NIEA Northern Ireland Environment Agency

An Agency within the Department of Agriculture, Environment and Rural Affairs

SBRI Government challenges. Ideas from business. Innovative solutions.

COMPETITION: Mobuoy Road Waste Remediation SBRI
Reference: SBRI_DA_313_009

SBRI End of Phase 1 Report Form

NOTE: The Authority reserves the right to amend this form and/or issue additional guidance notes on how it should be completed during the duration of the project.

This Report is the contractor's opportunity:-

- to describe the work undertaken during the project, what outputs were obtained and why these are relevant to the objectives of the Competition

- to explain and prove expenditure; and

- to develop a comprehensive report for contractor's to share with their stakeholders and those that may help further commercialisation pursuant to the terms of the contract.

The Authority may use the Report as part of the assessment for any Phase 2; it is therefore important that contractors complete the form as completely as possible.

The Report will be considered to be confidential and commercially sensitive by the Authority and its contents (other than the response to Section 5) will not be disclosed to third parties other than in accordance with the terms of the contract.

The Report must be submitted via **MobuoyRoadSBRI@sibni.org** within 14 days of the completion, or termination, date. The contractor is reminded that completion of this report is a contractual obligation and forms part of the payment terms. The report should be completed by the lead contractor, with input from any sub-contractors or project partners as appropriate. Please answer, wherever possible, on behalf of the business units, divisions, or companies which were involved in the work. If this is not possible (as a result of merger or acquisition, for example), please specify the organisation to which your answers refer.

Please answer the questions fully, but keep your answers succinct and no longer than necessary to provide a clear explanation. When describing technical solutions, please regard your audience as being someone familiar with the technology, but not an expert. The report may be done in narrative alone, however diagrams or pictures may be annexed to the Report where these aid clarity Please limit your response to a total of **ten sides of A4** plus **an additional limit of ten sides for any supporting diagrams or pictures**. (Please keep to a maximum limit of 5MB per email when submitting supporting information).
Because the true impact of an R&D project often takes several years to emerge, InnovateUK and the Authority may approach you for up to six years after project completion to follow up on the questions in this report. Your co-operation with any such follow up work is greatly valued.

1. Details

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Project Reference: [redacted] Sustainable leachate management solutions using energy crops

Total Contract Cost: (£s) [redacted]

Start Date: 1st November 2016 End Date: 30th April 2017

2. At the outset of the project what were your aims and objectives?

In N.Ireland there are key evidence gaps which are required to be filled in order to progress and develop the use of SRC willow for leachate management and environmental protection of water quality.These include (1) The efficacy of willow to manage leachate in N.Ireland's maritime climate. (2) The effect of rain-fall and its contamination reference its drainage into the open environment. (3) The requirements for regulation and need for lining / isolation. (4) The implementation on landfill / brownfield or even agricultural land. (5) The risk to ground and surface water contamination. (6) The risk of biomass contamination. (7) The cost effectiveness of such solutions.

Current dialogue with the environmental regulators and platforms available to perform R&D emphasise the importance of the activities proposed in this SBRI: (1) There is strong precedent in other parts of EU however not currently in N. or S. Ireland (some contained examples exist in GB - eg WRG (Waset Recycling Group). (2) DAERA / NIEA interest in exploring sustainable solutions for leachate management however they need convincing. (3) An approx €2m research platforms (from an AFBI led EU Interreg IVA ANSWER project) exists to help develop the necessary answers for confidence generation for regulators, councils, operators, SMEs. (4) Waste sector SMEs are keen to develop similar schemes to reduce leachate transport and treatment (NIWater) costs. (5) Many councils N & S are also exploring and searching for such environmental and sustainable solutions.Incorporating these technologies in Mobouy, together with other AFBI R&D, can contribute strongly to developing and furthering the uptake and implemntation of this sustainable leachate management technology.

The aims and objectives of this project were to try to obtain some clarity on a number of aspects related to the efficacy of whether SRC willows could function as an efficient management strategy for dealing with landfill leachates. Therefore the proposal was to investigate, essentially an evaluation of the opportunities to implement SRC willow technologies for both point and diffuse leachate sources incorporating LiDAR for surface modelling of hydrologically connected areas. This would therefore require:.

- An evaluation and assessment of volumes, constituents and concentrations, leachate variations and potential of SRC willow to manage these streams with a view to nutrient regulation and guidance.
- Estimation of low carbon biomass production and contribution to the growing biomass energy supply chain with assessment of carbon balances.
- Evaluation of early stage data emerging from the research lysimeters and Proof of Concept sites set-up recently within the EU ANSWER project (2011-2014) operated by Donegal County Council, also an AFBI and EU WaterPro project (2016-2019).Including:

- Total volumes of leachate produced on site and imported with rainfall effect on quantities.
- Quality variation and composition of the leachate over the period.
- Quantities treated via the ICW and the willows on an on-going basis.
- The effectiveness of the ICWs in treating the leachate.
- The effectiveness of the willows in treating the leachate.
- Hydraulic and nutrient Mass balances.

- Cause and extent of pooling / runoff and linkage to the timing and environmental control of the irrigation regime.
- The effect of the leachate irrigation on the health and survival of the SRC willow crop (yellowing due to N deficiency, toxicity of the leachate, anything else…)
- Ongoing monitoring of the plantation with regards to the above.
- The ongoing data from the continual analyser and resulting volumes recycled or discharged (volumes, nutrient contents, link to weather conditions). Even though the yearly phase of this SBRI is not ideal for plant growth, there is still nutrient/pollutant management functionality in the soil (adsorption, ion exchange, precipitation, organics stabilisation and transformation via macro & micro-organisms etc) and as such the effect of leachate irrigation is still important during Dec/Jan as well as June/July.

3. Please provide a summary of the outputs of the project and relate these to the original objectives. How do the outputs address the requirements of this competition? What are the recommendations?

Lysimeter Experiments

This research platform was constructed during the Interreg IVA ANSWER project which ended in 2014. This SBRI project enabled the commencement of functional use of this platform. As the period of the SBRI was from Nov to April (unfortunately the poorer months to prove the efficacy of a soil/plant treatment system, certain amendments were constructed to ensure full compliance with the "discharge regulations" enforced by the Republic of Ireland EPA - essentially no overflow of lysimeters to the environment. This was accomplished by (1) construction of a rain catchment system to deflect a proportion of the rainfall (approx. 27%) and (2) a recirculatory pumping system to drain the lysimeters back to the leachate well (**Fig 1**). The rainfall at the site is approx 2000mm/year (2207mm in 2014), the volume collected in each lysimeter is approximately as **Table 1** (calculated by monthly leachate variation as a proportion of total) – hence the need for the constructions as outlined above. It is not considered likely that a "lined system" will cope with this volume of water and as such the effect of soil / plant systems on leachate management and drainage water filtration needs to be examined in order to help build up a body of evidence on how the regulator could consider an alternative to (1) lining requirement or (2) a flushing principle.
With no reliably consistent leachate analysis from Mobuoy, it is hard to estimate potential nutrient bioremediation effect. Total N concentration of the Mobuoy leachate collected during the SBRI was 58mg/l NH_3-N (accounting for the majority of the N) and 0.1mg/l P. Chloride concentrations are relatively high however not considered to be at the level of obvious toxicity (Dimitrou et al., 2006). Chloride concentrations in excess of 600 mg/l could be approaching the point at which some effect of phyto-sensitivity potential could be observed (I. Dimitriou and P. Aronsson, 2005. This however is very similar to the standard leachate (average 69 mg N/l) obtained at the lysimeter research platform and which has been applied to these lysimeters from the beginning of January 2017 (at three different treatment rates and a control treatment). These rates are the equivalent of 1, 2 and 3 mm/day (only considered possible for the larger irrigation rates in lined sites during Summer months only). These correspond to an annual nutrient loading of 81,161 & 322 kg N/ha/year with incidental phosphorus loading of 0.5, 1 and 2 kg P/ha/year. These are similar to hydraulic loading rates from other licensed and operating SRC willow biofiltration schemes (**Table 2**) which are proving sustainable. Samples of the drainage waters and leachate have been collected on a 2-weekly basis and analysed in the laboratory. To date there have been no indications of pollution from the leachate in the drainage water samples (**Fig 2**). This is as expected as this is very early days for this research, time will generate more data for analysis for significance.

Nutrient Off-take

Average nutrient off-takes of nutrients (N, P and K) from each genotype at the 3-year harvest (AFBI data un-published) – as result of direct irrigation of Farm Yard Dirty Water at the AFBI Hillsborough site is illustrated in **Table 3**. These help inform (from a N.Ireland soil and climate context) actual potential nutrient off-takes of SRC willow receiving either point source or diffuse applications of waste water / leachate. Current Best Practice Guidance (compiled from literature from several geographical locations) is indeed similar to that prescribed in the "Best Practice Guidelines (AFBI/Teagasc)", when accounting for nutrient availability and nutrient use efficiencies. With an average off-take of 221 kg N/ha/year, application rates of even greater N would seem sustainable (efficiency of use & fertilisation). These nutrient loading calculations have also been used to scale the quantities of leachate irrigated at the Churchtown Proof of Concept site.

Proof of concept site – Churchtown

The site was planted with SRC willow in 2015 and had established by October 2016 (**Fig 3**). It has been irrigated since May 2016 (North side (2 zones) and Southside (2 zones) and was cutback (as per best practice) in Feb 2017. The crop is showing good health and strong development from a slow start (due to imported topsoil which was poor, compacted, effected by drought, lifeless and of low fertility). The site was inspected on 10th May 2017. It is growing back well after cutback (**Fig 4**). There were no signs of leachate pooling (or sludge ponds) or deterioration in crop health due to the leachate application. The crop was also a healthy green which was an improvement over the pre-irrigation phase when the crop was much yellower. It is likely that the leachate is not only providing a nitrogen supply for the crop but also a much needed water supply for extended dry periods. Water supply is crucial at times of willow establishment, especially on engineered sites with lower water holding potential than a standard agricultural site. All leachate and rainfall applied to the willow coppice ultimately is utilised by the crop or drains away through the central collection drains, is continually analysed and is discharged to the environment if the ammonia is below 3 mg/l (**Fig 5**).

Integrated Constructed Wetland (ICW)

In order to allow (permission from environmental regulator EPA) the landfill site to be constructed with SRC willows for leachate treatment (this is a relatively unknown technology application in Ireland and UK), two ICW systems were also constructed at this landfill site as seen in **Fig 3**. This allows the two technologies to work in conjunction with each other. The ICWs are able to take loading when the SRC willows cannot, for example, due to unknown treatment efficiencies when the crops are young, just established, just cut back, just harvested, during a rainfall event etc. The ICWs are proving to treat the leachate very efficiently (between 1st September and 21st May) with reducing ammonia concentrations from pond to pond and very low discharge concentration from the final pond. Data for 2017 is seen in **Fig 6**.

Leachate Variation and Nutrient Loadings

The monitoring of SRC willow Zone 1 & 2 and Zone 3 & 4 as well as the ICWs has continued throughout this SBRI. The quality of the leachate at Churchtown (from three leachate collection wells) is variable depending on rainfall, leachate height and extraction rates. Between 1st September and 31st March 2017 the ammonia-N concentration ranged from 18.7 mg/l to 125 mg/l with an average of 49mg/l. The hydraulic and nitrogen loading is summarised in **Table 4**. There have been some teething problems with the recent commissioning of this site where one side of the willow plantation has been receiving more irrigation than the other hence the variation in N loadings. Nitrogen loading is the limiting nutrient for this particular wastewater. This illustrates that since the start of the monitoring period, 265 kg Nitogen has been applied to the total surface area with a discharge of 56kg (assimilation rate of almost 80%). However the initially malfunctioning side of the plantation represents nearly 80% of this outfall due to erroneous overloading. Regarding zone 1&2 only, 138.7 kg of N applied, 11.8 kg N discharged ie, a soil/plant system N assimilation rate of over 90%.

SRC willow Inlet and Outflow volume balances.

Willows in the UK have been shown to have a potential transpiration rate of ~6.6 ± 0.5 mm/day though this can vary substantially due to water stress (Hall et al., 1998) which in turn can affect growth and yields (Linderson et al., 2007). However, different genotypes have been shown to exhibit differing levels of sensitivity to water stress which can impact on biomass production, water use, nutrient uptake and ultimately their bioremedation potential. Sustainable operation of schemes (**Table 2**) in N.Ireland have been functioning without issues such as pooling, runoff, ground water or surface water pollution at an average rate of about 1mm/day. This would of course vary from potential evapo-transpiration rates from 0 mm/day to potentially 6 mm/day but would suggest that a hydraulic loading of up to 3,600 m^3/ha/year could be reasonable and practical. As the SRC willow system at this PoC site is only mid establishment phase, it is unlikely that the water uptake capacity of the SRC plantation will be particularly close to its maximum capacity. This will be achieved when the crop is well established with a full root system and growing vigorously. **Table 5** summarises the hydraulic loadings between 1st September and 31st December 2016. The total hydraulic loading to SRC Zone 1 & 2 has been 1718 m^3 leachate + 4133m^3 rainfall (Met Eireann http://www.met.ie/climate-request/) and the discharge has been 728 m^3 (12%). SRC Zone 3 & 4 indicates a 43% discharge however this is largely due to the erroneous application of excess leachate to this side of the plantation. In total, 26% of the leachate + rainfall water volume was discharged.

An estimated rainfall volume from 1st January to 21st May 2017 (calculation from the average of Met Eireann data 1999-2015) is 789mm,or 9,900 m^3 over the 1.25 ha area for the period 1st September 2016 to 21st May 2017. This represents a total of almost 20,000m^3 + 5410m^3 leachate and a total of 5697m^3 discharged or 23% of loading over the whole willow area. This is made up from 9% from Zone 1&2 and a decreasing 37% from Zone 3&4 (**Table 6**).

Variations in leachate volume irrigated have become more constant towards the end of the year. Even at an average 17m^3/day leachate application rate, outlet flow maps rainfall very closely. I.e. there appears to be a sustainable utilisation of the hydraulic loading of the leachate by the soil plant system and outflows are as a result of rainfall events. When there is little rainfall, there is no significant outflow or discharge from the willow treatment system. However, this is not so apparent in Zone 3&4 due to the commissioning issues previously referred to. This pattern is seen in **Fig 7**.

SRC willow Discharge Ammonia Concentration

Rainfall data only exists up to 31st December 2016 as Met Eireann is five months behind with data inputs. January's data will become available on 7th June 2017. **Fig 8** illustrates the relationship between rainfall, outlet flow and ammonia concentration of the outflow. The peaks in discharge ammonia concentration are certainly not constant, in fact there are significant discharge events with very low ammonia concentrations and this can be seen for both zone 1&2 and zone 3&4. There are some ammonia concentration peaks which were as a result of a fault with the automatic ammonia analyser as manual ammonia analyses did not corroborate the result. On-going calibration is required as well as ongoing investigation. **Fig 9** is an illustration of one rainfall event. The rain during 14th to 17th October 2016 gave rise to a discharge and indeed an ammonia spike which subsequently receded. This data goes somewhere towards indicating that not all the discharge is necessarily contaminated with ammonia beyond discharge levels (**Fig 10**) and consideration of regulation incorporating a "first flush" principle would seem legitimate whereby an understanding that rainfall may wash out some of the recently irrigated leachate. This eventuality however can be minimised by incorporating immediate rainfall irrigation shut-off. Indeed, this will be reduced yet further when the plantation is fully established with full canopy cover, maximum root system improved soil percolation and nutrient adsorption and maximum evapotranspiration.

Recommendations at Mobuoy (or similar) - Emerging Mobuoy Strategy

The strategies outlined above all serve to reduce rainfall and prevent rainwater entering the waste mass and generating further contaminated leachate, utilising an evapo-transpirative biofilter cover with SRC willow. The LiDAR survey and interpretation would serve to divert surface water from the site, reducing the amount of leachate to manage. Underground hydrological assessment (limited Information) would detect and target areas for leachate collection, pumping, establishment of permeable barriers and extraction for filtration (willows / peat filters / ICWs).

Hydraulic and Nutrient Loadings

The total rain-fall in the area local to Mobuoy averages 853 mm (1981-2010 Met Office data http://www.metoffice.gov.uk/public/weather/climate/gcg10wbfm), with over half of this rainfall occurring during months of willow growth, at a time with significant soil/plant system evapo-transpiration. Average rainfall (April to October = 461mm), volume of leachate generated on the Mobuoy 46ha site = 212,000m^3. However the LiDAR scan (**Fig 11**) can help indicate the direction / relief and hydrological pathways and connectivity of this and other merging rainfall so as to reduce the clean rain water merging with waste and becoming polluted. This approach to reducing surface water accumulation in the former landfill areas is to redirect surface water flow away from the area. The topography currently directs water from a large area downhill and onto the site. Modifying the topography by adding drainage ditches to redirect flow around and away from the site could limit accumulating water to just the rain falling on the landfill areas itself. **Fig 12** illustrates inscribed drains into the digital elevation model and re-simulated overland flow. Flow off the drumlin, for example, would be directed into a drain and across the slope and into the river Faughan, rather than running downhill and into the waste area and in particular the developed lake below the old elevated landfill site (note change in the red – high TWI- areas between images). The formed lake water quality as illustrated in project 508164 (AFBI – Filters) exhibits elevated ammonia concentrations and biological toxicity. LiDAR can also be used to target the direction of overland flow thus facilitating accurate siting of willow plantations for interception.

Planting Area and Biomass Generation

Figs 13 & 14 illustrate a possible strategy incorporating the construction of up to 16.9 ha of SRC willow for (1) interception of overland flow, (2) management of rainfall reducing downflow to the waste mass and (3) management of leachate irrigated from collection areas (ponds, lagoons, sumps, borewells). This willow cap could reduce the percolating rainfall significantly while also managing the nutrient (N & P) loading of recycled or intercepted leachate (**Table 7**). 16.9 ha of SRC willow, once fully established could yield up to 340 fresh tonnes/year. The energy content of this biomass would be approximately 640 MWh or the equivalent of 61 m^3 heating oil (£25k/year) and a saving of 166 tonnes of CO_2e (Diesel Oil 0.259 $kgCO_2/kWh$) (https://www.gov.uk/government/publications/greenhouse-gas- reporting-conversion-factors-2016). It is clear the overall GHG emissions of these schemes will be very attractive when the offsetting of the energy crop harvest and use is taken into consideration. Current local supply chains for biomass conversion exist in the form of the dedicated biomass heat and combined heat and power generator markets (ref. DfI Renewable heat and power targets).

Research Continuation
The research platforms modified and monitored within this SBRI project have only just been commissioned and they have been monitored throughout the less favourable months for soil/plant system functionality; especially with such a young plantation which has only just been cut back in Feb 2017. The results and data to this stage are promising, however of extreme importance now will be the data going forward, during the growing seasons of 2017 and beyond. The Proof of Concept scheme will illustrate further the effect of rain fall on run-off (quantity and quanlity and enablement for discharge). In doing so, more data can be interpreted in order to try to define the extents and applicability of a "First Flush" principle (direct applicability to the Culmore site (RPS/ NIEA closure plan), landfill SMEs and of course Mobuoy Site) in terms of volume of rain, period between irrigation and rainfall for infiltration and minimum environmental risk. It is also important that the monitoring of the research lysimeters is continued to develop a fuller picture of the ability of the willows to manage quantities of leachate and importantly the extent of nutrient escape from the system, the physical effects of irrigation, mass balances of nutrient, hydrological balance with effect of Potential Evapotranspiration. This platform will also ultimately allow the assessment of the extent of biomass contamination (Heavy metals or Nitrogen).

4. Describe any changes to the original application. What was the reason for these changes? Please include any circumstances that aided or impeded the progress of the project and the actions taken to overcome them.

There were essentially no real changes made with reference to the original application. It had been explained during the interviews prior to the initiation of the SBRI project that the best months for running a project to examine the effect of a soil plant system in managing quantities of water and nutrient would have been from April through to September/October. This is especially the case for plantations which are only at the early establishment phase of their growth cycle. For these reasons, a lot of effort when into the construction of the rain deflection and irrigation recirculatory system as illustrated in **Fig 1**. These infrastructures reduced the likelihood of leachate/rainfall overflow and were essential due to the timing of the SBRI.

5. Please provide a brief, public facing description of the project objectives, work completed and the most significant outcomes of your work. The Authority reserves the right to amend the description before publication if necessary, but will consult you about any changes.

This project links the growing of energy crops with the sustainable recycling of landfill leachate and can serve to help with the transformation of how leachate is managed (safer, less costly, improved LCA) in N.Ireland while contributing to indigenous biomass production (SRC willow plantations) for the developing bioeconomy. This project is also exploring and addressing the practicalities, potentials and linkages with other compatible sustainable technologies (peat filters). There is strong precedent in other parts of the EU where willow coppice plantations are used for the management of landfill leachate. Currently this technology is not in use in N.Ireland. There is however growing interest from Landfill Operators and Environmental Regulators to investigate these potential solutions. The resulting benefits would include the facts that such solutions are low carbon and low cost in terms of running and construction, are sustainable, develop a biomass energy value chain, create employment opportunities, are localised, improve biodiversity and carbon sequestration and many others.
This project is addressing some of the key evidence gaps which are required to be filled in order to progress and develop the use of SRC willow for leachate management and environmental protection of water quality. The project illustrates that SRC willows are currently managing a range of waste water effluents and initial data is suggesting that significant quantities of the leachate loading (hydraulic & nutrient) is also being managed by the planations. This is apparent from data from both the research lysimeters and the proof of concept scale platforms. The effect of rainfall is also managed to a large extent with overall discharges being significantly reduced as a result of evapotranspiration and assimilation. Early data indicates that rainfall will not always lead to discharge, and when it does there can be, but not always, an ammonia discharge however this subsides. The lysimeter experiments have not indicated a breakthrough of nitrogen into the groundwater at this early stage. This would be an important part of any consideration for these activities to occur in unlined sites (this is currently the practice in Sweden). The irrigation of leachate to already contaminated sites, or on top of landfills however would seem to be a logical immediate employment option for these technologies. The use of willow plantations to manage and mitigate the polluting effects of leachate is well established in Sweden, with

schemes in operation since 2002, with 30 equivalent examples. These schemes are operating under the remit of the Swedish EPA. In N.Ireland there are several such schemes running on other waste waters (sewage, primary, secondary and tertiary effluents, agrifood residues, and farmyard dirty waters). Regulation currently does not allow the application of leachate to willows. AFBI has a number of conference, published and submitted papers illustrating the beneficial potential of willows for the management of dirty water. The Incorporation of these technologies in Mobouy, together with other AFBI R&D can contribute strongly to developing and furthering the uptake and implementation of this sustainable leachate management technology.

6. Describe the innovative aspects of the work including any new findings or techniques.

In contrast to the current practice of collection, treatment, tankering to sewage treatment works, further treatment and discharge to the environment, this method of leachate management addresses the leachate on-site and demonstrates absolute contribution to the circular economy.

Circular Economy

These technologies, in time, will remediate a site through denaturisation, bioaccumulation, conversion and nutrient and pollutant removal when willow biomass is harvested and removed (and filter media removed ref SBRI 508164). Certain constituents of the leachate will fertilise the energy crop which when harvested will displace local fossil fuel used for heat and electricity generation. Transforming waste generated leachate into energy has significant economic as well as environmental benefits adding further to the principle of the circular economy. One of the key benefits of SRC willows is the potential to produce an economically viable crop. Associated with the research and development (local academic Institutes and Universities) into the efficacy and environmental safety of these schemes comes the involvement of a number of varied SMEs and larger businesses. These SMEs include waste water management companies, agricultural contractors for land preparation, plant breeding and propagation operations, SRC willow planting and establishment specialists, specialist harvesting contractors, wood chip drying and processing, storage & transport, wood chip boiler providers and installers, biomass boiler maintenance and energy Service Contractors. These commercial businesses will realise local economic growth and prosperity that will further expand and grow contributing to wider social benefits and prosperity, a healthy environment and protecting human health and wellbeing. Effective leachate management from waste sites will improve base flow to river and water quality status in our rivers and river basin catchments, local ecology and biodiversity that subsequently supports potable water supplies, commercial (abstractions) and recreational activities (e.g. fishing).

Applicability

Ireland's climate is arguably even more suitable for these schemes than Sweden's (longer growing season, temperate climate, rare freezing events). Many landfills are located in remote areas some distance away from sewage treatment works and sewer connections. In these situations landfill leachate management on-site, using robust, environmentally sustainable, cost effective, low energy & labour options may be favoured. Leachate management by natural and sustainable locally sourced peat/ash filters followed by willow short rotation coppice (SRC) is believed to match these requirements.

7. Please give a description of how funds were spent with reference to the original budget and explain any significant variations.

The main variation between the original budget and how the funds were spent was with regards to staff time and associated overheads. However this was a relatively small variation and is attributed to the extent of journey and staff time required to build the rain defences and monitor the irrigation of leachate to the lysimeters during the wet winter months in order to keep within the EPA Regulations and Requirements. There was a shortfall in the subcontracting costs due to appropriate data being more easily obtainable (LiDAR). The unexpected Capital expense came as a result of construction requirements to comply with EPA regulations in ensuring excess leachate & rainfall was recycled to the leachate storage facility.

[redacted] [redacted] [redacted]

8. Describe any potential long-term collaborations/partnerships entered into. Please list the company and the role they played in the project.

It is clear that a long term partnership between AFBI, [redacted] and [redacted] has been strengthened further. [redacted] develop the use of sustainable treatment systems in Scandanavia and have been doing so in Northern and Southern Ireland in conjunction with the Northern Ireland based [redacted]. [redacted] has developed the concept and irrigation design of how willows can play a part at Mobuoy and other landfill sites. Largely as a result of this SBRI project, AFBI has been successful in a stage 1 consortium bid with Interreg VB NWE project GreenGo where such Gentle Remediation Options as those researched in this SBRI, are the foci of Brownfield developments of biomass plantations. The Stage 2 bid has been ongoing through this SBRI Phase and is due to be submitted during June 2017. There is a very real opportunity for long term future collaborations with the following private and public entities: (Société Publique d'Aide à la Qualité de l'Environnement SPAQuE – Belgium, Centre Wallon de Recherches agronomiques – Belgium, Association pour le redéploiement économique du basin sérésien AREBS – Belgium, Valorisation de la Biomasse asbl ValBiom – Belgium, Université de Lorraine UL – France, Université de Franche Comté UFC – France, ARKEMA France ARKEMA – France, Valterra Dépollution Réhabilitation VDR – France, Agri-Food and Biosciences Institute AFBI – UK, Hochschule Trier Institut für angewandtes, Stoffstrommanagement – Germany, [redacted], [redacted], [redacted] and Donegal County Council. This bid also includes The Environment Agency, [redacted] and [redacted]).

We have also entered into the following collaboration with QUB [redacted] who are also SBRI Mobuoy funding beneficiaries. We coordinated sampling rounds with and shared expertise/ experience and we intend to submit an industrial NERC CASE innovation application for a PhD project by July 2017 that could combine our technologies into a single system for landfills. We see this linkage as a strong candidate for a phase 2 (combining further organics and ammonia treatment systems).

9. Please describe how your company has gained from this project. What new business opportunities have been created? Do you expect your company to grow as a result of this project?

[redacted] and AFBI have worked closely developing sustainable SRC willow technologies in N & S Ireland over many years. As mentioned, [redacted] schemes currently exist which manage several different waste waters and these are regulated by the NIEA, local councils or the EPA. Our companies have undoubtedly gained in this project as a result of the close communications and co-operations with the NIEA and SIB, and with the opportunity of collating and interpreting some real, albeit early stage, data indicating the actual potentials of willows for leachate management. Currently this waste water cannot be legally applied to willows for its management.

10. Describe the potential for exploiting the work. Please identify any new IP which has been filed or for which filing is anticipated.

For many years now, AFBI and other government and state entities have worked with [redacted] of Sweden. [redacted] has many years experience in designing, developing and delivering sustainable waste water management solutions. In recent years, [redacted] has developed sustainable waste water management systems in N.Ireland (and RoI) in several sectors including municipal waste water (NIWater and RoI Local Authorities) and the agri-food sector. Although no commercially functioning solutions for sustainable leachate management currently exisit in N.Ireland, this project has been an extremely valuable development in terms of not only exploring these soilutions within N.Ireland but also with the close communications with the NIEA. This approach prooved successful in Sweden twenty years ago when a similar development vehicle (Laqua, Kristainstad and Lund Universities and Swedish EPA) facilitated the commercial employement of willow and peat filtration systems for leachate management. It is hoped that as confidence develops, there will be opportunities for commerciality as [redacted] and [redacted]. in conjunction with AFBI are poised to implement and develop these solutions in conjunction with local NI based Environmental Technology Companies. A phase 2 project could be a first opportunity for this commerciality to be realised.

Using soil/plant (willow) based filter systems for treating landfill leachate water from landfills is common practice in Sweden and licensed by the Swedish EPA. During the 1990s, several systems were established in Sweden for treating landfill leachate by irrigation of SRWC established either on restored parts of landfills or on adjacent arable fields[1,2,3,4,5,6]. Similar systems have been tested in the UK, USA, Poland and elsewhere[7,8,9,10]. Local treatment is preferred because of the following benefits:1) Manageing the leachate on-site, hencereducing and possibly ending the need for as much transportation off-site (saving of cost & carbon).
2) Lowereing energy requirement on site as mostly passive equipment required (may be small pumps and electronics only).
3) Removeing the contamination from the environment and potentially from the otherwise produced sewage sludge (see "REVAQ - Certified Wastewater Treatment Plants In Sweden For Improved Quality Of Recycled Digestate Nutrients For Agriculture. A safe and assured source of fertiliser).
4) Recycleing the nutrient on site by fertilising an energy crop which will enter a developing biomass value chain (ref EU and UK climate change, GHG reduction and Renewable Energy targets)
5) Promoteing local employment (willow companies, harvesters, processors, suppliers, irrigation, engineers etc)
Further IMPACTS which are also relevant to N.Ireland and can be benefitted from include:
6) An increase in the land area growing energy crops for supply into the biomass supply chain.
7) An increase in economic activity linked to a growing biomass energy supply chain.
8) An increase in indigenous biomass (non-imports) contribution to the targets of mitigating climate change (decarbonising energy supply), reduce fuel poverty and improve fuel security.
9) An increase in confidence of landfill operators and regulators in the opportunities and application of low energy sustainable leachate management techniques.
10) Protection of environmental water quality, and helping towards demands under the Water Framework Directive
11) Proving of the technology to facilitate further large scale environmental engineering projects to deal with leachate contaminated areas (landfill site Co. L/derry, Down, Antrim, Donegal, Monaghan, Tipperary – all currently looking for sustainable landfill solutions).
12) Facilitating N.Ireland collaboration and funds drawdown within the Horizon2020 & Interreg – with SMEs and Government departments.

In principle, leachate is collected and irrigated into willow both on and outside the landfill site area (**Fig 15**). In colder climates (as experienced more in Sweden than N. Ireland), there is a need for storage of water during the closed period from October to April. The storage lagoon is often used for pre-treating the landfill leachate. Depending on the quality of the leachate water, there may be a requirement for extra pre treatment (for example peat/ash filtration) before applying to the willow bio-filter.

1. ARONSSON, P. - PERTTU, K., 2001. Willow vegetation filters for wastewater treatment and soil remediation combined with biomass production. In *The Forestry Chronicle*. Vol. 77, no. 2, pp 293–299.
2. HASSELGREN, K., 1992. *Soil-Plant Treatment System. Landfilling of Waste – Leachate*, Chapt. 3.12, pp. 361-380. Christensen, T.H. – Cossou, R. – Stegmann, R. (Eds.), Elsevier

Science Publishers, Ltd.

3. DIMITRIOU, I. – ARONSSON, P., 2005. Willows for energy and phytoremediation in Sweden. In *Unasylva, Poplars and Willows*, vol. 56, no. 221. http://www.fao.org/docrep/008/a0026e/a0026e11.htm.
4. DIMITRIOU, I. – ARONSSON, P. – WEIH, M., 2006. Stress tolerance of five willow clones after irrigation with different amounts of landfill leachate. In *Bioresource Technology*, vol. 97, pp 150–157.
5. ARONSSON, P. - DAHLIN, T. – DIMITRIOU, I. 2010. Treatment of landfill leachate by irrigation of willow coppice – Plant response and treatment efficiency. In *Environmental Pollution*, Vol.158, pp 795–804.
6. DIMITRIOU, I. 2005. Performance and Sustainability of Short Rotation Energy Crops Treated with Municipal and Industrial Residues (Doctoral thesis). Uppsala : Swedish University of Agricultural Sciences, 2005. 38 p, ISBN 91-576-7043-9.
7. BIALOWIEC, A. – WOJNOWSKA-BARYLA, I. - AGOPSOWICZ, M., 2007. The efficiency of evapotranspiration of landfill leachate in the soil–plant system with willow *Salix amygdalina* L. In *Ecological Engineering*, 2007, Vol. 30, no. 4, pp 356-361.
8. GODLEY, A. et al., 2004. Landfill leachate nutrient recovery by willow short rotation coppice: I. Yield, tissue composition and wood quality. In *Arboricultural Journal*, vol. 27, no 4, pp 281–295.
9. JONES, D.L. et al., 2006. Phytoremediation of landfill leachate. In *Waste Management*, vol. 26, no. 8, pp 825–837.
10. ZALESNY, Ronald S. – BAUER, Edmund O., 2007. Evaluation of Populus and Salix Continuously Irrigated with Landfill Leachate II. Soils and Early Tree Development. In *International Journal of Phytoremediation*, Vol. 9, Issue 4, 2007, Pages 307 – 323.

Addendum – "SBRI 508163 - Sustainable leachate management solutions using energy crops"

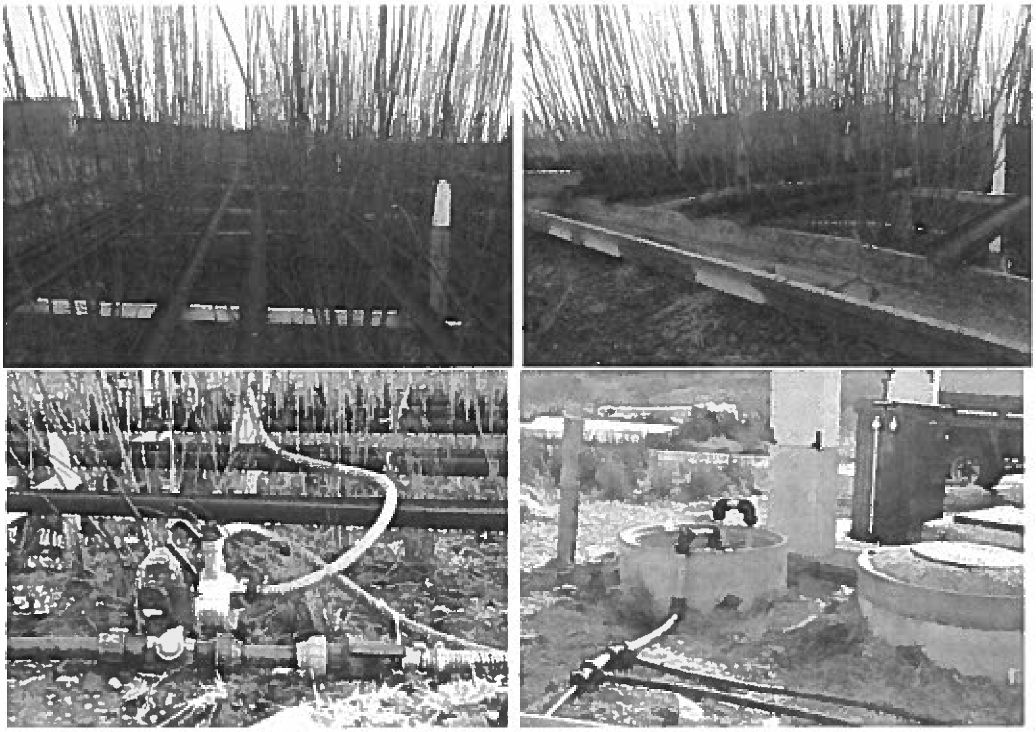


Fig 1. Rain deflection to enable compliance with EPA leachate irrigation regulations and evacuation.

Addendum – "SBRI 508163 - Sustainable leachate management solutions using energy crops"

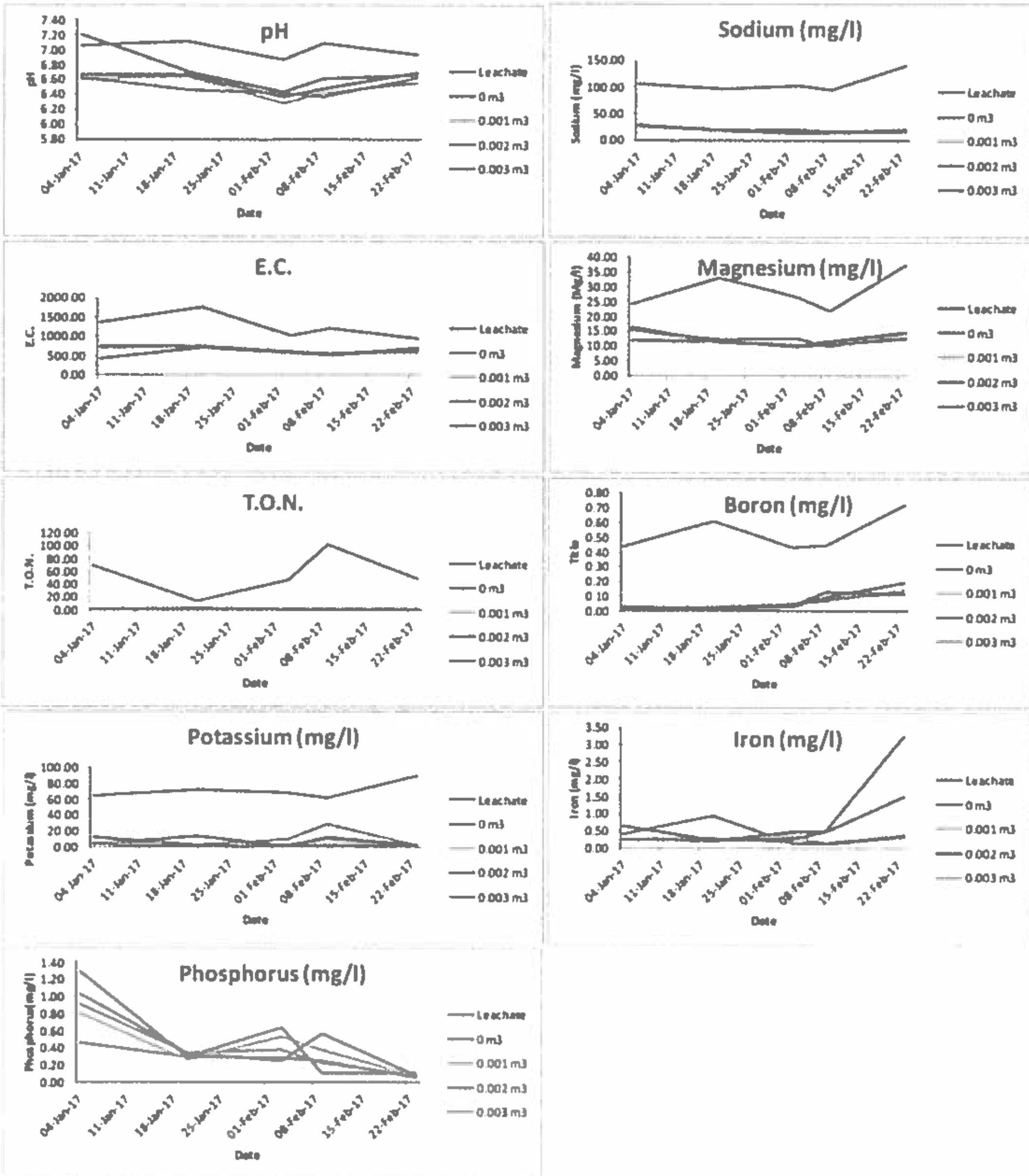


Fig 2 . Results from Research Lysimeter Platform

Fig 3. - The site has been irrigated since Mid 2016. Willows healthy and growing well (Oct 2016).

Fig 4– Willow regrowth post Cutback March 2017

Fig 5 – Willow module discharge point

Addendum – "SBRI 508163 - Sustainable leachate management solutions using energy crops"

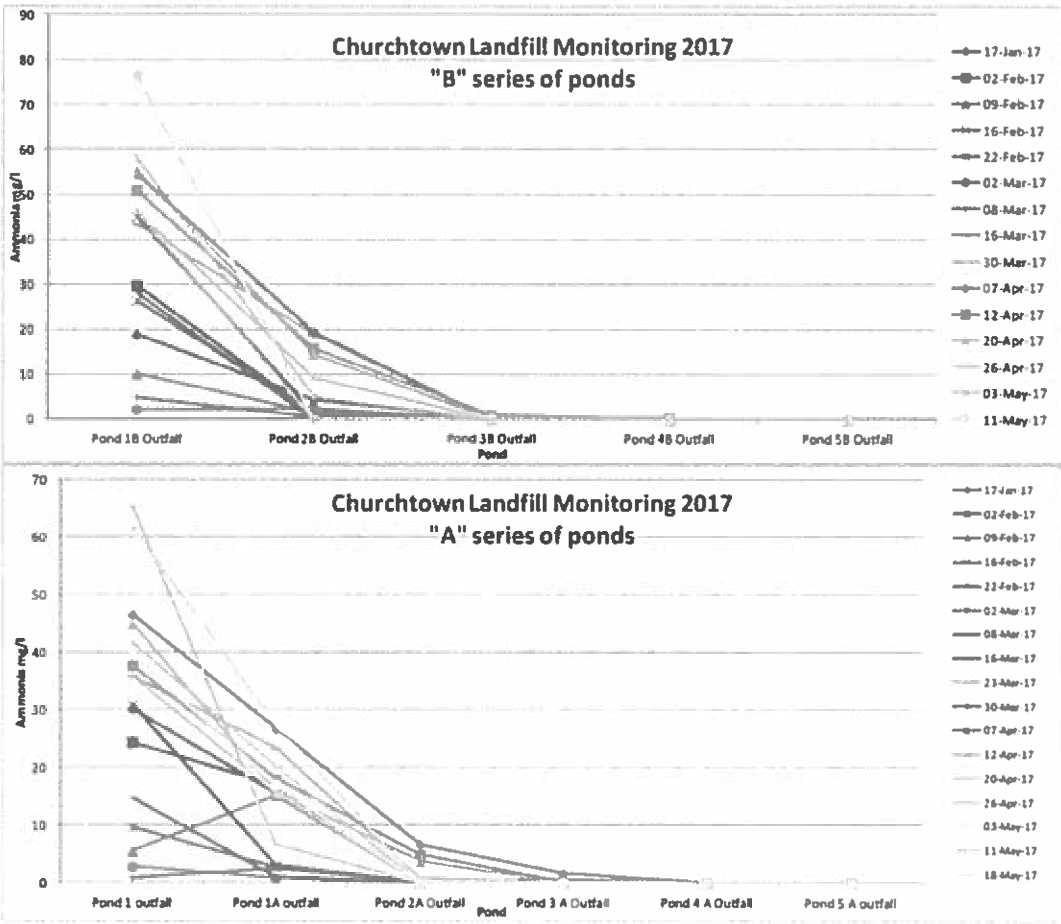


Fig 6 – Functionality of the Integrated Constructed Wetland

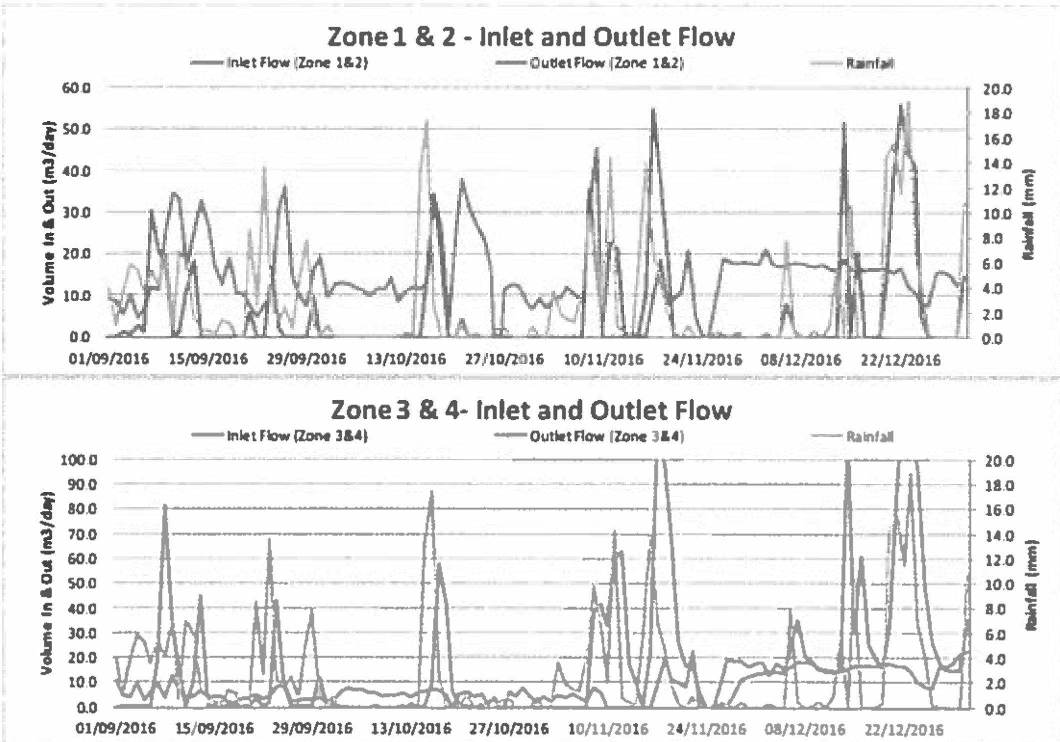


Fig 7 – Relationship between rainfall event and outfall.

Addendum – "SBRI 508163 - Sustainable leachate management solutions using energy crops"

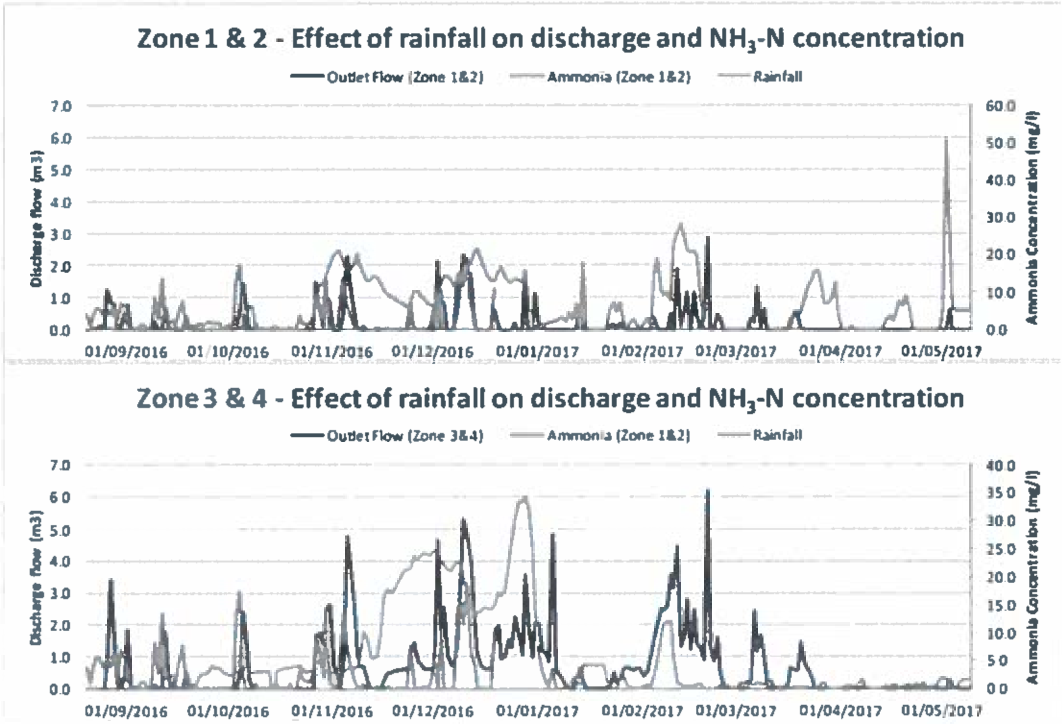


Fig 8 –Rainfall (limited data) and Outflow with Ammonia concentration

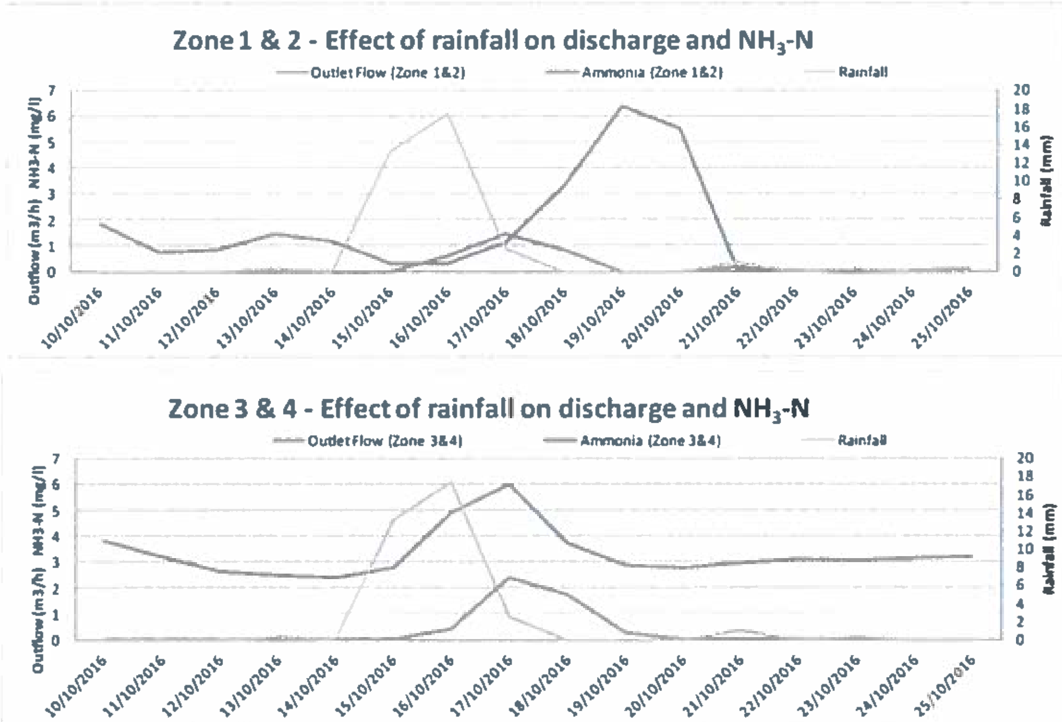
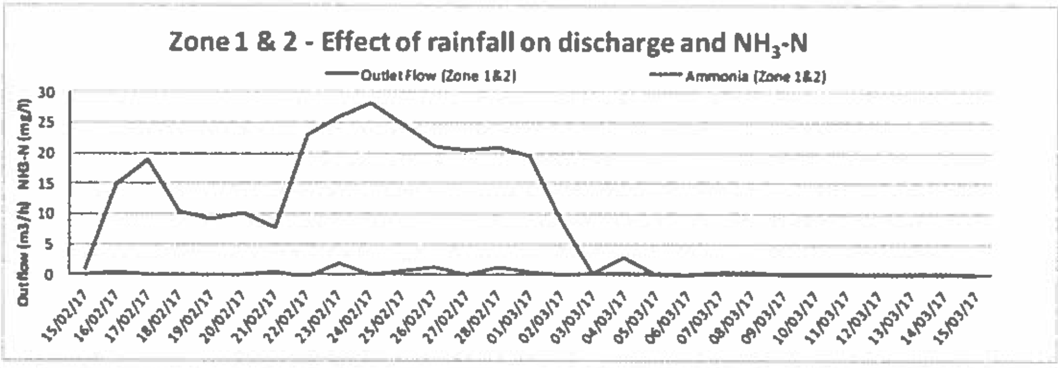


Fig 9 – Effect of rainfall on flushing of ammonia



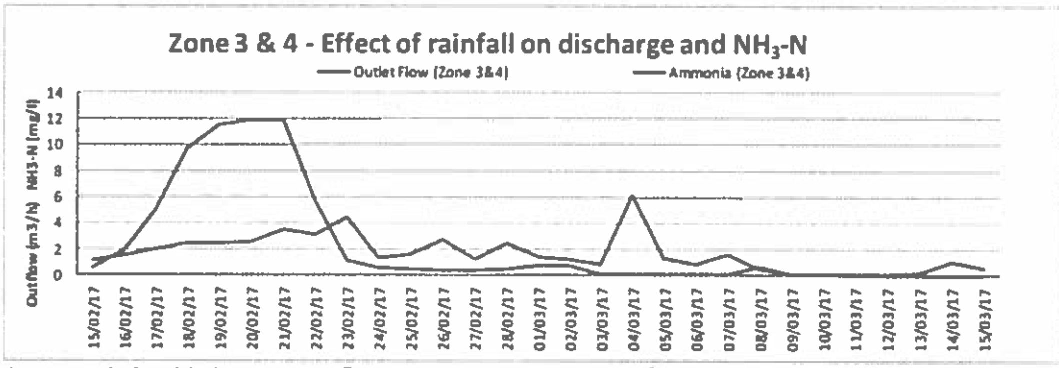


Fig 10. Relationship between outflow and Ammonia concentration

Fig 11 - Mobouy DTM2. shows the relief in the Mobouy site, hill shaded to highlight the topographic features such as drains, the river, banks and pylon foundations.

Fig 12 – Mobouy LiDAR interpretation for rainfall deflection

Fig 13 – A possible plantation and irrigation strategy (CAD of irrigation design & methodology)

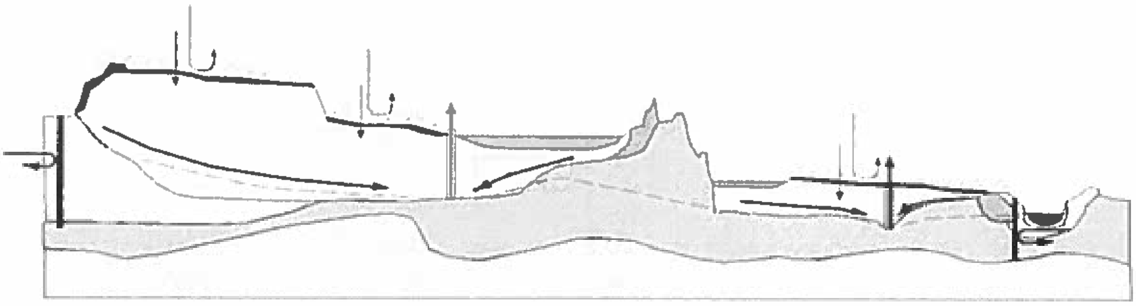


Fig 14. – Emerging Mobuoy Strategy

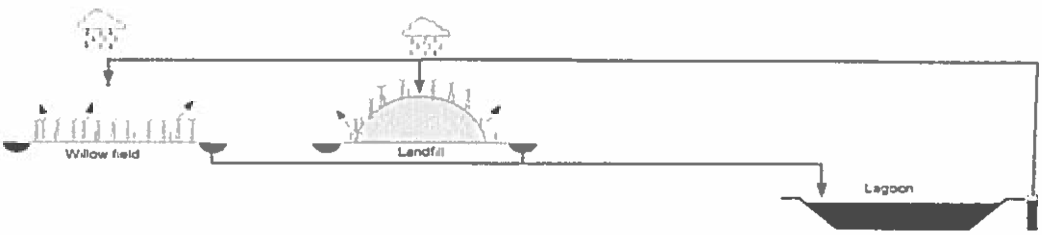


Fig 15. – Emerging Mobuoy Strategy

Month	Quantity of Leachate produced from site(m3)	% of leachate Generated	Lysimeter Volume (m3)
Jan	3114	12%	20
Feb	2598	10%	17
Mar	2521	10%	16
Apr	2023	8%	13
May	1512	6%	10
Jun	1397	6%	9
Jul	1304	5%	8
Aug	1766	7%	11
Sep	1918	8%	12
Oct	1761	7%	11
Nov	3172	13%	20
Dec	1833	7%	12
Total	24919	100%	159
Estimated Rainfall 2014 was			2207 mm
Lysimeter collects Nov to April			97 m3
Lysimeter collects May to October			62 m3

Table 1. Rainfall and volumes in lysimeters at Ballynacarrick Lysimeter site

WWTW	Loading	Est. PE	Irrigated (ha)	Hydraulic loading ($m^3 ha^{-1}$)	S Solids ($kg\ ha^{-1}\ y^{-1}$)	Nitrogen ($kg\ ha^{-1}\ y^{-1}$)	Phosphorus ($kg\ ha^{-1}\ y^{-1}$)
Site 1 (A)	Total	670		29422	1471	930	43
	Per ha		14	2102	105	66	3
Site 2 (B)	Total	200		16259	537	525	76
	Per ha		7	2323	77	75	11
Site 3 (C)	Total	105		15704	1225	427	57
	Per ha		5	3141	245	85	11
Site 4 (D)	Total	520		32266	549	365	50
	Per ha		15	2151	37	24	3
Site 5 (E)	Total	25		5664	751	261	34
	Per ha		1	5664	751	261	34

Table 2 - A summary comparison of currently functioning Point Source irrigation sites

Willow varieties	N ($kg\ ha^{-1}\ y^{-3}$)	P ($kg\ ha^{-1}\ y^{-3}$)	K ($kg\ ha^{-1}\ y^{-3}$)
Beagle	182.8	39.8	82.8
Endeavour	185.7	33.6	83.8
Mixture	203.2	38.2	87.8
Olaf	192.2	38.6	90.3
Sven	284.5	55.4	110.9
Terra Nova	225	41.4	93.7
Tora	276	51.3	108.1
average	221	43	94
average / year	74	14	31

Table 3 - Average nutrient off-takes of nutrients (N, P and K) from each genotype at the 3-year harvest (AFBI data un-published) – as result of direct irrigation of Farm Yard Dirty Water at the AFBI Hillsborough site.

	Application to willow area				Discharge from Willow area			
Willow Area	Total Volume applied to date	Daily Average	Mass NH_3 - N	Daily Averge NH_3 - N	Discharged from SRC	Daily Average	Mass NH_3 - N	Daily Averge NH_3 - N
	(m^3)	(m^3)	(kg)	(kg)	(m^3)	(m^3)	(kg)	(kg)
SRC Zone 1 & 2 (South)	2830.3	10.8	138.7	0.5	1150.6	4.4	11.8	0.0
SRC Zone 3 & 4 (North)	2580.2	9.8	126.4	0.5	4545.0	17.3	43.9	0.2
Total to the 2.5ha SRC area	5410.6	20.7	265.1	1.0	5695.6	21.7	55.7	0.2

Table 4 – Nutrient Balance from 1st Sept 16 to 21st May 17 (Leachate NH_3-N concentration = 49mg/l)

	Application to willow area		Discharge from Willow area		Rainfall		Total Volume + Rainfall		% Discharged
	Total Volume applied to date	Daily Average	Discharged from SRC	Daily Average	Total Volume	Daily Average	Total Volume	Daily Average	Total
Willow Area	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)
SRC Zone 1 & 2 (South)	1717.7	14.2	727.6	6.0	4132.5	34.2	5850.2	48.3	12%
SRC Zone 3 & 4 (North)	996.7	8.2	2180.8	18.0	4132.5	34.2	5129.2	42.4	43%
Total to the 2.5ha SRC area	2714.4	22.4	2908.3	24.0	8265.0	68.3	10979.4	90.7	26%

Table 5 – Hydraulic Loadings between 1st September 2016 and 31st December 2016 (121 days)

	Application to willow area		Discharge from Willow area		Rainfall		Total Volume + Rainfall		% Discharged
	Total Volume applied to date	Daily Average	Discharged from SRC	Daily Average	Total Volume	Daily Average	Total Volume	Daily Average	Total
Willow Area	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)
SRC Zone 1 & 2 (South)	2830.3	10.8	1150.6	4.4	9862.5	37.6	12692.8	48.4	9%
SRC Zone 3 & 4 (North)	2580.2	9.8	4545.0	17.3	9862.5	37.6	12442.7	47.5	37%
Total to the 2.5ha SRC area	5410.6	20.7	5695.6	21.7	19725.0	75.3	25135.6	95.9	23%

Table 6– Hydraulic Loadings between 1st September 2016 and 21st May 2017 (N.B. Estimated rainfall)

Field	**Area (ha)**	**Est. Evaporation (m^3) @ 200days x 3mm / day**	**Nutrient loading / Uptake (KgN) @ 49 mg/l NH_3-N**
A	4,8	28 800	1410
B	3,4	20 400	1000
C	8,7	52 200	2560
Total	**16,9**	**101 400**	**4970**

Table 7 - Biofiltration block estimation (N.B. Nutrient loading rates approximately 294 kgN/ha/year)