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Agricultural Need for Sustainable Willow Effluent Recycling

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ANSWER
(Agricultural Need for Sustainable Willow Effluent Recycling)

Use of Short Rotation Coppice (SRC) willow for the bioremediation of effluents and leachates: **Current Knowledge**

The ANSWER project was part-financed by the European Union's European Regional Development Fund through the INTERREG IVA Cross-border Programme managed by the Special EU Programmes Body.

The Project ran from 2010 to 2014.

There were seven partners:
Agri-Food & Biosciences Institute (AFBI) – Lead Partner
South West College
NI Water
ITSligo
Teagasc
Monaghan County Council
Donegal County Council

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14.15.903

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ANSWER
Agricultural Need for Sustainable Willow Effluent Recycling

The ANSWER project ran from 2010 – 2014. The primary objective of the project was to develop the use of Short Rotation Coppice (SRC) willow for the bioremediation of a range of effluents including municipal wastewater, landfill leachates and industrial effluents. Part of the work was in-depth scientific studies of the interaction between willow plants and effluent or leachate. A large spectrum of *Salix* spp.genotypes was screened from which a small number were selected for further study. Some of the factors impacting on plant health and their ability to bioremediate the wastewater stream included concentration, frequency and intensity of application. Preliminary studies indicated that there was almost no survival of bacterial pathogens such as e.g. *E. coli*, *Campylobacter* or *Salmonella* in the soil following irrigation. Investigations into the factors affecting overland flow of effluent, especially following a heavy rain event showed that movement of water across the surface of a willow plantation was limited and that there was limited risk in encountering nutrient pollution. At one site irrigation with municipal wastewater had no significant impact on earthworm, springtail or mite abundance. At a second site at high levels of irrigation with farm wastewater some reduction of earthworm number occurred.

One of the outputs of the ANSWER project is 45 ha of SRC willow at four sites in Counties Donegal, Monaghan and Tyrone being irrigated with municipal effluent from near-by Wastewater Treatment Works (WWTWs). Irrigation commenced in spring 2014 and can be seen as a cost-effective, environmentally friendly and sustainable technology for the management of wastewater streams

Landfill leachate is a particularly polluting and damaging material which can be problematic and expensive to treat conventionally. At two sites in Co. Donegal SRC willow is being investigated as a means of handling leachate. At one land fill site a series of lysimeters will enable the technology to be investigated at a small plot level while at the other site a capped landfill planted with willow, will be irrigated in conjunction with a constructed wetland.

There is huge potential for the uptake of this biological technology for wastewater management and a web-based Geographical Information System (GIS) data base has been developed to identify likely areas where it can be applied.

This technology is still in its infancy and the data and experiences gathered from the Donegal, Monaghan and Tyrone sites are going to be vitally important in refining, developing and further commercialising the technology. For that reason this ‘guide’ is setting out the best knowledge of using SRC willow for the bioremediation of effluents and leachates at the time of going to press. There is no doubt that as our local experience of the implementation of this technology increases the method will be suitably adapted.

Use of Short Rotation Coppice (SRC) willow for the bioremediation of effluents and leachates: current knowledge

1.0 INTRODUCTION

The treatment of wastewater in conventional Wastewater Treatment Works (WWTWs) is highly effective and in modern works will produce an effluent which is non-damaging, when discharged into waterways. However, WWTWs are very expensive to build and to run. They require major electrical power inputs to run pumps, aerators and other equipment - water utilities are, in many countries, the single greatest users of electricity. For example in the UK the water utilities use around 3% of the total energy produced. In addition to financial costs most of this energy is coming from fossil fuel sources and water treatment is therefore contributing large quantities of damaging greenhouse gas emissions to the atmosphere. Large WWTWs are required to treat the municipal effluent from large towns and cities. There are however hundreds of small treatment works dealing with effluent, often from only a few homes and people living in small rural settlements. It is therefore essential to develop cost-effective, environmentally friendly, sustainable approaches to wastewater management appropriate to rural communities. The use of fast growing woody plants for the bioremediation / phytoremediation of wastewater is a potentially useful approach to this problem.

Modern Sewage Treatment Works at Culmore Co. Londonderry

2.0 BIOREMEDIATION / PHYTOREMEDIATION

2.1 Using willows for the bioremediation / phytoremediation of effluents and other wastewater streams

Fast growing plants will utilise available nutrients in the soil. The willow (Salix spp.) genotypes bred for high biomass production are particularly productive, consistently yielding in excess of 10 dry t ha-1 yr-1 in most sites. In addition to willow, many woody plants have been tested for bioremediation including poplar (Populus spp), birch (Betula spp.), lime (Tilia spp.), cedar (Cedrela spp.) Dracaena spp, and some conifers (e.g. Podocarpus spp.). Willow is best suited for growing in maritime climate such as that experienced in Ireland. Willow is a temperate plant well suited to wet soils, has a long growing season, is easily coppiced (i.e. can be cut back regularly to ground level) is tolerant to many soil contaminants and is currently grown commercially for biomass as a fuel for wood-fired boilers producing renewable heat. The fact that willow has a higher water demand than almost any other agricultural crop means that significant volumes of effluent can be applied. The type of willow used in coppice plantations generally has a fine shallow root system with 85% situated in the top 20 cm of the soil profile. This not only improves stability but also provides an excellent receptive surface for the application of effluents and other wastewater streams.

2.2 What is bioremediation / phytoremediation?

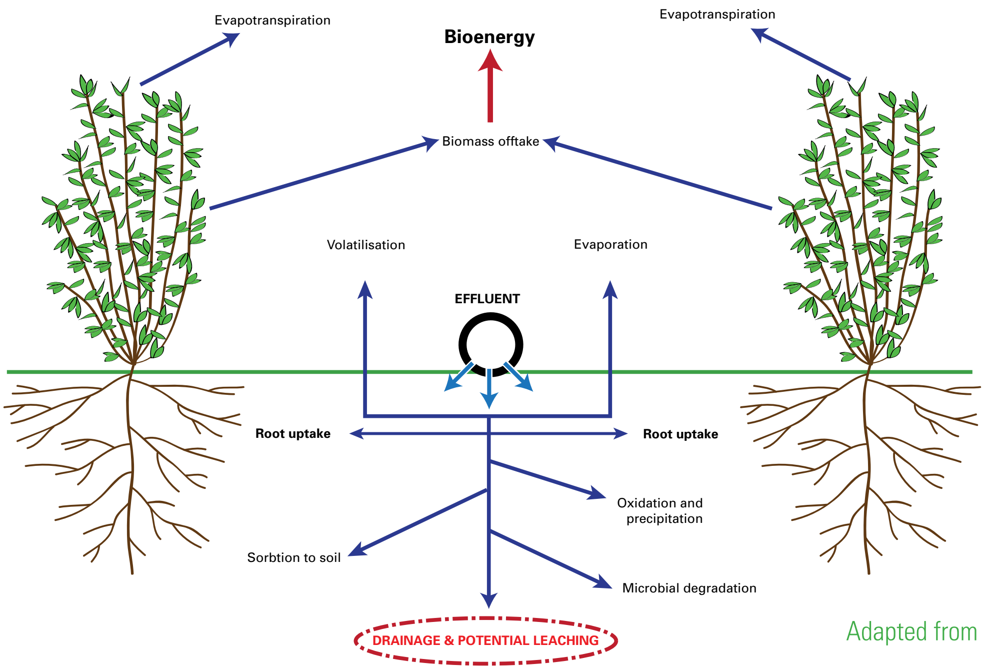
Bioremediation is the use of living organisms to break down or remove toxins and other harmful substances from soil and water. The organisms used may be micro-organisms such as bacteria or fungi, algae and plants. Often when plants are used, 'phytoremediation' is the preferred terminology. Plants, including woody plants, are used to restore previously contaminated sites and have been employed successfully on areas where there were high levels of heavy metals, industrial contaminants and even residues from the petro-chemical industry. Plants can also be used to manage large volumes of potentially damaging wastewater streams coming from inefficient WWTWs, certain industries - especially the food processing industry and the leachate from inactive landfill sites.

SRC willow after one year regrowth

Two year old poplar with irrigation pipework.

2.3 How does phytoremediation work?

Many plants when they are growing actively take up large volumes of water from the soil. This is driven by 'evapotranspiration'. Evapotranspiration refers to loss of water from the soil both by evaporation and by transpiration from growing plants. Plants utilise water from the soil, which is then lost to the atmosphere though the stomata in the leaves. If the water that is taken up by the plants is high in plant nutrients such as nitrogen (N) and phosphorus (P) then there will often be increased plant growth. In the rhizosphere (the plant root / soil interface) the plants act as a biofiltration systems which enables soil bacteria and other soil mechanisms to breakdown nutrients and contaminants before they can reach the groundwater. These processes are illustrated in Fig. 1.



Adapted from Jones et al 2006

Fig.1 Processes involved in using woody plants for the phytoremediation of wastewater streams.

2.4 Which plants can be used for phytoremediation?

When selecting plants to use to phytoremediate a wastewater stream there are a number of key characteristics which are highly desirable. These include:

- Fast growth, which will also normally be associated with high evapotranspiration rates i.e. the plants will utilise high volumes of water from the soil.
- Tolerance to potential contaminants in the wastewater stream.
- Ability to benefit from high nutrient levels, in particular N and P.
- Well developed fibrous root system which facilitates optimum water uptake and enables beneficial soil processes to occur.
- Potential end use for the plants.

Many different plants have been used for phtyoremediation including Alfalfa, Hybrid Poplar Trees, Blue-green Algae and some grasses. In many parts of the USA poplar has great potential. In Ireland SRC willow is considered to be the best candidate. Willow is fast growing and is a water demanding crop. Willow plants can use relatively high levels of N and P. Willow is also highly tolerant to many contaminants including some heavy metals. SRC willow is grown as a source of woody biomass which is used for the production of renewable energy.

2.5 What are the advantages / disadvantages of phytoremediation?

Advantages

- Cost effective method of dealing with large volume wastewater stream.
- Environmentally no negative impact on groundwater or surface water.
- Well suited for rural situations.
- Sites can be aesthetically pleasing.
- Sites once established are low maintenance.
- Is carbon saving requiring very little building or equipment and needing only a small amount of power to run the pumps. Compared to traditional WWTWs they can significantly reduce the amount of green house gases produced during water treatment.
- Sites have no noisy or expensive equipment and produce no smell or other distractions.
- Can handle a wide range of types of wastewater streams.

Disadvantages

- Requires suitable land close to (within 2km) the source of the effluent.
- Is slower than conventional methods.
- Is to some degree weather dependant and therefore may need a storage facility during periods of water-logged soils, frozen ground or during the winter.

2.6 Opportunities for phytoremediation in Ireland

2.6.1 *Wastewater Treatment Works:* Across Ireland there are hundreds of small inefficient WWTWs, which for much of the year, especially during the summer are non-compliant, discharging highly polluting effluent into small slow moving waterways. Often these works serve a small number of houses and would be prohibitively expensive to upgrade. They are most frequently in rural situations

Small waste water treatment works
(Inflow, aeration & settlement)

Closed landfill site showing recently engineered cap where there may be suitable land in close proximity, which could be developed as SRC willow phytoremediation sites. These are often old and due an upgrade as well as serving a population equivalent (PE) in excess of their design capacity. These factors, in conjunction with the tightening regulations dictating the treated effluent discharge quality (pressure from the Water Frameworks Directive and the Wastewater Treatment Directive), result in the requirement for discharge improvement. During the summer months in particular these effects are often compounded by the low flows in the receiving waters leading to poor dilution and exacerbated environmental damage and associated odours. The result being that some implementation of an infrastructure upgrade is often necessary. In order to avoid the significant costs and associated green house gas life cycles of traditional upgrades, SRC willow phytoremediation sites can be a feasible option as by definition, these rural WWTWs will often have land in close proximity for growing SRC willow.

2.6.2 *Septic tanks*: In the same way it is important to have a sustainable approach to the discharge from septic tanks. Completely lined zero discharge SRC willow systems are in use to manage the effluent from septic tanks.

2.6.3 *Industrial wastewater:* SRC willow is suitable for the management of many industrial wastewater streams, particularly high nutrient, high Biological Oxygen Demand (BOD) effluents which are produced by food processors. The treatment of such effluents is expensive both financially and environmentally when using conventional treatment works. Furthermore if the willow used for phytoremediation can be harvested and used to offset energy production from fossil fuels there is a double benefit.

2.6.4 *Farm wastewater:* SRC willow has been used successfully to manage farm wastewater which often contains high levels of nutrient and has a high BOD.

2.6.5 *Landfill leachate:* One of the most polluting and environmentally damaging effluents is the leachate produced by landfill sites. Landfills can continue producing leachate for many years after the site has been capped and closed, resulting in high ongoing costs for the site manager. Landfill leachate is highly contaminating, may contain heavy metals and can have a detrimental impact when introduced into a municipal treatment works. Careful deployment of SRC willow, perhaps growing on the cap could offer a cost effective and environmentally sustainable method of leachate management and recycling.

2.7 Use of SRC willow for the phytoremediation of effluents

2.7.1: *Principles of the technology:* Although the use of willow plantations for the recycling of effluents is in its infancy in Ireland, this technology application is currently being successfully employed elsewhere in the world, particularly in Sweden where treatment systems now operate under the guidance of the Swedish Environmental Protections Agency (EPA). Ireland's climate is arguably even more suitable for this practice as we have a longer willow growing season and the alternatives for effluent management are becoming more expensive environmentally and financially, particularly if they involve tankering or connecting to a sewer for treatment off-site.

Irrigation pipe-work into newly established SRC willow plantation

Many agri-food businesses, small rural treatment works and landfills are located in remote areas some distance away from major sewage treatment works and sewer connections and in these situations on-site effluent management using robust, environmentally sustainable, cost effective, low labour options may be favoured for many reasons.

In relation to the irrigation methodology, the guiding principle is that effluent should be applied in small doses and these volumes calculated to take account of soil and climatic conditions as well as the applied nutrient and hydraulic loadings of the effluent. This will ensure that the effluent has an adequate residence time in the active biofiltration root zone of the soil/plant system to ensure the removal of the nutrients present before any percolation through the system into the ground water. With regards to the nutrient uptake rates, it would be proposed to follow the Teagasc recommendations[1] (which are in line with UK RB209 Fertiliser Manual 8th Edition) when the crop is to be used for waste recycling purposes.

The biofiltration treatment system consists of four main components:

1. The environmentally controlled effluent distribution system (irrigation system).
2. Soil particles, which filter suspended solids and chemically fix dissolved components in the wastewater by adsorption, ion exchange and precipitation.
3. Macro and microorganisms, which transform and stabilise organic substances and transform nitrogen.
4. The willow plants themselves, which utilise macro and micronutrients in the waste for growth, and reduce the applied liquid volumes by high rates of transpiration. This plant root system also increases the filtration capacity of the soil and the activity of the micro/macroorganisms.

[1] http://www.teagasc.ie/publications/2010/20100223/Manual_Final_10feb10.pdf

An established willow plantation can assist in the management of effluents by means of high evapotranspiration. Simultaneously, hazardous compounds (e.g. ammonium and a range of persistent and potentially toxic organic substances) which could be present in landfill leachates and certain other effluents, are taken up by the willows or retained in the soil-plant system where they are denatured. A major measurable environmental contaminant in landfill leachate for example is ammonia. This is nitrified in the soil to nitrite and then to nitrate which is also a readily available plant fertiliser. A high concentration of ammonium ions in water is an environmental hazard, but if it is carefully monitored and applied, ammonium compounds can be a useful source of nitrogen for the willow plants.[2]

[2] Willows for energy and phytoremediation in Sweden - Short-rotation willow coppice is cultivated not only to produce biomass for energy, but also to treat waste products, taking up pollutants from soil and water - I. Dimitriou and P. Aronsson Ioannis Dimitriou and Pär Aronsson work in the Department of Short-Rotation Forestry, Swedish University of Agricultural Sciences, Uppsala, Sweden.
http://www.fao.org/docrep/008/a0026e/a0026e11.htm

3.0 SITE SELECTION

There are a number of options for dealing with a wastewater stream. These include: disposal down a sewer; treat via an on-site wastewater treatment plant / package plant and discharge; irrigate to local farmland; transportation by tanker to a local wastewater treatment works. However, as environmental regulations tighten and energy costs increase, these options can become less practical and affordable so the implementation of a low carbon environmentally sustainable solution such as irrigation to a fast growing energy crop e.g. SRC willow, can become increasingly attractive to handle any wastewater. If the irrigation to willow option is being pursued then care must be given to the site selection and several factors must be considered.

3.1 Location

Possibly the most influential factor when deciding on site selection is where the location of the arising wastewater or effluent is in relation to the land available for the establishment of a willow crop for biofiltration purposes. Suitable consideration of the potential use, in terms of appropriate biomass processing facilities, should also be kept in mind when scoping out such a project. The acceptable distance between the effluent production site and the willow irrigation site will depend very much on the volumes of effluent arising and the method by which the effluent is transported to the willow fields. If there are small quantities then the possibility of tankering may be practically and economically viable. However for larger volumes, this has not been the case and a pipeline and pump system is the natural choice for delivering the effluent to a storage tank and/or the irrigation site. Once the cost and carbon emissions of tankering effluent are taken into consideration, it becomes clear that an operation, using onsite storage and pumping to willow plantations close by, is a rational solution.

Planting SRC willow using a step-planter

3.2 Site slope and undulation

Given the above criteria, it is not always possible to find a perfect flat area of land for this activity as hills and undulations may be present. It is clear that this will give rise to a level of runoff which will have to be managed in one way or another. A small level of runoff can lead to channelling which in turn can exacerbate the extent of the runoff.

Management activities can include:

- Design irrigation so the least suitable areas receive lowest hydraulic loading and have significant buffer areas.
- Use of patterned (altered direction) planting of willows to increase soil surface roughness.
- Use of larger willow buffer strips.
- Introduce zoned irrigation time breaks.
- Employ bunding in certain areas.
- Employ an associated wetland / reed bed area.

3.3 Soil conditions

It is important to follow the recommendations[3] in terms of soil types which will provide acceptable establishment and yields, however willow is not an especially demanding crop when it comes to site requirements and will do well in differing soil types and environmental conditions. On occasion, areas for the growing of willow need to be constructed prior to planting. Although there can be concerns with the quality of the resulting growing medium, it is important to ensure as suitable a medium as possible is selected. These actions include up to a metre of substrate for the willow roots to grow into with a preference of 25 to 30cm good top soil for mechanical planting. It should also be recognised that heavy clay or highly compacted soils will result in poor percolation of rainfall and applied effluent into the rhizophere (leading to pooling and potential for runoff as well as potentially slow and restricted root growth) while very sandy soils may encourage soil absorption and percolation to too great an extent and give potential for leaching of nutrients and pathogens into the groundwater. As the willow crop develops and matures, certain beneficial changes are likely to occur in the soil with an increasing level of soil organic carbon, increased soil biodiversity (bacteria, protozoa, nematodes) and helpful root channel development to facilitate percolation and effluent spreading throughout the rhizosphere.

Currently, UK and Ireland regulation of this activity with landfill leachate, requires a sealed and capped area for leachate and any subequently contaminated rainfall arriving on the irrigation area. The application of this technology for dealing with landfill leachates is very much in its infancy in Ireland and UK and current research such as that explored in ANSWER, is serving to provide information for the gaps in our knowledge which currently exist.

3.4 Soil water availability

Willow requires more water than almost any other agricultural crop which serves to validate its high evapo-transpiration and biofiltration properties. This tolerance allows for occasional inundation which

[3] Caslin B., Finnan J and McCracken A. eds. (2011). Short Rotation Coppice willow: Best practice Guidelines. Teagasc and AFBI, pp. 71. [available online at: www.afbini.gov.uk/short-rotation-coppice-willow-best-practice.htm]

may occur from time to time given our climatic conditions. It should be noted however that even though this tolerance does exist, like other plants, willow roots do not function well in long periods of flooding where potential anaerobic root conditions might arise. However, if water becomes scarce, the plant will become stressed and close its stomata to conserve water, this will decrease the absorption of CO2 and slow down photosynthesis and the corresponding production of assimilated carbon and biomass growth. The process of irrigation, to a considerable extent, will prevent this from occurring.

3.5 Soil nutrient status

The crop is harvested every 3 to 4 years and in doing so, an amount of nutrient is removed from the site (essentially N, P & potassium (K)). Although willow has been shown to be extremely resilient to depleting levels of soil nutrition, it is preferable to maintain these levels within the nutrient guidance of the crop requirement. The irrigation of the effluents will serve to provide this.

3.6 People and domestic settlements

Although there does not tend to be any significant odours from these activities, it is prudent to ensure there are no local public concerns about this activity. This will normally be facilitated by local discussions and meetings however will be formally taken care of during the application processes with the regulator or local authority. If the site in question is likely to impact on the public, options for underground irrigation can be considered.

Fresh regrowth in the spring following a winter harvest

Established SRC willow plantation (approx 3 years old)

3.7 Utilities and services

The irrigation system will require electrical power; either single or 3 phase. At many potential sites, the availability of electricity and water will be close by however at some sites e.g. rural treatment works, the current wastewater treatment system may be no more than a combination of collection / retention tanks so power importation or renewable energy generation may be required.

3.8 Suitable effluents

Effluents from farmyards, fruit and vegetable processors, beverage, diary, other agri-food processors, composters, sewage treatment, leachates and many other operations have successfully or could be successfully recycled to plantations of willow grown as a biomass energy crop. Major constituents of wastewater will be N, P and BOD which, if allowed to enter the water bodies, would ultimately lead to excessive aquatic nutrient levels which could result in a eutrophic water status. As such, EU Directives and tightening local environmental legislation are causing more stringent consent limits on the discharge and the disposal of wastewater effluents and sludges. These tightening limits are leading to increasing costs for wastewater treatment which is often associated with higher capital expenditure, increased energy usage, higher carbon costs or the requirement for effluent transportation costs. The suitability of an effluent for treatment in this way will come down to several factors:

- The actual process giving rise to the effluent and whether the regulator can approve such an activity.
- The nutrient content of the effluent (what level of application will ultimately be sustainable and capable of regulatory approval).
- The consistency of the effluent.
- The potential yearly volumes and seasonality of generation of the effluent.

Depending on the quality of the effluent, there may be a requirement for some level of pre-treatment in order to reduce the concentration of certain constituents prior to irrigating to the willow. This may require adjusting pH, reducing the levels of BOD, Suspended Solids (SS), heavy metals or even N (eg NH_3 in certain landfill leachates).

Currently the Nitrates Directive allows for the all year round spreading of dirty water as long as suitable climatic conditions persist. With low nutrient concentration wastewaters like this, a very plausible proposal can be put to the regulator to consent to all year round irrigation. For more potent effluents, closed periods may be part of the consent conditions.

4.0 PLANTATION ESTABLISHMENT

The plantation should be established according to the best practice guidelines. It is invaluable to seek input from the private industry partners who will have important experience when it comes to suggesting the requirements of the site in terms of pre-planting land preparation (including work on ditches, culverts, hedges and other physical aspects which can improve the functionality of the site for willow production with effluent recycling) and machinery access.

After site selection (soil, pH, slope, elevation, access, proximity to waste stream, end product market for biomass chip), it is important that a good seed bed is prepared and cultivated to 25cm. Insecticide and herbicide treatment then follows. It is essential to use high quality and appropriately field trialled genotypes with characteristics such as high yield and disease resistance. It is important to remember also that the planting material is protected by Plant Breeders' Rights and thus planting stock must be obtained from specialist suppliers.

The preferred planting machinery is a Swedish Step Planter which plants in double rows 0.75m apart with 1.5m between rows, 0.6m spacing between plants within each row (15,000 cuttings ha^{-1}). Management of the crop post-planting up to cutback is crucially important as newly planted willow cannot effectively complete against most weeds. An application of pre-emergent herbicide prior to bud burst is recommended. At the end of the establishment year, the crop is cut back which encourages production of multiple shoots and prior to bud burst, an application of herbicide is recommended to control weeds.

Irrigation pipe with emitter cap releasing effluent

Irrigation pipe *in situ* in mature willow plantation

4.1 Irrigation Pipe laying

Current advice stands that the willow crop should be allowed a year, to establish an efficiently functioning root system, before any effluents are applied. Assuming this, a suitable occasion for the installation of the irrigation pipe-work is shortly after cutback. At this stage, when the cut back willow is commencing its re-budding, it is easy to see the double rows of willows and place the irrigation pipeline within these double rows (0.75m). Placing the field irrigation pipe-work along these double rows ensures that the pipes are kept clear of the wheels and cutting blades of the harvesting machinery. However, the irrigation pipe-work can be laid at anytime but it is more awkward when the willow crop is taller and denser. The placing of the main feed pipelines should be carried out with an understanding of the eventual harvesting methodology of the plantation. For this reason it may be a requirement to bury some pipes in order to keep them out of the way of the harvester. In certain circumstances however, and given that the harvest may not be until every 3 or 4 years, it may make practical sense to lift certain pipes prior to harvest and replace them subsequently.

4.2 Effluent application

An irrigation system should be chosen with several pre-requisites in mind. Essentially it must ensure the safe, reliable and even distribution of effluent throughout and across the whole irrigation field area, reducing as far as possible the occurrence of aerosols, odours and the potential of spreading disease. There are several methods by which effluents can be applied to willow plantations however the system described has received approval in both Northern and Southern Ireland and the regulators seem content that the processes and controls employed are compliant within the environmental requirements and monitoring and reporting regimes.

As SRC willow is commercially planted in double rows with 1.50m between double rows and 0.75cm within the rows, irrigation lines are surface laid every fourth row, i.e. at 9m intervals. Irrigation pipe work is installed allowing for 10 m un-irrigated margins and buffer zones at the edges of the willow plantation. The irrigation system consists of a storage facility (if required), pump, valves, filter, flow meter, main header pipes and irrigation pipe work with patented drip feeder caps or emitter points. Header lines are sized proportionately to the system requirements (taking account of the distance and elevation to be pumped and associated pressure and fluid velocity drops) and placed out of the way of field machinery or buried in places if required. Emitters are 3-4mm orifices covered by patented caps to ensure that a small amount of solids does not cause emitter blockages, that effluent moves horizontally ensuring distribution and that the creation of aerosols is prevented. The irrigation pump and associated equipment is controlled by a small computer (programmable logic controller or PLC). The irrigation of effluent will occur according to a timer, the sensory inputs, the internally programmed logic and the resulting motor outputs from the controller. The willow coppice is divided into zones approximately 0.5 ha in size to facilitate careful control over effluent application and each zone is independently and automatically irrigated (solenoid valves) depending on the sensory inputs (soil temperature, rainfall, soil moisture, zone irrigation). Data regarding the volumes irrigated and monitoring paramaters can also be used to feed into the controlling logic and can ultimately be uploaded via GPRS or modem facility to an on-line data handling application. The whole system should be automatically controlled under the careful scrutiny of the farmer or land steward. Running the system will however require some manual input on a week to week basis.

4.3 Monitoring

The requirement for monitoring the application of the effluent will help to satisfy the regulator that the technology is efficient, functional and compliant with the regulations set upon the activity. Monitoring will also help provide the necessary data and inputs to allow the irrigation system to react in real-time to the climatic conditions. Some of the monitoring requirements will also have a direct association with the consent or licence conditions set in force by the environmental regulator. The monitoring and reporting may require some or all of the following data to be gathered at intervals. Soil temperature, volume irrigated, groundwater and surface waterbody analysis, rainfall and possibly several other

Irrigation Real Time Flow Monitoring control panel


Programmable logic controller for automated irrigation control (13 ha site)

factors. Much of this monitoring can be done automatically and this data can also be used to feed into the controlling logic and can ultimately be uploaded via GPRS or modem facility to an on-line data handling application. The monitoring of the water however requires laboratory analysis and this data is not readily available automatically by remote sensors with affordable current technology.

4.4 Risks and risk mitigation

The irrigation of effluent to the willow plantation will continue automatically from day to day according to the preset logic and the external sensory data as outlined above. Keeping a careful eye on the whole system from time to time will reduce the risk of something going wrong and if something does happen then remedial action can be taken. With this in mind, the irrigation system should be designed with appropriate fail safes and alarm or notification facilities. The main concerns would be unplanned effluent release either during times when the climatic conditions do not allow (rainfall, waterlogging, snow) or due to a hardware malfunction (pipe rupture, pump not shutting off). The same is also true with regards to the efficiency of the system from the point of view of the operator. Effluent may not be irrigated on occasion due to pump malfunction, filter blockage, valve not responding, etc. With all this in mind, the inclusion of the following will help ensure risk mitigation to a large extent.

A **duty and standby pump** will avoid pump downtime and system inactivity. In the event of the duty pump not operating, an SMS alarm or email message should be triggered by any component of the pump system not operating correctly. The **default position** for all pumps and valves will be off, to minimise the risk of unplanned effluent release. An **automatic closed valve** would be an extra failsafe. This valve would automatically close when the pump stops due to the logic programme having run its course.

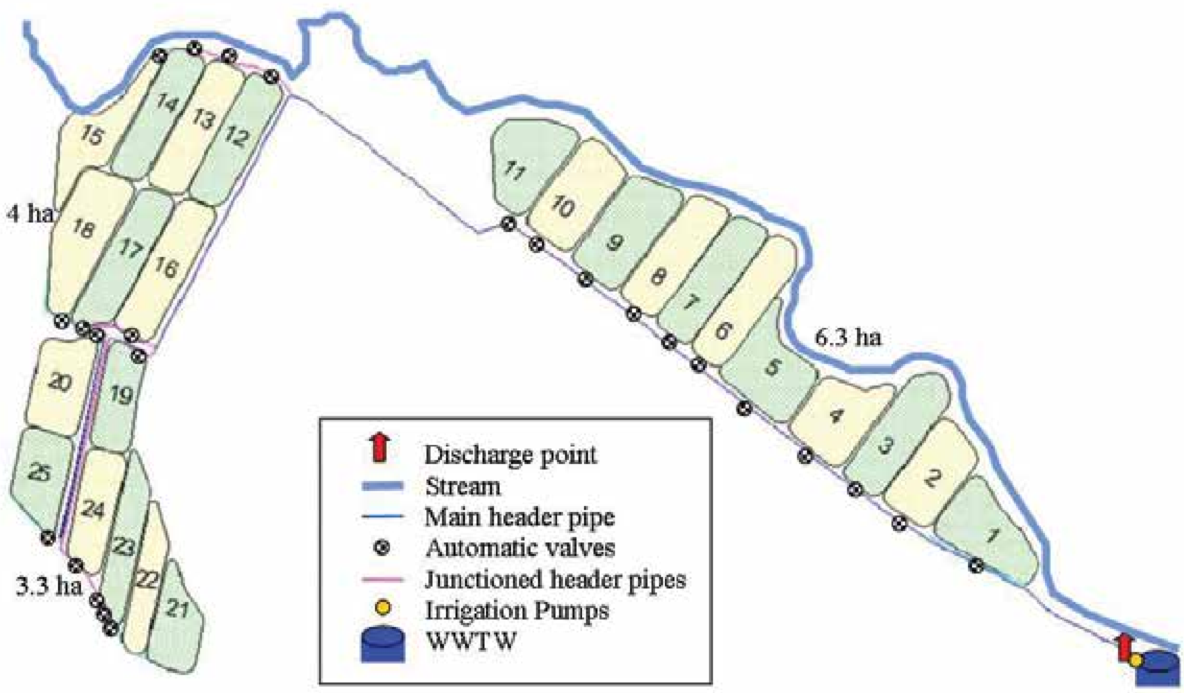
A **filter** is important to remove anything which might otherwise find its way into the field pipe system which could lead to blockages of the field effluent emitting apertures. This will reduce the risk of any

Bridgend Waste Water Treatment Works prior to refurbishment

Bridgend Waste Water Treatment Works post refurbishment uneven irrigation taking place in the irrigation zone and any long-term catastrophic blockages which may lead to the pipe-work having to be replaced. A **flow-meter** measuring the flow to the irrigation system will automatically log the actual volume applied to each irrigation zone per time period. This will also measure the flow rate which can be used within the programming logic to indicate signs of possible equipment malfunction (e.g. low flow rate might indicate filter blockage, pump obstruction, valve obstruction and high flow rate might indicate a problem such as a pipe breakage). Again in this eventuality an SMS alarm or email message should be triggered and the pump automatically switched off.

A system of **soil and air temperature monitoring probes** and **rain gauge** should be used to automatically inactivate the pump to prevent irrigation taking place in unsuitable environmental conditions such as saturated, frozen or snow covered soil.

The **application rate** should be only a proportion of the soil infiltration capacity which will minimise the risk of ponding or overland flow of effluent. The application of effluent should not commence until the crop has been **established for one full growing season** to ensure an acceptable level of crop water and nutrient uptake. The **intermittent application** (the functioning methodology of the regulator approved irrigation systems currently operating) of effluent will maximise the uptake of the applied effluent by the soil and plant system before the next effluent application is made. Irrigation pipes should not be laid closer than 15m from any streams / drains or other environmental water bodies.



Map of Bridgend plantation showing individual irrigation zones

4.5 Irrigation systems and controls

There are different systems and methodologies for wastewater irrigation[4]. The aim of whichever system employed should be to ensure an even distribution of effluent at a low level close to the soil surface to ensure reduced odours and aerosol formation maintaining hygiene. The hardware should be positioned in such a way as to not interfere with any harvesting or other agricultural machinery and should be manufactured from materials which are robust and long lasting. The overriding factor of course is that such systems should be economically practical to ensure these environmentally sustainable solutions are utilised.

With the overriding principle being to work with the infiltration and absorption capacity of the soil, it is important that the controls allow irrigation flexibility in order to take this into consideration. Current systems operating under regular approval are controlled as follows: Each zone (approximately 0.5ha in size) is separately controlled by the controller.

A **timer** will turn the pump on and the irrigation programme will commence. A **set** volume of effluent is pre-programmed to be irrigated to each zone per day and each **irrigation episode** is for a certain **volume**. These values can be altered depending on the zone size and infiltration capacity of the site. The controller will systematically rotate through the zones in such a way as to apply effluent to one (or more) zone at a time before moving on to the next zone. By the time the irrigation cycle returns to that particular zone, the soil will be ready for the next irrigation episode as the previously irrigated effluent will have by then infiltrated the soil. Once the whole programme has run, the pump turns off and waits to be automatically turned on for the next cycle programmed by the timer.

Any alarms which might trigger during this irrigation cycle (low flow, high flow, tank low level, soil temperature or rainfall) will turn the pump off ceasing irrigation and send a SMS or email to the operator if necessary. Only after this issue has been remedied (automatically or otherwise) will the irrigation recommence. Data can be uploaded either in real-time or at certain points of the day. This data may include temperature, rainfall, pump time, volume irrigated by zone and anything else which the controller is measuring. The control systems should be robust with little need for maintenance. It is advisable however to make sure the sensory equipment installed is robust and operational as they stand open to the elements, e.g. soil probes and rainfall measurement equipment can be disturbed by wildlife.

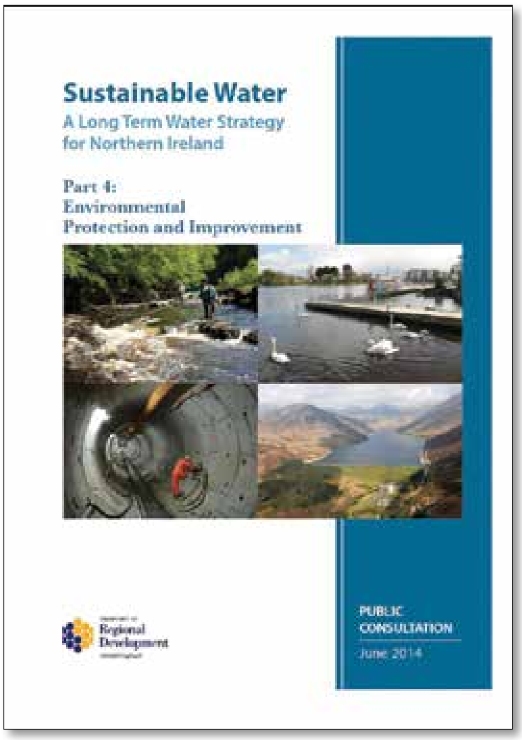
[4] BIOPROS project - SRP Guidelines -Published: 2008. European Commission within the Sixth Framework Programme (FP6) under the project "BIOPROS – Solutions for the safe application of wastewater and sludge for high efficient biomass production in ShortRotation-Plantations"

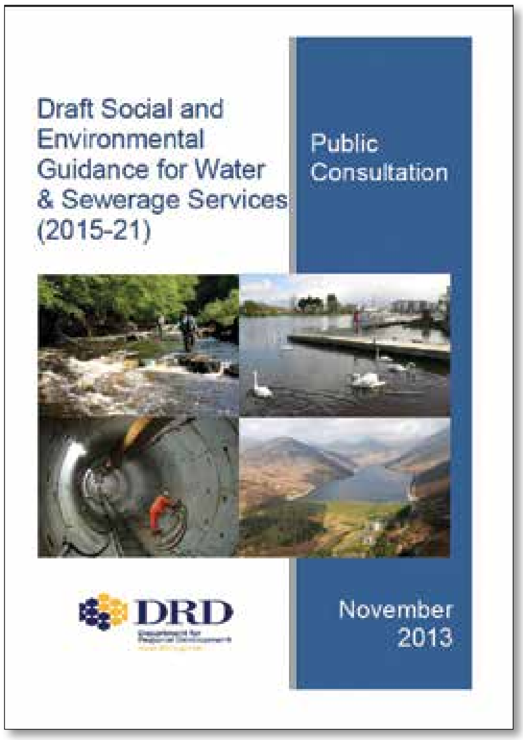
5.0 LEGISLATION & REGULATION

5.1 Northern Ireland

In N. Ireland, the Department of the Environment (DOE) consent to the discharges of wastewater to the environment in accordance with the Water (Northern Ireland) Order 1999 and this consent will be subject to many conditions. The awarded discharge certificate will have been assembled with full knowledge of the willow irrigation proposal, controls and mechanics. Part of the licensing procedure is the issuing of the intended consent to the public and all stakeholders for consideration and comment.

5.1.1 *Monitoring*: The wastewater shall be sampled and monitored in regards to a maximum daily and annual volume and the volume of effluent applied to the land area must be continually monitored. The effluent must be spread uniformly via an approved irrigation pipe network. The application of effluent shall not be permitted when the soil moisture level is greater than 80% (or otherwise stated), the soil is waterlogged, the land is likely to flood, the soil has been frozen for 12 hours or longer in the preceding 24 hours, the land is snow-covered or heavy rain is forecast within the next 48 hours. The application of effluent is not permitted to field slopes of greater than 20% and there must be no effluent application within 15 metres of any surface water body at any time, or within 50 metres of a borehole used for drinking water, spring or well. This excludes the monitoring boreholes.





Department of Regional Development consultation documents on Water StrategyV

During these conditions, alternative back up plans must be available such as storage, tankering off site or a variable discharge consent agreement must be in place.

Upstream and downstream water must be monitored and analysed on at least a quarterly basis for the following parameters:
Biochemical Oxygen Demand (BOD) (measured after 5 days at 20° C with nitrification suppressed by the addition of allylthiourea), Suspended solids (measure after drying at 105° C), Total Nitrogen, Total Phosphorous, pH and Dissolved Oxygen (milligrams per litre).

If the waterway breaches certain limits for the above then effluent irrigation may have to cease. These limits may vary depending on the receiving water body.

For groundwater, the positioning and number of boreholes can be advised and drilled by a reputable hydrology company. The ground water must be self monitored and analysed on at least a quarterly basis for the following parameters: Total oxadised Nitrogen, Total Phosphate, pH and if any visible oil or grease is contained. These will be site specific and again any level breeches may result in the irrigation activity having to cease.

Extracting groundwater sample from borehole

The borehole sample points for the groundwater monitoring shall be labelled and maintained so that they are freely available and accessible for inspection and/or sampling by the regulator and the agreed self-monitoring regime must be adhered to.

The treatment system must be maintained to ensure that the consent conditions are met at all times.

5.1.2 *Reporting:* The environmental regulator will insist on regular reports concerning these systems. Initially the intervals between reports could be as short as monthly. However as much of the day to day data can be automatically uploaded, this facilitates much of the reporting requirement. This data should be retained by the consent holder for a minimum of two years and should include volumes of effluent applied to the willows, effluent quality (Biochemical Oxygen Demand, Total Nitrogen, Total Phosphorus, Suspended Solids, pH), upstream and downstream water quality (Biochemical Oxygen Demand, Total Nitrogen, Total Phosphorus, Disolved Oxygen, Suspended Solids, pH), bore hole data (Total Nitrogen, Total Phosphorus, pH, Fats, Oils or Grease), soil (Phosphorus index) and climatic data such as rainfall & air temperature.

5.1.3 *Variable Discharge Consenting:* With the specific example of using willows to treat effluent from small scale rural treatment works, the environmental benefit of recycling as much of the treated effluent as possible to a willow crop thus reducing the total outfall to the stream, seems clear. Through cooperative working with the regulators and exploring ways and means of regulating these activities, there is an opportunity for better regulation which could be potentially missed.

As outlined, when effluent cannot be applied to the willow plantation due to adverse weather conditions (normally rainfall in Ireland but can be due to frozen ground or snow cover), then an alternative solution must be available for disposal of the effluent. With this technology, there will often be a requirement for a storage tank at or near the willow site. During this investigation it was quickly realised however that for small irrigation sites, which is the sector in which this technology can certainly play a vital role, the construction of a storage tank would represent a disproportionate financial and carbon cost and ultimately be impractical. Furthermore, the storage of effluent during wet periods when the streams are in flood and running fast and freely seems counterintuitive. These are the occasions when straight discharge to the stream does least damage due to the high level of dilution.

Variable discharge consenting, for the small (< 250PE) treatment works, allows a willow recycling option to work in tandem with a traditional treatment works. The first "proof of concept" project running on this methodology was recently commissioned in N. Ireland (CASE STUDY). The data will serve to outline to what degree this regulatory flexibility has on the overall functionality of the system and in essence what is the total quantity of nutrient being removed from the waterway and instead being recycled to a biomass plantation for future renewable energy requirements.

"…When these conditions prevail the treated effluent shall discharge to the nearby watercourse"

5.2 The Republic of Ireland

In the Republic of Ireland, the Local Authority Environment Section will want to investigate the proposal fully to confirm that the scheme is in compliance with regulation and is good practice. It is advisable to discuss proposals at an early opportunity. All potential risks associated with the irrigation of treated wastewaters to a willow plantation should be considered along with a number of pieces of legislation including:

- S.I 31/2014 - European Union (Good Agricultural Practice for the Protection of Waters) Regulations 2014 and
- SI 272/2009 - European Communities Environmental Objectives (Surface Waters) Regulations 2009 (as amended) and
- SI 9/2010 - European Communities Environmental Objectives (Groundwater) Regulations 2010 (as amended)

Wastewater treatment facility proposals will require the consideration of sensitivity of location with regard to site suitability, groundwater vulnerability, sensitive buildings and proximity to protected areas including water supply sources. Predicted removal rates for BOD, phosphorus and ammonia/nitrogen should be given with appropriately referenced documentation.
Any proposed development for wastewater treatment facilities should also include the consultation with the planning authority re land-use changes. The discharge to waters (surface or groundwater) will require a discharge licence under Section 4 of the "Local Government (Water Pollution) Act 1977 and 1990. The use of SRC willow plantation as part of a tertiary treatment proposal for an existing licensed discharge may require an application for a review of the discharge licence. The discharge licence application process may overlap to some extent with the requirement for planning permission where infrastructure is proposed.

From the point of view of a Public Authority looking to obtain permission for the construction of a system to irrigate in this manner, planning approval for the scheme must be sought under Article 8(1) of the Planning and Development Regulations, 2001 (S.I. No. 600 of 2001) - (refered to as a Part VIII application when the Council is making an application). This may often actually be the case when effluent is to be irrigated from a public wastewater treatment works.

Northern Ireland Nitrates Action Programme Guidance Booklet

EU Water Framework Directive

The information required for this application will include:

- Completed planning application.
- Copy of Site Notice.
- Copy of Newspaper Advertisement.
- Additional Contact Information form.
- Letter from landowners (permitting use of land).
- Written summary of proposal.
- Six copies of all drawings including the site plan 1:4000, site plan 1:200, sections 1:75.

It is strongly advised that the local authority Environment Section is made aware of the project well in advance of any application being made. The application and supporting documents will be assessed by, and commented on by a range of relevant / interested individuals and groups before approval is granted.

Certain concerns which are likely to be raised during the planning process may include:

- Will there be odours from the effluent? (restrictions on proximity can be put in place)
- Will there be any likelihood of contamination of wells? (monitoring and proximity restrictions can be put in place)
- Will the willows block out the sunlight?
- What will the crop do for biodiversity?

Public wastewater treatment plant proposals will require consultation with the EPA regarding appropriate certification or authorisation depending on the size (PE) of the wastewater treatment facility.

6 CASE STUDIES

6.1 Industrial Effluent Discharge - Linwoods

6.1.1 *Client and Background*: Linwoods milk processing and bakery operation near Armagh produces a wastewater which arises from the cleaning of equipment used in the processing of milk and in the bakery. The bakery contributes about 10% of the wastewater production. The processing plant operates six days a week and wastewater is produced seven days a week. Wastewater production is currently 385 to 400m^3 weekly (20,000 – 21,000m^3 annually) rising to approx 26,000m^3 annually. The raw wastewater is treated in a surface aerated tank. Aeration operates continuously for 15 hours daily. It is then switched off to allow particulate matter to settle with the effluent being drawn off the top and stored, while the sludge is removed to a sludge tank. Currently, the final effluent from the treatment facility is taken by road tanker to the Water Service sewage treatment works at Armagh on a daily basis. There is no facility for discharging the effluent direct from Linwoods' premises.

Effluent irrigation into recently harvested SRC willow plantation

Zonal distribution pipes with irrigation pipes prior to burial

6.1.2: *Objective and Challenge:* The client required an alternative method of managing its wastewater which would be more sustainable, lower cost and support the local farming economy. Partially treated wastewater was transported 7 miles by road tanker to the Water Service sewage treatment works at Armagh. This was expensive and emitted around 7.5 tonnes of carbon annually to the atmosphere. In addition, the Water Service was unable to accept any excess wastewater from Linwoods which limited any potential expansion of the bakery and milk processing facility.

6.1.3 *Solution:* A 12.9 ha plantation of short rotation willow coppice was established on a neighbouring farm which is irrigated with the partially treated effluent. The irrigation system consist of a storage tank, duty and standby pump, automatic and manual valves, filter, flow meter, main header pipes and irrigation pipe. Each zone is atomically irrigated (controlled by the PLC) depending on soil temperature, soil moisture, rainfall, zone irrigation volume history etc. Data regarding the volumes irrigated and monitoring data is recorded.

6.1.4 *Monitoring and Nutrient Loading:* The regulator enforces compliance with the 'Quality Conditions of the Waterway', the 'Conditions of Discharge', 'Conditions for Application' and the other 'General Conditions' with their own and the consent holders individual monitoring regimes. Soil moisture and volume of effluent supplied to the plantation (by zone) is monitored daily and the data supplied to the regulator on a yearly basis. A small stream crosses the proposed site which is sampled every two weeks to monitor its upstream and downstream water quality, however there is no discharge to this waterway. Upstream and downstream water samples are analysed fortnightly for (BOD, SS, Total oxidised N, Total oxidised P, pH, Dissolved O_2), these are also reported to the regulator as soon as they are available. The soils are analysed for P in accordance with the 'Phosphorus (Use in Agriculture) Regulations (Northern Ireland) 2006' and monitoring of the effluent continues at the Linwoods factory prior to discharge to willows (Chemical Oxygen Demand, BOD, SS, ToN, ToP, and pH).

The hydraulic and nutrient loading on the system at present tends to be approximately 2800 m^3/ha/ Year of effluent. This supplies about 150Kg Nitrogen/ha/year and 6Kg Phosphorus/ha/year – both of which are well within the sustainable level of nutrient assimilation by SRC willow.

6.1.5 *Benefits.* There were benefits in three areas:

Financially - The previous costs of transportation of the effluent the 7 miles to the treatment works has been replaced by the pipeline (from factory to irrigation site). The cost (COD and SS based) charged by the treatment works is now replaced by the gate fee charged by the farmer per m^3 of effluent (this alone is providing significant savings to the factory and earnings for the willow farmer). The irrigation system is robust, needs little maintenance and requires minimal operational and running cost.

Environmentally - There is no discharge to the stream with all the dirty water being recycled. There are carbon footprint savings in taking a vehicle off the road and diverting a waste stream from the treatment works activities and subsequent energy requirements. There is also the production of carbon neutral wood fuel for biomass boilers diverting energy use derived from fossil fuels.

Community - This project is stimulating and supporting the diversification of farming as well as ensuring the supply of local non fossil fuel wood biomass energy for the community.

6.2 Variable Effluent Discharge - Drumkee

6.2.1 *Client and Background:* Northern Ireland Water (NIW) are the sole provider of water and sewerage services in Northern Ireland, with over 780,000 domestic, agricultural, commercial and business customers. They are a government owned company (GoCo) – which is a statutory trading body owned by central government but operating under company legislation, with substantial independence from government. NIW is dedicated to providing the community it serves with water and wastewater services which meet regulatory requirements at the lowest sustainable cost.

Drumkee Waste Water Treatment Works prior to willow irrigation scheme

6.2.2 *Objective and Challenge:* As 2015 and the imposition of new water quality legislation including the EU Water Frameworks Directive approaches, the Wastewater and Farming and Food Industries are trying to find innovative ways to deliver compliance, while reducing costs and environmental impact. NIW is one such company and has recently embarked on their first twenty year contract to use SRC willow to clean wastewater from a small rural treatment works.

DRD Minister opens Drumkee, NIWater's first Proof of Concept SRC willow irrigation scheme. (also representatives of NIW, NIEA, AFBI, Resourceful Organics & landowner)

6.2.3 *Solution:* Screened and settled raw wastewater gravitates into a pump sump where two submersible pumps pump effluent from the effluent chamber (controlled by and high and low level float switches and environmental stimuli), through filters, along two mainline feed pipes (each from one of the two submerged pumps) to a 1 ha SRC willow plantation and biofiltration module. A rain gauge measures rainfall events and will automatically prevent irrigation taking place should soil moisture levels be too high. If such conditions persist, effluent will be discharged to the river. This has been agreed by the Northern Ireland Environment Agency (NIEA) under a 'Variable Discharge Agreement'. Soil temperature probes will be used to ensure that irrigation does not take place when the soil is frozen or snow has fallen. Automatic data recording of volume of effluent irrigated per day, soil temperature and rain fall is also active. This data will be supplied to the NIEA and NIW on a monthly basis by uploading to an on-line web-based application via GPRS link. There is also ongoing analysis of boreholes and the stream for ground and surface water quality.

6.2.4 *Monitoring and Nutrient Loading:* The regulator enforces compliance with the 'Quality Conditions of the Waterway', the 'Conditions of Discharge', 'Conditions for Application' and the other 'General Conditions' with their own and the consent holders individual monitoring regimes. The hydraulic and nutrient loading on the system at present is estimated to be between 1900 to 4000 m^3/ha/year of effluent. This supplies between 87 and 180 kg N/ha/year and between 6 kg and 14kg P/ha/year – both of which are well within the sustainable level of nutrient assimilation by SRC willow.

6.2.5 *Variable discharge consenting:* The project established a landmark change in NIW's regulations, namely 'Variable Consenting', allowing the discharge from a treatment system to be synchronised with the current environmental conditions. Discharges to waterways are far more diluted during times of heavier flow (principally rainfall), when application to land is least environmentally preferable. When stream flow is low due to low rainfall, application to SRC willow is far more environmentally sound than discharge into a low-flow /low-volume receiving water body. The Drumkee Project has proved this concept: according to NIW "This technology is the only one which offers zero carbon wastewater treatment."

6.2.6 *Benefits:* The benefits to NIW will be the improvement of the yearly outfall of pollution from the treatment works. A willow plantation has an estimated life of approximately 25 years and this scheme will be a beneficial improvement over the upgrading of the treatment works in terms of reduced carbon footprint, introduction of environmental sustainability, cost efficiency of treating the effluent and reduction in capital expenditure. In terms of carbon footprint and climate change, the growing of 1 ha of willow for biomass would not only contribute to the local farming community but produce approximately 10 tonnes processed dry wood chip per year which would provide approximately 39,000 kWh energy – enough to supply the heat requirement for about 1 to 2 domestic houses. Over 15 years, this project is estimated to save NIW 50% in cost and 1500% in CO_2 emissions.

6.3 Municipal Discharge (WWTW) – Bridgend project

6.3.1 *Client and Background:* This wastewater treatment works at Bridgend was installed in 1975 where the outfall discharges the treated effluent into the River Skeoge. The works themselves currently have a capacity equal to 260 PE, but serves a PE of approximately 500. The existing treatment works is based on the extended activated sludge process and the works comprises the following:

- Inlet Manhole
- Aeration/Settlement Tank
- Control Building/Store
- Outlet Manhole
- Outfall to River

The tank consists of two compartments- aeration and settlement. A 225mm diameter inlet sewer from the village and from a council estate feeds the aeration/settlement tank. An air blower in the control building feeds air distribution pipework in the aeration compartment of the tank. Following treatment within the aeration tank, wastewater overflows to the settlement compartment where it is allowed to settle prior to discharge to a 150mm diameter outfall pipe.

6.3.2 *Objective and Challenge:* The Skeoge River currently has a Q value (The EPA scheme of Biotic Indices and Quality (Q) Values) of 3, although it fluctuates between 2 and 3. This indicates that this river is moderately polluted and is classified as Class C meaning the river has little fishery potential and reduced amenity value because of unsatisfactory conditions. Therefore in order to assist with the increase of the Q value for the River Skeoge the amount of ammonium **(NH_4^+)** would need to be kept to a minimum for the treatment works at Bridgend.

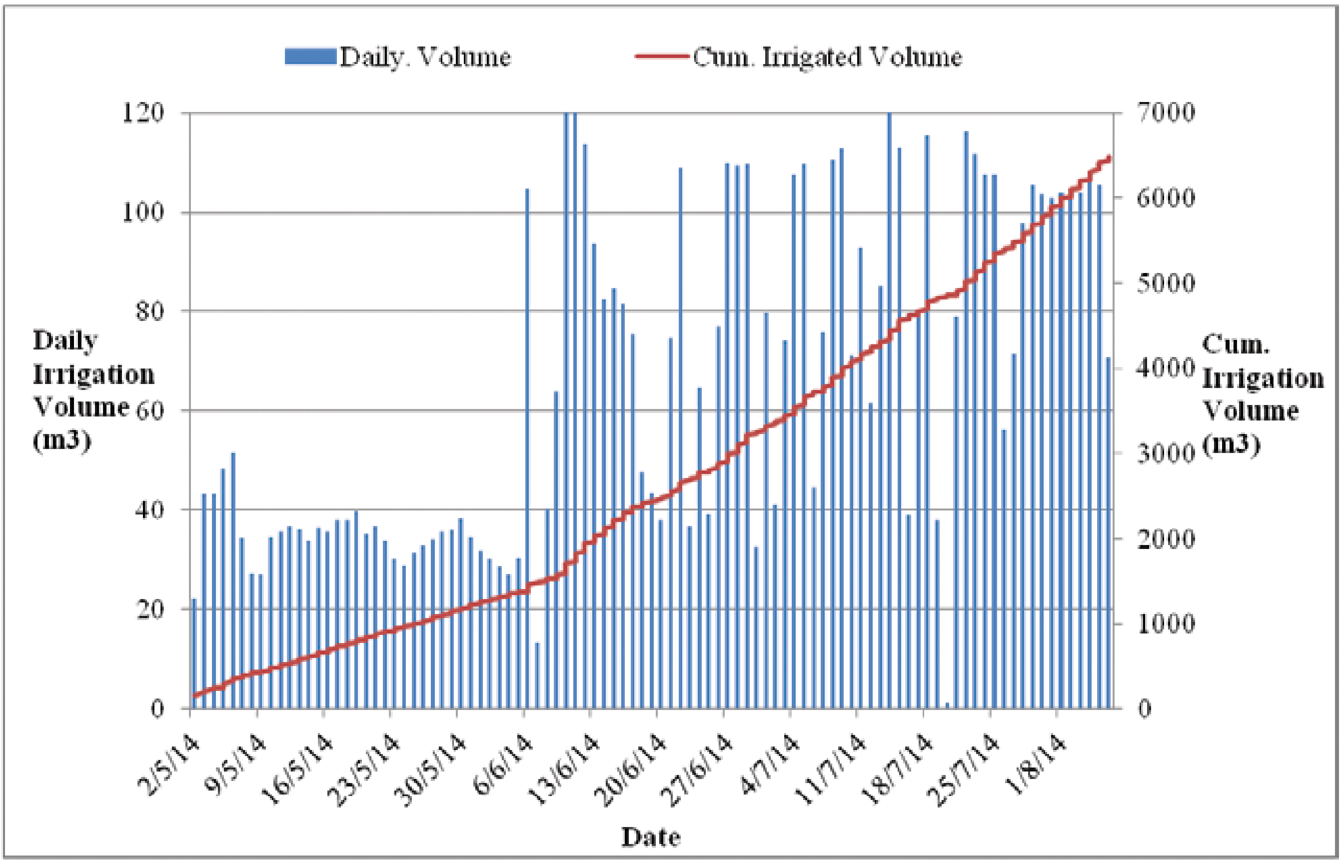
Automated solenoid valve assembly (controlling application to one zone)

Bridgend effluent storage tank with pump and filter assembly

6.3.3 *Solution:* Secondary treated wastewater overflowing from the settlement tank is pumped into a storage tank where it is stored and irrigated to a 14ha willow plantation. Automatic systems will prevent irrigation taking place should soil moisture levels be too high or when soil is frozen or covered with snow. Automatic data collection of volume of effluent irrigated per day, soil temperature and rainfall is uploaded to an on-line web-based application via GPRS link. There is also ongoing analysis of boreholes and the stream for ground and surface water quality.

6.3.4 ***Nutrient and hydraulic Loading:*** An estimated flow for 500 PE (estimated 31,000 m^3 yr-1) will give an irrigated hydraulic loading of approximately 2400 m^3 $ha^{-1}yr^{-1}$. At the measured outfall concentrations of N and P, these application rates are well within the Teagasc recommendations for SRC willow nutrient requirements and off-take.

6.3.5 *Benefits:* The benefits to Donegal County Council will be the improvement of the yearly discharge of pollution from the treatment works. A willow plantation has an estimated life of approximately 25 years and this scheme will be a beneficial improvement over the upgrading of the treatment works in terms of reduced carbon footprint, introduction of environmental sustainability, cost efficiency of treating the effluent and reduction in capital expenditure.



Graph showing daily and cumulative irrigated effluent volumes applied to Bridgend over a three month period.

6.4 Landfill leachate recycling

6.4.1 *Client and Background:* Donegal County Council is developing innovative methods to treat leachate / contaminated waters arising from a closed landfill. The landfill was closed in August 2000 and was temporarily capped. Under the conditions of the licence the site was not permitted to accept any other waste other than inert waste. No waste was accepted at the site after August 2000.

6.4.2 *Objective and Challenge:* To implement a sustainable treatment methodology for the management of the polluting leachate emanating from the landfill site thus negating the requirement for the cost and carbon intensive tankering of leachate off-site.

6.4.3 *Solution:* The use of a willow plantation to biofilter the leachate offers an achievable solution for improving significantly the environmental performance of the site. The landfill was reformed to create the necessary topography and clay cap material imported overlain by a suitable depth of top soil. Infrastructure was also included to allow for the collection and separation of leachate and rainfall allowing for the analysis of run-off and subsequent decision making as to the discharge or re-circulating of the leachate. The willows were planted during June 2014. The plantation was left to become established prior to the commencement of leachate irrigation planned for summer 2015.

Lysimeter with growing willow at Ballynacarrick landfill site

6.4.4. *Nutrient and hydraulic Loading:* Water balance calculation was carried out to estimate the volume of leachate formed to be approximately 24,000 m^3/year maximum. The hydraulic loading on the SRC willows will be substantial however the design of the site is such that any run-off will be collected, analysed and if necessary recycled to the cap for further biofiltration. The N loading from this volume of effluent will depend on the concentration in the contained and collected leachate which is variable depending on where it is currently collected for testing. Calculations and estimations indicate that the N loading will be within the nutrient assimilation capacity of the SRC willow plantation.

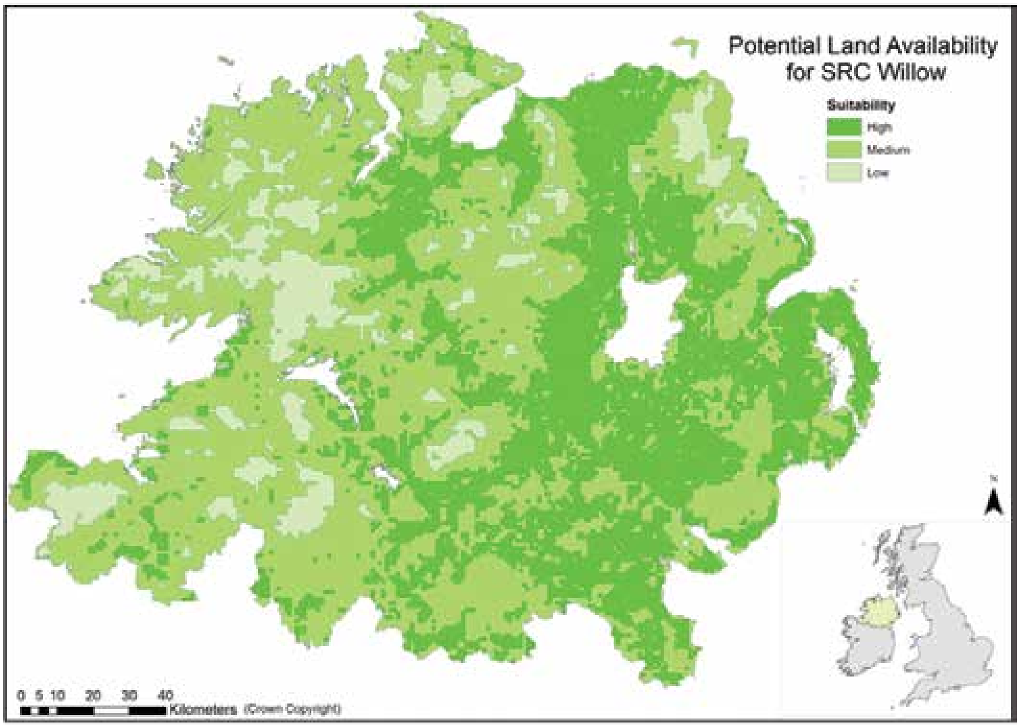
6.4.5 *Benefits:* The solution presented above offers an achievable solution for improving significantly the environmental performance of the site. It is an alternative to conventional restoration and while the technology has not been used in Ireland on this scale, experience from other countries has indicated that this solution offers a cost effective and sustainable solution for dealing with leachate at the site. The research that this site will generate will assist Donegal County Council, the EPA, NIEA, researchers and all other stakeholders concerned with the drive for effective sustainable engineering solutions for the capping of closed landfill sites and the subsequent handling of polluting leachates.

7.0 IDENTIFICATION OF SUITABLE LAND (GIS)

Identification of Land Suitability for Short Rotation Coppice (SRC) Willow and Bio-remediation of effluents using Geographical Information Systems (GIS) technology

Identifying the potential land suitability for Short Rotation Coppice (SRC) Willow is an important step in the drive for greater adoption of the energy crop, which is fast growing, high yielding and virtually carbon neutral. Willow has long been noted as the most suitable woody biomass crop for the region, given its ability to grow quickly in a wide range of conditions; however, yield potential will depend on specific factors unique to its particular location. The geographical area in question, Northern Ireland and the bordering counties of the Republic of Ireland, has a high dependency on imported energy which impacts on both energy security and the local environment. The challenge is to spatially identify the available and most suitable opportunities for the growth of sustainable and carbon neutral sources of energy.

The research utilised Geographical Information Systems (GIS) technology to address the spatial queries relating to the suitability of land for the adoption of renewable energy crops. Specifically, a Multi-Criteria Decision Analysis (MCDA) approach was adopted, where various conflicting parameters can be incorporated into a single conclusion. In excess of 100 primary and secondary datasets were integrated into the decision analysis, focusing on the most prominent parameters affecting willow growth, namely, soil conditions (composition, macro-nutrients and pH levels), site location (elevation, slope, current land-use, protected areas, access) and meteorological conditions (rainfall levels, growing days, frost days).



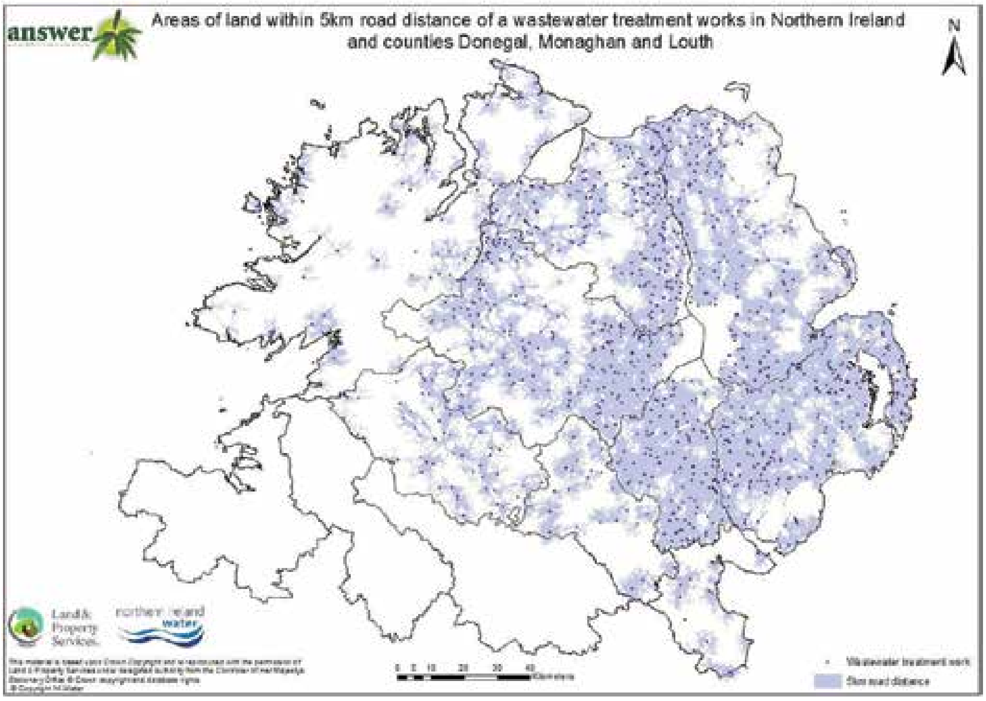
Geographical Information Systems (GIS) map of potential land suitability for growing SRC willow

Building upon existing knowledge of successful SRC Willow growth the various datasets were classified according to suitability and amalgamated by the associated parameter to develop an accurate representation for the region. This allowed for the MCDA to be conducted with the incorporation of the relevant parameters and preferential weighting given to the most influential variables. The resulting analysis identified potentially 870,000ha of 'high suitability' land, which was 33% of the total Northern Ireland and Republic of Ireland border county study area. Furthermore, only 11% of the total study area was classified as 'low suitability' for growing SRC Willow. The 'land suitability' map produced is the most accurate assessment of SRC Willow potential in the region to date.

In the study region, Northern Ireland comprised 70% of all the 'high suitability' locations identified, with a definitive spatial trend developing between the east and west of the region. The most prominent area identified extended from the North Coast, between Ballycastle and Portstewart, and southwards towards counties Monaghan and Louth. This encompasses the greater Lough Neagh region including towns such as Ballymoney, Magherafelt, Cookstown, Portadown and areas in proximity to Newry and Monaghan Town. The exception to this eastern trend was most notably the mountainous regions of the Mourne Mountains and the Glens of Antrim. Although less prominent, there were specific areas which displayed high potential for SRC Willow adoption in the remainder of Northern Ireland, such as the greater Omagh area of Co. Tyrone towards Ballygawley and the area surrounding Limavady and ranging towards Dungiven. In Co. Fermanagh there was a notable area directly adjacent to upper Lough Erne, particularly in the Lisnaskea and Newtownbutler areas which spread south to Belturbet in Co. Cavan and eastwards to Clones in Co. Monaghan.

The Republic of Ireland counties in the study showed limited sections of 'high suitability' locations; however, there were certain areas which have been identified. These sites were predominantly coastal; specifically locations surrounding towns such as Bundoran (Co. Donegal), Ballymote and Tobercurry (Co. Sligo), with a distinct area prominent in the Inniscrone and Rathlee region of County Sligo. Although there was not an excessive amount of 'high suitability' land identified in these counties, there was significant potential in certain regions; in County Donegal for example, the Ramelton area and the region eastward from Letterkenny which encompasses the greater Derry City area and southward to include the area surrounding towns such as Lifford (Co. Donegal) and Newtownstewart (Co. Tyrone).

Within the aforementioned counties there were significant areas classified as 'medium suitability' whereby one or several parameters influencing the successful growth of the crop failed to be within the most desirable range. Only 9% of the total area of County Donegal was classified as having 'high suitability', whilst a further 66% was identified as having 'medium suitability'; as a result, it may be possible to take measures to address the deficiency of a specific factor to obtain a successful high-yielding SRC Willow plantation. This is a benefit of the MCDA adopted in the study, whereby each parameter which has an influence on growth is developed and then subsequently incorporated to form an overall spatial representation. As a result, this permits the identification of the parameters which have specifically influenced the overall suitability classification. One example of this was soil pH levels across the study area in relation to successful SRC Willow growth. The analysis determined that 31% of the region had 'high suitability' on pH levels, whilst a further 47% was classified as 'medium



GIS map indicating areas of land within 5km of a Waste Water Treatment works

suitability', as it fell just outside the parameter for ideal conditions. In practice, a site which does not have an ideal pH for example can be amended by various measures such as liming to amend the soil acidity to an optimal level for SRC Willow growth.

The study is also unique as it includes the bio-remediation potential for SRC Willow; focusing on the proximity to effluent sources and the potential to access such sources. In the analysis of the bio-remediation related parameters specifically, the analysis identified that only 4% of the entire study region would be classified as having 'low suitability' for site access in relation to the existing infrastructure and road network. This was a positive indicator for the potential future development of SRC Willow uptake in that there is capability and capacity to utilise the sites identified.

The GIS analysis conducted represents the most detailed assessment of land suitability for SRC Willow in the region which will help landowners and other stakeholders to inform their decision making on the most suitable land for willow production and potential bio-remediation utilisation. The study offers new opportunities for landowners in the region, especially given the increased vulnerability of conventional agricultural production in the overall economy. Furthermore, it addresses the need to contribute towards renewable energy targets, reduce dependency on fossil energy and enhance the development of a more sustainable and indigenous energy region.

An important role is played by studies of this nature in encouraging the growth of renewable crops by transferring knowledge and increasing consumer confidence. Further to the practical application of the research, this study acknowledges the potential of GIS for other energy crops within the region. In addition, applying similar research principles elsewhere will further realise the potential for SRC Willow as a sustainable, renewable energy crop.

8.0 CONCLUSIONS THE FUTURE

The demands on the water utilities will continue to increase as regulations, government targets and society insist on cost-effective and environmentally sustainable approaches to wastewater management. Water treatment is energy demanding with the associated release of damaging green house gases (GHGs). Particularly in rural areas in many parts of Ireland, WWTWs are small, inefficient and frequently unable to produce an effluent which can be safely discharged to waterways and rivers and as such are non-compliant with EU water quality regulations. The cost of up-grading such works can be prohibitively expensive with high carbon footprints. For these reasons biological land based systems such as the use of SRC willow to bioremediate / biofiltrate effluents provides a very attractive alternative with the added advantage of presenting true recycling of nutrients which would otherwise cause waterway pollution into a sustainably produced low carbon renewable energy biomass fuel.

The technology is based on robust science conducted primarily in Sweden and Northern Ireland demonstrating the efficacy of using willow in this way. The establishment of industrial sized projects as part of ANSWER has demonstrated the commercial feasibility and practicality of developing willow treatment plantations. These sites have also given the regulators in both Irish jurisdictions the confidence to consent this approach. When SRC willow bioremediation was first discussed with the respective Environment Agencies there was real concern about the environmental risks associated with applying effluent or leachate to growing willows. While the regulators will examine very closely the proposals for any new scheme, in general there is a strong willingness to award appropriate consents in order to implement further sustainable low carbon wastewater treatment technologies.

This technology is best suited to small, remote WWTWs, which are in rural settings and are therefore frequently in close proximity to suitable agricultural land for growing SRC willow. The GIS studies carried out as part of the ANSWER project have identified that there is huge potential to plant and

Mature SRC willow plantation in winter.

irrigate large areas in Northern Ireland and the border counties of the Republic of Ireland. SRC willow can also be successfully used as a biofilter to bioremediate many industrial effluents, especially those with a high N and P content coming for food processing facilities. In addition if they have a high BOD this is retained and oxidise within the soil / plant system. It is therefore important to develop close working relationships between water utilities, industry and the agricultural community and farmers.

Perhaps the greatest challenge facing local councils and water utilities is how to treat landfill leacahte. Leachate from landfills can be a very damaging and highly polluting material. Furthermore WWTWs are reluctant or indeed are unable to process large volumes of leachate because of the negative impact it can have on the normal function of the works (high levels of NH_4^+/NH_3, Cl^-). Processing leachate through this route is also very expensive and represents a huge cost to local authorities.

While there is, understandably, reluctance to apply landfill leachate to otherwise uncontaminated SRC willow agricultural land, ANSWER has demonstrated the effectiveness of planting the cap of a closed landfill with SRC willow and using that to bioremediate the leacahte. This can involve importing top-soil on top of the cap in which to grow the willow and having a fully enclosed system that prevents any extraneous contamination of surrounding land or waterways. Nevertheless, once a healthy SRC willow crop has been established on top of the landfill site it will have the capacity to handle significantly large volumes of leachate. It is seen that over the next few years this approach to landfill leachate management may offer many opportunities for the sustainable treatment of leachate while protecting the environment from the effects of pollution from landfills.

There are many driving forces behind the implemention of this technology. They are essentially associated with economics, sustainability, reduction of energy usage at site, reduction of haulage of leachate and associated carbon footprint, the focusing of leachate recycling to non-food crops and away from food crops, fertilisation of energy crops for fuel security and displacement of fossil fuels to name a few! The removal of landfill leachate from the municipal wastewater treatment plant (WWTW) simplifies the activities and processes occurring there and removes the potential of sludge contamination by the myriad of compounds potentially present in the leachate. The sludge produced at the WWTW and used in agriculture for the fertilisation of food and feed crops should then potentially lead to greater food safety.

GLOSSARY

Effluent / wastewater: (treated or untreated), liquid waste or sewage discharged into a river, lake or the sea.

Environmental Protection Agency (EPA): is the environmental regulatory body in the Republic of Ireland with similar responsibilities as the NIEA.

Evapotranspiration: The combined process by which water is transferred from the land to the atmosphere by evaporation from the soil and other surfaces and by transpiration from plants

Leachate: a solution resulting from leaching of soluble constituents from soil, landfill, etc., by downward percolating ground water:

Leaching: the loss of water-soluble plant nutrients from the soil

Nitrates Directive: (http://ec.europa.eu/water/water_nitrates/indexen.htm): aims to protect water quality across Europe by preventing nitrates from agricultural sources polluting ground and surface waters and by promoting the use of good farming practices.

Northern Ireland Environment Agency (NIEA): An Agency within the Department of Environment which takes the lead in advising on, and in implementing, the Government's environmental policy and strategy in Northern Ireland. The NIEA is responsible for the regulation governing the recycling of wastes and the discharge of treated wastewater.

Surface run-off: The water flow that occurs when the soil is sealed, inundated or infiltrated to full capacity and excess water from rainwater, melt water or other sources flows over the land.

Waste Framework Directive: (http://ec.europa.eu/environmnat/waste/pdf/directive_waste.pdf) sets the basic concepts and definitions related to waste management, such as definitions of waste, recycling, recovery. It explains when waste ceases to be waste and becomes a secondary raw material (so called end-of-waste criteria), and how to distinguish between waste and by-products. The directive lays down some basic waste management principles: it requires that waste be managed without endangering human health and harming the environment, and in particular without risk to water, air, soil, plants or animals, without causing a nuisance through noise or odours, and without adversely affecting the countryside or places of special interest.

Wastewater Treatment Works (WWTWs): are industrial structures designed to remove biological or chemical waste from water thereby permitting the treated water to be discharged to waterways or used for other purposes. In Ireland most WWTWs treat a mixture of municipal effluent (e.g. sewage), stormwater and industrial wastewater.

Water Framework Directive: (http://ec.europa.eu/environment/water/water-framework/) Aims for 'good status' for all ground and surface water (rivers, lakes, transitional waters, and coastal waters) in the EU. The ecological and chemical status of surface waters are assessed according to the following criteria:

- Biological quality (fish, benthic invertebrates, aquatic flora)
- Hydromorphological quality such as river bank structure, river continuity or substrate of the river bed
- Physical-chemical quality such as temperature, oxygenation and nutrient conditions
- Chemical quality that refers to environmental quality standards for river basin specific pollutants.
- These standards specify maximum concentrations for specific water pollutants. If even one such concentration is exceeded, the water body will not be classed as having a "good ecological status".

APPENDIX 1

Additional Reading

SRC WILLOW

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European Union
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The ANSWER project was part-financed by the European Union's European Regional Development Fund through the INTERREG IVA Cross-border Programme managed by the Special EU Programmes Body.

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