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POTENTIAL FOR WASTEWATER MANAGEMNET USING ENERGY CROPS

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Abstract

In most countries within Europe there are numerous small rural Waste Water Treatment Works (WWTWs) often serving a small number of people equivalents (PEs). It is usually impractical and expensive to upgrade such WWTWs and yet they are often delivering potentially highly polluting effluent into streams and rivers. Short Rotation Coppice (SRC) willow, grown as an energy source, may be an ideal crop for the bioremediation of a variety of effluents and wastewater streams. As part of an EU funded (INTERREG IVA) project called ANSWER (Agricultural Need for Sustainable Willow Effluent Recycling) four Proof of Concept irrigation schemes were established ranging in size from 5 to 15 ha. One of the larger of these at Bridgend, Co. Donegal, Republic of Ireland was planted in spring 2013 and has been irrigated with municipal effluent since June 2014. Over 19,000 m^3 *of effluent has been applied to the willow thus preventing 617 kg N and 28.5 kg P from being discharged to a neighbouring stream. Using SRC willow for the bioremediation of effluent from small rural WWWTs offers a sustainable, cost-effective and practical solution to wastewater management in many countries. There may be also potential to use willow for the bioremediation of landfill leachates, within the footprint of the landfill site.*

Key words: *bioremediation, municipal effluent, Salix spp., willow*

INTRODUCTION

With the implementation of the Waste Water Frameworks Directive [3] increasing pressure is placed on water utilities and the agri-food sector to put in place sustainable approaches to wastewater management and the prevention of damage of environmental water quality due to both point and diffuse sources of pollution. In most European countries there are numerous small inefficient water treatment works often serving only a few 10s of people equivalents (PEs). In the Republic of Ireland there are over 500 such plants (Fig 1) with 206 treating water from fewer than 100 PEs [14]. In Northern Ireland there are 776 small (<250 PEs) Waste Water Treatment Works which represents 70% of the total wastewater treated in N. Ireland (NIWater, personal communication). These WWTWs are often old and usually situated in rural settings. The cost of upgrading them is prohibitive. Water utilities are therefore seeking approaches and technologies whereby they can manage the wastewater in a sustainable way while improving waste water discharges and reducing potential risks of pollution.

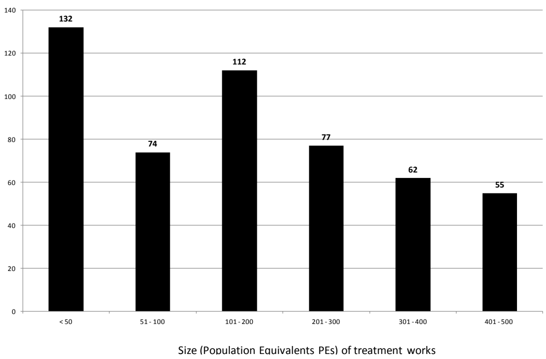

Fig 1. Number of small WWTWs treating effluent from less than 500 PEs in Republic of Ireland in 2012 [14].

Phytoremediation (bioremediation) is the use of plants to ‘treat’ wastewaters [12]. The plants utilise the nutrients and prevent their leaching into groundwater or their run-off into streams and ditches etc. Renewable energy crops and in particular Short Rotation Coppice (SRC) willow (*Salix* spp.) and poplar (*Populus* spp.) are particularly well suited for bioremediation of effluents and other wastewater streams [13]. SRC willow is fast growing, takes up large volumes of water and can utilise the nutrients, in particular nitrogen (N) and phosphorus (P). Willow can also, in some situations, be very effective in the bioremediation of heavy metals, in particular cadmium (Cd) and zinc (Zn).

The bioremediation process is illustrated in Figure 2. When effluent is applied to the surface it percolates through the soil. The willow roots act as a biofilter. The water is taken up by the plants, driven by evapotranspiration, and the soluble nutrients are utilised. There are also numerous soil mechanisms particularly in the rhizosphere by which nutrients including N and P are either absorbed or metabolised. In any effluent irrigation system such as this the concern is that nutrients will leach through the soil and contaminate the groundwater. However, in numerous studies carried out in Northern Ireland [15], Sweden [8, 9], Canada (Michel Labrecque, personal communication) and elsewhere there has been virtually no evidence of nutrient leaching.

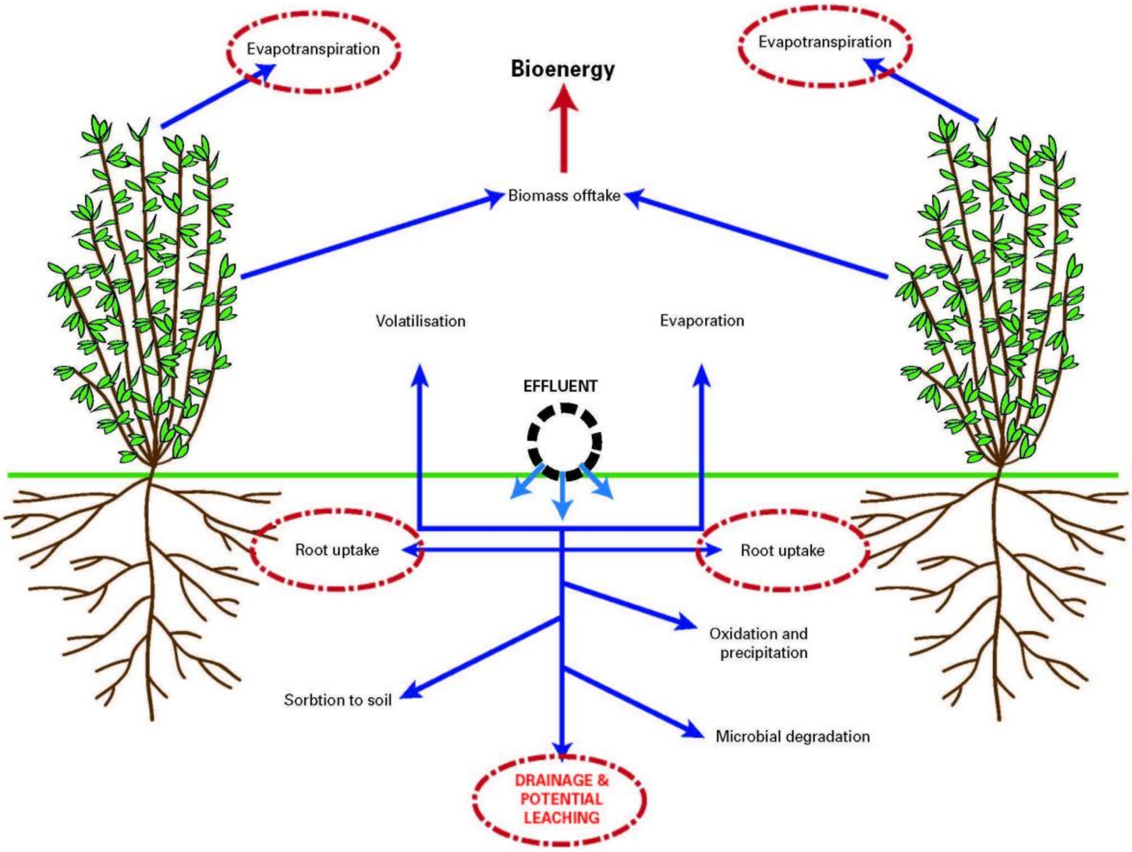

Fig. 2. Principles of SRC willow bio-filtration system.

SRC willow is grown as a source of biomass for the production of renewable energy. With significant UK government incentives, particularly in the form of the "Renewable Heat Incentive" (RHI) high quality wood chip for heat production has been profitable. The current (early 2015) slump in oil prices to unusually low levels means that heat production from alternative sources, including wood chips are significantly less competitive. However, it can be anticipated that oil prices will start to rise again, possibly later in 2015 or into 2016 [6].

Despite these pressures on renewable (wood) energy costs there are still many benefits from growing SRC willow. There are significant carbon (C) savings and reductions in damaging greenhouse gas emissions to be made helping mitigate against climate change. Furthermore if the benefits of using a plant based system for the phytoremediation / bioremediation and management of potentially very damaging wastewaters is added, the technology clearly has application in many countries and regions of the European Union.

The work described in this paper comes primarily from a European project called "Agricultural Need for Sustainable Willow Effluent Recycling" (ANSWER). The ANSWER project was part funded by the European Union's European Regional Development Fund (ERDF) through the INTERREG IVA Cross-border Programme, managed by the Special EU Programmes Body (SEUPB). The primary objectives of the project were to study the use of SRC willow for the bioremediation of municipal effluents and landfill leachates and to establish commercial scale proof of concept schemes to treat effluent from small non-compliant WWTWs [10]. The project was led by the Agri-Food & Biosciences Institute, which is an agricultural research organisation. Other partners included colleges of further education, local government county councils and water utilities. Details of the partners and their contributions to the project can be found at http://www.afbini.gov.uk/index/research/hp-work-area-environment-land/answer/answer-events.htm

MATERIALS AND METHODS

As part of the ANSWER project four commercial scale effluent irrigation schemes were established:

- Bridgend, Co. Donegal, Ireland (55^o 2' N: 7^o 22' W)

There were approximately 14 ha of land in three fields adjacent to a small WWTWs processing effluent from approximately 500 PEs. The land was flat and with the exception of one of the fields (approximately 2 ha) was reasonable, adequately drained agricultural soil. Before installing the irrigation system it had been grassland and so SRC willow had first to be established.

- Clontibret, Co. Monaghan, Ireland (54^o 12' N: 6^o 50' W)

There were approximately 6 ha in two fields within 300 m of a small WWTWs processing effluent form approximately 200 people. One of the fields had a slope. Before installing the irrigation system it had been grassland and so SRC willow had first to be established.

- Knockatallon, Co. Monaghan, Ireland (54^o 18' N: 7^o 8' W).

There were approximately 5 ha in two fields besides a small WWTs processing effluent from approximately 100 people. One of the fields had a severe slope while the other area was relatively flat. The soil conditions were poor and drainage in some areas significantly impeded. Before installing the irrigation system it had been grassland and so SRC willow had first to be established.

- Dromore, Co. Tyrone, Northern Ireland (54^o 30' N: 7^o 27' W).

There were approximately 15 ha in three large blocks which were just over 1 km from a rural WWTWs. This works is handling effluent from over 2,500 PEs but a proportion of the effluent (approximately 15 - 20%) will be drawn off to be applied to the SRC willows. The effluent will be applied to already established (6+ years) willow.

It is envisaged that the utility will utilise this SRC treatment module to investigate the efficacy of pumping effluent to the SRC Willow during different scenarios as follows:

1. During the WWTW peak loading times (three times in 24 hours), to reduce the flow through the treatment works.
2. When the flow in the river is lower - to reduce the impact of discharge on river water quality.
3. When there are elevated nutrient levels in the discharge - to reduce the impact of discharge on river water quality.
4. Ultimately, at a future date, to investigate the effect that the extraction of primary effluent (reducing the flow through the works) has on the overall running of the WWTW, the discharge quality and overall energy usage and carbon emissions.

The development of each of the schemes

incurred its own particular issues and complications while undergoing planning, establishment, commissioning and maintenance of the willows and irrigation system. More details about each scheme are to be found in the ANSWER project report [11]. For the purposes of this paper the focus will be on one of the schemes: Bridgend, Co. Donegal which will be described in more detail.

In late December 2011 land belonging to Donegal Creameries was identified in close proximity to the Bridgend Treatment Works. In spring 2013 approximately 14 ha was planted with willow using the current industry best practice [7] in order to give a final plant density of around 15,000 plants ha^{-1}. When the plants were established the irrigation pipe-work was laid during winter and spring 2013/14 in every forth double row with emitter orifices every 10 m (Photo 1).

Photo 1. Irrigation pipe, with outlet point, laid in an actively growing SRC willow planta

The irrigation system consisted of a storage facility, pump, valves, filter, flow meters, rising main, header pipes and irrigation pipe work. The 90 mm rising main stretched the entire length of the plantation, approximately 1.4 km into which 25 independently controlled solenoid valves were incorporated (Fig.3). Each valve, controlled by the central computer system, enabled individual zones to be independently irrigated according to a pre-programmed irrigation protocol.

The WWTWs was upgraded and in compliance with the Environmental Protection Agency requirements a holding tank was installed (Photo 2).

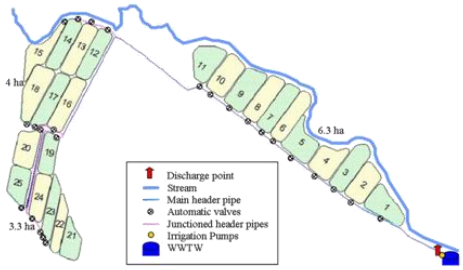

Fig. 3. Irrigation zones at Bridgend willow site.

At the time of construction remote recording equipment was installed to make it possible to monitor the activities (pumps, flows, tank levels, environmental indicators) at the site in real time.

Photo. 2. Holding tank at Bridgend WWTWs, Co. Donegal, Republic of Ireland

This is a very new technology and there were genuine concerns from both local communities and the regulatory authorities. Throughout the whole planning process the Local Authority Environment Section investigated the proposal thoroughly in order to ensure compliance with environmental regulation and good practice. Local community groups were consulted and their questions and concerns addressed. These questions were predominantly associated with gaining an understanding of what the schemes were about, the potential benefits, the proximity to houses and watercourses and potential for odours. The irrigation system was constructed with these risk abatement factors taken into account and incorporated irrigation area restrictions and methodologies. Potential risks (the consideration of sensitivity of location with regard to site suitability, groundwater vulnerability, and proximity to populations and protected areas including water supply sources) associated with the irrigation of treated waste waters to a SRC willow plantation were considered. There are several relevant pieces of European legislation which were taken into consideration. These include:

- S.I 31/2014 - European Union (Good Agricultural Practice for the Protection of Waters) Regulations 2014
- SI 272/2009 - European Communities Environmental Objectives (Surface Waters) Regulations 2009 (as amended)
- SI 9/2010 - European Communities Environmental Objectives (Groundwater) Regulations 2010 (as amended)
- Article8(1) of the Planning and Development Regulations, 2001 (S.I. No. 600 of 2001)

There are other significant areas of legislation such as the Ground Water Regulations, the Urban Wastewater Treatment Regulations, Environmental Impact - uncultivated semi-natural areas regulations, Shellfish and Bathing Waters Directives which may all be relevant but relate more directly to specific situations.

The national (Irish) Environment Protection Agency (EPA) was fully engaged at all stages of the process and so before committing to regulation on the surface irrigation of municipal effluent to SRC willow the EPA made a careful assessment of the possible environmental risks associated with the practice. Particularly important in these deliberations was access to robust independent science investigating the technology, especially research that had been carried out in Ireland where the maritime climate and relatively heavy rainfall could have been an important factor. Confidence on behalf of the regulators in Ireland (EPA) and Northern Ireland (NI Environment Agency) was largely based on many years of research conducted by the Agri-Food & Biosciences Institute (formerly the science service of the Department of Agriculture and Rural Development for NI).

RESULTS AND DISCUSSIONS

Bridgend, Co. Donegal, Ireland: The average daily effluent inflow to the WWTWs was approximately 80 – 90 m^3. Before the commencement of the ANSWER project the design capacity of the treatment works was for 250 PEs. The inflow was subject to aeration followed by settlement and discharge to a small adjacent stream, which at times, especially during dry periods and limited stream flow rate, had a negative impact on water quality. As part of the overall upgrading of the WWTWs incorporating irrigation of effluent to willows, the EPA required the construction of a 400 m^3 holding tank. This was put in place to store effluent during periods when irrigation to the willows was not possible. Currently the inflow is still subjected to aeration and settlement at which point it enters a sump from which it is pumped to the holding tank. The effluent being applied to the willows is drawn form this tank. In circumstances where the effluent cannot be irrigated to the willow plantation e.g. climatic conditions such frozen land, snow, heavy rain or as a result of equipment failure, the holding tank will fill to 95% at which point the sump uplift pump will stop and the effluent will discharge to the stream as it had prior to the construction of the SRC willow treatment scheme.

Each of the zones is irrigated for a specified time which is preset depending on its distance from the irrigation pump (flow rate), soil conditions and the hydrology of the site. As the distance from the pump at the treatment works to the furthest irrigation zones increases, so the pressure and flow rate will drop. Hence the distant zones will require longer irrigation periods in order to apply equal volumes of effluent. As the system is currently set, approximately 5 m^3 $zone^{-1}$ day^{-1} of effluent is applied which enables a maximum total daily application volume of around 130 m^3. This equates to 0.9 mm applied to the whole plantation daily and will be reduced accordingly, to match the inflow to the works. At present there are three irrigation cycles per day applying approximately 43 m^3 each. In accordance with

the Nitrates Directive, it is recognised that the application of effluent to the SRC willow plantation will be performed in a uniform manner and is not permitted when the soil is waterlogged, likely to flood, has been frozen for 12 hours or longer, is snow-covered or when heavy rain is forecast within 48 hours.
The effluent being applied at each of the four ‘proof of concept’ sites described above is similar, although the material currently being used at Knockatallon is essentially a primary effluent (Table 1).

Table 1. Effluent discharge quality from WWTWs

	Bridgend (mg/l)	Clontibbret (mg/l)	Knockatallon (mg/l)	Dromore (mg/l)
NH_3-N	10.6	32.3	27.2	1.1
Total-N	31.6	32.3	27.2	11.3
Total-P	1.5	4.7	3.6	1.6
SS	50	33	78	17
BOD	22.4	43.0	85.0	10.0
COD	93.0	130.0	180.0	n/a
pH	7.3	n/a	n/a	7.5

The management of the irrigation protocol is vitally important to assure that the hydraulic capability of the site is not exceeded, in which case flooding and / or surface run-off could occur. Equally important is to manage the nutrient loading and as such this technology is clearly a crop fertilisation approach and in no way any kind of waste disposal activity. Of particular importance in this respect are N and P. Nutrient guidance for SRC willow is given within the Willow Best Practice Guidelines [7]. At the level of irrigation at each of the sites the nutrient applications are all within the recommended guidelines (Table 2). The application rates represent yearly nutrient loadings within recommended crop requirements. By keeping the nutrient loading well within crop requirements the risk of N leaching to the groundwater or significant P build up in the soil are minimal.
The Bridgend irrigation system was commissioned in May 2014 and after a short commissioning period the irrigation rates were adjusted to manage the inflow of the WWTWs. (Fig. 4). By the end of December 2014 the total volume of effluent irrigated to the site was 19,537 m^3. This represents around 38% of the inflow to the treatment works.

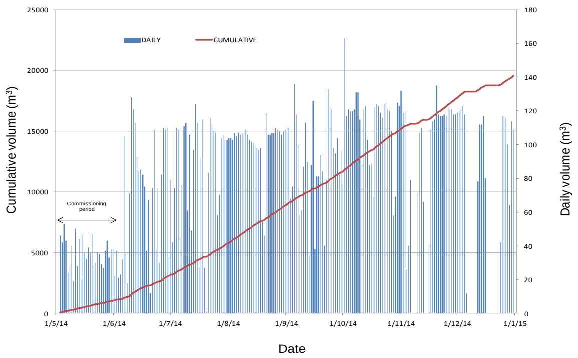

Fig 4. Daily and cumulative irrigation volumes (m^3) at the Bridgend WWTWs, Jun–Dec. 2014

There were some problems during the commissioning phase and on the 8th October it was found that one set point in the controls was causing a regular overflow to the river. It is anticipated that these figures will improve very significantly in subsequent seasons. Nevertheless, the total nutrients recycled to the willow were 617 kg N and 28.5 kg P. This means that during the period this quantity of N and P were not being discharged into the stream with the associated benefits of reducing environmental water pollution. Also the amounts being applied to the willow was well within the crop requirements, outlined above, and so will be removed from the site when the willows are harvested [7].
The efficacy of the system is being carefully and regularly monitored. Water samples are extracted from a number of deep boreholes around the site every two months and analysed for BOD, suspended solids, nitrate-N, phosphorus and total coliforms, to ensure no contamination of the groundwater has occurred. The soil is analysed periodically to detect any change in soil nutrient status, in particular any build up of P or the accumulation of heavy metals. The stream water will be monitored regularly and an improvement in water quality over time is anticipated.
Potential applications: There is an urgent need to find cost-effective and sustainable approaches to wastewater management.
This is important to ensure compliance with the EU Water Framework Directive as well as

to limit the use of fossil fuels and help reduce Green House Gas (GHG) emissions.

Table 2.Estimated nutrient and hydraulic loading at four willow sites irrigated throughout the year

	Bridgend		Clontibbret		Knockatallon		Dromore	
Loading	**Total**	**ha^{-1}**	**Total**	**ha^{-1}**	**Total**	**ha^{-1}**	**Total**	**ha^{-1}**
Est. Population Equivalents (PEs)	500		200		105		520	
Area willow irrigated (ha)	14		7		5		15	
Hydraulic loading (m^3 ha-^{1})	31,025	2,216	12,410	1,773	6,515	1,303	32,266	2,151
Suspended solids (kg ha^{-1} yr^{-1})	1,551	111	410	59	508	102	549	37
Nitrogen (kg ha^{-1} yr^{-1})	980	70	401	57	177	35	365	24
Phosphorus (kg ha^{-1} yr^{-1})	46	3	58	8	23	5	50	3

In most developed countries water utilities are the single greatest energy user, mainly electricity. Irrigation of municipal effluent to SRC willow is an ideal technology to achieve these objectives. SRC willow is well suited for small rural Waste Water Treatment Works which have a high probability of being close to land suitable for growing willows. In Ireland and the UK, environmental regulation is likely to make willow irrigation more onerous and expensive for WWTWs over 500 PEs, however, there may be certain circumstances whereby the use of SRC willow can reduce the volumes to be treated by conventional means, enabling certain WWTWs to attain discharge compliance. This is a solution for small scale problems and the area of willow needed may be relatively small. NIWater (the water utility in Northern Ireland with responsibility for water management) established a 1 ha proof-of concept willow plantation in 2013 treating effluent from a treatment works for approximately 25 PEs. The system has been running for over 18 months and during that time NO effluent has been discharged to the neighbouring stream, there has been no evidence of surface run-off into the stream and there has been no impact on the groundwater.

As the technology is still in its infancy in most parts of Europe the irrigation schemes tend to be over specified as it is difficult to anticipate unusual rainfall events which may lead to a potential risk of run-off or adverse impact on neighbouring buildings etc. While the hydrology of any given site, in Ireland, will probably determine the volumes of effluent applied it should be noted that irrigation rates are also calculated on crop need i.e. this is not regarded as a disposal mechanism, it is a crop fertilisation approach. This is particularly important in respect to N and P. In Northern Ireland, based on the UK Fertiliser Recommendations Manual [4] the application of 180 kg N ha^{-1} yr^{-1}, calculated from potential off takes, is currently agreeable. If the N is applied in conjunction with phosphorus (unbalanced crop requirement ratio e.g. biosolids or effluent), this may result in an accumulation of P in the soil which needs to be monitored. While this will probably not be a limiting factor for the municipal effluents being used at the four schemes described in this paper, it may be if wastewaters from industrial processes (e.g. agri-food, meat, milk processing facilities etc.) are being used. Solid organic fertiliser can be applied to P index 2 soils however this should cease when soils reach P index 3. The rate of P application will depend on the source of organic waste and the regulatory instrument it falls under. A level of 24 kg ha^{-1} yr^{-1} is a current workable estimate.

In order to illustrate the potential economic benefit of adopting this type of technology we present the following worked example. Note that the example does take into consideration any boiler, combustion or supply chain inefficiencies:

On the island of Ireland, there are over 1,000 small (<500PE) rural WWTWs. If it were assumed that just 10% are suitable for SRC willow for wastewater management and that the average plantation size is 6 hectares then there could be a total area of SRC willow in excess of 600 ha. Based on typical yields (10 odt ha^{-1} yr^{-1}) and an energy content of 5,300 kWh t^{-1} then there is the potential to generate a total heat output of approximately 32 GWh yr^{-1}. With the current estimated heating oil price at €57 l^{-1} (10.5 kWh^{-1}) this amount of energy has a value of €1.8m. In Ireland it is possible to grow, harvest, dry, store and transport SRC fuel for around €100 odt^{-1}. The current cost of wood fuel for small / medium scale biomass boilers is in the region of €181 odt^{-1}, i.e. approx €145 t^{-1} delivered at 20% moisture content. Hence, the annual production of 6,000 odt of SRC willow biomass could release €490,000 into the local economy.

In Ireland, especially in rural areas the predominant fuel counterfactual is oil, all of which is imported. Hence if the oil is displaced by wood fuel, the end user would also make savings compared to their existing oil fuel bill. For example a school heated by a 99 kW boiler running for 2,500 hr yr^{-1}, if oil is replaced with willow woodchip there could be a reduction in their annual fuel bill of almost €5,000. Hence, if 50 schools were heated with wood fuel, then there could be an additional benefit to the economy of €250,000 per annum. Furthermore, such projects could be installed and accredited under the Renewable Heat Incentive (RHI) as currently exists in N. Ireland [5]. An RHI scheme is proposed to be introduced in the Republic of Ireland by the beginning 2016. If the rate were similar to N. Ireland (6.3 pence (€0.08) per kWh of heat used) then based on the figures presented above, the school would receive an annual rebate of €19,800) meaning that for the 50 schools this would add up to almost €1m of additional wealth creation to the all Ireland rural economy.

If SRC willows were deployed on just 10% of these scenarios, it should be possible to significantly improve water quality with the additional benefits of enabling the development of a value chain and the boosting of the economy by about around €1.7m per year.

The cost of establishing a SRC willow irrigation scheme is significantly less than building a new or upgrading old inefficient treatment works. Often landowners are seeking alternative land use and potential opportunities for agricultural diversification. In some situations the water utility may pay the land owner a gate fee or stewardship fee which is an extra income stream. A major benefit of these solutions for point source pollution is the symbiotic development and support of a value chain for the production of carbon neutral bioenergy in the form of biomass from SRC willow. Wood is regarded as a carbon neutral fuel, as any CO_2 released during combustion was assimilated when the plants were growing.

The ANSWER project has enabled the establishment of four commercial scale irrigation systems treating effluent from actual WWTWs in order to enable them to meet EU and national standards for water quality. While the schemes are at an early stage of their development and will require careful management and monitoring over the next number of years it is still considered to be a sustainable and cost effective approach to wastewater management.

Landfill leachate: One of the most difficult wastewater sources to handle is landfill leachate. Landfill leachate disposal is a problem that is set to become a major issue for many European countries. Cost effective and environmentally sustainable solutions are required to address this growing issue. Council Directive 1999/31/EC [1] has set the goal of reducing biodegradable landfill waste by 35% of the waste produced in 1995 (80% of all waste was sent to landfill in 1995) by 2020.

However directives on recycling targets and packaging waste Directive 2008/98/EC and Directive 94/62 [2] were reviewed in July 2014 and further proposals were planned to phase out landfilling for recyclable wastes all together by 2025 (Plastics, paper, metals, glass and bio-waste). These measures are having an effect on landfill composition and the reduction of materials entering landfill. Existing landfills need to insure the transfer of spent materials back to the environment in a sustainable way.

High levels of ammonia (NH_3) are a major challenge for conventional WWTWs, however SRC willow has the potential to contribute a solution to sustainable and affordable management of a wide range of wastewater streams.

If carefully managed, the high ammonia levels can be accommodated allowing willows to cope with significant levels of leachate. At present in Ireland the EPA is not prepared to approve leachate application to normal agricultural soils or unlined sites. Hence current landfill leachate schemes using SRC willow are confined within the footprint of the existing landfill site. When the site is closed it is covered with a geo-textile membrane, primarily to capture methane (CH_4) gas and to prevent ingression of rainfall which would exacerbate the volumes of leachate production. If the cap is then further covered with soil it can be planted with willow.

There are several other factors which may need to be taken into consideration which may preclude planting willows. These include the presence of a network of gas collection pipe-work or inadequate depth of soil. Nevertheless, when plants have established a good root structure leachate being produced at the base can be applied on the top. The willows utilise the nutrients and effect bioremediation. If there is a heavy rain event excess water will be captured and reapplied when weather conditions are more conducive. Donegal County Council, Republic of Ireland is developing an integration of willow bioremediation on the top of an older landfill site (very effective during the summer growing season) along with constructed wetland (particularly effective during the winter months), however this scheme is only at its initial stages. More information can be found at the ANSWER website:
(http://www.afbini.gov.uk/index/research/hp-work-area-environment-land/answer/answer-events.htm.

CONCLUSIONS

SRC willow bioremediation is a cost effective, sustainable and practical method for the management of effluents originating from small rural Waste Water Treatment Works serving less than 500 People Equivalents. There is virtually no risk to ground water quality and by diverting the effluent away from rivers and streams there is an opportunity to significantly improve environmental water quality. The additional value of the biomass produced from irrigation schemes could make a major contribution to the local economy. Furthermore the displacement of oil-generated energy would be highly beneficial in reducing the carbon impacts of burning fossil fuels. There is also the potential for willows to be used in the management of landfill leachate, although at present this will have to be investigated within the foot-print of the landfill site.

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REFERENCES

[1]Anon., 1999, Council Directive 1999/31/ECof 26 April 1999 on the landfill of waste. The Council of the European Union
http://ec.europa.eu/environment/waste/landfill_index.htm

[2]Anon., 1999, Directive 2008/98/EC on waste (Waste Framework Directive)
http://ec.europa.eu/environment/waste/framework/

[3] Anon., 2000, Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. http://eur-lex.europa.eu/resource.html?uri=cellar:5c835afb-2ec6-4577-bdf8-756d3d694eeb.0004.02/DOC_1&format=PDF (accessed 16th Jan. 2015).

[4]Anon., 2010, DEFRA Fertiliser Manual (RB209)
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69469/rb209-fertiliser-manual-110412.pdf. (accessed 12th January 2015

[5]Anon., 2015, Renewable Heat incentive, Northern Ireland.
http://www.nidirect.gov.uk/index/information-and-services/environment-and-greener-living/energy-wise/energy-saving-grants/renewable-heat-incentive-rhi/rhi-for-non-domestic-customers.htm (accessed 21st

Jan. 2015)
[6]Anon., 2015, Goldman Sachs slashes oil price forecasts. Reuters. http://www.reuters.com/article/2015/01/12/us-research-goldmansachs-crude-idUSKBN0KL0RR20150112 (accessed 20th Jan. 2015)
[7]Caslin, B., Finnan, J., McCracken, A., 2010, Short Rotation Coppice Willow Best Practice Guidelines. Teagasc, OakPark; AFBI, Belfast. 66 pages.
[8]Dimitriou, I., Aronsson, P., 2011, Landfill leachate treatment with willows and poplars – Efficiency and plant response. Waste Management 30, 2137 – 2145
[9]Dimitriou, I., Aronsson, P., 2011, Wastewater and sewage sludge application to willows and poplar grown in lysimeters – Plant response and treatment efficiency. Biomass and Bioenergy 35, 161 – 170
[10]McCracken, A., Black, A., Cairns, P., Duddy, A-M., Galbally, P., Finnan, J., Johnston, C., McLaughlin, C., Moss, B., Mulligan, O., Walsh, L., 2014, Use of Short Rotation Coppice (SRC) willow for the bioremediation of effluents and leachates: Current knowledge. ANSWER project, Agri-Food & Biosciences Institute: 44 pages
[11]McCracken, A., Black, A., Cairns, P., Duddy, A-M., Galbally, P., Finnan, J., Johnston, C., McLaughlin, C., Moss, B., Mulligan, O., Walsh, L., 2014, Use of Short Rotation Coppice (SRC) willow for the bioremediation of effluents and leachates: Project Report. ANSWER project, Agri-Food & Biosciences Institute. 64 pages
[12]Mirck, J., Isebrands, J. G., Verwijst, T., Ledin, S., 2005, Development of short-rotation willow coppice systems for environmental purposes in Sweden. Biomass and Bioenergy 28, 219 - 228
[13]Riddell-Black, D., Agbasiere, N., Briere de l'lsle, B., Davis, R., Hudec, B., McCracken, A. R., Sugiura, A., Tyrrel, S. F. and Werner, A., 2008, Potential Long Term Effects of A WaterRenew System - A Synopsis. (Waste Water Polishing Using Renewable Energy Crops) http://www.amazon.com/Potential-Effects-Water-Renew-System/dp/1898920621
[14]Shannon, D. Wall, B. Flynn, D., 2012, Focus on urban waste water treatment in 2012. Irish Environmental Protection Agency, P.O. Box 3000, Johnstown Castle Estate, County Wexford, Ireland. 60 pages
[15]Werner, A., McCracken, A., 2008, The use of Short Rotation Coppice poplar and willow for the bioremediation of sewage effluent. Aspects of Applied Biology. Biomass and Energy Crops III, 90, pp. 317-324