

**The Effectiveness of an Integrated Constructed Wetland
System in the Treatment of Abattoir Effluent**

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Abstract - *“The Effectiveness of an Integrated Constructed Wetland System in the Treatment of Abattoir Effluent”*

Integrated Constructed Wetland's have been used in a wide variety of situations in recent times as a sustainable and economical alternative for the treatment of contaminated wastewaters. Only once however has such a system been constructed and utilised for the treatment of abattoir effluent, within the UK. The Lancashire based abattoir which put the system into operation in November 2006 allowed for a twelve month study to be carried out on their new wastewater treatment facility. This study investigated how effectively the Integrated Constructed Wetland system could treat abattoir effluent, which contains high loads of organic nutrients. Of particular importance to the study was the subsequent impact(s) that such a system may present to the natural and human environment. A sampling programme was carried out over a one year period, focusing specifically on surface waters within the system and ground waters beneath the system. All samples were tested by a UKAS accredited laboratory for a variety of key pollution indicators. Results were averaged; percentage reduction figures gained and subsequently graphed alongside average seasonal rainfall and temperature figures. It was discovered that the system is effective and displays a lot of potential to be used not only in this area of the industrial sector, but many others also. Critically, the study exposed a number of ways in which the system could be improved, including re-use of grey water to add to its sustainability, exertion of a greater level of process control through self monitoring and reed harvesting to minimise addition of unnecessary nutrients to the system.

Keywords:

- Integrated Constructed Wetland (ICW);
- Abattoir effluent;
- Wastewater treatment;
- Environmental impact;
- Human impact;
- Biodiversity.

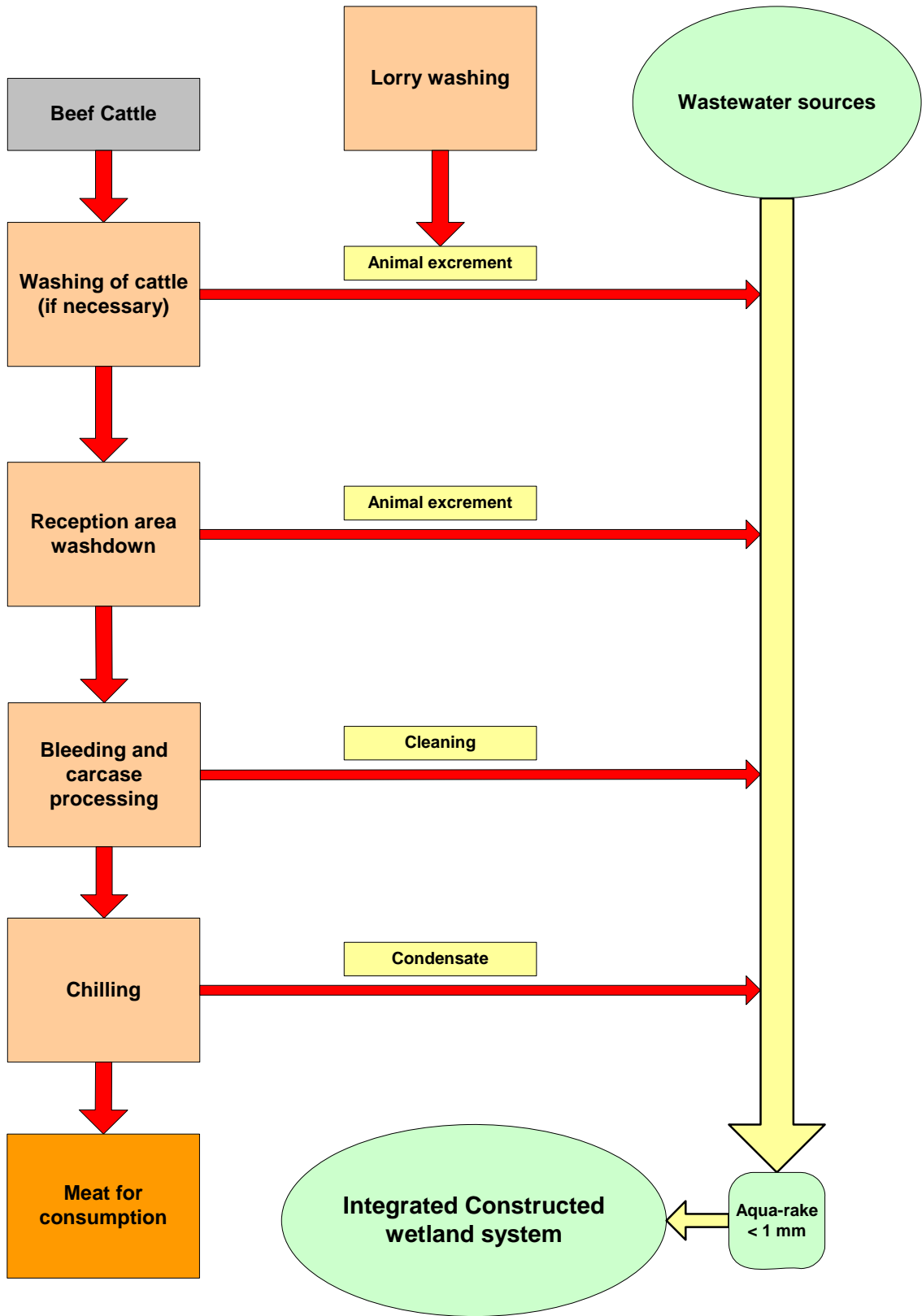
Introduction - “*The Effectiveness of an Integrated Constructed Wetland System in the Treatment of Abattoir Effluent*”

Abattoirs are typically seen as an area of industry that can be potentially quite significant polluters. Their role is to slaughter food animals and prepare them for the food market to a standard that is fit for human consumption. Environmental impacts arise due to the high intensity use of energy and the mass amount of by-products produced. Green *et al* (2006) state that their recent investigation into UK production practices calculated that the energy required to produce 1kg of beef is 28MJ. Although this includes farming practices, a significant proportion of this energy usage was found to be from within the meat processing industry.

However, of greater importance in this paper will be the possible effects that the meat processing industry may have upon the environment as a result of wastewater production. Kurup (2007) claims that meat processing industries produce large volumes of high strength wastewater. Similarly Woodward (2001) states that almost every operation involving slaughtering and processing animals results in wastewater. The Environment Agency have set benchmark water usage figures of 0.7 – 1.0 m³ of potable water per head of cattle (Environment Agency, 2008). This means an average sized abattoir slaughtering 1000 head of cattle per week will produce a minimum of 700 m³ of wastewater each week, which will require treatment. Green *et al* (2006) established that meat production and processing is significant in terms of eutrophication, for which their research suggests it contributes around 11% to total EU-wide impacts. Thus demonstrating that there is a link between abattoirs and pollution of the aquatic environment.

As can be seen in Fig 1: Flow diagram of wastewater generation, there are a variety of activities at different stages in the red meat production process that leads to the creation of highly polluted wastewaters. This includes both organic and chemical constituents. In the case of this study whether or not these wastewaters cause pollution will be determined by the effectiveness of the Integrated Constructed Wetland Systems ability to treat the effluent and prevent it from polluting the local natural environment.

Fig. 1: Flow diagram of wastewater generation



In spite of this the need for local abattoirs can not be underestimated, East Anglia Food Link (2008) proposes that local abattoirs are needed to conserve natural and cultural heritage, while they may also assist in preserving a diverse farmed landscape and a dynamic rural economy. They further suggest that local abattoirs reduce food miles and the emissions that contribute to global warming, as well as reducing the distances that live animals have to travel, minimising stress and reducing the risk of spread of disease. This argument therefore suggests that having abattoirs locally in the UK has a positive effect on the economy, environment and animal welfare issues.

This paper specifically aims to look into how Integrated Constructed Wetlands (ICW's) could contribute in helping abattoirs to become more sustainable, while control potential pollution at the same time. Currently the system has only been used by one abattoir (Dunbia Sawley Abattoir, situated in Lancashire England) within the UK. This has been in use for just over one year, but with in depth study yet to be carried out on its effectiveness and environmental impact.

The Integrated Constructed Wetland Concept

Natural wetland systems have often been described as the “earth’s kidneys”, because they filter pollutants from water that flows through on its way to receiving lakes, streams and oceans (EPA, 2004). In essence ICW's are designed to mimic these natural systems. “Constructed wetlands for water treatment are complex, integrated systems of water, plants, animals, microorganisms, and the environment” (Davis *et al*, 1994). As such they could be a potentially valuable option for low-cost, effective and sustainable treatment of many forms of wastewater, including that of an average sized cattle abattoir.

Advantages:

Wang et al (2004, P.1069) explains that an Integrated Constructed Wetland is an artificial wastewater treatment system involving many mechanisms such as aerobic and anaerobic biodegradation, sedimentation, filtration, adsorption / biosorption, plant and microbe uptake, reduction, oxidation, and volatilisation. They claim good effluent is normally achieved at a low cost, and can be applied on agricultural lands or

discharged to nearby water courses. Likewise Fujita research (2005) claims that ICW's reduce concentrations of suspended solids, biochemical oxygen demand (BOD5), chemical oxygen demand (COD), nitrogen, phosphorus, and coliform bacteria (often by up to 98%). Fujita (2005) also suggest that "integrated constructed wetlands can provide a habitat for wildlife and act as a tourist attraction for the community." Similarly Harrington and Ryder (2002) pronounce that ICWs are distinguished from other constructed wetland approaches because they are designed to facilitate the widest possible range of ecological conditions normally found in natural wetlands, including those of soil, water, plant and animal ecology.

Disadvantages:

Ellis *et al* (2003) makes the case that constructed wetlands lack the full range of aquatic functions exhibited by natural wetlands and are not intended to provide species diversity. Sharing the pessimistic stance on the topic is the Department of Agriculture and Rural Development for Northern Ireland (2006) who suggests that although constructed wetlands are viewed by many as a potentially low cost means of dealing with dirty water, they are unlikely to be a low cost solution because, as Wang *et al* (2004, P.1069) point out "the land requirement is high". This is a worthy statement and unless the company proposing to develop such a system has a large quantity of suitable land at their disposal; preferably with clay based soil as outlined by Woodward (2001) and Kurup (2007); then it could result in considerable financial burden.

Gustafson *et al* (2002) argues that large flows, (caused by excessive wastewater flows or by natural events such as torrential rains) into the system can impair treatment by washing pathogens and nutrients through the media; this can lead to short-or long-term reduction in the ability of the system to provide treatment. Similarly Forbes *et al* (2004) declare that "reliability is questionable and ICW's appear to be vulnerable to heavy rainfall, which can cause outflow nutrient levels, especially Phosphorous, to rise. Infrequent, this may be no worse than leaching and run-off from irrigated or land spread areas, but frequent episodes are potentially disastrous to water systems." In addition to this Lorion (2001) claims that colder conditions slow the rate at which the wetland is able to break down contaminants. This opinion is supported by Thiel

(1999) who declares that every micro organism has an optimum temperature for growth; with most of the well characterised bacteria functioning best at temperatures from 25 °C – 40 °C.

This literature has exposed that ICW's may not be an ideal habitat for fauna, that the large land area required may result in major expense and that the UK climate may not be suitable for the system to operate effectively as large amounts of precipitation can reduce treatment ability and cause pollution, while cold winters could also serve as a detriment to the systems effectiveness since most bacterial life requires relatively warm conditions in order to function fully.

Plant Functions

Harrington and Ryder (2002) state that the vegetation used in ICW's performs a variety of functions. These include cleansing, facilitating in the sorption of nutrients, filtering out suspended solids, and through the use of appropriate emergent vegetation odours and pathogens can be controlled. The choice of vegetation used is therefore of tremendous importance if the ICW system is to be effective. Through research carried out by Burton et al (2007) it was found that the plants within a constructed wetland should differ and be sub-divided into regions, they claim that "The first region should be planted with a combination of *Carex* (common sedge) and *Zantedeschia aethiopica* (Arum Lily). The second region should be planted with *Zantedeschia aethiopica* (Arum Lily) and *Typha capensis* (Bullrush). Region three should be planted with Arum lilies and Region 4 should be planted with *Persicaria decipiens* (willow-weed)." However making no mention of sub-divisions is Ellis *et al* (2003), whose opinion regarding the most appropriate choice of plant species also differs. Ellis *et al* (2003), believes the common reed (*Phragmites australis*) should be used due to its ability to thrive in nutrient rich situations, combined with its high level of tolerance to pollutants.

Generally researchers' opinions do differ in this area; however it has become clear that it is recommended to choose a species that is indigenous to the area, hereby providing a high level of ecological value. As the common reed (*Phragmites australis*)

is native to the British Isles it would seem to be an appropriate choice given its innate ability to survive in areas with vast levels of nutrients and pollutants.

Predicted Effectiveness of Treatment

Gustafson *et al* (2002) claims “a properly operating constructed wetland should produce an effluent with less than 30 mg/litre BOD (biochemical oxygen demand, a measure of organic material) and less than 25 mg/litre TSS (total suspended solids).” However Grant and Griggs (2002) suggests that BOD and Suspended Solids values of under 5 mg/litre are typical for these systems and some will support fish and a wide range of invertebrates in the final effluent. While Forbes *et al* (2004) are more sceptical in their research and imply that the evidence for constructed wetland contaminant removal from agricultural wastewaters is not conclusive. They claim that “BOD, Nitrogen, Phosphorus and Pathogen removal are good, though not always to levels likely to be specified by UK Environmental and Water Authorities.”

It is therefore inconclusive and not possible to predict exactly how effectively an ICW could treat abattoir effluent. However, consultants employed by Dunbia abattoir have formulated what they describe as a ‘plug flow’ model, which attempts to predict how effectively effluent can be cleansed, based on the total area of reeds in the system, along with the volume and concentration of the effluent inlet.

It is reasonable to anticipate that levels of contaminants will be reduced to one degree or another provided the system is correctly designed, implemented and managed. Literature suggests that ICW’s have already been successful in the treatment of contaminated storm water, domestic sewage, landfill leachate, winery wastewater, cheese factory wastewater and agricultural effluents.

Pollution Control

Quevauviller (2006, P.24): “A wastewater is composed of water; carrying a lot of suspended solids and dissolved substances which were not present originally (the pollutants)”. If the abattoir wastewater is not properly separated from the aquatic environment before it is treated to a level where discharge is legal (as determined by

the Environmental Authority in a discharge consent agreement) water pollution can and likely will occur.

Woodward (2001, P.393) states in the case of artificial wetlands, protection of groundwater by installing an appropriate impermeable liner is a major design consideration. While the Environment Agency (2008) declares that impermeable floors should be used in all land based effluent storage areas, as this prevents any contaminated drainage entering watercourses or draining into the land. Forbes *et al* (2004) have indicated that “accidental discharge or leakages and leaching of effluent from storage tanks and vessels are the most common reasons for pollution incidents in Northern Ireland.”

Based on reason it is therefore important to ensure that the entire base of an integrated constructed wetland system is made impermeable. Researchers such as Woodward (2001) and Kurup (2007) believe that manufactured impermeable liners are a good option or compacted clay if the site has this to offer.

A primary indicator of pollution in this study will be Biochemical Oxygen Demand. This test displays a leading capacity to recognise the quality of wastewaters. The Wilkes University Centre for Environmental Quality (2008) recognises that BOD is used by regulatory agencies in monitoring wastewater treatment facilities, as well as the quality of surface waters. They report that BOD is “the biochemical oxygen demand of the water and it is related to the concentration of the bacterial facilitated decomposable organic material in the water.” As such this will act as a main indicator in identifying the quality of effluents treated by the ICW system, because abattoir effluent consists predominantly of organic wastes (see Fig.1).

Pollution could lead to prosecution under the Water Resources Act 1991 and as such should act as a deterrent to shareholders of a business in terms of allowing pollution to happen, as it could result in large financial penalties and diminished public image, along with potential custodial sentence for company directors.

Impact on Humans

As described by the Environment Agency in their 'Guidance for Red Meat Processing' paper (2003), currently high volumes of abattoir effluent are being spread on land within the UK as a means of disposal. However this guidance now puts particular emphasis on the operator to implement the BAT (Best Available Technique), under the Pollution Prevention and Control (England and Wales)(Amendment) (No. 2) Regulations 2003. BAT requires steps to be taken to prevent or, where this is not practicable, to reduce emissions to the environment. Mittal (2007) proclaims that land-application of blood and gut contents from abattoirs is liable to cause public nuisance due to odours and environmental concerns, and, when applied on the soil surface it is unsightly and there is potential for disease transmission. Reduction in land spreading will also have positive effects on the efforts being made by the EU in trying to reduce soil nitrate levels (through the Nitrates Directive 91/676/EEC).

ICW's appear to be a more controlled manner of abattoir effluent disposal as it can be stored in the system and / or treated a sufficient amount to allow safe release to the environment. Also as described by Forbes *et al* (2004) "Very few researchers record or remark upon odour problems with ICW's and of the sites visited during a wetlands symposium (at Johnstown Castle, Co. Wexford, ROI, 24-26 May, 2004), the two farm and the two rural catchment ICW's were not noticeably odorous despite warm humid conditions."

However, the systems ability to effectively treat the effluent without causing pollution is again of prime importance where human health is concerned. This is due to the link between public health and polluted waters. Boualam and Volterra (2002) state that "Specific health risks appear, when fresh water, extracted from eutrophic areas, is used for the production of drinking water". Some of the symptoms which they have linked directly to the consumption of such waters include gastro-enteritis, hepatitis, liver damage, nausea, headache and muscle pain.

A further impact on humans as described by a number of researchers, including Lorion (2001), Grant and Griggs (2002) and Kurup (2007) are from a financial

viewpoint. The ICW system has been described by each as being “low cost”. This is because the effluent can be treated by natural means, as opposed to sending it to sewer and gaining treatment at the local treatment works (very costly). As such this can improve the bottom line of a business and therefore increase profitability.

Aims: *“The Effectiveness of an Integrated Constructed Wetland System in the Treatment of Abattoir Effluent”*

The aim of this research project is to identify how effectively an Integrated Constructed Wetland system can reduce levels of pollutants in abattoir effluent. An integral part of this study shall also be to assess the systems impact upon the natural environment and human population.

This should allow for an informed decision to be made on whether or not a system of this nature could be used as a sustainable alternative to energy intensive methods of wastewater treatment / disposal used in this area of the industrial sector; such as biological effluent treatment plants and land spreading; where the later of the two can also be a public health threat and facilitator of significant nuisance.

It is envisaged that before the study is drawn to a close, recommendations shall be made where appropriate, which shall lead to increases in efficiencies, hereby further improving the systems effectiveness.

Methodology: *“The Effectiveness of an Integrated Constructed Wetland System in the Treatment of Abattoir Effluent”*

This methodology was designed for the sampling of wastewater from within the Integrated Constructed Wetland System. The sampling programme was carried out over a period of one year (November 2006 – November 2007). It was based on recommendations made within ISO 5667-10:1992, Water Quality – Part 6: Sampling: Section 6.10 Guidance on Sampling of Wastewaters (Barbour, 2008).

For every sample taken the method used was spot sampling. It is stated within ISO 5667-10:1992 that “spot samples are essential where the objective of a sampling programme is to estimate the compliance with standards”. It was therefore envisaged that this would be the most appropriate method to use as it enabled assessment of compliance with discharge consent limits assigned by the Environment Agency.

The sampling points were decided upon prior to starting the sampling programme. This was from the inflow pipe to each pond. As a result the samples were taken from a flow, rather than being from standing water. This reduced the possibility of capturing abnormal samples from stagnant waters.

Following consultation with the laboratory responsible for analysing the samples it was decided that 1 litre plastic sterile bottles would be used. These containers were used to help prevent losses due to adsorption, volatilization and contamination by foreign substances. Other desirable factors that were met included high resistance to breakage, practicable size, shape and mass, cost effective, good sealing efficiency and good potential for cleaning and re-use (ISO 5667-3).

Manual sampling equipment used included a sample pole with a container attached at one end and a separate measuring jug. These were both made from an inert material, and as such did not influence sample results (ISO 5667-2).

Prior to starting, the equipment was always cleaned with detergent and water, and finally thoroughly rinsed with clean water.

Samples were taken from ‘clean’ to ‘dirty’, i.e. working backwards from the final (discharge) pond to the first inlet lagoon. Equipment was rinsed with clean water between each sample, meaning a large container of clean water was made available during every sampling procedure. The potential for cross contamination between cleaner samples with the more recently received dirty effluent was hereby greatly minimised.

Before sampling commenced, the inlet pipes were cleaned in order to remove scale, sludge, bacterial films etc. Again, this helped lessen chances of abnormal results.

A 1 litre sample was taken on a weekly basis of the discharge effluent (to assess if discharge consent limits were being met), the influent to the first lagoon and the inlet to every pond in between (to assess effluent quality in the system, which helped determine if any changes needed to be made in an attempt to increase efficiencies).

An agreement was set up with the laboratory to have the sample bottles delivered on-site the day before each sampling date, and subsequently collected on the day when samples were taken. The bottles arrived and left in freeze boxes, and were pre-labelled (i.e. company site name, sample point and date), leaving the sampler only having to fill in the time when each sample was taken.

While the samples were still in the care of the company, they were always preserved in a dark, cool place (0°C - 4 °C). Thus lessening the chances of any further microbiological growth, which could affect test results.

Chain of custody forms were completed in triplicate and the samples signed over to the courier. The company's copy of each transfer was kept on file for future reference.

All samples were analysed by Severn Trent Laboratories Ltd, who are registered with The United Kingdom Accreditation Service (UKAS), and have individual UKAS accreditation for all parameters tested for (i.e. BOD, COD, Total Suspended Solids, Ammoniacal Nitrogen, Nitrates, Nitrites, Total Oxidised Nitrogen, Total Nitrogen, Phosphorus, Total Coliform Bacteria, E. coli, Enterococci and pH).

Groundwater sampling – the exact same procedure applied for the sampling of groundwater, substituting horizontal flow pipes for vertical borehole pipes (designed to allow the sample pole easy access to groundwater situated directly below the ICW system). This was carried out on a monthly basis as opposed to weekly, as advised by the Environment Agency.

Two people took on responsibility for the entire sampling programme, including the author of this paper and an environmental officer employed by the company who owns the ICW system. In order to ensure the same sampling techniques were used,

both individuals received extensive training from an experienced environmental consultant prior to initiation of the programme.

Results: *“The Effectiveness of an Integrated Constructed Wetland System in the Treatment of Abattoir Effluent”*

Pollution Indicator	Average Levels of Pollutant (mg/l)		Percentage Change between TP 1 and LP 8 (%)
	Inlet to System (Top Pond 1)	Final Discharge Pond (Lower Pond 8)	
<i>BOD</i>	1269.00	2.60	-99.80 ↓
<i>COD</i>	2300.00	54.00	-97.65 ↓
<i>TSS</i>	332.00	14.00	-95.78 ↓
<i>Phosphorus</i>	38.00	0.68	-98.21 ↓
<i>Total Nitrogen</i>	228.00	8.40	-96.32 ↓
<i>Total Oxidised Nitrogen</i>	0.48	4.01	+88.03 ↑
<i>Nitrates</i>	1.00	3.87	+74.16 ↑
<i>Nitrites</i>	0.30	0.73	+58.90 ↑
<i>Amoniacal Nitrogen</i>	138.00	5.01	-96.37 ↓

Figure: 2: Table showing average percentage change in levels of pollutants between the inlet and outlet of the Integrated Constructed Wetland system (Nov 2006 – Nov 2007).

The results clearly identify that as the effluent flows from the beginning of the ICW system, to the end, significant reductions in the levels of pollutants take place; often by up to and above 95%.

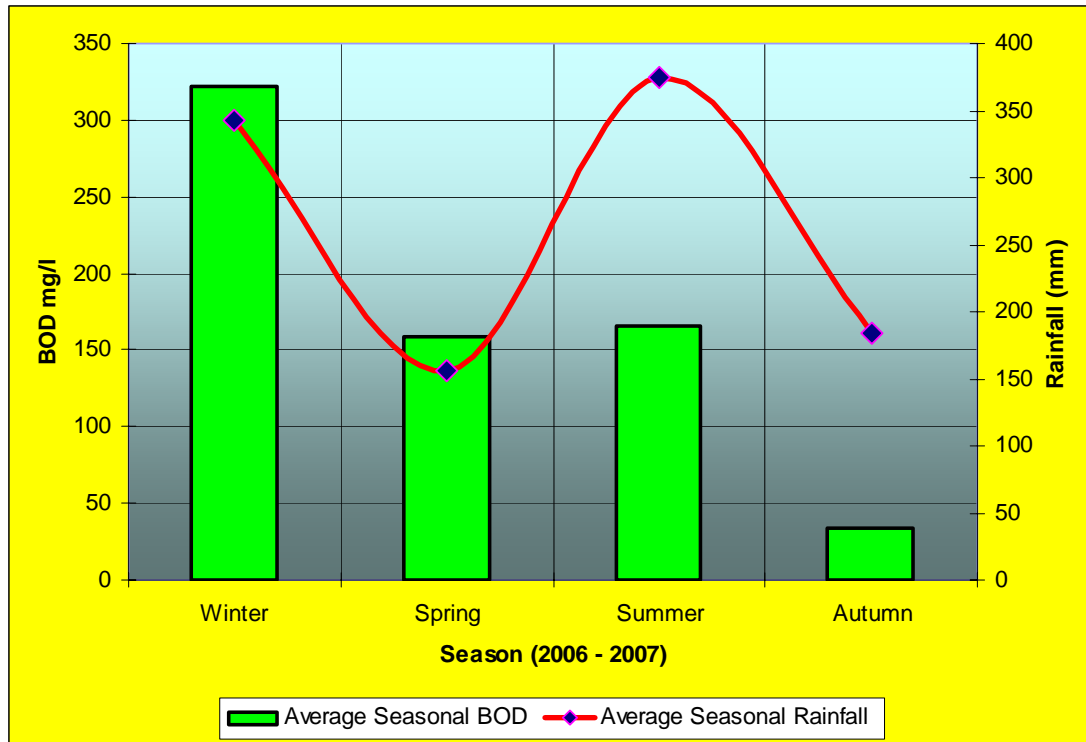


Figure 3: Graph showing seasonal variations in Biochemical Oxygen Demand (BOD) within the ICW system and the average rainfall during each season (winter 2006 – autumn 2007).

Source of mean climatic conditions, as demonstrated in Figure 3: The Met Office (2008).

As can be seen in the graph, there is a definite connection between the systems effectiveness as a wastewater treatment facility and the average seasonal volumes of rainfall that it is exposed to. The two seasons where levels of BOD are highest (winter and summer) can be linked directly to when the volumes of rainfall were at their highest (winter and summer).

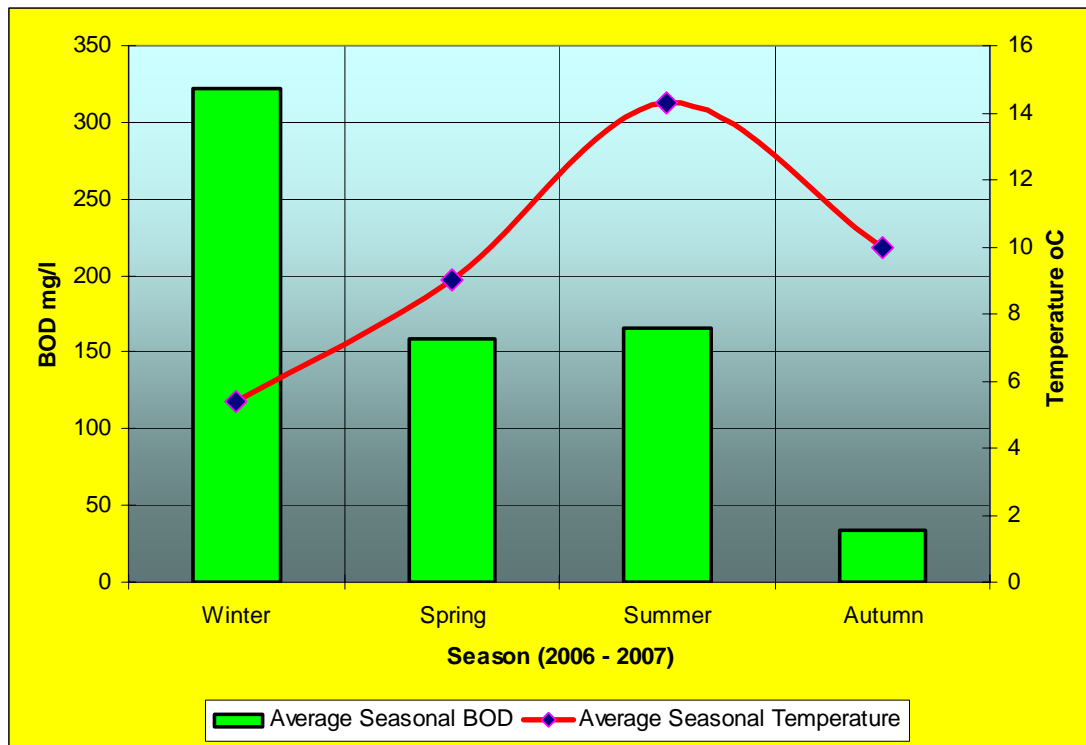


Figure 4: Graph showing seasonal variations in Biochemical Oxygen Demand (BOD) within the ICW system and the average temperature during each season (winter 2006 – autumn 2007).

Source of mean climatic conditions, as demonstrated in Figure 4: The Met Office (2008).

The connection between the systems effectiveness as a wastewater treatment facility and the average seasonal temperatures is slightly more ambiguous. However this link can not be ruled out as can be seen in the graph; where a low mean winter temperature resulted in a poor level of treatment, while a moderate mean temperature the following autumn lead to a very high standard of treatment.

Discussion: “*The Effectiveness of an Integrated Constructed Wetland System in the Treatment of Abattoir Effluent*”

The one year sampling programme has provided a unique insight into the relatively new concept of sustainable wastewater treatment. This study should provide the red meat industrial sector with an in depth look at one way in which they may be able to further reduce costs, while play their part in sustaining a clean and prosperous environment for all. Although it is hoped that the results of this study would also go some way in swaying the viewpoint of the Environmental Authorities in the UK and Ireland, who currently demonstrate a sceptical attitude towards the construction and use of Integrated Constructed Wetlands; invariably because they possess a lack of expertise in the given area, as the concept is a relatively new one in this part of the world.

Overall Effectiveness

With reference to Figure 2, it can be seen from these results that levels of pollutants often decrease dramatically. In fact an average reduction of more than 95% was achieved in six out of the nine pollutants tested for. Gustafson *et al* (2002) claimed that once an ICW becomes fully operational an effluent with less than 30 mg/litre BOD and less than 25 mg/litre TSS could be achieved. This study has shown average figures of 2.6 mg/litre BOD and 14.0 mg/litre TSS were achieved, which proves that the system is effective. These results, along with the others showing significant reductions are very impressive, especially as the system is yet in its infancy.

However, as Figure 2 also demonstrates there were three pollutants that actually rose in concentration as a result of being treated by the ICW system, namely: total oxidised nitrogen, nitrates and nitrites. This occurrence can be explained by referring to the widely understood cycle of nitrogen. In essence what has transpired in this situation is that these three pollutants are actually a by-product from the decomposition of total nitrogen and ammoniacal nitrogen, which are both high in concentration upon inlet to the system (average of 228 mg/l and 138 mg/l respectively). This helps to demonstrate why concentrations of oxidised nitrogen, nitrates and nitrites typically rise by 58 % – 88 %. Much like the effluent is a by-product of red meat production in the first place,

these three pollutants become the quintessential by-product of this method of effluent treatment.

Climate - Precipitation

As indicated by The Wilkes University, Centre for Environmental Quality (2008), BOD is a prime indicator for quality of both waste and surface waters. Therefore in this study the BOD sample results were used in attempting to identify any trends over the 12 month period. Referring to Figure 3, it can be seen that when levels of precipitation rise, the effectiveness of the ICW system falls. Results indicate that when seasonal precipitation total was more than 300 mm (summer and winter), then average levels of BOD in the system were typically above 160 mg/l. Whereas when seasonal precipitation total was less than 200 mm (spring and autumn), then average levels of BOD in the system were typically below 160 mg/l. This key finding concurs with both Gustafson *et al* (2002) and Forbes *et al* (2004), who found through their research that ICW's can be vulnerable to heavy rainfall and as such can negatively impact on the systems treatment capabilities. An explanation for this occurrence can be linked to the time in which the effluent is allowed to gain treatment and also the surface area contact gained during treatment. High levels of rainfall will wash effluents through the system quickly and as such this results in a lack of contact between the effluent and reeds / micro-organisms in the system, which provide the bulk of the treatment. In addition to this, settling of suspended solids (sedimentation) becomes inhibited as a result of faster flowing waters, which allows these solids unexpected entry to lower ponds, were waters should ideally become 'polished' at this stage prior to discharge to surface waters.

Climate - Temperature

In a similar light results from this study correspond with the views of Lorion (2001), who suggested that colder conditions slow the rate at which ICW's are able to break down contaminants. As demonstrated in Figure 4, a certain link between atmospheric temperature and the systems ability to reduce levels of BOD can be observed; most profoundly perhaps during the winter. Here, a low mean temperature of below 6 °C coincided with a high average BOD of more than 300 mg/l. While more temperate

conditions in spring, summer and autumn lead to average BOD levels in the region of 150 mg/l and below. Interestingly however was in finding that when the mean seasonal temperature was at its greatest, during the summer, the BOD level was still fairly high, in that it was second only behind the coldest season, winter. This poor result of BOD can be explained by looking back on the extremely high, all be it uncharacteristic, levels of rainfall during the summer months of 2007. The negative impact which high rainfall can have on the system, seemingly overpowers the positive impact that mild conditions can have upon the systems functionality. However, temperature does play its part in the treatment process and this can be explained by understanding the concept that temperature can and does impact on the growth and activity levels of micro-organisms. As outlined by Thiel (1999), the warmer the atmospheric temperature the better, as most bacteria demonstrate their optimum growth rate to be in the 25 °C – 40 °C region.

Groundwater

After calculating average levels of BOD found in groundwater's immediately beneath the ICW system, it was established that at each of the six boreholes sampled, typical levels of BOD ranged between 1 – 2 mg/l. Wilkes University (2008) state that “a sample with a BOD between 1 and 2 mg/l indicates a very clean water”. These results therefore point out two pieces of information that are of vast importance to this study. Firstly that during the one year period when the sampling programme was being carried out, there was no pollution / contamination of groundwater occurring in this vicinity. Secondly it helps prove that the design and construction of the system was very competently executed, the appropriate use of compacted clay soils and artificial impermeable membranes has meant that there is minimal or no transfer of effluent from the system into groundwater. This further helps to signify that soils immediately between the ICW system and groundwater's are also incurring minimal detrimental impacts. The results act as a breakthrough when held in the context of the opinion of Forbes *et al* (2004) who implied that leakages and leaching of effluent from storage tanks and vessels are the most common reason for pollution incidents. This study has shown that through good design and manufacture, natural storage facilities such as this one can display a high level of impervious integrity, and thereby shows no direct connection with groundwater.

Impact on Humans

Odour and pathogens were outlined as being the two main potential negative side effects arising from the ICW system, as far as human health and comfort were concerned. Having monitored levels of pathogens (Total Coliform Bacteria, *E. coli* and Enterococci) during the twelve month period, all results showed a high degree of inconsistency and as a consequence few conclusions could accurately be drawn. Even though on occasions levels of some pathogens did appear to be quite high, more often than not negligible counts were made in most samples. It could therefore be argued that these spontaneous results occurred by natural means, through faecal contamination of the waters by ducks / birds and other wildlife making use of the new habitat creation. It is therefore thought that testing of pathogens should cease with immediate effect, because in the first instance, a vast quantity of money is required for testing of pathogens, while it uses up precious time for those who manage the system in terms of time taken to obtain samples. This time and money could be better utilised on the system, in areas such as provision for self monitoring equipment, process control and plant / fauna care. Also as farmers have no compulsory requirement placed upon them to monitor levels of pathogens contained within raw animal manure which is spread on land, it can be deemed quite reasonable to suggest that this testing should not be required on an effluent treatment system that can treat effluents to the obvious extent that this one can i.e. to clean water.

Like with all effluent treatment facilities, odour is expected to be a problem to one extent or another. Abattoir effluent is no exception, due to its content of animal excrement, blood and factory washings (as outlined in Figure 1). Indeed two odour complaints arose during the early stages of this study, from nearby residents. This finding therefore contradicts Forbes *et al* (2004) who noted that “very few researchers record or remark upon odour problems with ICW’s”. However, while two odour complaints did arise, effective management of the system at this point meant that no more odour nuisances occurred for the remainder of the study. It was found that odour was only an issue when the first pond (lagoon) was very full, this in turn allowed winds to sweep the rising odours from this highly polluted effluent and steer them in the direction of nearby residences. To counteract this, effluent was pumped to the system in a more controlled fashion to allow the levels to not only drop in the lagoon,

but throughout the system. As a result any odour problems diminished and the effectiveness of the system actually increased as the lower levels allowed for a greater surface contact between the effluent and reeds / micro organisms.

Habitat Restoration

What is perhaps most pleasing about this system is how it can fit in with both the landscape and nature itself. This is a huge plus in the modern day, where aesthetic appeal and biodiversity feature so highly on the agenda of local authorities and the wider European community. Harrington and Ryder (2002) explained that ICW's are designed to facilitate the widest possible range of ecological conditions normally found in natural wetlands, including those of soil, water, plant and animal ecology. The way in which this system became inhabited over the twelve month study shows that Harrington and Ryder (2002) are exactly correct in their assumptions. For instance, ducks became a regular sight swimming on the lower ponds where waters become 'polished' prior to discharge to surface waters. Birds living in nearby trees fly above and around the system as they can feed on the array of insect creatures and flies living throughout the ponds, who in turn feed on micro organisms and algae. While species of snail and newt have been viewed in the vicinity of the discharge point from the system, which effectively demonstrates nature's way of proving how successful the system has been. The foundation of this ecological success is based upon the selection of reeds used in the system, *Phragmites australis*. Being indigenous to the area it thrives all year round, and withstands the high concentrations of nutrients contained in the upper ponds, hereby providing an appropriate habitat and breeding ground for insects, which are the backbone of this small but flourishing food chain.

Fujita (2005) suggest that "integrated constructed wetlands can provide a habitat for wildlife and act as a tourist attraction for the community". While it is clear a habitat for wildlife is provided, currently ICW's are not widely being used as a tourist attraction. However, it is felt that this is a very feasible option for the future, especially in the case of lower, cleaner ponds which display the highest capacity for ecological value, with minimal to no odour problems even when standing in the direct locality of them. If local authorities were to set up ICW systems for the treatment of sewage generated by man, for example the sewage generated by a small village, they

could also look into the potential for it to be used as a tourist attraction, or more likely an area for locals to walk their dogs. If correctly managed systems such as this could have positive impacts on local biodiversity, which is so rapidly diminishing in the modern world of today; not to mention having a positive effect on global warming and reducing the infinite costs that are tied up with current methods of sewage treatment.

Conclusion: *“The Effectiveness of an Integrated Constructed Wetland System in the Treatment of Abattoir Effluent”*

Literature on the topic of constructed wetlands is plentiful and diverse, but with specific regards to the treatment of abattoir effluent it is negligible. The main arguments for the use of ICW's are that they are a natural and sustainable method of wastewater treatment, which is economical to run and has a positive impact on biodiversity. This study has indicated that the system is effective in the treatment of abattoir effluent, and in doing so causes minimal environmental impact. The UK climate is not ideal for systems of this nature due to high levels of precipitation and low temperatures at certain times of the year. However, with effective management procedures in place the use of the system can be manipulated in such a way so as to get the most out of the system when conditions become ideal.

It is hoped that the findings from this study will act as a spring board for action for a number of both private and public organisations. Namely the red meat processing industry and possibly other similar industry who wish to reduce costs and become more sustainable, perhaps as part of an ISO 14001 Environmental Management System. While UK and Irish Environmental Authorities should be encouraged by the findings, especially at a point in time when biodiversity, pollution control and global warming figure so high on the agenda of new EC legislation, agreements and targets.

Recommendations: *“The Effectiveness of an Integrated Constructed Wetland System in the Treatment of Abattoir Effluent”*

Following an eighteen month period of sampling investigations, research and study, a number of special areas of interest with regards this particular ICW system have been identified. Perhaps most importantly is that of process control. It is envisaged that if a greater level of process control could be exerted, through a self monitoring approach then the systems effectiveness could reap the benefits. Currently the only means of gaining knowledge of the systems performance is to send samples for analysis and then wait for up to ten days before results are returned. This is simply too large an interval and does not allow for quick enough action to be taken, such as recirculation of effluents. A key recommendation is therefore aimed at encouraging the company to invest in self monitoring equipment, such as an ammonia spectrometer, which would allow instant results to be achieved, meaning immediate action could be taken for the good of the system.

The system itself is a sustainable one, considering the minimal use of fossil fuels. However, it is believed that it could become more so through reuse of grey water by pumping it from the discharge pond to the dirty lorry wash. As water reduction features highly in the company objectives and targets for the next financial year, this water reuse makes both environmental and economic sense. In addition to this, special attention should be given to ensuring as little water is sent to the ICW's in the first instance (as the discharge consent license indicates that no more than 220 m³ can be discharged per day); so all drips should be mended, trigger operated hoses put into operation and all rainwater sent directly out as clean water as opposed to getting caught up in foul drains and subsequently sent to ICW's. This will also mean levels of ponds will be kept lower, thus providing better treatment, less odour emissions and increased treatment time which will allow the nitrogen cycle more time to fully transpire thereby reducing levels of total oxidised nitrogen, nitrates and nitrites to a greater extent than is being achieved currently.

Finally it is recommended that harvesting of reeds is carried out intermittently, as presently when reeds die off extra nutrients are being put back into the system, which is making it more difficult to effectively reach discharge parameters for pollutants.

Acknowledgements: *“The Effectiveness of an Integrated Constructed Wetland System in the Treatment of Abattoir Effluent”*

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