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# 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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# 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 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 from 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 vertical 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 which 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 RBTS design 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.

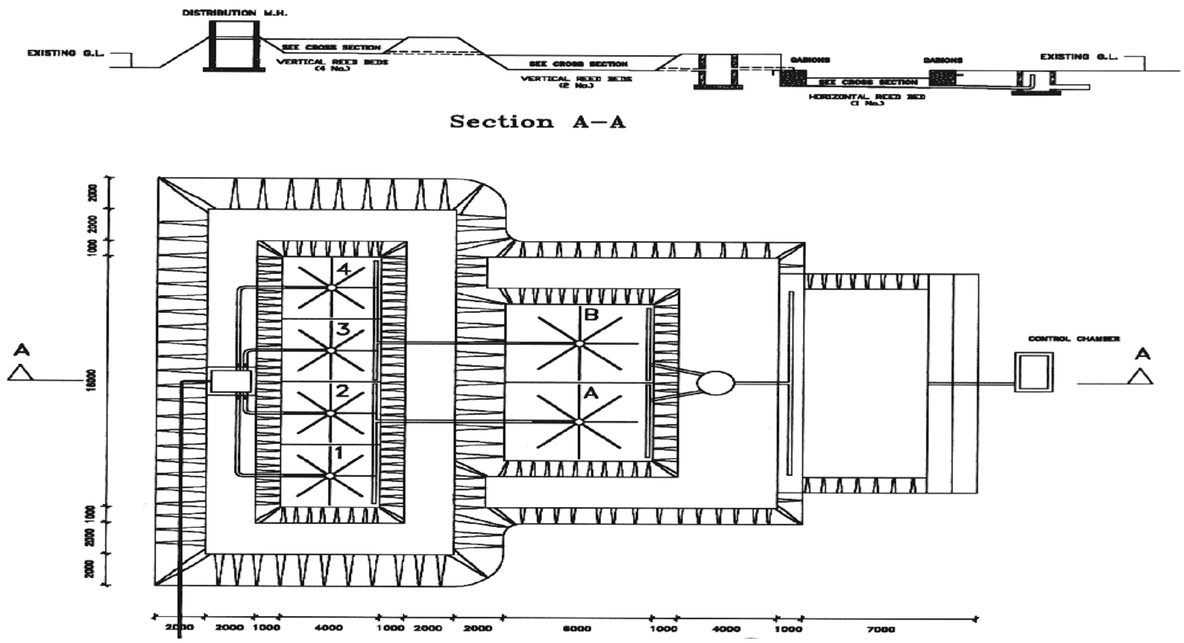


**Fig.1. Colecott Hybrid Reed Bed System.**

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 of 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).

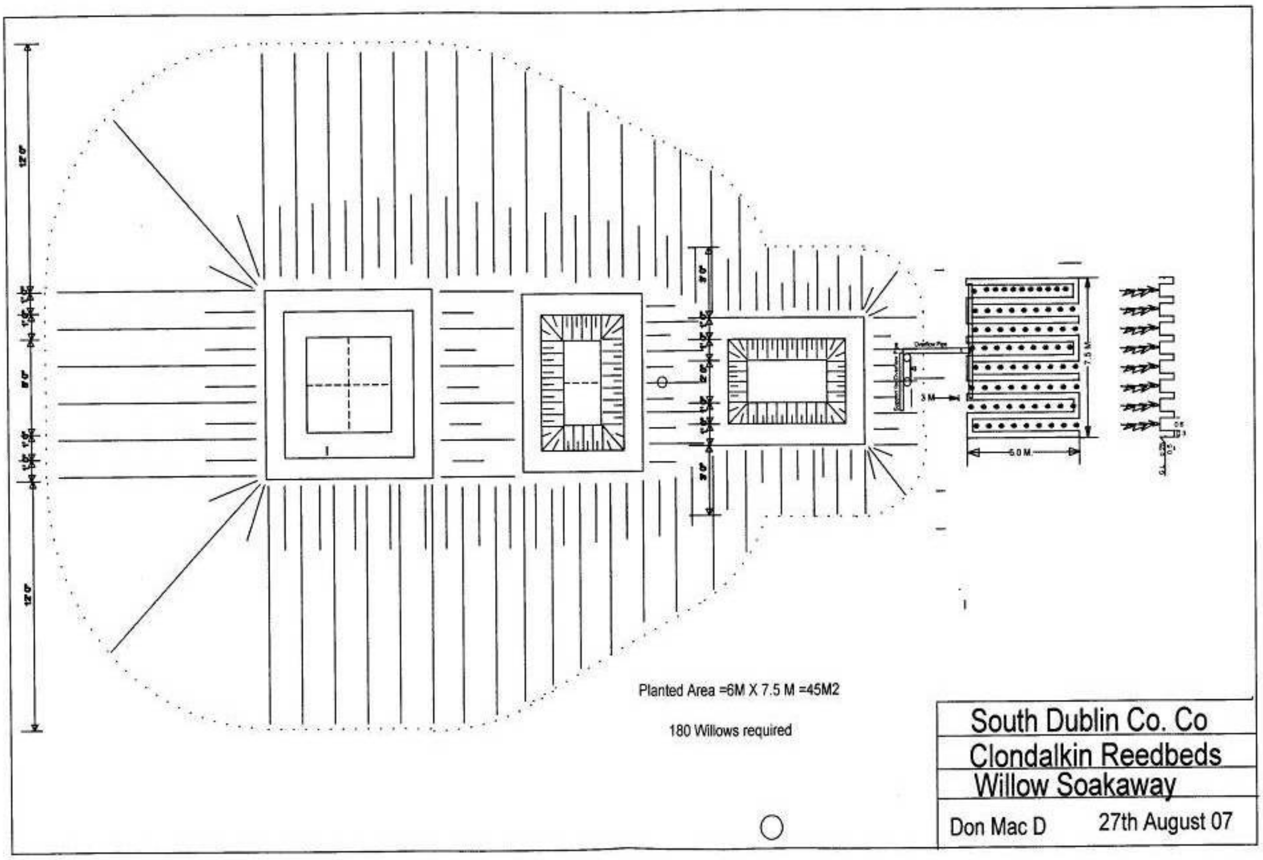


**Fig 2** Lynche's lane hybrid reed and willow bed facility.

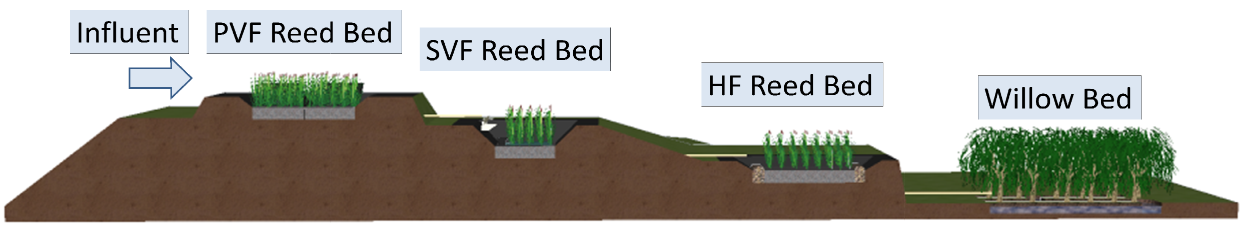


**Fig 3** Longitudinal section through site at Lynche's Lane.

**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 2-8°C 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 $2.3 \times 10^{-7}$ 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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