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A Review of Zero Discharge Wastewater Treatment Systems Using Reed Willow Bed Combinations in Ireland

Sean O'hOgain
Technological University Dublin, Sean.Ohogain@tudublin.ie

Liam McCarton
Technological University Dublin, liam.mccarton@tudublin.ie

Anna Reid
Technological University Dublin

See next page for additional authors

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Authors
Sean O'hOgain, Liam McCarton, Anna Reid, and John Turner

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

S. O'Hogain, L. McCarton, A. Reid and J. Turner.

Development Technology in the Community Research Group, School of Civil & Building Service Engineering, Dublin Institute of Technology, Bolton Street, Dublin 1, Ireland

(E-mail: sean.ohogain@dit.ie ; liam.mccarton@dit.ie)

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;

(i) Describes a willow system using a membrane liner, which results in zero discharge (Ministery of Environment and Energy, 2003a).

(ii) 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.

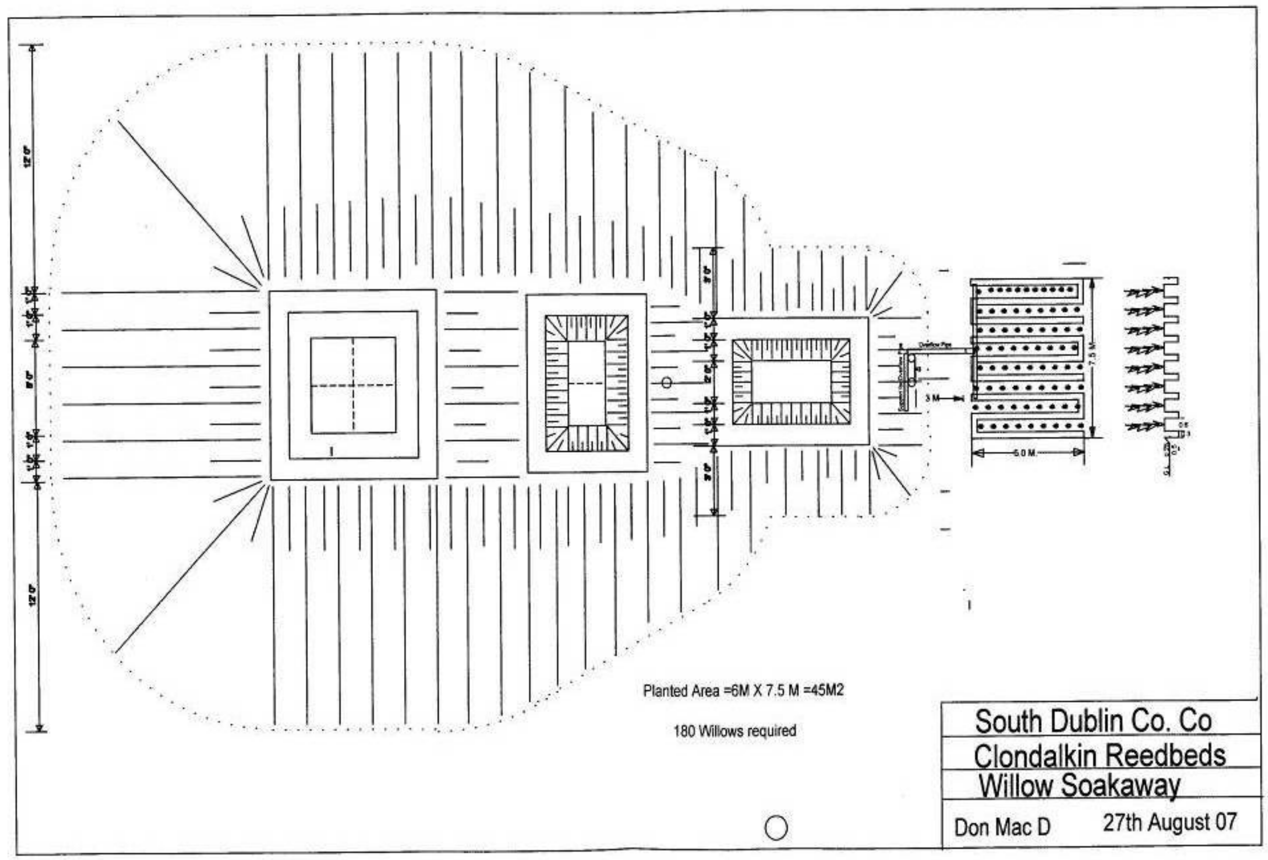

Fig 1 Lynches lane hybrid reed and willow bed facility

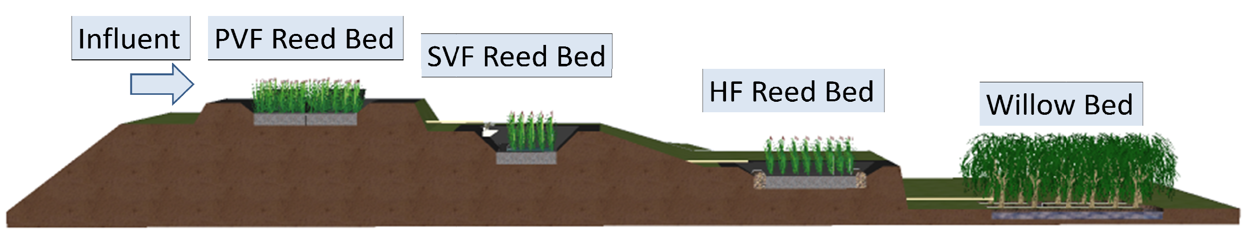

Fig 2 Longitudinal section through site at Lynches Lane

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.

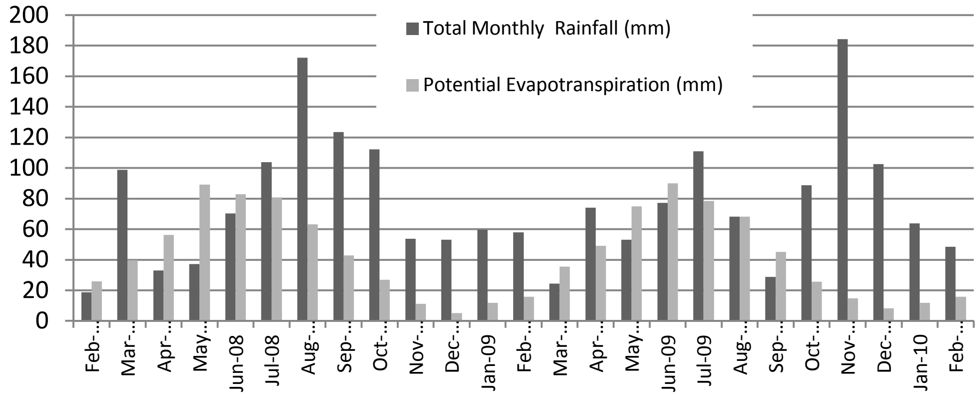

Fig 3 Total Rainfall over monitoring period

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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