winter. SSF systems depth should not exceed 60 cm. One possibility to add an extra 10-30cm soil layer which calculated into the level of freeze into the soil which allows the operating system to not froze and still has hydraulic capacity to conduct the applied water. This is a disadvantage due to the level of the flow is below of the root system. According to Jenssen (2008), locations where extensive periods of air temperature <-20 °C experienced a seasonal storage for the winter waste load might be necessary.

It is interesting that subsurface flow constructed wetlands impose several unique design elements which are widely used in Nordic countries but it is scarcely in Finland. The unique designs elements (e.g. artificial aeration, blanket cover) ensure the usability of treatment systems in cold climate. The Surface Flow and Sub-surface Flow wetlands bring unique devise to Finland. Surface Flow wetland may be impulsive to residents whom use their dwellings for temporary periods in summer time and have low nutrition load in their wastewater. Sub-surface wetlands are advised to residents whom use their summer houses as permanent home or frequently accommodated. However, improper installation design, negligent maintenance and unacceptable operational use may lead to fatal failure therefore extra attention may be paid on these criteria to eliminate additional costs and ensure whole year operation without extra time spent on maintenance.

A properly designed insulated wetland is able to achieve high levels of BOD removal, by preventing the system from hydraulic failure and freeze. Treatment performance will improve after the first growing season. It is advised to use a well decomposed organic material to eliminate the affect of additional nutrient load in treatment efficiency. According to Kadlec (2009) a careful design needs to be implemented about which plants will be used in the constructed wetlands because some plants do not favor some mulch material. If the wrong material used for blanket cover, the plants may be intolerant and die or do not develop properly. Jenssen (2008), Wallace (2000, 2005) and Nivala (2007) have noticed in their studies that horizontal subsurface flow wetlands without a design of artificial aeration do not transfer enough oxygen to the roots to satisfy both phosphorus and nitrogenous removal under cold weather but systems installed with artificial aeration pump achieved same retention results as in warmer regions for nutrients. However, snow and ice used as insulation may be enough to reach reduction limits if the wastewater is minimally loaded with nitrogen and phosphorus.

It seems that sub-freezing environments require some type of insulation strategy for constructed wetlands depending on climate zone. Dead leafs of decayed vegetation material has been found as one good method insulating the constructed wetlands. Frequent problem with leaf litter application is that heat gets lost at the not evenly distributed spots. Wallace study (2005) showed that even small breaches could result in substantial heat loss. Mulch initially was used as a cover to reduce the odour and sunscald affects but nowadays it is used to protect the system from freezing. According to Kadlec and Wallace in the book of Treatment Wetlands (2009) the mulch was first times used as an insulation media in 1996 on a subsurface flow constructed wetland. The collected data showed that an additional blanket cover highly effective keeping the system away from freeze. Later on, a computer modelling systems based on Wallace work (2000) calculated that mulch can prevent the system from freeze as low as -20 ºC.

Constructed treatment wetland nowadays considered as reliable system and gained wider use in different application areas e.g. wastewater treatment, agricultural run-off reduction. Removal of phosphorus is low unless some special media with high sorption capacity is used. Artificially aerated systems improve organic matter and nitrogen removal, especially in winter times, the most anticipated times when satisfactory reduction removals are expected. TSS removal was also noticed in aerated systems.

The following things like temperature, clogging, aeration need to be considered when designing constructed wetlands. Cost related elements are need to be considered as well as land area for construction, soil construction, liner, rooting medium, wetland plants, and hydraulic control structures. The fee of these elements depends from the market price value.

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