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SHORT-ROTATION COPPICE SYSTEM:
ENVIRONMENTAL APPLICATIONS FROM NORTHERN AND REPUBLIC OF IRELAND

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SHORT-ROTATION COPPICE SYSTEM: ENVIRONMENTAL APPLICATIONS FROM NORTHERN AND REPUBLIC OF IRELAND

By,

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Introduction

The treatment of wastewater in modern wastewater treatment plants (WWTPs) is highly effective. The process involves piping wastewater to a plant where contaminants are removed, resulting in relatively clean effluent that is typically discharged into waterways. However, this effluent can contain a trace amount of nutrients or other contaminants, which can contribute to the pollution of surface waters. WWTPs are very expensive to build, maintain, and operate, and involve energy-intensive processes. For larger communities, those treating more than one-hundred-thousand gallons of wastewater per day, WWTPs can be efficient and effective. Small, rural communities producing relatively low volumes of wastewater may find these systems to be uneconomical.

In Ireland and Northern Ireland, there are hundreds of small, rural settlements with less than 1000 residents (Shannon et al. 2014; Northern Ireland Water, personal communication). In these communities, it is essential to develop economical, environmentally sound, and sustainable alternatives to a more expensive WWTP. A system of treating wastewater via irrigation of willow (*Salix* spp.) stands is successfully being pilot tested at a WWTP in Drumkee, Northern Ireland (Figure 1 and Figure 2). Willow is a temperate plant well suited to wet soils, has a long growing season, is tolerant to many soil contaminants, and can be easily coppiced (i.e., can be cut back to ground level once every three years, and will regrow). The technology has been subsequently scaled up at several sites, including a WWTP in Bridgend, Ireland (Figure 2) (McCracken and Johnston 2015).

Figure 1. Irrigation point within plantation (Laqua Wastewater Irrigation System). (Photo: C. Johnston.)

Figure 2. Geographical location of phytoremediation sites. (Map data: Google; SIO, NOAA, U.S. Navy, NGA, GEBCO. Image: Landsat/Copernicus.)

Using Willow to Manage Wastewater in a Short-Rotation Coppice System

An alternative to WWTP processes is to use partially-treated wastewater to surface irrigate a phytoremediation system (Mirck et al. 2005). Phytoremediation is a process where plants are used to break down or remove contaminates in water and soil. Fast-growing plants, such as willow, can filter wastewater, breaking down and bio-accumulating nutrients and other contaminates.

Willow genotypes are bred for high-biomass production (Elowsona 1999). These trees are able to biofilter considerable amounts of wastewater while consistently yielding more than four dry tons per acre per year at suitable sites (Forbes et al. 2017). Many woody plants have been tested for phytoremediation, however, willow has proved to be a superior choice (Dimitriou and Aronsson 2011; Zalesny et al. 2009). In parts of Ireland, willow is currently grown commercially for biomass as a fuel for producing renewable heat and power (Rosenqvist and Dawson 2005). Willow also has a higher water demand than almost any agricultural crop (Caslin et al. 2015). This allows WWTPs to apply significant volumes of effluent to willow plantations. The type of willow used in coppice plantations generally has a fine, shallow root system with 80% situated in the top 20 inches of the soil profile. This not only improves coppice stand stability but also provides an excellent receptive irrigation surface for the application of effluent.

Proof of Concept Small-Scale Demonstration—Drumkee, Northern Ireland

At Drumkee Waste Water Treatment Works in Drumkee, Northern Ireland, project personnel developed an approach in August 2013 to engineer and retrofit a willow phytoremediation system to an existing WWTP (Figure 3).

In Drumkee, raw wastewater from a local settlement of approximately 22 people is initially screened to remove large solids, and then settled in a retention chamber/septic tank. It then travels through a gravel filter before it is pumped through filters along two mainline feed pipes to a 2.5-acre willow plantation. The effluent is distributed evenly across the plantation using a series of irrigation pipes with discharge points.

As well as the employment of human vigilance and common sense, a rain gauge measures rainfall events and provides data so that irrigation is automatically stopped if soil moisture levels reach field capacity. Soil temperature probes are also used to ensure that irrigation does not take place when the soil is frozen or snow has fallen. When such environmental conditions persist, effluent accumulates in a sump "buffer" to the point where it may start to discharge to the river. The Northern Ireland Environment Agency (NIEA) permits this flexibility through a "variable discharge consent."

The volume of effluent irrigated per day is automatically recorded, and soil temperature and rainfall data are also collected and monitored. This data is supplied to the NIEA and the local water utility on a monthly basis by uploading to an online web-based application. Borehole and stream waters are continually analyzed for ground and surface water quality.

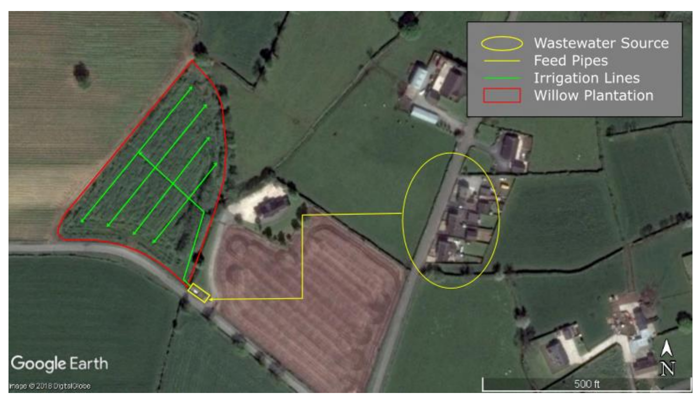

Figure 3. Drumkee small scale WWTP and willow **biofiltration** system. (Map data: Google, DigitalGlobe. Amended by C. Johnston and N. Hart.)

Reduction in Water Body Nutrient Loading

The hydraulic and nutrient loading in local water bodies is reduced by fertilizing the willow with the potentially polluting nitrogen (N) and phosphorus (P) rather than discharging to the environment (Table 1). Measurements using a trip switch and timer indicate that less than 10% of the inflow was discharged to the watercourse as a result of the irrigation shut-off. Irrigation with 90% of the inflow resulted in the fertilization of the **short-rotation coppice** (SRC) willow crop with 173 lb of N and 12 lb of P received from the WWTP, ensuring good, vigorous growth. The application of N and P at these rates sits well within the recommended nutrient requirements of the SRC willows, ensuring sustainability of soil nutrient and avoiding nutrient build-up (DEFRA 2010). In 2015, 53 green tons of willow biomass was then harvested.

Landmark Changes to Environmental Regulations

Environmental regulations can be challenging to meet with novel technology and methods, as regulations often lag behind technological advances. The success of “ANSWER,” a project funded by the European Union (EU), has paved the way to establish a landmark change to environmental regulations through “variable discharge consenting.” This regulation allows for greater flexibility in the amount of effluent allowed to be discharged into receiving waterways and willow plantations. Prior to the implementation of this regulation for small WWTPs, storage of wastewater would have been required during periods when land application was not allowed.

The primary objective of the ANSWER (Agricultural Need for Sustainable Willow Effluent Recycling) project was to develop the use of SRC willow for the bioremediation of a range of effluents, including municipal wastewater, landfill leachates, and industrial effluents. The project was financed in part 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.

Table 1. Volume, nitrogen, and phosphorus recycling from the WWTP and application rate to an acre of willow.

	Volume		Nitrogen		Phosphorus	
	(Gallon/year)	(Gallon/acre/year)	(Pound/year)	(Pound/acre/year)	(Pound/year)	(Pound/acre/year)
Inflow to WWTP	502,000		192.0		13.2	
Recycled to SRC willows	451,800	182,915	172.8	70.0	11.9	4.8
Approx. Discharged to Environment	50,200	20,324	19.2	7.8	1.3	0.5

Variable discharge consenting allows WWTPs to vary the amounts of effluent that is released to waterways depending on the prevailing environmental conditions. During periods of heavy rainfall or precipitation, land application of effluents is not permitted because the soil cannot absorb it, and there is a risk of pooling and runoff to surface water systems. However, these large precipitation events increase stream flows, which significantly dilutes any effluent released to the waterways. When stream flow is low due to low rainfall, application of effluent to willow plantations is far more environmentally sound. The Drumkee Project demonstrates the effectiveness of this responsive application method. In addition to functioning water treatment, this approach is potentially a "carbon negative" solution for wastewater treatment if the carbon sequestration by the crop and its ultimate substitution of fossil fuel (heat produced from biomass as opposed to oil) is taken into consideration. This system has since been replicated on other larger sites.

Costs and Benefits of Willow Wastewater Treatment

Benefits to the water utility include a massive reduction (90%) in the yearly output of pollution from the WWTP and the reuse of nutrients as a fertilizer on willow-agriculture crops. A willow plantation is expected to thrive for approximately 25 years. In comparison to upgrading WWTPs through traditional means, this scheme represents a very beneficial improvement via reduced carbon footprint, environmental sustainability and cost efficiency of treating the effluent. This reduces capital expenditure and a contributes to a bioenergy value chain supporting many different avenues of employment. In 2013, the turnkey costs for the establishment of the willow plantation and the installation of all the pipework and system was approximately £20,000 ($28,000 US), the majority of the costs being used for designing the system. Over 15 years, this project is estimated to save the water utility 50% in costs and 1,500% in carbon dioxide (CO_2) emissions. Carbon sequestration savings equaled 3,300 lb CO_2/acre/year and fossil fuel displacement (i.e., heat produced from biomass against a counterfactual of oil) from 5 ton/acre/year of willow biomass saved approximately 20,000 lb CO_2/acre/year. Despite this project being small, the economic feasibility of a similar project could be improved greatly with increased scale. Much of the site refurbishment and system requirements are similar whether for a 2.5-acre system or one ten times that size.

Larger-Scale Willow Development—Bridgend, Ireland Wastewater Treatment Works

The WWTP in Bridgend, Ireland was installed in 1975 on the south side of the River Skeoge where the outfall pipe discharges the treated effluent (Figure 4). The facility was designed to serve about 260 people, however, it is now serving a population of about 500 and needs improvement. The wastewater is from household domestic uses and some stormwater runoff. The wastewater passes through a screen and is subsequently aerated, meaning that oxygen is added to promote the growth of aerobic bacteria and to reduce the biological oxygen demand (BOD) of the wastewater. The solids in the wastewater are allowed to settle before the effluent is discharged into the river.

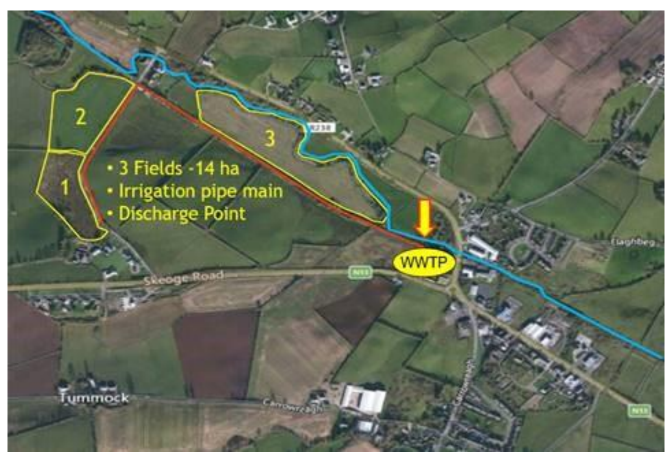

Figure 4. Bridgend WWTP and 35 acres of adjacent SRC willow. (Map data: Google, DigitalGlobe. Amended by C. Johnston.)

Testing Treated Effluent as Fertilizer on Farmland

One component of the EU ANSWER project was to improve water quality through reduction of nutrients that are discharged to water bodies. To address this concern, a willow plantation on farmland neighboring the WWTP was irrigated with part, or all, of the effluent from the Bridgend works. The ANSWER team was testing whether the irrigation of established willow would result in the overall reduction of discharge to the waterbody and ultimately lead to an improvement in the water quality. In 2013, 35 acres of willow were established and cut back as per best practice for establishment (Caslin et al. 2015). A fully automated pressure equalized irrigation system was constructed and commissioned in the early summer of 2014. This system has recycled about 50% of the inflow, over 21 million gallons of effluent containing approximately 5,500 lb of nitrogen and 265 lb of phosphorus. The first harvest occurred at the beginning of 2017 and yielded 620 green tons of biomass that was used for dedicated biomass heating or combined heat and power generation (Figure 5).

Figure 5. Harvest, spring 2017, with good yields and sound site integrity. (Photo: C. Johnston.)

Conclusion

These projects have led to significant reductions in effluent discharge to receiving waters. In addition, significant quantities of nutrients, such as nitrogen and phosphorous, are being recycled to willow bioenergy crops rather than disposed of to the water environment. Biomass yields from both Drumkee and Bridgend are high with excellent crop vigor, indicating an effective and sustainable phytoremediation solution for wastewater management. These projects are going a long way towards demonstrating the cost, environmental, and practical benefits which can be realized by employing such sustainable treatment methods for societal wastewater management. In time, a more thorough cost/benefit analysis from more data will reveal the true extent of the financial benefits.

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For More Information

You can find out information about the ANSWER project and the 2016 Poplar and Willow Forum here:

Johnson, C. 2016. Sustainable Wastewater Management Using Coppice Willow Energy Plantations YouTube video.

McCracken, A., A. Black, P. Cairns, A. Duddy, P. Galbally, J. Finnan, C. Johnston, et al. 2014.Use of Short Rotation Coppice (SRC) willow for the bioremediation of effluents and leachates. ANSWER (Agricultural Need for Sustainable Willow Effluent Recycling).

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Poplar and Willow Forum. 2016.

GLOSSARY

biofiltration—Utilizing biology for the processing of wastewater, capturing harmful chemicals, denaturing, and nutrient utilization.

short-rotation coppice (SRC)—A plantation managed by coppicing on short rotation (e.g., willows on a 3- to 4-year harvest rotation).

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