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Lynches Lane Reed & Willow Bed Facility Final Report South Dubin County Council

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Lynche's Lane Reed and Willow Bed Wastewater Treatment Facility - Final Report

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Lynche's Lane Reed and Willow Bed Facility
FINAL REPORT

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Glossary of terms

adsorption The adherence of gas, liquid or dissolved chemical to the surface of a solid

aerobic Pertaining to the presence of elemental oxygen

ammonification Bacterial decomposition of organic nitrogen to ammonia

anaerobic Pertaining to the absence of all oxygen (both free oxygen and chemically bounded oxygen

anoxic Pertaining to the absence of free oxygen but with nitrate, nitrite or sulphate present

BOD_5 - 5-day Biochemical Oxygen Demand
COD - Chemical Oxygen Demand
CO_2 - Carbon dioxide
CH_4 - Methane
CW - Constructed Wetland
CWs - Constructed Wetland Systems
denitrification The use of chemical compounds and physical processes to kill microorganisms
EPA - Environmental Protection Agency
ET - Evapotranspiration

ET_c - Potential Crop Evapotranspiration

ET_o - Reference Evapotranspiration
EU - European Union
EC - European Community
HCW - Hybrid Constructed Wetland
HF - Horizontal Flow
HF CWs - Horizontal Flow Constructed Wetland Systems
HSF - Horizontal Subsurface Flow
HWTS - Hybrid Reed and Willow Bed Wastewater Treatment System
H_2O - Water
H_2S - Hydrogen Sulfide
Kc - Crop coefficient
KJN - Kjeldahl-nitrogen
NaCl - Sodium Chloride also known as salt
N_2 - Nitrogen Gas
N_2O - Nitrous oxide (commonly known as laughing gas)
NO_2 - Nitrite
NO_3 - Nitrate
NH_3 - Ammonia gas
NH_4 - Ammonia
nutrient A chemical substance that provides a raw material necessary for the growth of a plant or animal
OTR - Oxygen Transfer Rate
O_2 - Oxygen
P - Phosphorus
p.e. - population equivalent
percentile is the value of a variable below which a certain percent of observations fall
P-M - Penman-Monteith Equation
PVF - Primary Vertical Flow
RBTS - Reed Bed Treatment System

SFS -	Subsurface Flow System
sorption	action of absorption or adsorption
short-circuit	A faster, channelized flow route that results in a lower actual hydraulic residence time that theoretical hydraulic residence time
SVF -	Secondary Vertical Flow
TSS -	Total suspended solids
VF -	Vertical Flow
VF CWs -	Vertical Flow Constructed Wetland Systems
volatilisation	Evaporation at relatively low temperatures

1. Executive Summary

Context and content of study

This final report will present results from a two year study to monitor the performance of a hybrid reed willow bed facility at Lynches Lane, in the administrative area of South Dublin County Council (SDCC). Design specifications for the facility are presented. Monitoring results for a two year period including influent and effluent parameters, rainfall, potential evapotranspiration, and soil classification are also presented and discussed. During the two year monitoring period the system achieved a zero discharge. This report will discuss the potential application of similar systems within South Dublin County Council administrative area. This is in the context of a recent EU judgment which declared that Ireland has failed to fulfill its obligations regarding domestic wastewaters disposed of through individual waste water treatment systems. The development of an appropriate zero discharge wastewater facility similar to the one operating successfully at Lynches Lane, has the potential to address this source of environmental pollution in Ireland.

Design Innovation and Characteristics

Reed Bed

A municipal application of a hybrid reed bed treatment system (RBTS) was designed and constructed. It treated the wastewater from the Parks Deptartment Depot and a private house. The hybrid design for Lynch's Lane RBTS was based on modifications to the Max Planck Institute Process (MPIP). The constituent parts of the design were a septic tank, a pump sump, two stage vertical flow beds, a secondary settlement tank, a horizontal reed bed and an outlet chamber and outfall pipe. This facility operated successfully until 2007, when SDCC wished to incorporate an extra wastewater load of approximately 10 pe.

Willow Bed

Modifications to the original design included the construction of a willow bed facility in 2008. The willow bed consists of eight ridges and nine channels. The wastewater flows through channels around the ridges on top of which the willow trees were planted. The willow bed is constructed from local soil which was classified as very stiff, homogenous clay. The permeability coefficient of the subsoil within the willow bed was determined from twelve undisturbed samples. The average permeability was 2.3×10^{-7} m/s. This represents a practically impermeable soil. The willow bed was sized at $3m^2$/p.e.

Monitoring Regime

The reed and willow bed facility was monitored for two years. Samples were taken aseptically at four points within the system and transported to the laboratory within 4 hours and stored between 2-8ºC in accordance with ISO / IEC 17025:2005 (ISO 17025, 2005). The physico-chemical analysis tested for nitrate, ammonia, kjedahl, pH, total suspended solids(TSS), orthophosphate, chemical oxygen demand (COD) and biochemical oxygen demand (BOD). Samples for microbiological analysis were taken in sterile bottles to ensure no cross- contamination. They were analysed for the time dependent parameters, Coliforms and *E. Coli*. All analysis of water quality parameters was carried out in a Irish National Accreditation Body (INAB) accredited laboratory as per Standard Methods (AWWA, 2005).

Reed Bed Performance

The variability of influent, characteristic of small schemes, was evident. Removal values for COD and BOD were comparable with results achieved at other hybrid systems built in Ireland (O'Hogain, 2003). Suspended solids removal was slightly lower, at 85 %. Coliform and *E.coli* removal rates were also marked at 94% respectively. Nitrate and phosphate removal rates for the reed bed system were unsatisfactory, as reported in previous studies (O'Hogain, 2004).

Willow Bed Performance.

No outflow was observed from the willow bed during the monitoring period. There were frequent periods when the willow bed was dry throughout. This left three possible pathways for the effluent. These were, passage through the soil, absorption to the roots and evapotranspiration of the wastewater, and or evaporation in the open trenches due to climatic factors such as wind and sunlight. To determine percolation through the soil, a series of soil tests were performed. The average permeability of the samples was 2.3×10^{-7} m/sec. From this we may conclude that the wastewater is being removed primarily by evapo-transpiration effects.

CONCLUSIONS

During the two year monitoring period the Reed bed willow bed system at Lynche's Lane Co. Dublin effectively achieved zero discharge. This was achieved using a design figure of $2m^2$ per p.e. for the vertical beds, $1m^2$ per p.e. for the horizontal bed and $3m^2$ per p.e. for the willow bed.

RECOMMENDATIONS

1. **The development of an appropriate Zero Discharge Wastewater Facility has the potential to address the source of individual wastewater treatment systems (IWTS) pollution in Ireland. The technology could be successfully adapted by South Dublin County Council to install pilots in other similar small scale community wastewater treatment facilities.**

2. **There is a need to develop guidelines within the Irish context, based on a comprehensive list of evaluation criteria to provide decision makers with a complete overview of the existing aspects of reed willow bed combination systems.**

3. **The potential application of a reed and willow bed combination, to sites not served by sewerage infrastructure, and/or to sites where existing wastewater treatment system require upgrading is worthy of exploration by South Dublin County Council.**

4. **South Dublin County Council should pilot this design in sites where no sewerage infrastructure is available.**

The study also produced two papers. The first, titled **"The operation of hybrid reed bed and willow bed combinations in Ireland-Zero Discharge and the potential for no monitoring of domestic applications of this combination"** was presented to the 2nd Irish Conference on Constructed Wetlands for Wastewater Treatment and Environmental Pollution Control, 1-2 October 2010 in UCD. It was published in the proceedings.

The second paper, titled "**A Review of Zero Discharge Wastewater Treatment Systems using Reed Willow Bed Combinations in Ireland"** was presented to the 12th International Conference on Wetland Systems for Water Pollution Control in Venice (Italy), 4-8 October 2010. It was subsequently published in the journal Water Practice and Technology, Volume 6, issue 3.

Introduction to Reed Bed and Willow Bed Wastewater Treatment Facilities

2.1 Reed beds.

Reed beds have been used for the last 50 years to treat wastewater, in Europe (Vymazal, 2006). They are essentially a lined structure filled with a media, of gravel and/or sand, with reeds planted in the upper zone. The influent is passed through the beds either horizontally or vertically. The design has evolved from horizontal reed beds through vertical beds to hybrid beds and latterly compact vertical flow beds (Weedon, 2006). Wastewater treatment is by a combination of sedimentation, filtration, aerobic/anaerobic degradation, ammonification, nitrification/ dentrification, plant uptake and matrix adsorption (Brix,1993). Initial designs were predominantly horizontal and the process was referred to as the root zone system. The media used was soil with a hydraulic conductivity in the range of 10^{-4} m sec^{-1}. This design criteria proved problematic resulting in clogging, and the eventual adoption of gravel/washed sand as a medium. This revision led to the large scale use of reed beds to treat wastewater, and other wastes, throughout Europe and saw the European Guidlines published (Cooper et al., 1996). In developing reed beds, the emphasis was on the reduction of treatment surface area while increasing treatment efficiency. Pioneering work by Kathe Seidel in the 1950's had involved the use of vertical beds, where the influent passed vertically through the media, rather than the horizontal movement through the horizontal beds (Seidel, 1976). The efficiency of vertical beds over horizontal beds in treating wastewater has seen their use increase, especially over the last ten years.

2.2 Horizontal subsurface flow

Horizontal subsurface flow (HSF) wetlands typically employ a gravel bed planted with wetland vegetation. The water is kept below the surface of the bed and flows horizontally from the inlet at one end through a flat gently sloping bed of 1–2% slope to the outlet. The water level in the bed is typically controlled by an outlet level control device Figure 1.

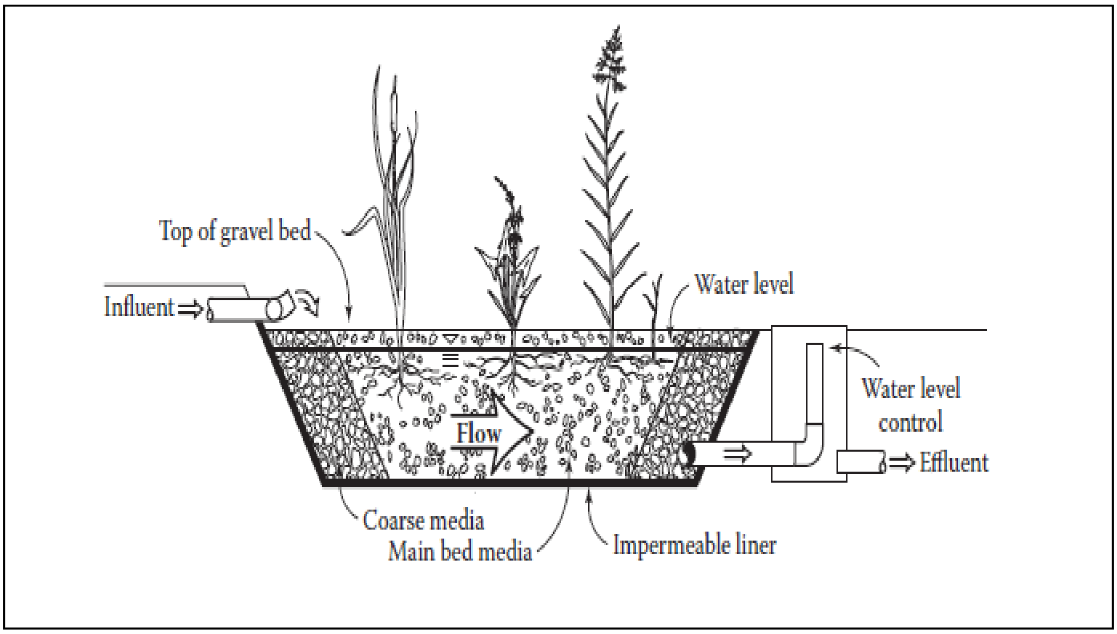

Figure 1 Horizontal subsurface flow, (Cooper et al., 1996)

2.3 Vertical Flow

Vertical flow (VF) reedbeds distribute water across the surface of sand or gravel bed planted with wetland vegetation. The water is treated as it percolates through the plant root zone and bed medium. Figure 2 illustrates a typical cross section through a VF reed bed.

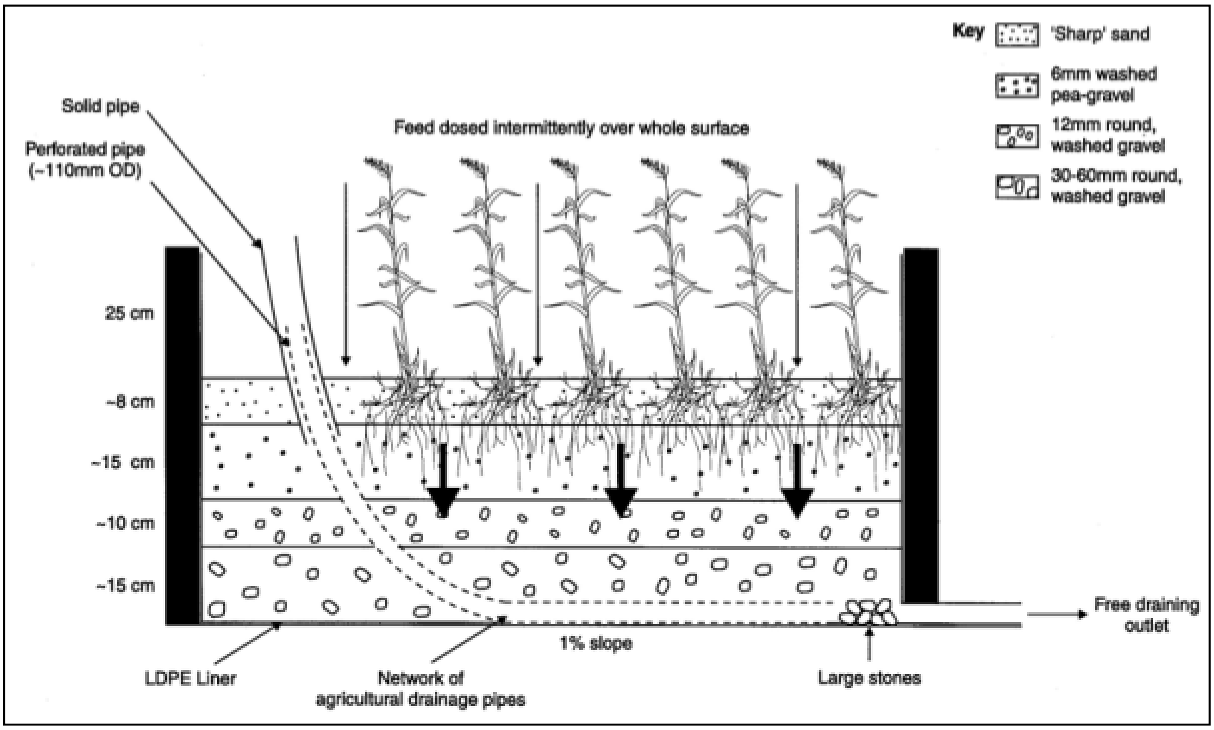

Figure 2 Vertical flow (Cooper et al., 1996)

2.4 Hybrid Reed Beds

A further development is the hybrid design. This is a system where vertical and horizontal beds are combined, such that the influent is passed sequentially through primary and secondary vertical beds and then a horizontal. These systems were accompanied by a pond, in some cases. Many of these systems are derived from original hybrid systems developed by Seidel at the Max Planck Institute in Germany.

2.5 Compact Vertical Reed beds

The latest development in reed bed design is the compact vertical reed bed. This is a single bed with a media of sand only, thus reducing maintenance by avoiding the requirement for bed rotation, which is necessary with conventional vertical beds. In Ireland municipal wastewater has been treated by horizontal reed beds, and hybrid reed beds. Treatment efficiency has been reported as good, with horizontal beds treating the discharge from various types of package plants, and hybrid beds treating municipal wastewater (O'Hogain, 2001). Figure 3 illustrates an application developed in Denmark using a vertical flow compact reed bed with single graded sand bed and sedimentation tank as pre-treatment and recirculation

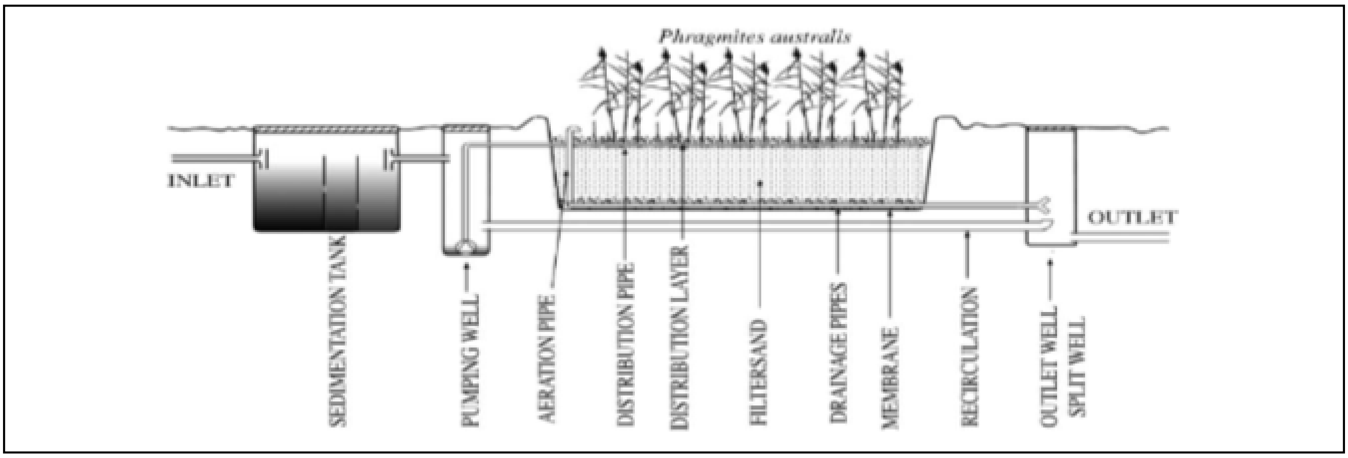

Figure 3 VF compact reed bed with single graded sand and sedimentation tank as pre-treatment and recirculation (Brix, 2006)

2.6 Treatment Mechanisms in Horizontal and Vertical Flow Reed Beds

Table 1 presents a summary of the main removal mechanisms of wastewater constituents in both horizontal flow and vertical flow reed beds.

Table 1 Predominant removal mechanisms in reed beds treatment systems (Cooper et al., 1996)

Wastewater constituent	Removal mechanism
Suspended Solids	Sedimentation Filtration
Soluble organics	Aerobic microbial degradation Anaerobic microbial degradation
Nitrogen	Ammonification followed by microbial nitrification and denifrication Plant uptake Matrix adsorption Ammonia volatilisation
Phosphorus	Matrix sorption Plant uptake
Metals	Adsorption and cation exchange Complexation Precipitation Plant uptake Microbial oxidation/reduction
Pathogens	Sedimentation Filtration Natural die-off Predation UV irradiation Excretion of antibiotics from roots of macrophytes

2.7 Willow Beds.

Denmark was the first country to experiment with willow treatment systems (Ministry of Environment, 2003a and b). Major research began there with the introduction of their action Plan 1 in 1987. Awareness of, and action to ameliorate the negative implications of phosphorus discharge to the environment were the drivers of these investigations. As a result the Danish Ministry of Environment and Energy developed guidelines for treatment systems for population equivalents of up to 30. Two sets of guidelines were produced for willow cleaning facilities:

1. Describes a willow system using a membrane liner, which results in zero discharge.

2. Describes a willow system without a membrane liner with allows some soil infiltration. This system is intended for adoption in areas of clay soil, where infiltration is low. This system also results in a zero discharge.

These guidelines and the studies which led to them aroused interest in other countries. Though the sizing was large, of the order of $30m^2$ per population equivalent (pe), and the structure was a modified vertical reed bed in terms of media and distribution, the zero discharge was of great interest to researchers. As a result Willow soakaway's were installed in various parts of the UK. These consisted of two distinct methods of construction and operation. The first type of design operated by dividing the planted willow area to receive the wastewater, into two or three smaller areas. These relatively flat areas received the treated wastewater in succession. Every month to six weeks a new section is placed on line and the previously saturated section rested for 2 months. The rotation is effected by moving pipework. This rotation of the areas, giving rise to the alternation between saturation and rest, offsets any binding of the soil which would restrict the permeation of the liquid. A second method of distribution consisted of a channel which meanders through the planted area, allowing the water to percolate through the banks of the channel and into the soil. A fall in the channel of 1:300 is required, and so this design is more appropriate to sloping sites.

The traditional varieties of willow used were, *Salix triandra*, *S. purpurea* and *S. viminalis*. Trees were grown from seedlings about 20 cm long, and it was recommended that care must be taken so that they get established without too much competition, for the first two years. Common to both designs was the recommendation that the willows be free from weed competition in the first year.
A typical Danish willow bed design is illustrated in Figure 4.

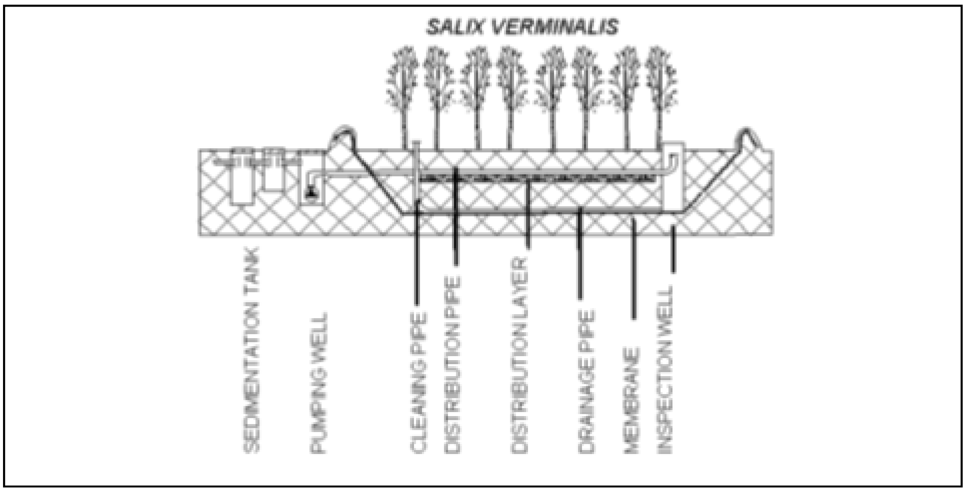

Figure 4 Typical Danish willow bed design with no outflow (Brix, 2004)

2.8 Treatment Mechanisms in Willow Bed Wastewater Treatment Systems

Water Balance

The concept of water balance is used to describe the hydrologic regime in a willow watershed. Figure 5 illustrates a schematic showing the water balance for a typical willow bed wastewater treatment system. The principle components affecting the over all water balance in the system are the wastewater inflow (Q_{in}), rainfall (P), potential evapotranspiration through the foliage (ET_o), change in storage of the surface water reservoir (S_s), change in storage of the groundwater reservoir (S_g), capillary rise from the subsoil and deep percolation through the subsoil and any over flow from the system defined as outflow (Q_o). If we average over many years of record it can be assumed that the change in storage of the ground and surface water reservoir will be zero, as will the balance between capillary rise and deep percolation within the deep subsoil.

The water balance equation for an annual period would take the form: $\mathbf{P + Q_{in} = ET_o + Q_o}$

Figure 5 Typical water balance in a willow bed wastewater treatment system

As discussed in section 2.7, studies on willow bed systems in Denmark have shown that evapotranspiration rates are the important factor in these systems. The following section describes this process in more detail.

Evapotranspiration

When a wet surface comes in contact with unsaturated air evaporation occurs. Thus, evaporation is the process whereby liquid water is converted to water vapour and removed from the evaporating surface. Plants move water from soil to their leaves from where it is then evaporated to the air. This is called transpiration. Thus, transpiration is the vaporization of liquid water contained in plant tissues and the vapour removal to the atmosphere. Nearly all water taken up by a plant is lost by transpiration and only a tiny fraction is used by the plant.

Potential Evapotranspiration (ET_o)

Solar radiation, meteorological processes, soil and physiology of plants control evaporation and transpiration. Evaporation and transpiration occur simultaneously and it is not easy to distinguish between these two processes. When plant cover is only a small portion of the total surface area, or the plant is small, evaporation is the dominant flux (rate of transfer). As plant cover increases or the plant is well developed transpiration becomes dominant. Therefore, often these two terms are combined together into potential evapotranspiration. Potential evapotranspiration (ET_o) is defined as "The amount of water transpired in a unit time by a short green crop completely shading the ground, of uniform height and never short of water" (Penman, 1956). Figure 6 illustrates schematically how the climatic factors (radiation, temperature, wind speed, humidity) are combined with a grass reference crop height (typically well watered grass) to give a standard value for the potential evapotranspiration for a given location.

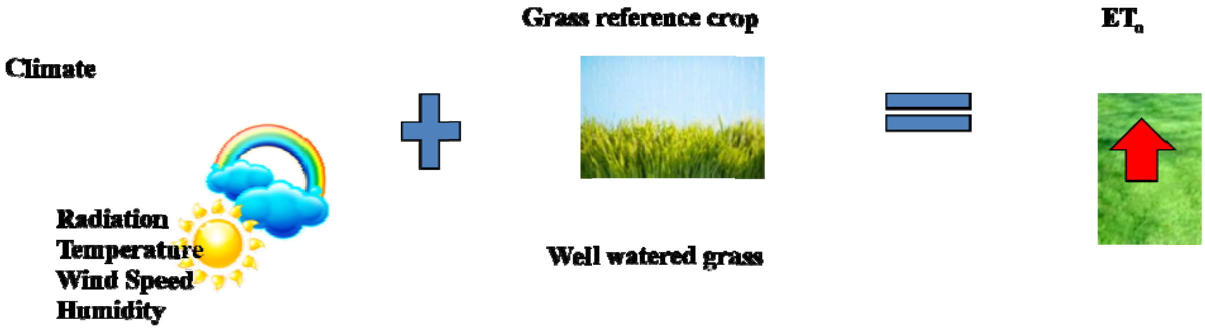

Figure 6 Factors effecting Potential Evapotranspiration (ETo)

Crop Evapotranspiration (ET_c)

Willow beds utilise the principle of evapotranspiration to achieve a reduction in wastewater volume, potentially resulting in achieving a zero discharge wastewater treatment system. However, willows exhibit a higher rate of evapo-transpiration than the value expected from calculations using reference crop evapo-transpiration parameters for a standard crop height (grass). To account for willow beds where plants can grow anywhere from 3 – 4 metres in height, the standard grass potential evapotranspiration value is multpilied by a factor, K_c. K_c depends on such parameters as crop height, albedo (reflectance) of the crop and soil surface, canopy resistance, evaporation from soil etc. Figure 7 illustrates this concept further. Danish studies have established higher values of K_c of 2.5 for willow beds.

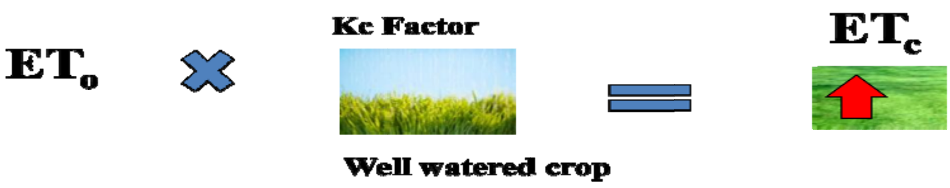

Figure 7 Crop Evapotranspiration Value, ET_c

Clothesline and Oasis effects

Willow beds experience enhanced rates of evaporation when warmer dry air flows across vegetation with higher water availability. This results in enhanced rates of evaporation by using sensible heat from the airflow. This process is known as the oasis effect. This is illustrated in the right hand side of Figure 8.

In willow beds, the vegetation height is typically greater than that of the surrounding environment. This results in a significantly different roughness condition in the vicinity of the willow bed. Where broadsiding of the wind occurs horizontally into the taller vegetation of the willow bed, this results in turbulent transport of sensible heat into the canopy and transport of vapour away from the canopy. In addition, the internal boundary layer above the vegetation may not be in equilibrium with the new surface. Therefore, evaporation from the isolated expanses, on a per unit basis, may be significantly greater than the calculated potential evapo-transpiration. This effect is known as the clothesline effect.

Figure 8 illustrates these processes.

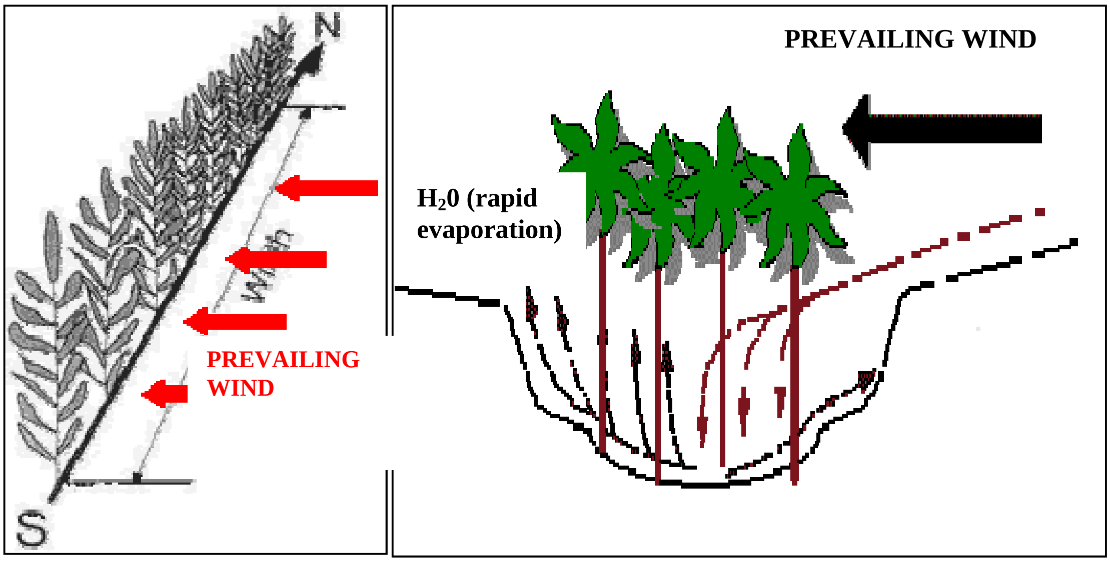

Figure 8 Clothesline and oasis effects (Brix, 2006)

2.9 Reed bed and Willow bed Combinations – Case Study.

A brief summary of two case studies is presented to illustrate the treatment mechanisms and processes discussed.

2.9.1 Centre for Alternative Technology (CAT) in Machynlleth, Wales.

One of the first practical applications of the reed bed and willow bed combination was at the Centre for Alternative Technology in Machynlleth, Wales. CAT has no connection to mains sewerage and have to treat their wastewater independently. As part of their function as an education centre, they employ a mixture of treatment systems to demonstrate alternatives. A multi-stage system was put in place. Solids liquid separation occurs in a settlement tank. The wastewater is then passed for treatment through a hybrid reed bed system, a small pond, and finally, polishing and disposal in a willow bed/coppice. The sewage is finally discharged to the river Dulas. The system has no power requirements. Settled sewage sludge is composted together with straw and soiled paper-towels and then re-used on site. The system was sized at 2 m^2 per pe for the vertical reed beds, 1 m^2 per pe for the horizontal beds and 3 m^2 per pe for the willow bed. Detailed results are not available but the system complied with all water quality discharge standards.

2.9.2 Colecott Reed and Willow Bed facility, Co. Dublin Ireland.

The first Irish municipal application of a hybrid reed bed treatment system (RBTS) was designed and constructed at Colecott, County Dublin in the administrative area of Fingal County Council. The catchment area consisted of 10 county council cottages and four mobile homes with a population of 48 and the existing wastewater treatment plant was a septic tank and a percolation area. The constituent parts of the design comprised a septic tank, a pump sump, two stage vertical flow beds, a secondary settlement tank, a horizontal reed bed and an outlet chamber and outfall pipe to a nearby stream. Figure 9 shows a plan and elevation of the system as constructed. The population equivalent was taken as 60, allowing future population development of 25%. Design figures, sizing etc. were largely based on the European Guidelines (Cooper, 1996). Previous studies focused on the construction, maintenance and performance of the beds. These studies showed satisfactory secondary treatment (O'Hogain and Gray, 2001; O'Hogain, 2003). However, nitrate and phosphate levels in the effluent were unsatisfactory.

To upgrade the level of treatment supplied consideration was given to discharging the effluent to a willow bed. The design area chosen for Colecott was 1.5 m^{-2} pe^{-1}. This was based on varying recommendations of 1 and 2 m^{-2} pe^{-1}, and was chosen as a median figure. The population equivalent was taken as 60, resulting in a surface area of 90m^2. A series of 17 trenches were dug, with a dividing trench to create separate areas to facilitate rotation of the inflow feeder pipe. Two species of willow, *Salix triandra*, and *S. viminalis* were planted at approximately a half meter apart. A total of 360 willows were planted, each approximately a half meter high. An outflow pipe was placed in each end trench. Seven parameters were monitored, ammonia (N-NH_3), nitrate (N-NO_3), orthophosphate (PO_4^{3-}-P), pH, biochemical oxygen demand (BOD), chemical oxygen demand (COD) and suspended solids (SS). All were analysed in the laboratory, using APHA 1995 standard methods (APHA, 1995).

Results.

Hydraulic Loading.

The dry weather flow averaged over the monitoring period was 6.84 m^3 d^{-1}. The incidence of storm events was quite pronounced. The rainfall exceeded 10 mms d^{-1} on five occasions, resulting in daily flows of between 10.6 and 14.6 m^3 d^{-1}. It exceeded 20 mms d^{-1} on three separate occasions resulting in daily flows of between 16.15 to 143.37 m^3 d^{-1}. The latter event occurred with recorded daily rainfall of 74.6

mms. The inputs to the RBTS show all the characteristics of small sewage schemes (Metcalf and Eddy, 1991). The pumping volumes were erratic even during DWF. Little infiltration is a trend shown for pumping volumes and storm events.

Overall Reed Bed and Willow bed Performance.

The performance of Colecott Reed and Willow Bed Sewage Treatment system showed very high performance rates for certain parameters, e.g. Chemical Oxygen Demand, 95% removal, Biochemical Oxygen Demand, 92% removal, Suspended Solids, 100% removal and Ammonia 65 % removal. However optimum performance was not reached with regard to Nitrates and Phosphates. The installation of the willow bed at Colecott RBTS lead to Zero discharge from the system, for most of its first year of operation. Over the two year sampling period of the 24 sampling days 10 sampling days saw no outflow from the willow bed. A significant contribution to the treatment of the final effluent, where effluent was discharged from the willow system, resulted from passage through the willow bed. Willow bed treatment saw 6% COD removal, 71% BOD removal, 22% ammonia removal and 20% nitrate removal. SS solids were not present in inflow or outflow. However it was the entrance of surface water volumes, far in excess of design volumes, that resulted in effluent discharges from the willow bed.

Table 2 presents a summary of the results from Colecott Reed and Willow Bed Wastewater Treatment Facility.

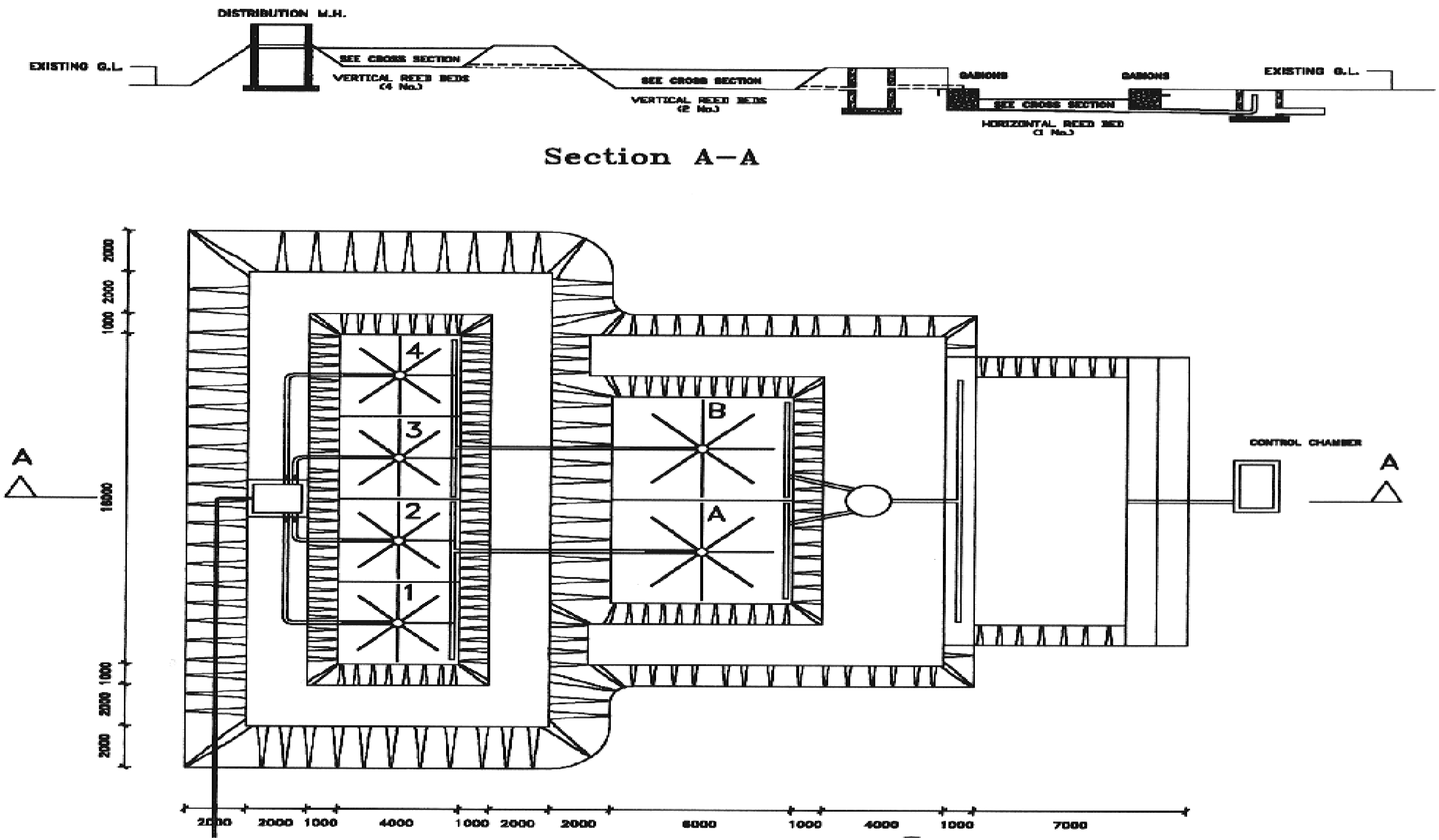

Figure 9 Plan and Section of Colecott Reed and Willow Bed Wastewater Treatment Facility, Co. Dublin.

Parameter	**Influent**		mg l-1			**PWB**		mg l-1			**Percentage**	**Reduction**	**overall**
											Reed Bed & Willows		
	Mean	S.D.	Median	Min	Max	Mean	S.D.	Median	Min	Max	Mean	S.D.	Median
COD	704	240	683	73	1255	40	31	29	0	123	95	10	98
BOD_5	492	259	420	55	1240	16	19	8	0	90	92	10	95
SS	109	58	103	24	268	0	0	0	0	0	99	6	100
NH_4-N	51	21	55	4	88	7	9	3	0	28	61	82	86
NO_3	2	6	0.1	0	31	11	8	9	2	35	-26	253	43
PO_4	31	14	30	3	40	21	11	19	6	50	-111	670	44
pH	7.3	0.3	7.28	6.7	7.95	7.36	0.33	7.42	6.4	8.17			

Table 2 Monitoring results for overall Reed Bed and Willow Bed performance at Colecott RBTS for the period September 2003 to August 2005.

3. Lynches Lane Hybrid Reed and Willow Bed Wastewater Treatment Facility

3.1 Site Location

A hybrid reed bed treatment system (RBTS) was designed and constructed at Lynch's Lane, County Dublin in the administrative area of South Dublin County Council (SDCC). The catchment area consisted of a local authority depot and a private house. The existing system was a septic tank and a percolation area. The depot was upgraded to service the local county council workers. This upgrading consisted of the installation of larger toilet and other facilities. The existing topography was flat with a slope of less than 1%. The natural soil comprises an impermeable clay. Figure 10 shows an aerial view of the facility and associated works.

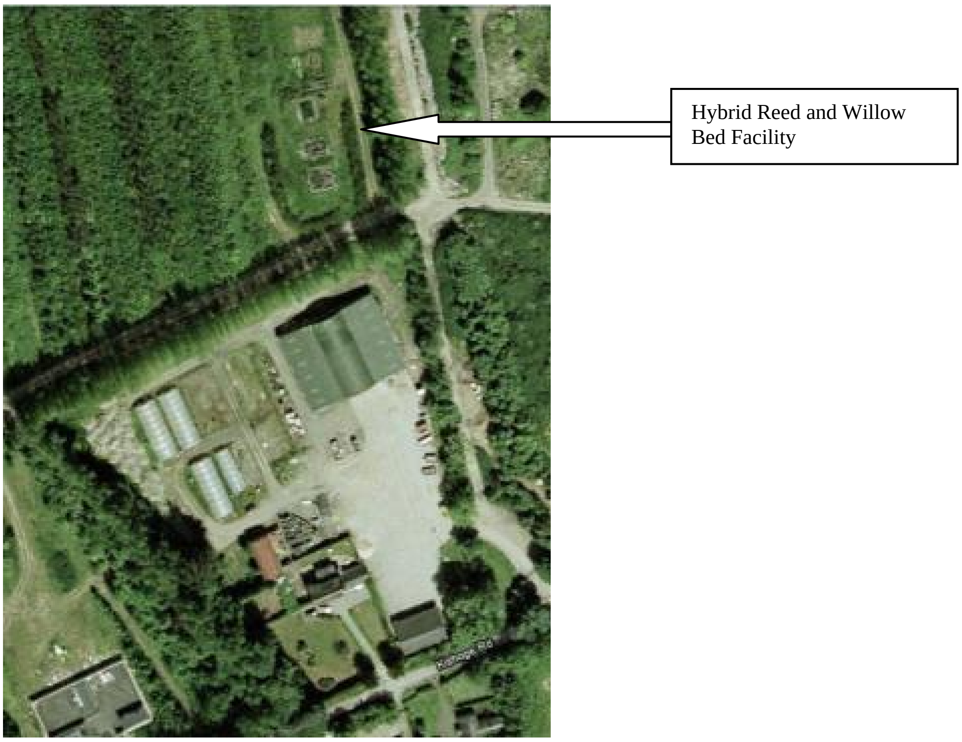

Figure 10 Lynches Lane RBTS facility (Source: Google Maps)

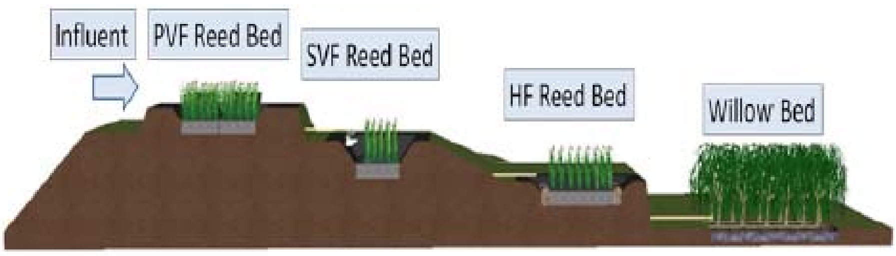

Figure 11 Schematic through the Hybrid Reed and Willow Bed Wastewater Treatment Facility

3.2 Facility Design & Installation

This hybrid reed and willow bed sewage treatment (HWTS) system currently services the Parks department depot at Grange, Lucan, Co. Dublin. The initial system was commissioned in 2002. It was designed for a population equivalent of 15. This resulted in a design flow of 3.0 m^3 day^{-1}. A willow bed tertiary filter system was installed in 2008. Figure 11 shows a cross section through the final site, which includes the willow bed facility. Initially the RBTS served a local authority depot and a private house. The wastewater flowed by gravity to a septic tank. From the tank it overflowed to a pump sump, where it was pumped to the HWTS. The wastewater flowed by gravity through the system. Figure 12 shows the the parks department depot serviced by the HWTS.

Figure 12 Parks Department Depot Lynches Lane

The flat nature of the site, meant a slope had to be created, as a slope is a requirement of a hybrid RBTS. This was achieved by compacting earth on the site of the bed. The slope also required that a pump be used to deliver the wastewater to the RBTS. The reed bed site was 30 m from the site of the toilets, showers and the house. A septic tank was installed with a pump sump added. The septic tank had a volume of 5.22 m^3. The pump sump was sized at 4.2m^3, using a standard manhole with an overflow, 0.6m from ground level, connected to the final outlet. The pumps were two Flygt submersible pumps, which had a capacity of 3.5 litres/second.

The wastewater collection system discharges via a 110mm pipe to the septic tank. From here it overflows to the pump sump, where on reaching the level of the pump, the influent is automatically pumped to the primary vertical flow reed bed, via a 110 mm rising main. No distribution chamber is used. Instead the incoming 110 mm pipe is fed into four separate 110 mm distribution pipes, each fitted with a valve, enabling the feed to the bed to be rotated, if required. Figure 13 shows the septic tank and pump sump with control panels.

Figure 13 Pump Sump and Control Panel

The vertical beds were sized at 2m^2 pe^{-1}, to achieve BOD removal and complete nitrification on two vertical stages. The necessary height gradient required the existing ground level be raised 4m. This was constructed using earth repeatedly compacted. The vertical flow beds were sized at 32 m^2. The final primary vertical flow (PVF) bed sizing was 16 m^2 consisting of four beds at a total sizing of 4 m^2 per bed and a secondary vertical bed (SVF) sizing of 8 m^2 made up of two beds. A high-density polyethylene liner was laid, cut and welded in situ, in accordance with the guidelines.

It was decided to vary the depths recommended in the guidelines, but to retain an overall depth of media of 0.6m . The depths of the two bottom layers were 15 cm each while the depth of the 6 mm diameter washed pea-gravel was increased from 15 cm to 20cm. The sharp sand layer was reduced to 10 cm. The sand was selected using the Grant method, with a value for the test of 45 seconds.

The distribution system installed on the PVF beds consisted of an 110 mm inflow pipe with valve, feeding a 120 L plastic tank. This tank was modified to allow four 25 mm pipes to exit from the base of the tank and to deliver the influent to separate parts of the bed. Figure 14 shows this arrangement of 25 mm pipes, from the tank, via two elbows to the bed itself, which was to facilitate complete wetting of the bed surface.


Figure 14 Primary vertical beds showing inlet pipes, valve and distribution pipes

The distribution system installed on the SVF beds consisted of two 110 mm inflow pipes feeding two tipping buckets. These tipping buckets when full tip into a distribution tank. This distribution tank is divided in four, with a 25 mm pipe distributing the waste water over the full surface of the bed. The HF bed was excavated and the media supported by large stones. The liner was as the VF beds. The influent from the secondary tank was fed by a 110 mm ϕ pipe at a height of 0.25m above the stones. The outfall from the HF bed was through a 150 mm diameter to a nearby stream. *Phragmites australis* were the reeds used. Figure 15 shows the SVF beds with division, inlet pipes and tipping bucket distribution system.

Figure 15 SVF beds with division, inlet pipes and tipping bucket distribution system

Figure 16 shows the tipping bucket system installed on the SVF to provide a pulse of wastewater in to system. The system works on gravity and requires no power and minimal maintenance.

Figure 16 Tipping bucket system to SVF

Willow bed

The willow bed was added to the system in 2008 to deal with the extra wastewater load from an emergency halting site constructed nearby. It consists of eight ridges and nine channels. The wastewater flows through channels around the ridges on top of which the willow trees were planted. The willow bed is constructed from local soil which was classified as very stiff, homogenous clay. The permeability coefficient of the subsoil within the willow bed was determined from twelve undisturbed samples. The average permeability was $2.3x10^{-7}$ m/s. This represents a practically impermeable soil (Whitlow, 2001). The willow bed was sized at $3m^2$/p.e. Figure 21Figure 19 and Figure 20 shows the seasonal variation in willow bed operating conditions.

Figure 17 Entrance to emergency halting site

Figure 18 Septic tank and pump sump with control panel

Figure 19 Willow bed operating during winter 2010

Figure 20 Willow bed operating during summer 2010

Figure 21 shows a plan view of the treatment facility. Table 3 presents a summary of the design parameters for the facility.

Table 3 Characteristics of Reed and Willow Bed Wastewater Treatment Facility

	PVF bed	SVF bed	HF bed	Willow bed
Design Surface Area / pe	2 m^2/pe	1 m^2/pe	1 m^2/pe	3 m^2/pe
Surface Area	30m^2	15m^2	15 m^2	45m^2
Number of Cells	4	2	1	Number of ridges 8, Number of channels 9
Area provided for influent	16 m^2	8 m^2	1.8m^2	Average channel/ridge width 0.44m
Media Depth	0.6m	0.6m	0.6m	channel/ridge depth 0.54m
Porosity	0.37	0.37	0.37	

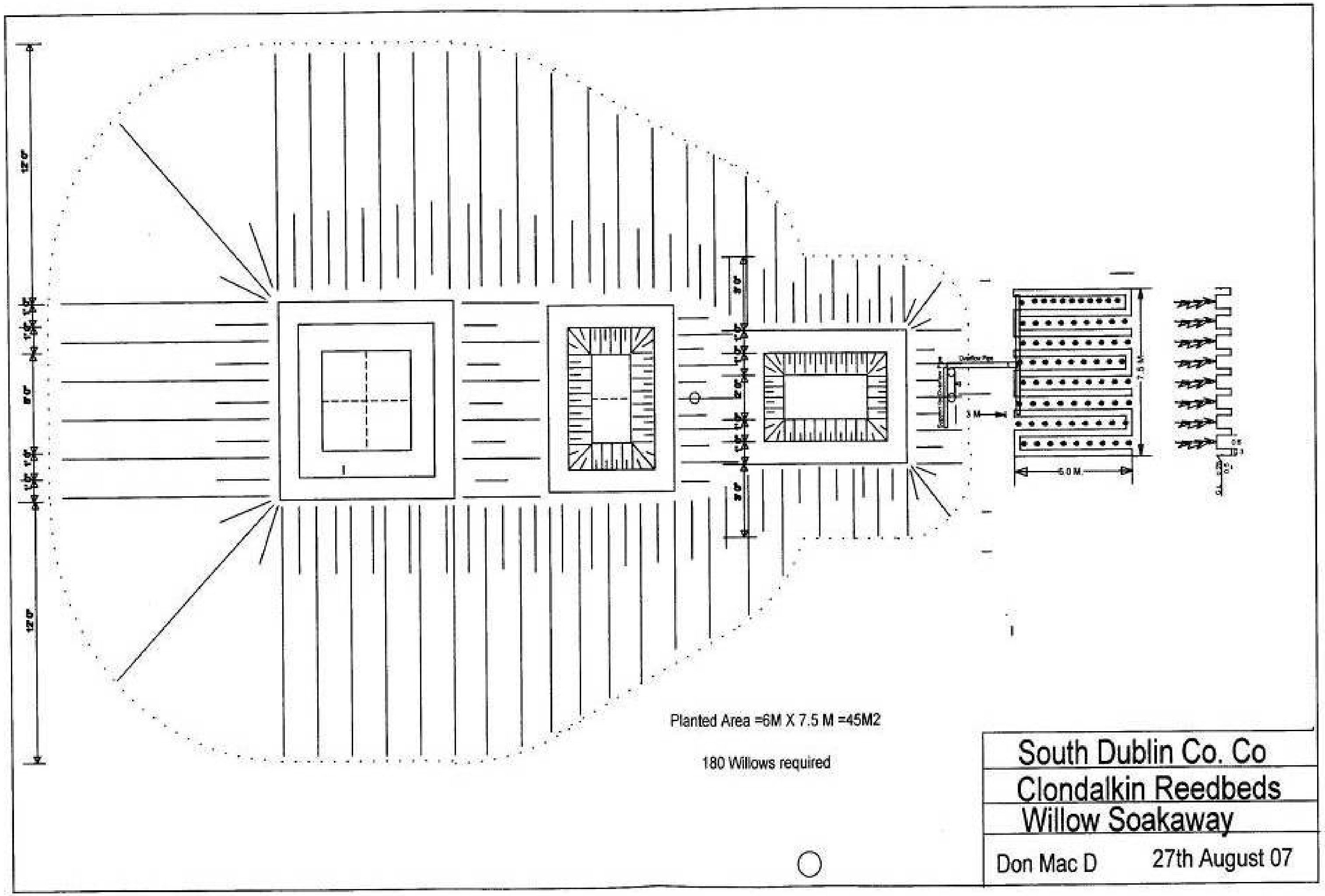

Figure 21 Plan View of Hybrid Reed and Willow Bed Wastewater Treatment Facility, Lynches Lane, Co. Dublin

3.3 Monitoring Regime

The reed bed was monitored for two years. Samples were taken aseptically at four points within the system and transported to the laboratory within 4 hours and stored between 2-8ºC in accordance with ISO / IEC 17025:2005 (ISO 17025, 2005). The physico-chemical analysis tested for nitrate, ammonia, kjedahl, pH, total suspended solids (TSS), orthophosphate, chemical oxygen demand (COD) and biochemical oxygen demand (BOD). Samples for microbiological analysis were taken in sterile bottles to ensure no cross- contamination. They were analysed for the time dependent parameters, Coliforms and *E. Coli*. All analysis of water quality parameters was carried out in a Irish National Accreditation Body (INAB) accredited laboratory as per Standard Methods (AWWA, 2005).

Figure 22 Sampling regime at SVF reed bed

3.4 Results

3.4.1 Pumps.

The pumps were set for four-minute intervals. The volume of each pulse was 0.885 m^3. These pulses were of the order of 3-6 per day.

3.4.2 Flows

The average hydraulic loading rate during two year monitoring period from 2008 to 2010 was 4.7m^3/d with an average 22 p.e. This is equivalent to 214 l/p.e./day. From February 2011 to March 2011 the average hydraulic loading rate was 2.6 m^3/d. This is equivalent to a p.e. of 13.

Figure 23 outlet pipe from Horizontal flow bed to willow bed

3.4.3 Weed control.

Poor growth in the first years, resulted in areas being covered by weeds in the Spring and Summer. This resulted in vigorous reed growth of nettles and grasses on the PVF beds. Reed growth on the SVF beds was poor over the first years of the project resulting in grass colonisation of large areas of the beds. On the HF bed reed growth was vigorous, though with some invasion of the reed species Schoenoplectoris Lasustris. This was of no concern as it can also be used as a reed in RBTS systems.

Figure 24 Weeding control of SVF bed

3.4.5 Seasonal Variation in Rainfall, Potential Evapotranspiration and Kc factors

Meteorological data was taken from the Irish Meteorological Service data monitoring station located approximately 3 km from the site and from the onsite weather station. Figure 25 shows the monthly rainfall totals (mm) and potential evapotranspiration (mm) together with crop evapotranspiration for willow for the period February 2008 to February 2010 inclusive. Total rainfall for 2008 and 2009 was 930mm and 936mm respectively. Average monthly rainfall over this period was 76.8mm. Potential evapotranspiration increased during the months May – August with the minimum value recorded during December.

Figure 25 Monthly rainfall, potential evapotranspiration and crop evapotranspiration

3.4.6 Soil Classification

Soil samples were taken at representative intervals throughout the site. Results of the laboratory experiments indicated a uniform soil type with a moisture content of 20%, Plasticity Index 10%, Organic Content 4.5%. The soil was classified as a very stiff, homogenous clay. Soil conditions were consistent throughout the site to depths of 1.2m. Permeability of the subsoil within the willow bed was determined by taking twelve undisturbed soil samples. The falling head test was used to determine the permeability coefficient of each sample. The average permeability of the samples was 2.3×10^{-7} m/sec. Figure 26 shows sampling of the subsoil within the willow bed.

Figure 26 soil sampling in willow bed

3.4.7 Biomass Audit

A total of 180 willow cuttings were planted in February 2008. Three willow varieties were planted namely *Salix triandra*, *S. purpurea* and *S. Viminalis*. In Winter 2009 a biomass audit was carried out. Plant loss averaged 40%. The successful willows were planted in the beds adjacent to the inflow. The biomass audit determined the average plant height to be 1.9m with a range of 1m to 3.1m. Stem thickness ranged from 6mm to 24mm with an average thickness of 14mm. A second biomass audit was carried out in spring 2011. The height and diameter of the plants was sampled. The height was sampled by using linear meter from the ground level to the apex. The diameter was measured at 0.30m from the ground, where the mark from previous measurement was, using a digital calliper. Then the average diameter and the average height were calculated. Appendix 2 presents a summary of the data. Figure 27 shows an example of the biomass audit where each willow was tagged and measured.

Figure 27 Biomass audit showing tagging of willows

3.4.8 Wastewater Treatment Plant Performance

Table 4 presents a summary of the monitoring results for the 24 month period.

Table 4 Overall wastewater treatment performance for Lynches Lane Facility

	Influent (Sewage)					Horizontal Flow reed Bed (Effluent)					Percentage Removal		
Parameter	**Mean**	**S.D.**	**Median**	**Min**	**Max**	**Mean**	**S.D.**	**Median**	**Min**	**Max**	**Mean**	**S.D.**	**Median**
NH_4 (mg l^{-1})	45	40	28	3	144	13	12	12	0	41	71	71	56
KJN as N (mg l^{-1})	44	31	35	4	117	13	12	11	0	45	70	71	69
NO_3 (mg l^{-1})	5	10	1	0	40	34	47	4	0	19	-586	-353	-418
PO_4 (mg l^{-1})	4	4	2	0	14	2	1	2	1	6	45	73	17
Coliforms (MPN/100ml)	2389261	4808118	1198000	1	24196000	133685	402744	10462	31	1986300	94	92	99
E.coli (MPN/100ml)	711074	1459254	233300	1	7270000	40572	121023	1710	10	579400	94	92	99
COD (mg l^{-1})	289	206	327	33	890	37	26	32	0	105	87	88	90
BOD_5 (mg l^{-1})	129	99	136	4	316	11	15	4	1	58	91	85	97
TSS (mg l^{-1})	101	117	60	17	524	15	22	9	1	96	85	81	85
pH	8	1	8	7	12	7	0	7	7	8	-	-	-

Figure 28 shows a summary of the treatment efficiency at each stage of the plant. Appendix x presents a more complete breakdown of the treatment performance at each stage of the plant over the monitoring period.

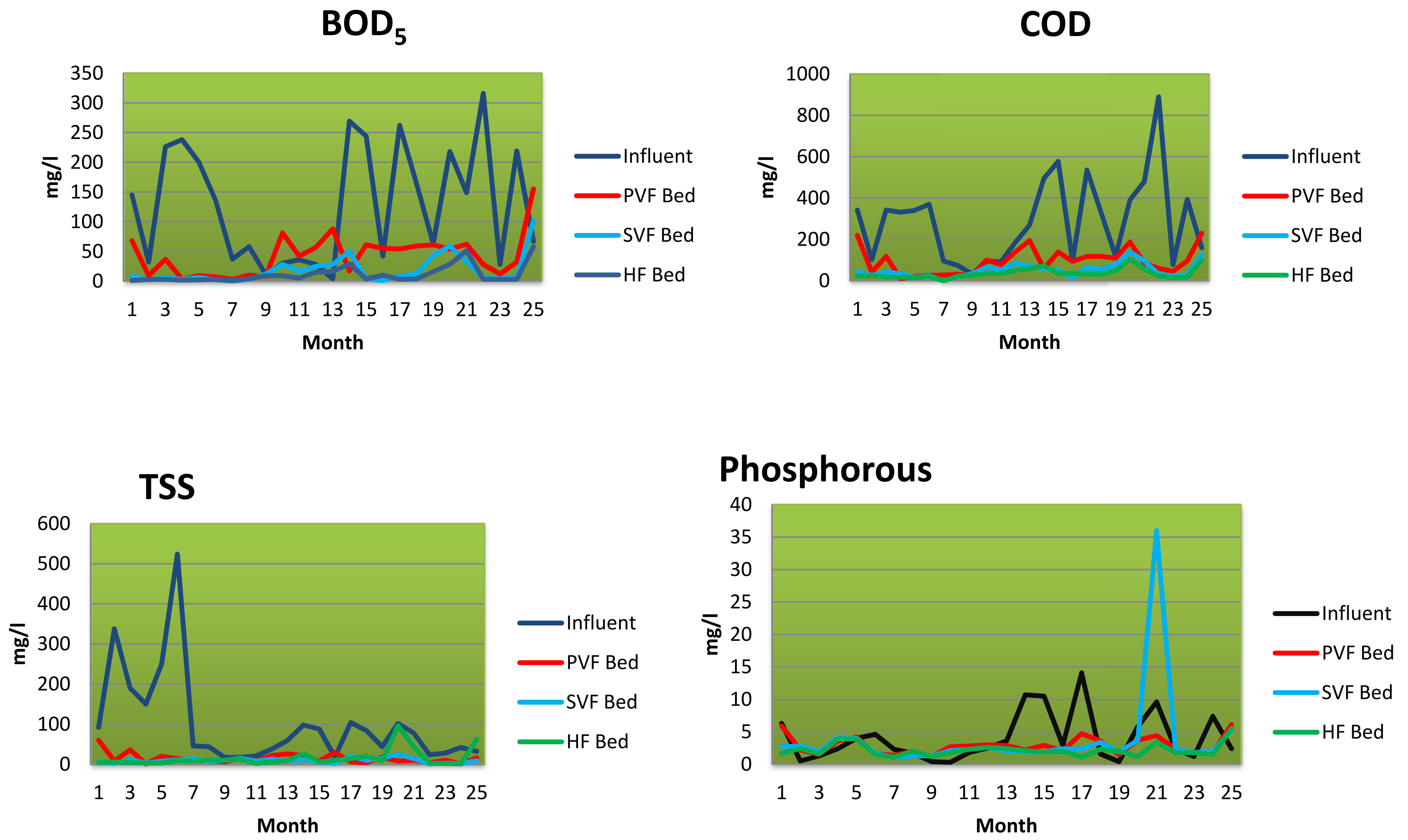

Figure 28 Treatment plant results for each treatment stage

3.5 DISCUSSION OF RESULTS

Reed Bed Performance

The variability of influent, characteristic of small schemes, is evident (Metcalf and Eddy, 2002). Removal values for COD and BOD were comparable with results achieved at other hybrid systems built in Ireland (O'Hogain, 2003). Suspended solids removal was slightly lower, at 85 %. Coliform and *E.coli* removal rates were also marked at 94% respectively. Nitrate and phosphate removal rates were unsatisfactory as reported in previous studies (O'Hogain, 2004).).

Willow Bed Performance.

No outflow was observed from the willow bed during the monitoring period. There were frequent periods when the willow bed was dry throughout. This left three possible pathways for the effluent. These were, passage through the soil, absorption to the roots and evapotranspiration of the wastewater, and or evaporation in the open trenches due to climatic factors such as wind and sunlight. To determine percolation through the soil a series of soil tests were performed. The average permeability of the samples was 2.3×10^{-7} m/sec. From this we may conclude that the wastewater is being removed primarily by evapo-transpiration effects.

A more detailed presentation and discussion of the results is presented in Appendix 1.

CONCLUSIONS

During the two year monitoring period the Reed bed willow bed system at Lynche's Lane Co. Dublin achieved zero discharge. This was achieved using a design figure of $2m^2$ per p.e. for the vertical beds, $1m^2$ per p.e. for the horizontal bed and $3m^2$ per p.e. for the willow bed.

DISCUSSION

The potential application of a reed and willow bed combination to sites not served by sewerage infrastructure is worthy of exploration. The typography of settlement in Ireland consists of numerous isolated dwellings, not connected to collective treatment systems. Onsite individual wastewater treatment systems (IWTS) are the primary method used for the treatment and disposal of domestic wastewater from these dwellings. A conventional IWTS typically consists of pretreatment within either a septic tank or some form of mechanical aeration system, followed by filtration through a soil percolation area. The suitability of a site for the development of IWTS is assessed using the methodology outlined within the EPA 2009 Code of Practice (EPA, 2009). These guidelines are aimed at defining subsoil conditions that will provide an acceptable level of treatment for wastewater effluent. The methodology includes a desk study and on site assessment including visual inspection, trial hole test and percolation tests. A percolation test is required to determine the assimilation capacity of the subsoil. The guidelines specify a minimum unsaturated subsoil depth of 1.2 m below the invert of the septic tank percolation trenches and a maximum high groundwater level of at least 1.5m below original ground surface, before the site may be deemed suitable for on-site treatment of domestic wastewater effluent. Many IWTS continue to be sited in areas not geologically suited to such systems. Flooding risks due to global warming effects have altered the risk assessment of many existing septic tank sites. A recent European Court of Justice (EU, 2009) ruling found that Irelands legislation, as regards on site systems, does not comply with Articles 4 and 8 of the Waste Directive (75/442/EEC). The commission in its judgment, specifically listed design and operational areas such as, incorrect construction, unsuitable siting, insufficient capacities, maintenance and inspection together with the inactivity of competent administrative authorities. The commission stated that the current legislation governing the construction and siting of septic tanks is not suited to the geological and soil characteristics generally found in Ireland. The Irish Government in response to the court judgement announced its intention to draft legislation to introduce a licensing and inspection system for existing septic tank systems (Cussen, 2009). The development of an appropriate zero discharge wastewater facility has the potential to address the source of IWTS pollution in Ireland.

The Danish EPA has produced guidelines for a number of small-scale onsite treatment solutions for use in rural areas. If the guidelines are followed no monitoring of the systems are required (Brix, 2004). Correct sizing of the willow systems specific to the irish climate and soil conditions is critical to performance and adaptability. Based on DIT's pilot projects direct application of the Danish guidelines to Ireland is not appropriate. There is a need to develop guidelines within the Irish context, based on a comprehensive list of evaluation criteria to provide decision makers with a complete overview of the existing aspects of reed willow bed combination systems.

The potential application of a reed and willow bed combination, to sites not served by sewerage infrastructure, and/or to sites where existing wastewater treatment system require upgrading is worthy of exploration by South Dublin County Council. The ease of construction, the use of locally available material and the lack of outflow/effluent make a reed willow bed combination a sustainable solution in sites where no sewerage services are available.

Given the performance of the reed willow bed combination at Lynche's Lane, South Dublin County Council should pilot this design in sites where no sewerage infrastructure is available.

RECOMMENDATIONS

1. **The development of an appropriate Zero Discharge Wastewater Facility has the potential to address the source of individual wastewater treatment systems (IWTS) pollution in Ireland. The technology could be successfully adapted by South Dublin County Council to install pilots in other similar small scale community wastewater treatment facilities.**

2. **There is a need to develop guidelines within the Irish context, based on a comprehensive list of evaluation criteria to provide decision makers with a complete overview of the existing aspects of reed willow bed combination systems.**

3. **The potential application of a reed and willow bed combination, to sites not served by sewerage infrastructure, and/or to sites where existing wastewater treatment system require upgrading is worthy of exploration by South Dublin County Council.**

4. **South Dublin County Council should pilot this design in sites where no sewerage infrastructure is available.**

The study also produced two papers. The first, titled **"The operation of hybrid reed bed and willow bed combinations in Ireland-Zero Discharge and the potential for no monitoring of domestic applications of this combination"** was presented to the 2nd Irish Conference on Constructed Wetlands for Wastewater Treatment and Environmental Pollution Control, 1-2 October 2010 in UCD. It was published in the proceedings.

The second paper, titled "**A Review of Zero Discharge Wastewater Treatment Systems using Reed Willow Bed Combinations in Ireland"** was presented to the 12th International Conference on Wetland Systems for Water Pollution Control in Venice (Italy), 4-8 October 2010. It was subsequently published in the journal Water Practice and Technology, Volume 6, issue 3.

4. Maintenance of Lynche's Lane Hybrid Reed and Willow bed System.

The system at Lynce's Lane consists of:

1. **Two pumping stations.**
2. **Two sets of pumps.**
3. **Two pumping Control panels.**
4. **Pipework.**
5. **Four Primary Vertical Reed Beds.**
6. **Two Secondary Vertical Reed Beds.**
7. **A horizontal Reed Bed.**
8. **A Willow Bed.**

A maintenance schedule must regularly check these constituent parts for any evidence of malfunction, damage, wear and tear or vandalism. This should be at least weekly, or more frequently if possible. A separate notebook/diary for the facility should be opened at the start of each year and all observations recorded in this by the personnel responsible for maintaining the facility. Phone numbers of various interested/relevant parties should also be in this diary, i.e. pump suppliers, SDCC personnel relevant to the facility and electricians etc responsible for the facility.

4.1.Pumping Stations

The first pumping station is located behind the emergency halting site. This sump gathers the wastewater from the emergency halting site. The cover is locked. The second pump sump is located in the Depot, to the right of the Main shed door in the SDCC Depot. This cover consists of two heavy steel doors.

4.2.Pumps

The two sets of pumps are located in the above pump sumps.

4.3.Pump Clocks

The two pumping control panels, which record the number of pumping hours for each set of pumps are located near each of the two pump sumps. The control panel for the pumps of the Emergency halting site are located behind the site in a locked and caged box. The control panel for the pumps in the depot are located in the locked tool section of the main Depot Shed. As the halting site is no longer in use there is no need to check this section for working order. Periodic checks on the status and condition of the equipment and utilities are recommended.

For the working pump sump regular checks should be carried out, weekly if possible. These should record working status, water levels, pump function and depths. Sludge build up should also be checked, using a stick and rag method if possible. Desludging may be required periodically, and the most accurate way to determine the need for desludging is to determine the depth of sludge in the sump. If the level is such that the sludge is being recirculated and being pumped to the reed bed, the sump should be desludged.

The pump floats should also be checked for depth and to see if they are in working order. In Lynche's Lane it is recommended that two people are involved in checking the working order of the pumps. One person present at the pump sump and the other observing the entry of the effluent onto the reed bed.

The control panel/pumping clock is an important part of the overall facility. It shows the pumping hours and also allows the pumps to be switched off in cases of emergency or pump maintenance. Regular daily recording of pumping hours will lead to the build up of data on the overall facility. It will enable volumes to be calculated etc. However, these records will also serve as early warning indicators of trouble within the system. Reduced pumping hours may indicate a blockage, pump malfunction or even a leak. Increased pumping hours may be a result of pump floats being stuck, infiltration etc. The first clue to problems may/will show up in the pumping hours. If the pumping hours can be recorded daily, in a diary specific to the reed bed willow bed facility, and as a daily load not just as a total, then an early warning of any system problems will exist. If this cannot be done daily then it should be carried out at least bi-weekly.

4.4.Pipework

Problems with pipework will largely be to do with blockages, infiltration, leaks, or subsidence.

4.5.Four Primary Vertical Reed Beds

The four primary reed beds (PVB) are located at the rear of the depot, behind the main shed and road. The primary beds are the first ones, at the higher part of the reed bed. They are fed by a rising main from the pump sump which feeds via 110 mm pipe into four 150 litre plastic header tanks. The effluent is distributed onto each bed via 25 mm pipes. The reed bed is a lined structure with layers of geavel topped by a layer of sharp sand. The area is divided into four even beds.

Each header tank is fitted with an on/off switch. This facilitates rotation of the beds, where this is required. A vertical bed allows passage of the effluent though from top to bottom and is also characterised by dosing and rotation. The effluent is pulsed or dosed onto the vertical bed in such a manner as to allow passage of the effluent completely through the bed and allow the effluent to drain fully through and allow passage or air through the bed after the effluent has drained. The bed is dosed and microorganisms in the bed consume the organic matter. In fact a vertical reed bed operates rather like a Trickling filter, in that when it is being dosed, the interstitial spaces serve as sites for microorganisms and these spaces fill up as microorganism growth occurs. After a few days of dosing the percolation time of the effluent within the bed will be reduced to a trickle. This time can be measured, or a rota can be set for the number of beds such that clogging is not allowed to occur. To operate such a rota all that is required is the switching off of the inflow into one bed and the switching on of another vertical bed. This is what is referred to as rotation.

Regular maintenance of the primary vertical beds should be carried out weekly. This should involve checking the header tanks, the inlet and outlet pipes. Weeds and solids can become lodged in the header tanks and these should be removed (Figure 29).

Figure 29 Primary vertical beds with weeds colonising the header tank and the bed

Where the outlet pipes block, simple agitation or in more extreme cases air pressure will suffice to clear them. For the last period of operation, since the emergency halting site was closed, no rotation has been required and all four beds have been fed at all times. If it is felt that rotation is required, if clogging occurs, a rota of two days on six days off may be introduced on the primary beds. Invasion of weed species (nettles in particular) is difficult to avoid. Ponding of the bed in early spring will remove weeds and rabbits (See Figure 30 below).

Figure 30 Ponding of reed beds to remove weeds and rabits

4.6.Two Secondary Vertical Reed Beds

The two secondary vertical beds (SVB) are in sequence below the primary beds. The two secondary beds are each fed by 110 mm pipes. One pipe comes from the two right hand side PVB's and the other pipe comes from the left hand side PVB's. The SVB are automatically fed once the PVB's are switched on. Dosing is via two tipping buckets and outlet 25 mm pipes. Regular maintenance of the secondary vertical beds should be carried out weekly. This should involve checking the tipping buckets, the inlet and outlet pipes. Weeds and solids can become lodged in the tipping buckets and these should be removed. Where the outlet pipes block, simple agitation or in more extreme cases air pressure will suffice to clear them. For the last period of operation, since the emergency halting site was closed, no rotation has been required and all beds have been fed at all times. If it is felt that rotation is required, if clogging occurs, a rota of two days on six days off may be introduced on the primary beds. This rotation will rest the SVB's also. Invasion of weed species (nettles in particular) is difficult to avoid.

4.7.Horizontal Reed Bed

The horizontal reed bed (HB) is fed by a 110 mm pipe discharging the effluent from the secondary vertical beds. This is also a lined structure but it is of a single gravel only. Flow is horizontally through the bed and the bed is full at all times. The level of the wastewater in the HB can be controlled by an elbow. Clogging should not occur on the HB. Regular maintenance of the HB should be carried out weekly. This should involve checking the inlet and outlet pipes. Figure 31 shows the inlet pipe to the horizontal flow bed.

Figure 31 Inlet pipe to Horizontal flow bed, from secondary vertical beds.

4.8 Willow Bed

The hybrid reed bed discharges to the willow bed (WB). This consists of a series of trenches planted with three different species of willow. They are fed from the HB bed by a 110 mm pipe. The effluent flows from one trench to another. Regular maintenance of the WB should be carried out weekly. This should consist of examination of the inflow pipe, examination of willow growth, and where necessary removal of weed species. It is recommended that a third of the crop be cut back each year in rotation.

5. Maintenance Troubleshooting Guide.

This section serves as a maintenance reference guide. The possible condition or situation giving rise to the problem is first identified. The possible cause or reason is then given, together with other clues that will aid the user in diagnosing the source of the problem. Finally a remedy for each condition is proposed.

5.1 Clogging of reed Beds.

A hybrid reed bed contains two different types of reed bed. A horizontal reed bed and a vertical reed bed. Both are named after the direction or passage of the wastewater through the bed. Effluent passes horizontally through a horizontal reed bed. The bed is full at all stages and the level in the bed is/can be controlled by an elbow. A vertical bed allows passage of the effluent though from top to bottom and is also characterised by dosing and rotation. The effluent is pulsed or dosed onto the vertical bed in such a manner as to allow passage of the effluent completely through the bed and allow the effluent to drain fully through and allow passage or air through the bed after the effluent has drained. The bed is dosed and microorganisms in the bed consume the organic matter. In fact a vertical reed bed operates rather like a Trickling filter, in that when it is being dosed, the interstitial spaces serve as sites for microorganisms and these spaces fill up as microorganism growth occurs. After a few days of dosing the percolation time of the effluent within the bed will be reduced to a trickle. This time can be measured, or a rota can be set for the number of beds such that clogging is not allowed to occur. To operate such a rota all that is required is the switching off of the inflow into one bed and the switching on of another vertical bed. This is what is referred to as rotation.

Clogging can occur in either bed. However, a certain amount of clogging is part of the operation of vertical beds. Clogging should not occur on a horizontal bed.

Condition or situation	**Reed bed/s clogging**	
Possible source/reason	Other clues	**Remedy.**
Inadequate resting	Occurring on all beds	**Increase resting time of beds**
Inadequate maintenance	Accumulation of solids and reed debris	**Remove solids and reed debris**
Infiltration of surface or rainwater	Increase in pumping hours	**Identify source of infiltration and repair**
Inadequate distribution	Ponding near distribution pipes	**Improve distribution**

5.2 Odour

Odour from a wastewater treatment plant is a nuisance and almost impossible to avoid in some form or other. However, reed beds show a lower incidence of odour than most conventional WWT plants. The two main sites of odour in a hybrid reed bed are the distribution onto the vertical beds and the distribution onto the horizontal bed. Any other persistent sources of odour should be checked.

Condition or situation	**Odour**	
Possible source/reason	Other clues	**Remedy.**
Algae on horizontal bed	Horizontal bed flooded bed	**Reduce water level on horizontal**
Lack of desludging of Septic/settlement tank	Excessive solids in influent	**Desludge**

5.3 Flow

Interruption or reduction of flow is something that can be difficult to spot until it is a problem. Regular recording of pumping hours gives an accurate picture of the plant in operation. Reductions or increases in flow are easy to spot if records are kept. There should be daily or at the least bi- weekly recording of the pumping hours, in a specially designated diary for this purpose. Regular weekly inspections of the plant in operation (during active dosing onto the vertical beds) together with regular recording of pumping data is a good maintenance schedule. This schedule should also include checking the pump sump/septic tank and the pump floats.

Condition or situation	**Low inflow**	
Possible source/reason	Other clues	**Remedy.**
Supply interruption upstream of RBTS	Influent not fully wetting the bed/s Reduced outflow from horizontal bed	**Source site of interruption and repair**
Blockage of pipes leading to beds	Reduced pumping hours	**Identify blockage and clear.**
Pump and/or pump floats require servicing	Reduced volume per pump pulse	**Service pump or pump floats**

5.4 Power Failure

Power failure can occur at anytime and for many reasons. It may also occur when no one is on site.

Condition or situation	Power failure	
Possible source/reason	Other clues	**Remedy.**
Damage to power line	No electricity on site	**Contact local electricity supplier**
Prolonged down time due to storm damage or other unpredictable occurrence	Information from supplier	**Turn off all appliances. Empty the horizontal bed of treated effluent to accommodate overflow from pump sump. Raise outlet elbow to increase retention time.**

5.5 Pump Failure

Pump failure will show up if the pumping hours are being recorded. However pump failure can occur for many reasons. Regular weekly inspection together with good data will show up pump failure.

Condition or situation	Pump failure	
Possible source/reason	Other clues	**Remedy.**
Pump requires servicing or replacement	Electricity available on site	**Replace or service pump. Prepare horizontal bed for overflow.**

5.6 Chemical Spill

Some chemicals are toxic to the reeds and willows, although both plants are characterised by robust behaviour. Follow emergency safety instructions.

Condition or situation	Chemical Spill	
Possible source/reason	Other clues	**Remedy.**
Spillage of storage tank, transport accident.	Reported to relevant authorities	**Attempt routing of spillage away from RBTS, or intercepting. If it gains access to the bed, identify and seek expert opinion.**
Unknown chemical Spillage	Smell and/or visually observe damage to bed reeds. media or	**Identify chemical, where possible seek expert opinion.**

5.7 Reduced Flow

Condition or situation	Reduced flow	
Possible source/reason	Other clues	**Remedy.**
Pipe blockage between Inlet and outlet	Inflow as normal Normal pumping hours	**Identify source of blockage and clear.**
Pierced liner	Reduced waterlevel in horizontal bed.	**Identify leakage source in liner, and repair.**

5.8 Snow / Frost

Condition or situation	Reduced flow	
Possible source/reason	Other clues	**Remedy.**
Low Temperatures	Wastewater flowing over frozen beds	**Manually break ice. Influent will gain access and treatment will continue.**

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5.9 Damage to Reeds

Condition or situation	Damage to reeds	
Possible source/reason	Other clues	**Remedy.**
Wind/storm damage of reeds.	**Evidence of broken and damaged shoots and dead sections**	**Remove. Replant if necessary. Consider shelter hedge / fence.**
High Temperatures	**Wilting of reeds, Increased evapo- Transpiration.**	**Increasae number of pump pulses by reducing volume pumped.**
Disease/Fungi	**Visible markings**	**Seek expert advice.**

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Appendix 1 Reed Bed Performance Analysis

Influent

Month	Ammonia	KJN	Nitrate	Orthopho	Coliforms	E.Coli	COD	BOD	TSS	pH
Feb-08	75.8	69.35	0	6.3	1732900	275500	342	145	92	8.59
Mar-08	10.15	15.1	26.89	0.5	206.4	31.3	103	32	338	11.74
Apr-08	3.79	36.09	1.02	1.3	1	1	342	226	190	11.85
May-08	40.82	49.33	0	2.4	2920	310	332	238	150	10.03
Jun-08	36.48	45.6	40	4	6967	2496	340	200	250	9.98
Jul-08	28.24	42.34	26.66	4.6	2419600	920800	370	136	524	9.43
Aug-08	23.53	23.02	0	2.3	2419600	980400	96	37	46	7.38
Sep-08	18.81	18.85	4.21	1.7	1553100	218700	74	58	44	8.97
Oct-08	2.9	3.72	7.31	0.4	1986300	155300	33	11	17	7.48
Nov-08	15.07	14.96	0	0.3	128100	24500	95	30	17	8.52
Dec-08	22.94	22.51	0	1.8	2419600	233300	92	36	21	8.01
Jan-09	40.03	34.51	0.22	2.5	344800	198630	185	28	38	7.75
Feb-09	40.4	39.98	0.58	3.6	1986300	648800	270	4	60	8.38
Mar-09	119.18	96.62	0.31	10.7	107600	27780	495	269	98	7.68
Apr-09	115.12	99.79	0.27	10.5	3448000	1439000	578	244	88	7.49
May-09	32.62	31.69	3.63	2.9	1119900	178200	95	42	18	7.86
Jun-09	143.58	116.69	0.53	14.1	7270000	7270000	536	262	104	7.54
Jul-09	27.52	27.64	1.15	1.6	2419600	648800	327	165	84	7.87
Aug-09	7.26	10.87	0.93	0.4	980400	110600	119	63	44	8.6
Sep-09	70.3	72.71	0	5.8	24196000	388000	391	218	102	7.11
Oct-09	98.16	75.6	0.71	9.6	2419600	1986300	480	149	78	7.51
Nov-09	23.81	24.54	1.73	2.4	686700	435200	890	316	24	7.96
Dec-09	16.92	21.98	2.22	1.2	686700	387300	79	28	28	8.43
Jan-10	99.88	80.51	4.16	7.4	1198000	1203300	394	219	42	7.35
Feb-10	21.19	20.66	0	2.4	198630	43600	160	67	32	8.43

PVF Bed

Month	Ammonia	KJN	Nitrate	Orthophosh	Coliforms	E.Coli	COD	BOD	TSS	pH
Feb-08	25.54	20.07	4119.46	5.9	1553100	167000	220	68	60	7.01
Mar-08	25.61	7.76	110.44	2.2	68930	62940	42	9	8	7.85
Apr-08	13.3	11.75	76.77	1.5	488400	241960	118	37	36	7.41
May-08	0.15	0.49	137.64	3.6	630	310	11	3	1	8.43
Jun-08	4.31	8.46	78.62	4.2	1794	832	20	9	20	7.04
Jul-08	7.2	6.11	74.51	1.6	410600	344800	26	7	14	7.04
Aug-08	0.45	1.26	60.29	1.4	176900	63800	28	3	9	5.53
Sep-08	8.86	7.3	0.27	2	648800	93300	32	10	9	7.93
Oct-08	8.98	8.05	2.88	1.2	686700	204600	27	8	6	7.67
Nov-08	30.02	27.29	0.13	2.7	90600	32700	101	81	15	8.18
Dec-08	29.22	23.92	0	2.8	517200	111200	78	42	9	8.03
Jan-09	42.53	35.3	1.02	3	307600	77010	139	57	22	7.91
Feb-09	31.99	29.93	0.18	2.9	488400	166400	195	88	26	8.36
Mar-09	18.78	16.28	0.18	2.2	41	10	58	17	22	7.61
Apr-09	61.96	48.07	0	2.9	3890	12220	139	61	8	7.66
May-09	22.63	26.6	3.68	2.1	1732900	131700	94	55	30	8.6
Jun-09	72.47	52.36	0.49	4.7	38730	4570	118	54	6	7.69
Jul-09	27.24	20.76	0.97	3.6	770100	33600	118	59	4	7.37
Aug-09	16.18	17.09	0.84	1.5	727000	104600	109	61	18	7.56
Sep-09	53.89	52.09	0.09	3.7	410600	21100	187	54	8	7.47
Oct-09	50.66	34.58	3.99	4.4	173290	51720	85	62	10	7.51
Nov-09	21.08	21.23	57.19	2.4	120330	61310	60	28	4	7.66
Dec-09	15.05	13.64	0	1.8	111990	111990	46	12	10	8.06
Jan-10	17.97	12.98	3.32	1.8	61310	12460	96	32	2	7.4
Feb-10	55.56	48.98	0.27	6.1	61310	17220	230	155	16	7.65

SVF Bed

Month	Ammonia	KJN	Nitrate	Orthophosha	Coliforms	E.Coli	COD	BOD	TSS	pH
Feb-08	3.84	2.47	47.67	2.7	198630	43520	45	9	7	6.88
Mar-08	0.94	2.9	253.57	2.8	3050	2560	27	2	2	7.26
Apr-08	0.7	0	158.2	1.9	15600	9280	42	6	12	7.2
May-08	0.21	0.5	123.33	4.2	547.5	62	35	<4	3	7.55
Jun-08	1.91	4.5	110.46	4	1216	160	16	6	8	7
Jul-08	0.22	0	108.09	1.7	33600	12200	24	2	11	7.03
Aug-08	0	2.01	42.26	1	37900	1732.9	0	0	14	6.6
Sep-08	4.49	4.99	8.06	1.3	141360	32550	19	3	7	7.57
Oct-08	10.73	9.35	2.53	1.3	2419600	547500	35	12	10	7.85
Nov-08	22.63	20.01	0	2.1	53000	17500	66	28	15	7.87
Dec-08	25.83	23.13	0	2.3	579400	110000	53	16	8	7.82
Jan-09	34.46	28.33	0.44	2.6	77010	11860	85	25	13	7.94
Feb-09	18.63	16.08	0.35	2	46110	6050	71	28	8	8.06
Mar-09	27.35	23.06	0.04	1.9	520	200	58	50	12	7.64
Apr-09	19.84	10.56	105.57	1.9	12010	200	50	4	7	7.06
May-09	3.29	3.14	135.07	2.4	579.4	63	15	1	2	7.11
Jun-09	36.25	30.65	8.28	2.3	241960	7760	64	9	20	7.3
Jul-09	24.14	18.97	0.8	3.4	365400	7400	55	12	10	7.49
Aug-09	15.98	15.51	0.89	1.9	920800	90900	80	43	15	7.54
Sep-09	43.71	40.31	0.53	3.7	461100	17300	140	59	25	7.63
Oct-09	44.23	29.26	0.97	36	187200	637000	96	33	14	7.84
Nov-09	16.31	16.27	1.86	2.4	34480	11370	32	5	1	7.67
Dec-09	13.02	16.32	0	1.8	29090	15000	25	4	3	7.64
Jan-10	15.39	11.03	3.15	2	13760	1440	28	6	2	7.64
Feb-10	48.08	44.18	0	5.3	86040	24810	127	101	9	7.63

HF Bed

Month	Ammonia	KJN	Nitrate	Orthophosh	Coliforms	E.Coli	COD	BOD	TSS	pH
Feb-08	5.61	5.05	86.07	1.7	1553	517.2	23	1	4	6.89
Mar-08	0.34	2.9	118.86	2.4	4870	4170	26	3	6	7.32
Apr-08	0.98	0	117	1.6	2490	1890	18	3	4	7.33
May-08	0.1	0.59	104.46	3.9	5540	1710	17	2	3	7.38
Jun-08	0.54	4	100.56	3.9	1659	450	15	2	3	6.96
Jul-08	0.31	0	115.58	1.5	143900	62000	20	3	9	7.19
Aug-08	0	6.54	40.8	1.1	13140	1119.9	0	1	8	6.57
Sep-08	2.31	2.7	4.39	2	24890	1090	22	4	11	7.56
Oct-08	10.09	8.72	3.68	1.2	1986300	214300	28	9	10	7.75
Nov-08	12.58	11.82	0.58	1.8	39300	11000	34	9	13	7.44
Dec-08	22.99	18.96	0.27	2.3	10900	3100	36	5	2	7.53
Jan-09	29.52	21.39	0.53	2.6	12670	1710	50	15	6	7.64
Feb-09	18.8	14.18	0.62	2.4	9640	2210	59	16	9	7.81
Mar-09	22.05	19.07	0	2.1	31	10	72	29	27	7.54
Apr-09	15.18	11.62	88.07	1.9	2160	100	36	4	6	7.27
May-09	14.69	13.32	35.57	2	241960	579400	35	10	10	7.23
Jun-09	8.59	8.47	3.28	1.1	5940	620	32	3	14	7.44
Jul-09	17.89	15.79	1.64	2.3	10462	332	33	4	20	7.37
Aug-09	14.29	44.78	1.82	2	517200	76300	49	16	9	7.46
Sep-09	24.1	22.4	0	1.2	54750	1610	105	28	96	7.77
Oct-09	39.19	30.34	1.2	3.4	198630	30760	57	51	44	7.6
Nov-09	11.76	10.62	7.8	1.8	2620	1340	24	3	3	7.58
Dec-09	12.37	10.75	2.13	1.8	4430	2380	15	3	2	7.62
Jan-10	8.38	6.11	4.25	1.5	980.4	201.4	18	3	1	7.59
Feb-10	41.46	40.57	0.89	5.5	46110	15970	100	58	62	7.67

Influent vs PVF		Influent (Sewage)				
Parameter	**units**	**Mean**	**S.D.**	**Median**	**Min**	**Max**
Ammonia as N	**mg/l**	45	40	28	3	144
KJN as N	**mg/l**	44	31	35	4	117
Nitrate as N	**mg/l**	5	10	1	0	40
Orthophosphate as P	**mg/l**	4	4	2	0	14
Coliforms	**MPN/100ml**	1545023	1612404	1198000	206	7270000
E.coil	**MPN/100ml**	740702	1482939	254400	31	7270000
COD	**mg/l**	289	206	327	33	890
BOD	**mg/l**	129	99	136	4	316
TSS	**mg/l**	101	117	60	17	524
pH	**pH Units**	8	1	8	7	12

		Primary Vertical Bed effluent					Secondary Vertical Bed effluent				
Parameter	**units**	**Mean**	**S.D.**	**Median**	**Min**	**Max**	**Mean**	**S.D.**	**Median**	**Min**	**Max**
Ammonia as N	**mg/l**	26	20	23	0	72	17	15	16	0	48
KJN as N	**mg/l**	22	16	20	0	52	15	13	16	0	44
Nitrate as N	**mg/l**	189	820	1	0	4119	44	68	3	0	254
Orthophosphate as P	**mg/l**	3	1	3	1	6	4	7	2	1	36
Coliforms	**MPN/100ml**	386046	455982	176900	41	61310	238399	505792	46110	62	2419600
E.coil	**MPN/100ml**	85174	86378	62940	10	344800	64337	161694	11370	62	637000
COD	**mg/l**	95	63	94	11	230	52	34	45	0	140
BOD	**mg/l**	43	35	42	3	155	19	24	9	0	101
TSS	**mg/l**	15	13	10	1	60	10	6	9	1	25
pH	**pH Units**	8	1	8	6	9	7	0	8	7	8

		Horizontal Bed (Effluent)				
Parameter	**units**	**Mean**	**S.D.**	**Median**	**Min**	**Max**
Ammonia as N	**mg/l**	13	12	12	0	41
KJN as N	**mg/l**	13	12	11	0	45
Nitrate as N	**mg/l**	34	47	4	0	119
Orthophosphate as P	**mg/l**	2	1	2	1	6
Coliforms	**MPN/100ml**	133685	402744	10462	31	1986300
E.coil	**MPN/100ml**	40572	121023	1710	10	579400
COD	**mg/l**	37	26	32	0	105
BOD	**mg/l**	11	15	4	1	58
TSS	**mg/l**	15	22	9	1	96
pH	**pH Units**	7	0	7	7	8

Results of performance analysis of PVF, SVF and HF reed beds can be found in Table 5. It shows 91% in BOD_5 removal, 85% TSS removal, 70% KJN removal and 45% PO_4 removal.

Table 5 Lynches Lane overall performance results

		Percentage reduction		
Parameter	**units**	**Mean**	**S.D.**	**Median**
Ammonia as N	**mg/l**	71	71	56
KJN as N	**mg/l**	70	62	69
Nitrate as N	**mg/l**	-586	-353	-418
PO_4	**mg/l**	45	73	17
Coliforms	**MPN/100ml**	91	75	99
E.coil	**MPN/100ml**	95	92	99
COD	**mg/l**	87	88	90
BOD_5	**mg/l**	91	85	97
TSS	**mg/l**	85	81	85

Table 6 Influent concentrations

		Influent concentration				
Parameter	**units**	**Mean**	**S.D.**	**Median**	**Min**	**Max**
Ammonia as N	**mg/l**	45	40	28	3	144
KJN as N	**mg/l**	44	31	35	4	117
Nitrate as N	**mg/l**	5	10	1	0	40
PO_4	**mg/l**	4	4	2	0	14
Coliforms	**MPN/100ml**	1545023	1612404	1198000	206	7270000
E.coil	**MPN/100ml**	740702	1482939	254400	31	7270000
COD	**mg/l**	289	206	327	33	890
BOD_5	**mg/l**	129	99	136	4	316
TSS	**mg/l**	101	117	60	17	524
pH	**pH Units**	8	1	8	7	12

Table 7 Efluent concentrations

		HF Effluent concentration				
Parameter	**units**	Mean	S.D.	Median	Min	Max
Ammonia as N	**mg/l**	13	12	12	0	41
KJN as N	**mg/l**	13	12	11	0	45
Nitrate as N	**mg/l**	34	47	4	0	119
Orthophosphate as PO_4	**mg/l**	2	1	2	1.1	6
Coliforms	**MPN/100ml**	133685	402744	10462	31	1986300
E.coil	**MPN/100ml**	40572	121023	1710	10	579400
COD	**mg/l**	37	26	32	0	105
BOD_5	**mg/l**	11	15	4	1	58
TSS	**mg/l**	15	22	9	1	96
pH	**pH Units**	7	0	7	6.57	8

Lynches Lane showed variable influent loadings Table 6. This is characteristic for small sewage schemes. However, the hybrid constructed wetland treatment plant showed that it has ability to deal with occasionally high BOD_5 and TSS loads.

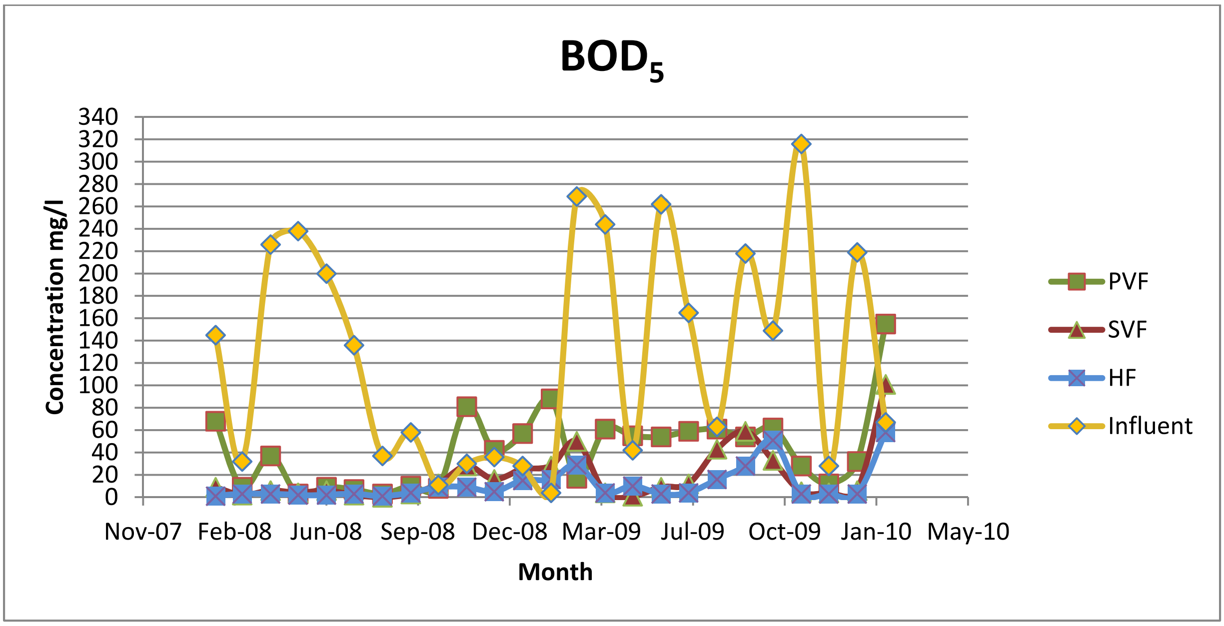

Figure 32 Concentration of BOD_5 through treatment stages

The mean influent concentration of BOD_5 was 129 mg/l varying from 4mg/l to 316 mg/l. The effluent concentration of BOD_5 was largely independent of inlet concentrations. After the SVF stage most of the BOD_5 was removed.

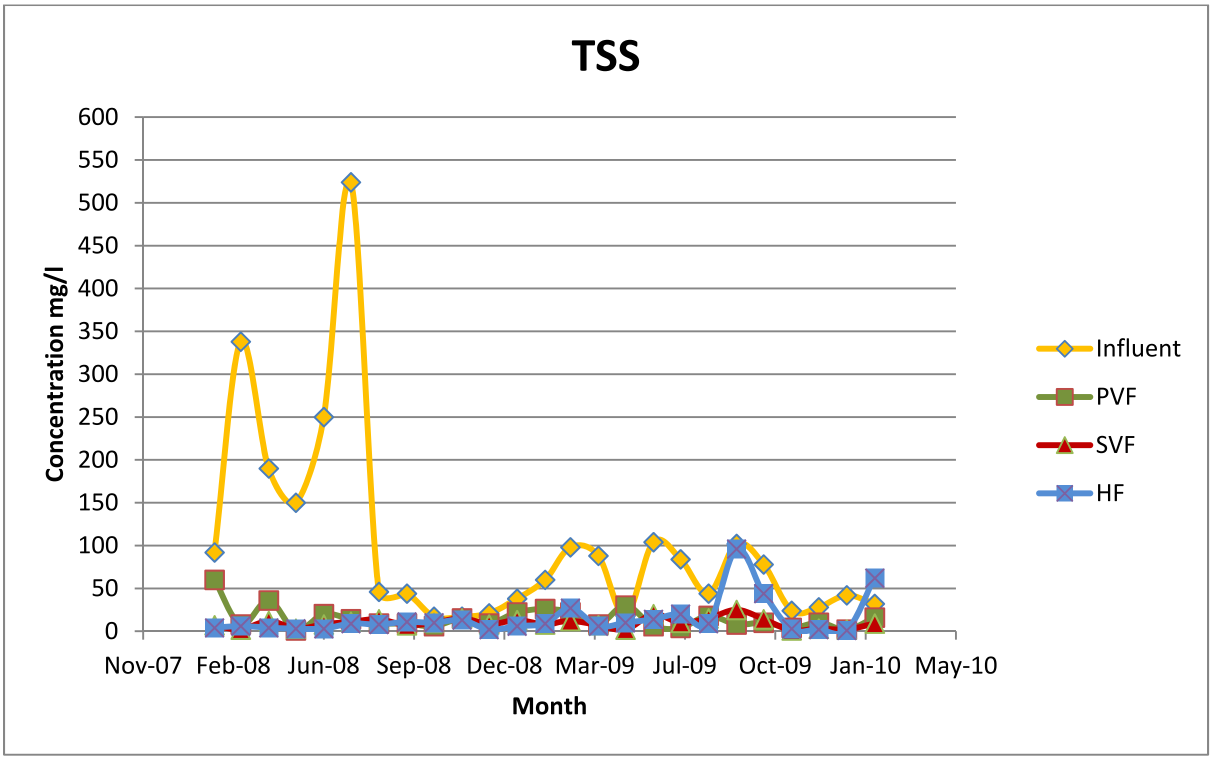

Figure 33 Concentration of TSS through treatment stages

The mean influent concentration of TSS was 101mg/l varying from 17mg/l to 524mg/l.

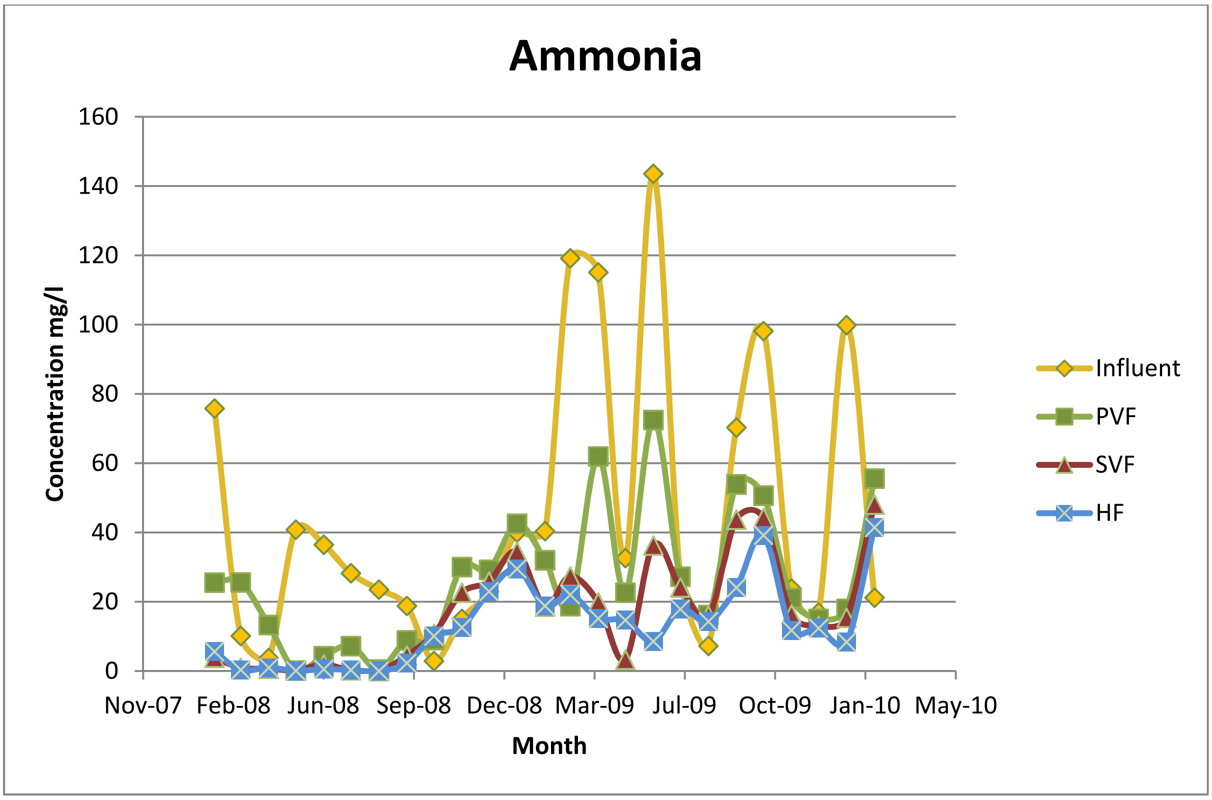

Figure 34 Concentration of Ammonia through treatment stages

The relationship between influent concentration and treatment performance was observed (Figure 34). The mean influent concentration of ammonia was 45mg/l varying from 3mg/l to 144mg/l. The mean effluent concentration of ammonia was 13mg/l varying between 0mg/l to 41mg/l. Mean removal of 42% was achieved in the PVF stage reed bed. The mean effluent ammonia concentration from PVF stage was further reduced by 35% in SVF bed and by 23% in HF bed (**Error! Reference source not found.**). The overall mean percentage reduction was 71%.

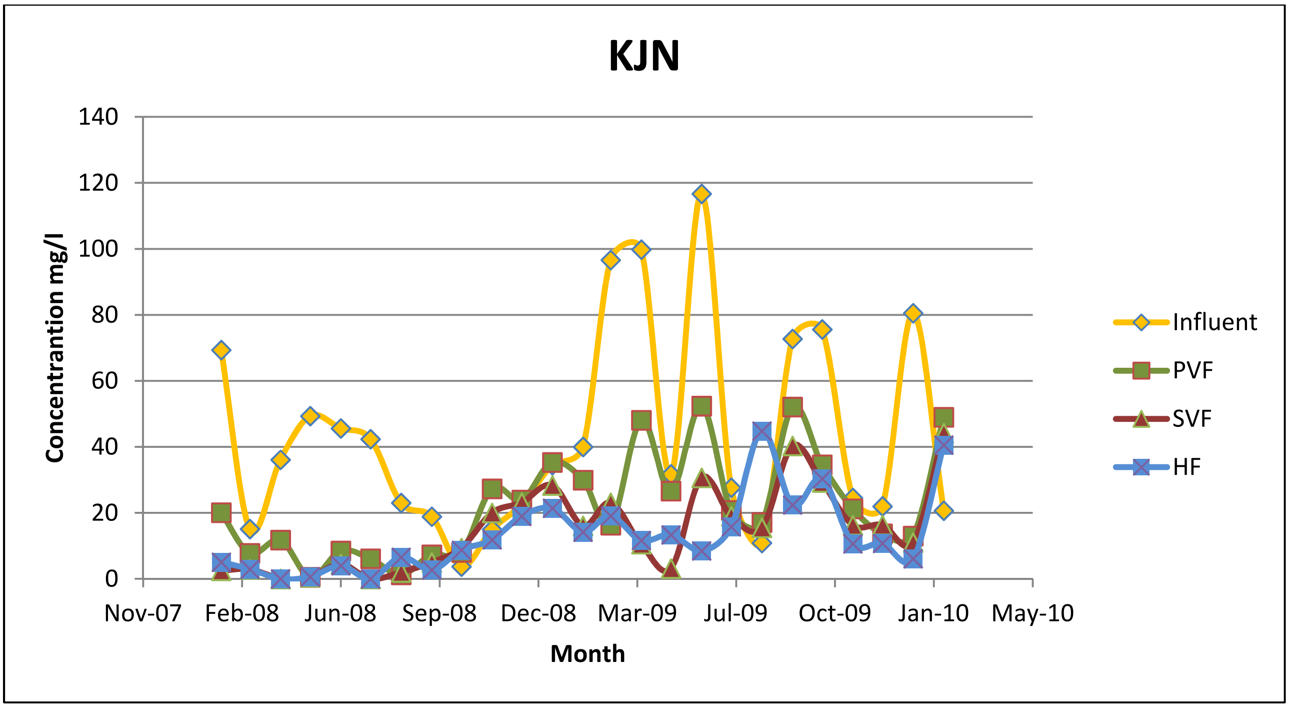

Figure 35 Concentration of KJN through treatment stages

There is a clearly visible relationship between Ammonia and KJN concentration. Ammonia accounts for the highest contribution to KJN concentration. This might be due to ammonification processes in the anaerobic septic tank.

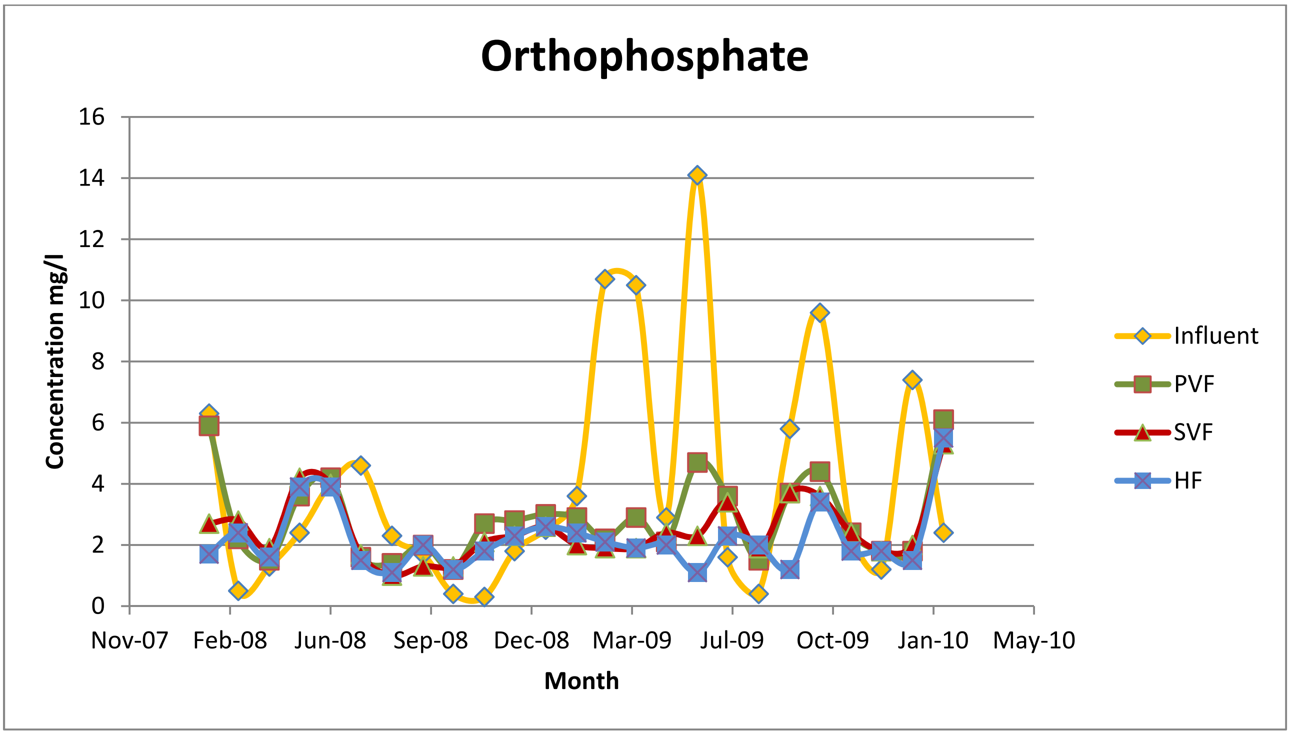

Figure 36 Concentration of Orthophosphate through treatment stages

The mean influent concentration of orthophosphate was 4mg/l varying from 0 to 14 mg/l. The mean effluent orthophosphate concentration was 2mg/l varying from 1mg/l to 6mg/l. The mean percentage reduction was 45%.

Table 8 Mean percentage reduction of pollutants between treatment stages

	Mean percentage reduction		
	PVB	**SVB**	**HF**
Ammonia as N	42	35	23
KJN as N	50	32	11
Nitrate as N	-3763	77	24
Orthophosphate as P	28	-31	42
Coliforms	75	38	44
E.coil	89	24	37
COD	67	46	28
BOD_5	67	55	41
TSS	85	38	-61

Seasonal performance differences

Seasonal differences in BOD, TSS, KJN pollutants removal can be seen in Figure 37. Summer season was taken from May to October and winter season from January to April.

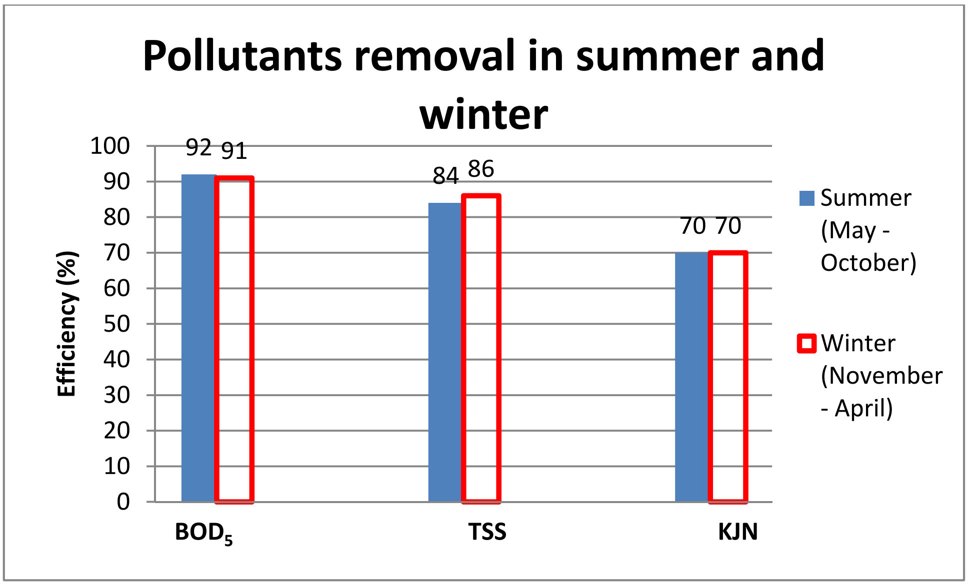

Figure 37 Pollutants removal in summer and winter

Performance differences between summer and winter during 24 months monitoring period of the CWs in case study were found to be not insignificant for BOD_5, TSS and KJN.

Appendix 2 Biomass Audit

Biomass audit April 2011		
Ridge	Diameter(mm)	Height(m)
1st	23.16	2.64
	24.28	2.77
	27.47	2.18
	44.6	3.2
	19.72	2.74
	18.53	2.32
2nd	38.86	2.62
	12.73	1.64
3rd	30.85	2.73
	31.54	3.11
	29.8	2.81
	30.66	2.82
	31.64	3.05
4th	17.06	2.48
	29.34	3.43
	19.46	2.48
	30.54	2.87
	15.78	2.62
	14.07	2.24
	34.68	3.19
	16.51	2.88
	23.78	2.48
	21.1	2.59
	33.87	2.95
5th	33.23	2.75
	36.18	3.79
	26.65	3.71
	31.56	2.87
	27.22	2.58
	25.57	2.61
	18.79	2.47
	29.61	3
	21.12	2.32
6th	19.14	1.75
	23.63	2.95
	39.47	3.76
	11.69	1.88
	31.34	3.31
	28.95	3.02
average	26	3
min	11.69	1.64
max	44.6	3.79

"The operation of hybrid reed bed and willow bed combinations in Ireland-Zero Discharge and the potential for no monitoring of domestic applications of this combination" was presented to the 2nd Irish Conference on Constructed Wetlands for Wastewater Treatment and Environmental Pollution Control, 1-2 October 2010 in UCD. It was published in the proceedings.

The operation of hybrid reed bed and willow bed combinations in Ireland- Zero Discharge and the potential for no monitoring of domestic applications of this combination.

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Abstract
This paper will briefly trace the development of reed beds, the treatment mechanisms involved and the evolution of the more popular designs, with emphasis on the hybrid reed bed. It will also present a review of the concept of using willow beds to deal with waste water. It will examine the Danish guidelines. It will also review the application of willows to treat effluent from a hybrid reed bed system and the evolution of this system in England and Wales. The theory of willow bed treatment will also be discussed with particular emphasis on the factors that effect evapotranspiration. Two alternative designs for a willow soakaway will also be presented. The concept of a reed willow bed combination to treat municipal and domestic wastewater has been tested by the School Civil and Building Services Department of Dublin Institute of Technology, for the past number of years. Two sites have been tested in this eight year period, with promising results in the first. Based on this design a second installation was commissioned. This paper will present a case study of the first hybrid reed bed and willow bed system installed in Colecott, Co. Dublin, under the auspices of Fingal Co. Council. It will present design criteria. A brief discussion of the two year monitoring programme will be presented. The case study will also include a critique of the system and its operation. The paper will then describe the second reed and willow bed installation at Lynche's Lane, Co. Dublin under the auspices of South Dublin Co. Council. The results of the two year study to monitor the performance of the reed willow bed facility at Lynches Lane, Co. Dublin, Ireland, will be presented. The zero discharge achieved over the 24 month period will be reviewed. The application of this system to the Irish situation will be discussed. The Danish experience with the production of their Willow guidelines and the need for no monitoring will be compared with the position Ireland now finds itself in as a result of the recent EU judgment
Key Words: reed beds**,** willow beds, combinations, zero discharge, guidelines.

Introduction.

A recent European Court of Justice (EU, 2009) ruling found that Irelands legislation, with regards to wastewater treatment site systems, does not comply with Articles 4 and 8 of the Waste Directive (75/442/EEC). The commission stated that the current legislation governing the construction and siting of septic tanks is not suited to the geological and soil characteristics generally found in Ireland. The Irish Government in response to the court judgement announced its intention to draft legislation to introduce a licensing and inspection system for existing septic tank systems (Cussen, 2009). It is against this background that the results of this study are presented. The development of an appropriate zero discharge wastewater facility has the potential to address the source of individual wastewater treatment systems (IWTS) pollution in Ireland.

Background

Reed beds.

Reed beds have been used for the last 50 years to treat wastewater, in Europe (Vymazal,2006). They are essentially a lined structure filled with a media, of gravel and/or sand, with reeds planted in the upper zone. The influent is passed through the beds either horizontally or vertically. Design has evolved on horizontal reed beds through vertical beds to hybrid beds and latterly compact vertical flow beds (Weedon, 2006). Treatment is by a combination of sedimentation, filtration, aerobic/anaerobic degradation, ammonification, nitrification/ dentrification, plant uptake, matrix adsorption etc (Brix,1993). Initial designs were predominantly horizontal and the process was referred to as the root zone system. The media used was soil with a hydraulic conductivity in the range of 10^{-4} m sec^{-1}. This design criteria proved problematic resulting in clogging, and the eventual adoption of gravel/washed sand as a medium (Cooper et al., 1996). This revision led to the large scale use of reed beds to treat wastewater, and other wastes, throughout Europe and saw the European Guidlines published (Cooper, 1990). In developing reed beds, the emphasis was on the reduction of treatment area while increasing treatment efficiency. Pioneering work by Kathe Seidel in the 1950's had involved the use of vertical beds, where the influent passed vertically through the media, rather than the horizontal movement through the horizontal beds (Seidel, 1976). The efficiency of vertical beds over horizontal beds in treating wastewater has seen their use increase, especially over the last ten years. A further development is the hybrid design. This is a system where vertical and horizontal beds are combined, such that the influent is passed sequentially through primary and secondary beds and then a horizontal bed (Burka and Lawrence,1990). These systems were accompanied by a pond, in some cases. The latest development in reed bed design is the compact vertical reed bed. This is a single bed with a media of sand only, thus reducing maintenance by avoiding the requirement for bed rotation, which is necessary with conventional vertical beds. In Ireland municipal wastewater has been treated by horizontal reed beds, and hybrid reed beds. Treatment efficiency has been reported as good, with horizontal beds treating the discharge from various types of package plants, and hybrid beds treating municipal wastewater (O'Hogain,2001).

Willow beds.

Denmark was the first country to experiment with willow treatment systems (Ministry of Environment, 2003a and b). Major research began there with the introduction of their action Plan 1 in 1987. Awareness of, and action to ameliorate the negative implications of phosphorus discharge to the environment were the drivers of these investigations. As a result the Danish Ministry of Environment and Energy developed guidelines for treatment systems for population equivalents of up to 30. Two sets of guidelines were produced for willow cleaning facilities:

1. Describes a willow system using a membrane liner, which results in zero discharge.
2. Describes a willow system without a membrane liner with allows some soil infiltration. This system is intended for adoption in areas of clay soil, where infiltration is low. This system also results in a zero discharge.

These guidelines and the studies which led to them aroused interest in other countries. Though the sizing was large, of the order of $30m^2$ per population equivalent (pe), and the structure was a modified vertical reed bed in terms of media and distribution, the zero discharge was of great interest to researchers. As a result Willow soakaway's were installed in various parts of the UK. These consisted of two distinct methods of construction and operation. The first type of design operated by dividing the planted willow area to receive the wastewater, into two or three smaller areas. These relatively flat areas received the treated wastewater in succession. Every month to six weeks a new section is placed on line and the previously saturated section rested for 2 months. The rotation is effected by moving pipework. This rotation of the areas, giving rise to the alternation between saturation and rest, offsets any binding of the soil which would restrict the permeation of the liquid. A second method of distribution consisted of a channel which meanders through the planted area, allowing the water to percolate through the banks of the channel and into the soil. A fall in the channel of 1:300 is required, and so this design is more appropriate to sloping sites.

The traditional varieties of willow were used, *Salix triandra*, *S. purpurea* and *S. viminalis*.. Trees were grown from seedlings about 20 cm long, and it was recommended that care must be taken so that they get established without too much competition, for the first two years. Common to both designs was the recommendation that the willows be free from weed competition in the first year. Willows exhibit a higher rate of evapo-transpiration than the value expected from calculations using evapo-transpiration parameters. This was established to be due to the crop evapo-transpiration parameter, Et_c. This was normally calculated using a crop efficiency of 1. However for the sizing of willow wastewater systems a value of 2.5 was found to be more appropriate. This was due to a range of factors among them crop height, Albedo (reflectance) of the crop-soil surface and Canopy resistance. Other contributing factors are the "Clothesline" and "Oasis" effect. Therefore the ability of a willow bed soakaway to evapotranspire a body of wastewater is of a higher order than previously accepted prior to this Danish work.

Reed bed and Willow bed Combinations.
Centre for Alternative Technology(CAT) in Machynlleth, Wales.

One of the first practical applications of the reed bed and willow bed combination was at the Centre for Alternative Technology in Machynlleth, Wales. CAT has no connection to mains sewerage and have to treat their wastewater independently. As part of their function as an education centre they employ a mixture of treatment systems to demonstrate alternatives. A multi-stage system was put in place. A solids liquid separation occurs in the settlement tank, then the wastewater is passed for treatment through a hybrid reed bed system, a small pond, and finally, polishing and disposal in a willow bed/coppice. The sewage is finally discharged to the river Dulas**.** The system is powered by gravity. Settled sewage sludge is composted together with straw and soiled paper-towels and then used on site. The System was sized at 2 m^2 per pe for the vertical reed beds, 1 m^3 for the horizontal beds and 3 m^3 for the willow bed. Detailed results are not available but the system complied with all water quality discharge standards.

Case Study 1: Colecott Reed and Willow Bed facility, Co. Dublin Ireland.
The first Irish municipal application of a hybrid reed bed treatment system (RBTS) was designed and constructed at Colecott, County Dublin in the administrative area of Fingal County Council. The catchment area consisted of 10 county council cottages and four mobile homes with a population of 48 and the existing wastewater treatment plant was a septic tank and a percolation area. The hybrid design RBTS was based on modifications to the Max Planck Institute Process (MPIP) (Seidel et al., 1978; Burka and Lawrence, 1990). The constituent parts of the design were a septic tank, a pump sump, two stage vertical flow beds, a secondary settlement tank, a horizontal reed bed and an outlet chamber and outfall pipe to a nearby stream. The population equivalent was taken as 60, allowing future population development of 25%. Design figures, sizing etc. were largely based on the European Guidelines (Cooper, 1990). Previous studies focused on the construction, maintenance and performance of the beds. These studies showed satisfactory secondary treatment (O'Hogain and Gray,2002; O'Hogain,2003). However, nitrate and phosphate levels in the effluent were unsatisfactory. To upgrade the level of treatment supplied consideration was given to discharging the effluent to a willow bed (Grant et al, 2000). The design area chosen for Colecott was 1.5 m^{-2} pe^{-1}. This was based on varying recommendations of 1 and 2 m^{-2} pe^{-1}, and was chosen as a median figure (Grant et al, 1996). The population equivalent was taken as 60, resulting in an area of $90m^2$. A series of 17 trenches were dug, with a dividing trench to create separate areas to facilitate rotation of the inflow feeder pipe.

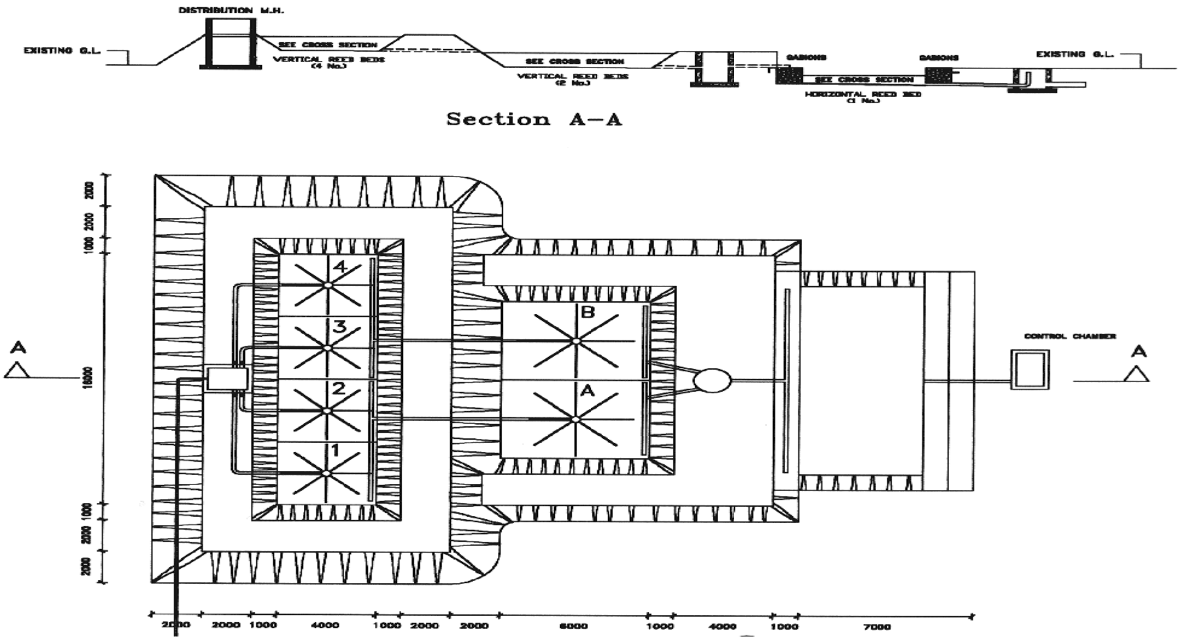

Fig.1. Colecott Hybrid Reed Bed System.

Two species of willow, *Salix triandra*, and *S. viminalis* were planted at approximately a half meter apart, and this lead to the planting of 360 willow plants, each approximately a half meter high. An outflow pipe was placed in each end trench. Seven parameters were monitored ammonia (N-NH_3), nitrate (N-NO_3), orthophosphate (PO_4^{3-}-P), pH, biochemical oxygen demand (BOD), chemical oxygen demand (COD) and suspended solids (SS). All were analysed in the laboratory, using APHA 1995 standard methods (APHA, 1995).

Results.

Hydraulic Loading.

The dry weather flow averaged over the monitoring period was 6.839 m^3 d^{-1}. The incidence of storm events was quite pronounced. The rainfall exceeded 10 mms d^{-1} on five occasions, resulting in daily flows of between 10.6 and 14.6 m^3 d^{-1}. It exceeded 20 mms d^{-1} on three separate occasions resulting in daily flows of between 16.15 to 143.37 m^3 d^{-1}. The latter event occurred with recorded daily rainfall of 74.6 mms. The inputs to the RBTS show all the characteristics of small sewage schemes (Metcalf and Eddy, 1991). The pumping volumes were erratic even during DWF. Little infiltration is a trend shown for pumping volumes and storm events.

Overall Reed Bed and Willow bed Performance.

The performance of Colecott Reed and Willow Bed Sewage Treatment system showed very high performance rates for certain parameters, e.g. Chemical Oxygen Demand, 95% removal, Biochemical Oxygen Demand, 92% removal, Suspended Solids, 100% removal and Ammonia 65 % removal. However optimum performance was not reached with regard to Nitrates and Phosphates. The installation of the willow bed at Colecott RBTS lead to Zero discharge from the system, for most of its first year of operation. Over the two year sampling period of the 24 sampling days 10 sampling days say no outflow from the willow bed. A significant contribution to the treatment of the final effluent, where effluent was discharged from the willow system, resulted from passage through the willow bed. Willow bed treatment saw 6% COD removal, 71% BOD removal, 22% ammonia removal and 20% nitrate removal. SS solids were not present in inflow or outflow.

However it was the entrance of surface water volumes, far in excess of design volumes, that resulted in effluent discharges from the willow bed.

Parameter	Influent		mg l-1			PWB		mg l-1			Percentage Reed Bed & Willows	Reduction	overall
	Mean	S.D.	Median	Min	Max	Mean	S.D.	Median	Min	Max	Mean	S.D.	Median
COD	704	240	683	73	1255	40	31	29	0	123	95	10	98
BOD_5	492	259	420	55	1240	16	19	8	0	90	92	10	95
SS	109	58	103	24	268	0	0	0	0	0	99	6	100
NH_4-N	51	21	55	4	88	7	9	3	0	28	61	82	86
NO_3	2	6	0.1	0	31	11	8	9	2	35	-26	253	43
PO_4	31	14	30	3	40	21	11	19	6	50	-111	670	44
pH	7.3	0.3	7.28	6.7	7.95	7.36	0.33	7.42	6.4	8.17			

Table 1. Experimental results for overall Reed Bed and Willow Bed performance at Colecott RBTS for the period September 2003 to August 2005.

Recommendations

The exclusion of surface water from all reed beds is an important design principle, not often explicit in the literature. It was found to be similar in the case of willow beds.

Case Study 2: Lynches Lane Hybrid reed and willow bed facility, Co. Dublin, Ireland.

Facility Design & Installation

This hybrid reed and willow bed sewage treatment (HWTS) system currently services the Parks department depot at Grange, Lucan, Co. Dublin. The initial system was commissioned in 2002. It was designed for a population equivalent of 15. This resulted in a design flow of 3.0 m^3 day^{-1}. Presently, three sites are served by the system, a local authority depot, a private house and a travellers halting site. A willow bed tertiary filter system was installed in 2008. Fig 2 shows a plan of the facility. Fig 3 shows a cross section through the site. The wastewater flows by gravity to a septic tank. From here it overflows to a pump sump, where it is pumped to the HWTS. The wastewater flows by gravity through the system. The vertical beds were sized at $2m^2$ pe^{-1}, to achieve BOD removal and complete nitrification on two vertical stages (Cooper, 1999). The beds were lined with a high-density polyethylene liner. An overall depth of media of 0.6m comprised the two bottom layers of 15 cm each, 20cm of 6mm diameter washed pea-gravel and 10cm sharp sand layer. The sand was selected using the Grant method, with a test value of 45 seconds (Cooper et al, 1996).

Fig 2 Lynche’s lane hybrid reed and willow bed facility.

Fig 3 Longitudinal section through site at Lynche’s Lane.

Monitoring Regime

The reed bed was monitored for two years. Samples were taken aseptically at four points within the system and transported to the laboratory within 4 hours and stored between 2-8ºC in accordance with ISO / IEC 17025:2005 (ISO 17025, 2005). The physico-chemical analysis tested for nitrate, ammonia, kjedahl, pH, total suspended solids(TSS), orthophosphate, chemical oxygen demand (COD) and biochemical oxygen demand (BOD). Samples for microbiological analysis were taken in sterile bottles to ensure no cross- contamination. They were analysed for the time dependent parameters, Coliforms and *E. Coli*. All analysis of water quality parameters was carried out in a Irish National Accreditation Body (INAB) accredited laboratory as per Standard Methods (AWWA, 2005).

Results

Flows

Inflows were recorded daily, weekly and monthly. The average hydraulic loading rate was 4.7 m^3/d. The average combined p.e. was 22.

Reed Bed Performance
Table 2 presents a summary of the monitoring results for the 24 month period.

	Influent (Sewage)					Horizontal Flow reed Bed (Effluent)					Percentage Removal		
Parameter	Mean	S.D.	Median	Min	Max	Mean	S.D.	Median	Min	Max	Mean	S.D.	Median
NH_4 (mg l^{-1})	45	40	28	3	144	13	12	12	0	41	71	71	56
KJN as N (mg l^{-1})	44	31	35	4	117	13	12	11	0	45	70	71	69
NO_3 (mg l^{-1})	5	10	1	0	40	34	47	4	0	19	-586	-353	-418
PO_4 (mg l^{-1})	4	4	2	0	14	2	1	2	1	6	45	73	17
Coliforms (MPN/100ml)	2389261	4808118	1198000	1	24196000	133685	402744	10462	31	1986300	94	92	99
E.coli (MPN/100ml)	711074	1459254	233300	1	7270000	40572	121023	1710	10	579400	94	92	99
COD (mg l^{-1})	289	206	327	33	890	37	26	32	0	105	87	88	90
BOD_5 (mg l^{-1})	129	99	136	4	316	11	15	4	1	58	91	85	97
TSS (mg l^{-1})	101	117	60	17	524	15	22	9	1	96	85	81	85
pH	8	1	8	7	12	7	0	7	7	8	-	-	-

Table 2. Overall Treatment Performance at Lynche's Lane Hybrid Bed System for the two year monitoring period February 2008 to March 2010.

Discussion of Results
The overall results of the 24 month monitoring regime are shown in Table 2. The variability of influent, characteristic of small schemes, is evident (Metcalf and Eddy, 2002). Removal values for COD and BOD were comparable with results achieved at other hybrid systems built in Ireland (O'Hogain, 2003). Suspended solids removal was slightly lower, at 85 %. Coliform and *E.coli* removal rates were also marked at 94% respectively. Nitrate and phosphate removal rates were as unsatisfactory as reported in previous studies (O'Hogain, 2004). The effluent was marginally in breach of guidelines (2000/60/EC, 2000).

Willow Bed Performance.
No outflow was observed from the willow bed during the monitoring period. There were frequent periods when the willow bed was dry throughout. This left three possible pathways for the effluent. These were, passage through the soil, absorption to the roots and evapotranspiration of the wastewater, and/or evaporation in the open trenches due to climatic factors such as wind and sunlight. To eliminate percolation through the soil a series of soil tests were performed. The average permeability of the samples was 2.3×10^{-7} m/sec. From this we may conclude that the wastewater is being removed primarily by evapo-transpiration effects.

CONCLUSIONS
During the two year monitoring period the Reed bed willow bed system at Lynche's Lane Co. Dublin achieved zero discharge. This was achieved using a design figure of $2m^2$ per p.e. for the vertical beds, $1m^2$ per p.e. for the horizontal bed and $3m^2$ per p.e. for the willow bed.

RECOMMENDATIONS
The installation of the willow bed at Colecott RBTS lead to zero discharge from the system, for most of its first year of operation. The combination of a reed bed and a willow bed facility installed and monitored in Lynches Lane, has resulted in a zero discharge over the two year study period. Studies are ongoing within the Dublin Institute of Technology into developing applications for reed willow bed combinations for new build and retro fit individual wastewater treatment systems (IWTS). The Danish EPA has

produced guidelines for a number of small-scale onsite treatment solutions for use in rural areas. If the guidelines are followed no monitoring of the systems are required (Brix, 2004). Correct sizing of the willow systems specific to the Irish climate and soil conditions is critical to performance and adaptability. Based on DIT's pilot projects direct application of the Danish guidelines to Ireland is not appropriate. There is a need to develop guidelines within the Irish context, based on a comprehensive list of evaluation criteria to provide decision makers with a complete overview of the existing aspects of reed willow bed combination systems. The development of an appropriate zero discharge wastewater facility has the potential to address the source of IWTS pollution in Ireland.

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A review of zero discharge wastewater treatment systems using reed willow bed combinations in Ireland

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Abstract
The concept of a reed willow bed combination has the potential to achieve a zero discharge wastewater treatment system. This paper will present results from a two year study to monitor the performance of a reed willow bed facility at Lynches Lane, Co. Dublin, Ireland. Outline design specifications for the facility will be presented. Monitoring results for a two year period including influent and effluent parameters, rainfall, potential evapotranspiration, and soil classification will be presented and discussed. During the two year monitoring period the system achieved a zero discharge. This paper will discuss the potential widespread application of similar systems in Ireland. This is in the context of a recent EU judgment which declared that Ireland has failed to fulfill its obligations regarding domestic wastewaters disposed of through individual waste water treatment systems. The development of an appropriate zero discharge wastewater facility has the potential to address this source of environmental pollution in Ireland. This paper will discuss the sizing and operation of such systems specific to the climate and soil conditions based on current knowledge and experience. Areas for further studies will be discussed.

Keywords: reed beds**,** willow beds, combinations, zero discharge, evapotranspiration

INTRODUCTION

The typography of settlement in Ireland consists of numerous isolated dwellings, not connected to collective sewage treatment systems. According to EU accepted figures there are about 400,000 septic tanks in Ireland (DELG/EPA/GSI, 2010). Bylaws relating to monitoring and inspection of these facilities currently apply in one local authority (Cavan County Council, 2004). The discharge of poorly treated sewage is responsible for many watercourses not presently meeting their quality objectives. A recent EU judgment ruled that Ireland "has failed to fulfill its obligations as regards domestic wastewaters disposed of in the countryside through septic tanks and other individual wastewater treatment systems" (EU, 2009). It is against this background that the results from a two year monitoring programme of a hybrid reed bed system discharging to a willow bed facility are presented and discussed. This facility has resulted in a zero discharge over the two year study period. The importance of appropriate guidelines to the design and operation of such systems specific to the Irish climate and soil conditions will be discussed based on current knowledge and experience. Preliminary findings and areas for further study will be discussed.

REED BEDS

Reed beds have been used for the last 50 years to treat wastewater, in Europe (Vymazal, 2005). The design has evolved from horizontal reed beds through vertical beds to hybrid beds, and latterly compact vertical flow beds (Weedon, 2003). The principle mode of treatment is a combination of sedimentation, filtration, aerobic/anaerobic degradation, ammonification, nitrification/dentrification, plant uptake and matrix adsorption (Brix, 1993). The efficiency of vertical beds over horizontal beds in treating wastewater has seen their use increase, especially over the last ten years. In Ireland municipal wastewater has been treated by horizontal reed beds, and hybrid reed beds. Treatment efficiency has been reported as satisfactory, with horizontal beds treating the discharge from various types of package plants, and hybrid beds treating municipal wastewater (O'Hogain, 2001). The latter applications have not achieved the values reported for hybrids with recirculation of effluent. This is particularly the case with regard to the nutrients nitrate and phosphate. In an effort to achieve low cost and sustainable nutrient removal, the addition of willow beds to the hybrid system was conceived.

Guidelines

The design of constructed wetlands in Ireland is governed by the EPA Code of Practice (EPA, 2009). Table 1 summarises the criteria set out in these guidelines.

Table 1 Criteria for constructed wetland systems receiving septic tank effluent (EPA, 2009)

System Type	Area Required	Minimum System Size	Loading Rates	Length / Width Ration
Horizontal flow reed bed – gravel (SFS)	5 m^2/p.e.	25m^2	-	3:1
Vertical flow reed bed – gravel (SFS)	1.5-3 m^2/p.e.	15m^3	8l/m^2 per dose (maximum)	2.5:1
Vertical flow reed bed – sand (SFS)	5-6m^2/p.e.	15m^2	5-15 l/m^2 per dose for 2-5 doses per day	2.5:1
Soil based constructed wetland (FWS)	20 m^2/p.e.	100m^2	-	5:1

WILLOW BEDS

Denmark was one of the first countries in Europe to conduct research into willow wastewater treatment systems. The Danish research prompted pilot studies in other countries. Willow soakaway's were installed in various parts of the UK (Living Water Ltd, 2010). These consisted of two distinct methods of construction and operation. The first type operated by dividing the planted willow area into smaller treatment sections, with each section dosed in succession. Every month to six weeks a new section is placed on line and the previously saturated section rested for 2 months. A second method of distribution consisted of a channel which meanders through the planted area, allowing the water to percolate through the banks of the channel and into the soil. The traditional varieties of willow used were *Salix triandra*, *S. purpurea* and *S. viminalis* (Grant et al., 1996). Other studies have investigated the application of willow vegetation filters for the production of renewable energy in the form of biomass. Currently there are five municipalities in Sweden utilizing willow vegetation filters as a complement to conventional wastewater treatment methods (Hasselgren, 1998).

Characteristics of Willow Wastewater Treatment Systems

The purification efficiency of willow treatment systems has been demonstrated in several countries (Borjesson, 2006), (Perttu, 1999). Performance of systems has varied depending on site specific conditions, influent, design and operational and maintenance regimes. Some general performance characteristics of properly designed willow treatment systems can be defined as follows (Brix, 2006)

- All wastewater is evaporated to the atmosphere on an annual basis.
- Nutrients and heavy metals are removed by harvesting the willows (or accumulate in the bed).
- Sizing of beds is determined by the difference between precipitation and evapotranspiration.

Sizing Requirements

Under Danish conditions, evapotranspiration of willow systems has been reported as of the order of 1500mm/yr (Brix, 2006). Evapotranspiration rates can be calculated using the equation $ET_c=ET_0k_c$. ET_0 refers to the evapotranspiration from a reference surface and is a climatic parameter expressing the evaporation power of the atmosphere and can be determined from meteorological data for a given site. ET_c is the evapotranspiration from a specific, disease free, well fertilised crop, grown in a large field, under optimum soil and water conditions and achieving full production under the given climatic conditions . ET_c can also represent the maximum amount of wastewater that can be applied to the system. The ratio between crop evapotranspiration and reference evapotranspiration is called k_c. This parameter depends on many criteria including crop height, reflectance of the crop soil, canopy resistance, evaporation from the soil etc. Other contributing factors include the clothesline and oasis effects. The layouts of willow systems tend to be long narrow beds located perpendicular to the prevailing wind direction. The clothesline effect happens where, turbulent transport of sensible heat into the canopy, and transport of vapour away from the canopy, is increased by the broad siding of wind horizontally into the taller vegetation. The oasis effect is characterised by areas where vegetation has higher soil water availability than the surroundings. Hot dry air flows across and creates rapid evaporation using sensible heat from the air. The effect of the clothesline and oasis effects combined, is to increase the value of k_c for willow plantations.

Guidelines

The Danish Ministry of Environment and Energy developed two sets of guidelines for treatment systems for population equivalents of up to 30 as follows;

7. Describes a willow system using a membrane liner, which results in zero discharge (Ministery of Environment and Energy, 2003a).
8. Describes a willow system without a membrane liner with allows some soil infiltration. This system is intended for adoption in areas of clay soil, where infiltration is low (Ministery of Environment and Energy, 2003b)

There are currently no Irish guidelines for the design of willow wastewater treatment systems.

REED AND WILLOW BED COMBINATIONS

Colecott Reed and Willow Bed facility, Co. Dublin Ireland

Colecott was one of the first the hybrid reed bed systems to treat municipal wastewater in Ireland (O'Hogain, 2003). The facility was fitted with a willow bed tertiary treatment in 2002. The performance of the Colecott system showed very high removal rates for certain parameters, e.g. Chemical Oxygen Demand (COD), 95%, Biochemical Oxygen Demand (BOD), 92%, Suspended Solids (SS), 100% and ammonia 65 % removal. Willow bed treatment (O'Hogain, 2004) saw a further 6% COD removal, 71% BOD removal, 22% ammonia removal and 20% nitrate removal. SS were not present in inflow or outflow to the willow bed. Over 24 months of monitoring the willow bed saw zero discharge for 12 of these months. Failure of the system to achieve zero discharge over the entire monitoring period was attributed to infiltration of surface water to the sewage system through redirected household surface water connections.

CASE STUDY: LYNCHES LANE HYBRID REED AND WILLOW BED FACILITY, CO. DUBLIN, IRELAND

Facility Design & Installation

This hybrid reed and willow bed sewage treatment (HWTS) system currently services the Parks department depot at Grange, Lucan, Co. Dublin. The initial system was commissioned in 2002. It was designed for a population equivalent of 15. This resulted in a design flow of 3.0 m^3 day^{-1} . Three sites are served by the system, a local authority depot, a private house and a travellers halting site. A willow bed tertiary filter system was installed in 2008. Fig 1 shows a plan of the facility. Fig 2 shows a cross section through the site. The wastewater flows by gravity to a septic tank. From here it overflows to a pump sump, where it is pumped to the HWTS. The wastewater flows by gravity through the system.

The vertical beds were sized at $2m^2$ pe^{-1}, to achieve BOD removal and complete nitrification on two vertical stages (Cooper, 1999). The beds were lined with a high-density polyethylene liner. An overall depth of media of 0.6m comprised the two bottom layers of 15 cm each, 20cm of 6mm diameter washed pea-gravel and 10cm sharp sand layer. The sand was selected using the Grant method, with a test value of 45 seconds (Cooper et al, 1996).

Monitoring Regime

The reed bed was monitored for two years. Samples were taken aseptically at four points within the system and transported to the laboratory within 4 hours and stored between 2-8ºC in accordance with ISO / IEC 17025:2005 (ISO 17025, 2005). The physico-chemical analysis tested for nitrate, ammonia, kjedahl, pH, total suspended solids(TSS), orthophosphate, chemical oxygen demand (COD) and biochemical oxygen demand (BOD). Samples for microbiological analysis were taken in sterile bottles to ensure no cross- contamination. They were analysed for the time dependent parameters, Coliforms and *E. Coli*. All analysis of water quality parameters was carried out in a Irish National Accreditation Body (INAB) accredited laboratory as per Standard Methods (AWWA, 2005).

Results

Flows

Inflows were recorded daily, weekly and monthly. The average hydraulic loading rate was 4.7 m^3/d. The average combined p.e. was 22.

Fig 1 Lynches lane hybrid reed and willow bed facility

Fig 2 Longitudinal section through site at Lynches Lane

Rainfall and Potential Evapotranspiration

Meteorological data was taken from the Irish Meteorological Service data monitoring station located approximately 3 km from the site. Fig 3 shows the monthly rainfall totals (mm) and potential evapotranspiration (mm) for the period February 2008 to February 2010 inclusive. Total rainfall for 2008 and 2009 was 930mm and 936mm respectively. Average monthly rainfall over this period was 76.8mm. Potential evapotranspiration increased during the months May – August with the minimum value recorded during December.

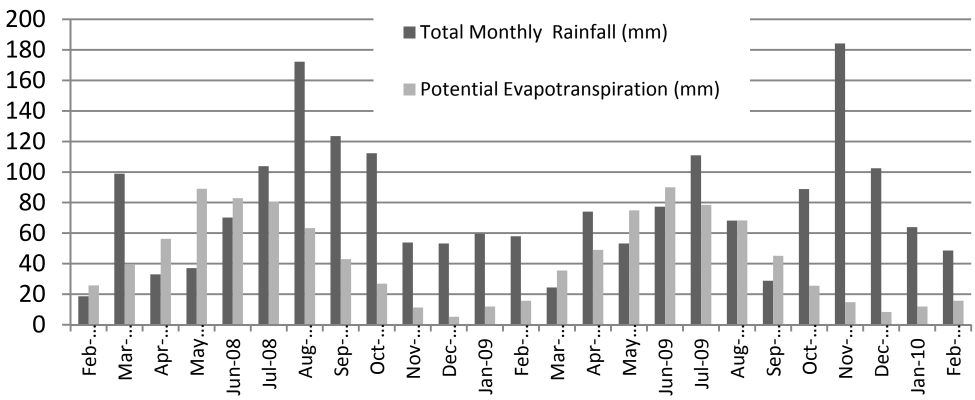

Fig 3 Total Rainfall over monitoring period

Soil Classification

Soil samples were taken at representative intervals throughout the site. Results of the laboratory experiments indicated a uniform soil type with a moisture content of 20%, Plasticity Index 10%, Organic Content 4.5%. The soil was classified as a very stiff, homogenous clay. Soil conditions were consistent throughout the site to depths of 1.2m. Permeability of the subsoil within the willow bed was determined by taking twelve undisturbed soil samples. The falling head test was used to determine the permeability coefficient of each sample. The average permeability of the samples was 2.3×10^{-7} m/sec.

Biomass Audit

A total of 180 willow cuttings were planted in February 2008. Three willow varieties were planted namely *Salix triandra, S. purpurea* and *S. Viminalis.* In Winter 2009 a biomass audit was carried out. Plant loss averaged 40%. The successful willows were planted in the beds adjacent to the inflow. The biomass audit determined the average plant height to be 1.9m with a range of 1m to 3.1m. Stem thickness ranged from 6mm to 24mm with an average thickness of 14mm.

Wastewater Treatment Plant Performance
Table 2 presents a summary of the monitoring results for the 24 month period.

	Influent (Sewage)					**Horizontal Flow reed Bed (Effluent)**					**Percentage Removal**		
Parameter	**Mean**	**S.D.**	**Median**	**Min**	**Max**	**Mean**	**S.D.**	**Median**	**Min**	**Max**	**Mean**	**S.D.**	**Median**
NH_4 (mg l^{-1})	45	40	28	3	144	13	12	12	0	41	71	71	56
KJN as N (mg l^{-1})	44	31	35	4	117	13	12	11	0	45	70	71	69
NO_3 (mg l^{-1})	5	10	1	0	40	34	47	4	0	19	-586	-353	-418
PO_4 (mg l^{-1})	4	4	2	0	14	2	1	2	1	6	45	73	17
Coliforms (MPN/100ml)	2389261	4808118	1198000	1	24196000	133685	402744	10462	31	1986300	94	92	99
E.coli (MPN/100ml)	711074	1459254	233300	1	7270000	40572	121023	1710	10	579400	94	92	99
COD (mg l^{-1})	289	206	327	33	890	37	26	32	0	105	87	88	90
BOD_5 (mg l^{-1})	129	99	136	4	316	11	15	4	1	58	91	85	97
TSS (mg l^{-1})	101	117	60	17	524	15	22	9	1	96	85	81	85
pH	8	1	8	7	12	7	0	7	7	8	-	-	-

Table 2 Overall Treatment Performance.

DISCUSSION OF RESULTS

Reed Bed Performance
The overall results of the 24 month monitoring regime are shown in Table 2. The variability of influent, characteristic of small schemes, is evident (Metcalf and Eddy, 2002). Removal values for COD and BOD were comparable with results achieved at other hybrid systems built in Ireland (O'Hogain, 2003). Suspended solids removal was slightly lower, at 85 %. Coliform and *E.coli* removal rates were also marked at 94% respectively. Nitrate and phosphate removal rates were as unsatisfactory as reported in previous studies (O'Hogain, 2004). The effluent was marginally in breach of guidelines (2000/60/EC, 2000).

Willow Bed Performance.
No outflow was observed from the willow bed during the monitoring period. There were frequent periods when the willow bed was dry throughout. This left three possible pathways for the effluent. These were, passage through the soil, absorption to the roots and evapotranspiration of the wastewater, and or evaporation in the open trenches due to climatic factors such as wind and sunlight. To eliminate percolation through the soil a series of soil tests were performed. The average permeability of the samples was 2.3×10^{-7} m/sec. From this we may conclude that the wastewater is being removed primarily by evapo-transpiration effects.

CONCLUSIONS

During the two year monitoring period the Reed bed willow bed system at Lynche's Lane Co. Dublin achieved a zero discharge. This was achieved using a design figure of $2m^2$ per p.e. for the vertical beds, $1m^2$ per p.e. for the horizontal bed and $3m^2$ per p.e. for the willow bed.

INDIVIDUAL WASTEWATER TREATMENT SYSTEMS (IWTS) IN IRELAND

The typography of settlement in Ireland consists of numerous isolated dwellings, not connected to collective sewage treatment systems. Onsite individual wastewater treatment systems (IWTS) are the primary method used for the treatment and disposal of domestic wastewater from these dwellings. A conventional IWTS typically consists of pretreatment within either a septic tank or some form of mechanical aeration system, followed by filtration through a soil percolation area. The suitability of a site for the development of IWTS is assessed using the methodology outlined within the EPA 2009 Code of Practice (EPA, 2009). These guidelines are aimed at defining subsoil conditions that will provide an acceptable level of treatment for wastewater effluent. The methodology includes a desk study and on site assessment including visual inspection, trial hole test and percolation tests. A percolation test is required to determine the assimilation capacity of the subsoil. The guidelines specify a minimum unsaturated subsoil depth of 1.2 m below the invert of the septic tank percolation trenches and a maximum high groundwater level of at least 1.5m below original ground surface, before the site may be deemed suitable for on-site treatment of domestic wastewater effluent. Many IWTS continue to be sited in areas not geologically suited to such systems. Flooding risks due to global warming effects have altered the risk assessment of many existing septic tank sites. A recent European Court of Justice (EU, 2009) ruling found that Irelands legislation, as regards on site systems, does not comply with Articles 4 and 8 of the Waste Directive (75/442/EEC). The commission in its judgment, specifically listed design and operational areas such as, incorrect construction, unsuitable siting, insufficient capacities, maintenance and inspection together with the inactivity of competent administrative authorities. The commission stated that the current legislation governing the construction and siting of septic tanks is not suited to the geological and soil characteristics generally found in Ireland. The Irish Government in response to the court judgement announced its intention to draft legislation to introduce a licensing and inspection system for existing septic tank systems (Cussen, 2009).

RECOMMENDATIONS

It is against this background that the results of this study are presented. The development of an appropriate zero discharge wastewater facility has the potential to address the source of IWTS pollution in Ireland. The combination of a reed bed and a willow bed facility installed and monitored in Lynches Lane, has resulted in a zero discharge over the two year study period. Studies are ongoing within the Dublin Institute of Technology into developing applications for reed willow bed combinations for new build and retro fit IWTS systems. The Danish EPA has produced guidelines for a number of small-scale onsite treatment solutions for use in rural areas. If the guidelines are followed no monitoring of the systems are required (Brix, 2004). Correct sizing of the willow systems specific to the irish climate and soil conditions is critical to performance and adaptability. Based on DIT's pilot projects direct application of the Danish guidelines to Ireland is not appropriate. There is a need to develop guidelines within the Irish context, based on a comprehensive list of evaluation criteria to provide decision makers with a complete overview of the existing aspects of reed willow bed combination systems.

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