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

Registered Company Name: Byrne Looby Partners (UK) Ltd

Registered Address: Abbot House, Pilgrims Court, Sydenham Rd, Guildford, GU1 3RX

Report Author: [redacted]

Telephone Number: [redacted]

E-mail Address: [redacted]

Project Reference: SBRI [redacted]

Total Contract Cost: (£s) [redacted]

Start Date: 03/10/2016 End Date: 31/05/2017

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

The aim of this project was to complete a validation assessment of the use of various binders and add mixtures - in relation to their use in Soil Mix Technology - for the successful containment and remediation of groundwater exiting the Mobuoy Road Waste Site. Specifically, the investigation was designed to assess potential soil-binder mixes to create both low-permeable walls (to contain and direct groundwater flow) and install Permeable Reactive Barrier to clean the flow of contaminated groundwater.

The following objectives where defined to achieve the above aims:

1. Assess the Mobuoy Road Waste site to achieve a full understanding of the existing contamination problem, and to inform the design of an appropriate Ground Investigation for retrival of samples and testing program. Specific tasks included:
   - Consultation with NIEA
   - Review all available site information,
   - Assessment of groundwater and soil/water/waste characterisation from existing data
   - Completion of site reconnaissance/walkover survey.
2. Complete preliminary modelling of the ground conditions to inform the requirements of the proposed Construction.
3. Design, specify, undertake and supervise a Ground Investigation to obtain representative samples of parent ground and Contaminated Groundwater suitable for laboratory soil mixing trials from Mobouy Waste Site.
4. Define Soil mix Laboratory Testing Schedule. Specific tasks included:
   - Literature review of existing proven PRBs and add mixtures
   - Define Testing program,
   - Procure Suitable Binders and add mixtures.
5. Laboratory mixing of in-situ samples and to analyse the various properties of soil mixed samples. Specific testing included:
   - Classification testing on retrieved parent ground material
   - Chemical testing on retrieved Ground water samples
   - Range of Column tests to assess various binder mixes for PRB
   - Chemical testing on column eluate
   - Range of Constant Head Permeability tests in a triaxial cell to assess low permeability barrier.
6. Analysis of all laboratory data and reporting of results.

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?

1. Ground Investigation and Sample Collection

Following consultation with NIEA, and specification of a Ground Investigation (with approval of Contractor RAMS), a ground investigation was completed by Causeway Geotech Ltd in Nov 2016. Two trial pits where excavated under the supervision of Byrnelooby to obtain two sets of control ground type samples for use in the laboratory trial testing. The first trail pit was completed near to the River Faughan with strata comprising samples of naturally-occurring Gravelly Clayey Sand – representative of parent material for installation of low permeable barriers or PRBs adjacent the River Faughan. The second trail pit was completed in a known hotspot of contamination (as directed by the NIEA from review of existing site data), with strata comprising shredded municipal solid waste and Clayey Sand. The spoil from each trial pit was carefully mixed at surface to produce homogenous samples of each control ground type and delivered and stored under controlled conditions at Queens University Soil Testing Laboratory. Prior to mixing with binder for columns tests or permeability tests, samples were screened through 20mm sieve to remove large particles - generally comprised only 5 -10% of the mixed material and generally consisted of large gravel pieces or large pieces of broken glass or plastic. The Particle Size Distribution of the control ground samples are presented in Figures 1 and 2 (in Appendix A).

During the ground investigation, samples of groundwater (GW) where sampled for use in the laboratory investigation; however, given low yield in existing standpipes, two further repeat visits where required to obtain sufficient groundwater for the assessment. Two Permeant/ Groundwater types were mixed in the laboratory from the obtained groundwater samples from various boreholes across the site; approximately 60 gallons of GW Sample 1 and GW Sample 2 where created for use in PRB Column tests. The water quality chemistry of these composite samples is presented in Table 1 (Appendix A).

2. PRB ‘Gate’ Assessment

2.1 Test Methodology

Column test cells were constructed at Queens University Workshop PMMA plastic (as per CEN_TC_292_N1384), and were 35cm in height and 10cm of internal diameter. Porous stones where installed into the top and base caps and filter paper installed during column setup. 2 No. Standpipes of 1m length (2mm internal diameter glass rods) were installed in the column, 7.5cm from the base and 7.5cm from the top of the standpipe (at 15cm separation) to measure hydraulic gradient across the sample and preform the joint role of determining permeability during the column test.

A total number of 20 column tests were completed using 5 different binder types. Table 2 provides details of the binder constituents and moisture requirements prior to beginning the column tests.

All binders were mixed with parent samples as a wet mix (as per installation methodology in-situ), prior to being placed in columns. The "Optimum Dry Binder to Water mix" in the table above details the ratio of 'water' to binder that was made prior to mixing with the parent soil. This ratio was defined by visual assessment by Deep Soil Mixing Ltd as being suitable for pumping in-situ. Note the 'water' used was either GW Sample 1 or 2, depending on the particular column test that was being set up i.e. the GW used for setting up the column was the same as that used to permeate the column.

For all column tests where binder was used, a ratio of 30% by dry unit weight was used.

When creating the column media, binder and water – the latter being groundwater - was mixed as per the ratios detailed in Table 2, then added gradually to the designated portion of parent ground type whilst mixing constantly. The media was placed and compacted in three layers into the column as per CEN_TC_292_N1384.

Permeant flow in columns was from base to top. A constant head was applied (by applying controlled pressure to a sealed GW drum). The applied permeant at base was equivalent to 10kPa above column base datum (i.e. a head of 1m applied at column base). Sufficient flow was initially applied to get output flow; then it was stopped and the column left to saturate for 3 days. Columns were permeated until approximately 2 times the equivalent void ratio (1.5litres) of output leachate was obtained (to ensure flushing of the sample and to obtain 'steady state' conditions/results). Following sampling of eluate for chemical testing (into the glass jars supplied for chemical testing) took place, with glass bottles sub-sampled as necessary for the chemical testing laboratory's requirements (i.e. syringed with filters where necessary into vials), output flows where measured at intervals (along with head difference in standpipes) to obtain flow rate and define permeability values.

2.2 Results

The following subsections detail the results of analysis of the column leachates, for each of the different binder types investigated. The results of contaminant concentrations and permeability results from each column test are presented in Appendix B.

2.2.1 No Binder Added

Samples N1A and N2A represent site soils placed in the column and leached with composite groundwaters - Type 1 and 2. There is little difference in the leaching properties of these 2 columns, although Column N2A, which had Type 2 water applied, shows a significant reduction in dissolved iron in the produced leachate. The concentrations of arsenic, PAHs, nitrate nitrogen, nitrite nitrogen and ammoniacal nitrogen are all decreased within the leachate from both columns. The concentrations of chromium and zinc are decreased in the leachate from column N1A and all other tested parameters increase in the leachates for both columns.
With respect to the waste soil columns, W1A and W2A, the wastes were found to leach at significantly higher concentrations for all parameters with the exception of PAHS.
The results of the column leaching indicate that some of the parameters in the soil are leachable and can contribute to the concentrations of contaminants observed in groundwater.
Assessment of permeability from column tests indicate a permeability of 1.8×10^{-7}m/s and 3.8×10^{-6}m/s for the natural ground type and waste ground type respectively.

2.2.2 EHC

EHC is an "off the shelf" product, composed of controlled-release carbon, zero valent iron (ZVI) particles and nutrients used for the in-situ treatment of groundwater and saturated soil impacted by heavy metals and persistent organic compounds, such as chlorinated solvents, pesticides and energetics.

Results from Column tests indicate that EHC mixed with soil or waste soil is not considered appropriate for use at this site. The mixture results in a significant release in iron to the leachate, which if discharged in the River Faughan, could result in the formation of iron oxide precipitates in the river and, therefore, adversely impact upon river quality. It also results in increased concentrations of copper, nickel and zinc at levels greater than EQS values for salmonid rivers. Little improvement was observed by mixing the wastes with EHC; the overall impact was a decrease in the observed leachate quality.
Permeability assessment indicates that addition of EHC binder induced minor improvement (i.e. increase) in the permeability of the Natural Soil; however, this leads to a significant negative reduction in permeability for the waste material.

2.2.3 Mulch

Fine-graded mulch was obtained from a local commercial tree surgeon and mulch supplier, although no data is available for mulch background chemical quality. As mulches are derived from the chopping and shredding of wood products, their chemistry can be expected to reflect the environment that trees or shrubs have been planted in and, therefore, may be quite variable in nature. The mulches used in these experiments were from a single source and, accordingly, are expected to be fairly homogeneous.
In examining mulch alone, there is an indication that for some parameters, such as dissolved chromium, copper, zinc, sulphate and nitrate, there is an improvement in leachate quality for both soil with mulch and waste with mulch. For other parameters such as arsenic, iron, nickel, nitrite nitrogen and ammoniacal nitrogen, there is a significant decrease in leachate quality. It is considered that these metals may be leaching from the mulch and it may be necessary to identify a mulch source with low heavy metal content. With respect to the nitrogen compounds, these are typically leached from organic-rich soils and the results not unexpected.
Permeability assessment indicates that addition of mulch binder induced a significant improvement (i.e. increase) in the permeability of the Natural Soil; however, this leads to a significant negative reduction in permeability for the waste material.

2.2.4 Zeolite & Mulch

Zeolite is a large group of minerals consisting of hydrated aluminosilicates of sodium, potassium, calcium, and barium. It is commonly used as cation exchangers and molecular sieves. Literature review reveals that recent studies have shown that Zeolite PRBs are effective at Ammonium Removal. Samples N1D, N2D, W1D and W2D are for columns where the mulch was pre-mixed with a zeolite prior to mixing with the soil. Leachate from these columns shows a significant improvement with respect to nitrogen compounds, sulphate, chromium, copper, zinc, and PAH's when compared to CO concentrations. Where the column was mixed with waste, minimal improvement is observed.
Permeability assessment indicates that addition of mulch plus Zeolite binder induced a significant improvement (i.e. increase) in the permeability of the Natural Soil; however, this leads to a significant negative reduction in permeability for the waste material.

2.2.5 EHC & Mulch

Results from the EHC plus mulch mixture is considered similar to EHC only, and is shown to make no or minimal improvement on leachate quality.
Permeability assessment indicates that the addition of EHC plus mulch binder induced a minor improvement (i.e. increase) in the permeability of the Natural Soil; however, this leads to a significant negative reduction in permeability for the waste material.

2.3 Discussion

The results of the column test have identified the potential for the use of mulch and mulch mixed with zeolite as a PRB to treat some of the contaminants in the groundwater at the Mobouy Road site. The test results for mulch alone and zeolite plus mulch show promise in reducing the concentrations of inorganic and organic nitrogen compounds, sulphate and some heavy metals to concentrations that are below environmental quality standards. These experiments focussed on a 'proof of concept' idea to determine if soil mixing could be applied to create a permeable reactive barrier. Further experiments are required to optimise the mix design with respect to soil to mix ratio and the ratios of the additives for mulch / binder mixes.

The use of EHC as a single additive in the mix design is not recommended due to the significant release of iron from the EHC. EHC plus mulch looks promising as arsenic is reduced, however, Iron leaching remains high and it would be necessary to undertake geochemical modelling to determine if iron would attenuate on formation once groundwater has passed through the PRB and becomes more oxidizing.

Arsenic leaching in Mulch and Mulch plus Zeolite binder mixes appears problematic and may require the addition of further additives) to remove this contaminant. It may be possible to obtain low arsenic mulches and this should be explored in further experimentation. Failing that, the mix may be altered to include a synthetic zeolite, in addition to the one used in these experiments; or use of bone meal phosphate to attenuate arsenic released from the mulch.

Further experiments and modelling should be undertaken to assess the impact on varying permeability and thickness of the PRB to further reduce contaminant discharge to surface waters off-site. These models can also be used to assess the best location for placing a PRB to allow best protection of the receiving waters.

A soil mixed PRB placed within the waste and utilising the mix design described above does not appear to be a solution for use at this site. However, this does not preclude the use of Soil Mix PRBs in Natural Soils in areas of Natural Ground surrounding known hotspots of waste material. While some metal contaminants are reduced compared to no binder addition, for natural soil, column tests indicate metal contaminants significantly increase for waste soils. However, with respect to sulphate and the nitrogen compounds, there is improvement using mulch and mulch plus zeolite. Modification of the mix designs may result in further improvements.

It is important to note that contaminant behaviour in groundwater is controlled by contaminant speciation and redox chemistry, as well as the presence of sorptive sites onto which the contaminant may sorb. Some parameters, such as chloride, are conservative and will not readily sorb to a media. To remove these parameters some dosing is required to precipitate insoluble compounds. While precipitation may be useful to remove the dissolved iron released from the PRB media or to remove chloride, doing so increases the risk of fouling and clogging of the formation.

2.4 Recommendations

A soil mixed PRB is able to remove contaminants leaching from soils and wastes at Mobouy Road site. Specifically, the use of Mulch and Mulch plus Zeolite has indicated significant decreases in sulphate and nitrogen compounds, while at the same time leading to beneficial, 10 fold increase in the permeability of the mix. Nevertheless, it is necessary to undertake further bench top experiments to develop an optimised mix design prior to onward site trial. Consideration may be given to the use of batch equilibria tests prior to the column tests to allow examination of a number of binder modifications and also faciolitate selection of a reduced number of binder mixes within the column experiments. Fate and transport modelling should be undertaken to assess impact of column leachates on receiving waters using the site boundary as the compliance point. This information can then be used to assess optimum distance from boundary for a PRB. At the Mobouy Road site, the western boundary is immediately adjacent to the river. If the PRB can be placed to contain leachate produced by the waste, at a distance up-gradient of the site boundary, there if the possibility that further attenuation may occur as the groundwater moves down gradient, thereby reducing the risk to the river.

3. Low Permeability 'Funnel' Assessment

Constant head permeability tests in a tri-axial cell were completed on both Ground Type Samples (i.e. both Natural Soils and Waste Soils) obtained from the site. A total of 6No permeability tests were completed using varying proportions of cement, bentonite and waste, with Pulversised Fuel Ash (PFA) as binder agents. Given that PFA is a waste product itself, the investigation was designed to optimise/maximise the proportion of PFA as a suitable alternative to standard cement and bentonite slurry mixes in the construction of soil mix low-permeability barriers.

Results of Low permeability funnel assessment are presented in Table 3 (Appendix A), and indicate relatively low permeability for all mixes investigated, with permeability values ranging from $6.6x10^{-9}$m/s to $4.5x10^{-10}$m/s. The increased ratio of PFA is shown to have only negligible effect on the permeability obtained and it was shown that lowest permeability obtained related to the highest proportion of PFA relevant to the mix completed on natural soil material.

For all low permeability Funnel tests, 30% binder content was used. Further sensitivity tests, reducing the overall binder content but maintaining a high proportion of PFA for funnel assessment, should be completed to fully optimise the most economical mix design.

4. Groundwater Flow Assessment

Funnel and gate PRB systems are often of lower permeability than the aquifer units they are installed in. Installing low permeability material within a permeable aquifer will inhibit the natural flow of groundwater and will result in groundwater levels rising and/or altering the natural groundwater elevation and flow direction. As such, an initial simple steady-state groundwater flow model has been constructed to support the assessment of how groundwater flow might be affected when a 'Funnel and Gate' PRB system is installed, with the main objective being to assess the lower permeability limit for both the funnel and gate system, based upon a set of idealised hydrogeological conditions, to ensure that groundwater levels do not rise too close to the ground surface and/or groundwater flow direction is not significantly altered.

The installation of the PRB system was simulated by applying a low permeability funnel zone and a separate permeability zone for the gate. The permeability values of each zone were altered to investigate the effects on the local groundwater flow regime. Suitable permeability values for each zone were set to ensure that groundwater levels did not rise to within 1m of the ground surface and that groundwater flowed through the funnel system towards the gate. The initial permeability values for the funnel and gate zones were set at $1x10^{-10}$ m/s and $1x10^{-8}$ m/s. At this low permeability it was found that the groundwater mounded at the surface in discrete locations and the flow direction was reversed along the funnel, resulting in groundwater flowing away from the gate zone and around the funnel. To prevent the groundwater from flowing away from the gate and ultimately increasinhg the capture area of the funnel system, the permeability of the gate had to be increased to readily permit the flow of water through the gate and induce flow through the funnel system towards the gate. With the permeability of the funnel zone set to a constant value of 1×10^{-10} m/s, it was found that the permeability of the gate zone had to be increased to 1×10^{-6} m/s to allow for an effective capture area for the funnel system and to ensure water levels remained below 1m of the ground surface. As such, the increased permeability afforded by the Mulsh and Mulsh plus Zeolite Binders is shown to be a critical parameter requirement for the PRB and to ensure valid groundwater flow on the site.

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.

No major changes have occurred from the originally proposed application. Very favourable results have been generated from both PRB (gate) assessment and the Low Permeable Barrier (funnel) assessment, with both assessments indicating that readily available waste materials (i.e. Mulsh and PFA, respectively) are shown to be highly effective major components for use in the proposed binders.

Minor delays to program and additional expenditure were incurred due difficulty in retrieving suitable quantities of Groundwater leachate; however, this was overcome by increasing the amount of Column cells (for the time critical PRB assessment) and marginally reducing the scope of the Groundwater flow model investigation.

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.

It is believed that a combination of Soil Mix Technology (SMT) and Permeable Reactive Barrier (PRB) Technology may provide a partial remediation strategy for the Mobuoy Road Waste Site. This project has provided a first stage proof of concept for a combined containment and on-site remediation of contaminated groundwater flow to the River Faughan. Specifically, this project has highlighted potential add mixtures for a low permeable barrier (acting as a funnel), as well as potential add mixtures for intermittent PRBs (acting as groundwater gates) to be constructed along the boundary of the River Faughan in order to effectively control and clean the flow of contaminated groundwater.

This project has used extensive laboratory testing on representative samples taken from Mobuoy Road Waste Site, mixed with a range of binders, some of which are waste products, to enhance the use and increase validation of SMT to this site. The investigation successfully defined suitable add mixtures for both the low permeability barrier (groundwater funnel) and permeable reactive in-ground barriers (groundwater gate).

The results of this Phase 1 analysis has provided proof of concept and informed an initial mix design for further laboratory testing (to optimise the mix design) and for a Phase 2 site trial installation and assessment.

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

The proposed remediation defined in this project comprises the novel combination of two relatively new technologies; Permeable Reactive Barriers technology and Soil Mix Technology. Currently, both technologies are still in at various stages of evolution and development. The combination of these two technologies provides an innovative and highly cost effective methodology for the construction of Permeable Reactive Barriers.

Historical construction of these barriers have comprised replacement of ground with a reactive medium, however, recent innovation using SMT or injection allows the mixing of reactive media with parent ground. Similarly, historical installation methods have comprised excavation and replacement, unsupported to shallow depths or requiring expensive retention, such as sheet piling or cased augured boreholes where barriers are required to extend to considerable depths. Recent innovation using injection methods and SMT, allows the relatively quick installation of PBRs and impermeable walls to considerable depths, negating the requirement to remove and dispose of potentially contaminated ground from site, reducing the potential of airborne contamination during construction and reducing the potential for handling and the associated risks to construction personnel and other surrounding receptors.

A current disadvantage of SMT construction methods is the lack of control over the uniformity of the treatment zone, which can significantly reduce the remedial performance of the PRBs and impermeable barriers. Significant advancements in soil mix technology, specifically optimising the homogeneity of deep soil mix columns, have been made in recent years by Deep Soil Mixing. This technology has been applied with great success, mainly to the stabilisation of poor or incompetent grounds/soils within the construction industry. The use of an innovative double auger mixing head, in comparison to standard single auger mixing heads, provides significant increased reliability over mix homogeneity and, resultantly, in the overall performance of the proposed remediation design. It is envisaged that this technology would be utilised in Phase 2 site trials and eventually deployed as viable and successful remedial construction techniques.

As such, the Phase 2 assessment will provide verification of the combination PRB and SMT.

Further innovative aspects that have been investigated and proven successful as part of this Phase 1 investigation comprised the concept verification of two waste products for use as Binder components. During the investigation to assess suitable Binder materials for use in PRBs, mulch, a fine graded waste wood chipping sourced locally from a tree surgeon and landscaping business, has been successfully shown to reduce the concentrations of inorganic and organic nitrogen compounds, sulphate and some heavy metals. Similarly, in the investigation into binders for the creation of low-permeable barriers, waste Pulverised Fuel Ash, has been shown to provide a suitable addition to commonly used cement bentonite binders, successfully leading to the reduction in permeability and reducing the overall quantity of both cement and bentonite products needed in the mix.

The testing methodology for PRBs in this investigation incorporated the innovative use of standpipes in standard column cells, and thereby allowed the assessment of permeability during the column test using constant head techniques (i.e. where a constant flow pump was not available). This methodology was shown to be successful in estimating permeabilities with a high degree of repeatability, which also provides significant savings in time and expenditure as a separate permeability test was not required for each PRB Mix assessments.

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

Amended version with commercial sensitive information removed

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

Working relationships between all organisations involved in this project team have been formed leading to associated knowledge transfer between different specialist disciplines.

As a result of the relationships built within this project team (specifically Deep Soil Mixing, ByrneLooby and Queens University), other avenues of research into soil stabilisation have been generated and it is proposed to investigate both testing methodologies and various potential binder types as part of the development of the knowledge base for this new, innovative and ever-expanding technology.

Discussions regarding SMT and its potential for both use in soil stabilisation and contaminant remediation has highlighted the lack of industry awareness in this technology. As such, a seminar, hosted at Queens University in September, is currently being organised by a number of members of this project team, in collaboration with Northern Ireland Geotechnical Group to promote and publicise SMT and its various applications. It is intended to discuss the results of this investigation at this seminar, highlighting the construction of PRBs and the use of waste products as binders, as a potential application of Soil Mix Technology.

The roles undertaken by members of the team are as follows:

ByrneLooby
[redacted] - [redacted] has project managed this project, providing GI site supervision, setup, monitoring and analysis of laboratory testing, liaison with relevant stakeholders, sub-contractors and other technical key project members and has produced the project documentation/reports.
[redacted] - [redacted] has provided an advisory role, reviewing and approving documentation pertaining to this project.

Deep Soil Mixing
[redacted] (Deep Soil Mixing) - [redacted] has provided an Assistant Project Manager Role in this project, defining potential site restrictions to potential remediation options, and input into soil mix design.
[redacted] - [redacted] has provided an advisory role, providing important input from the contractor's perspective.

White Young Green
[redacted] - [redacted] was WYG's project hydrogeologist for works completed to date (by WYG) at the Mobuoy Waste Site. His extensive knowledge of the site, its associated constraints and its Hydrogeological characterisation provided great value to the project. [redacted] has provided an advisory input into the intrusive GI works and groundwater characterisation and has undertaking high level groundwater modelling to predict alterations/variations to groundwater flows from the proposed remedial solution and define the physical property requirements of the funnel and gate system.
[redacted] - [redacted] specialises in the behaviour of contaminants in the environment, and is a remediation expert. [redacted] has experience in undertaking R&D and technical review for various organisations and universities and has direct experience working on the Mobuoy Waste Site. On this project, [redacted] has undertaken internal peer review of results and provided input into both the remediation design, interpretation of test data, conclusions and the appropriate geochemistry of the effective functioning of a valid PRB.

Queens University
[redacted] (Queens University Belfast)
[redacted] has undertaken and supervised the proposed soil mixing and testing regimes for this project at Queens University Soil testing laboratory (along with [redacted]), as well as providing valuable interpretation and analysis of geotechnical permeability data.

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?

Given the success of this first stage assessment, where the investigation into combined PRB and Soil Mix Technology has provided proof of concept, the project team is keen to further develop an optimised mix design for both the PRB gates and funnel for use at Mobuoy Waste Site, implementing a site trial and, ultimately, taking the concept through to installation on the site and use in construction in general.

Working relationships between all organisations involved in this project team have been formed leading to associated knowledge transfer between different specialist disciplines.

As a direct result of the collaboration between different members of different disciplines, a seminar has been organised to promote and publicise SMT and its various applications to the Northern Ireland construction industry. It is intended to discuss the results of this investigation at this seminar, highlighting the construction of PRBs and the use of waste products as binders, as a potential application of Soil Mix Technology.

It is hoped that increased industry awareness will generate increased sales of Soil Mix Technology application and lead directly to increased revenue and company growth.

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

The combination of two relatively new technologies, (i.e. Permeable Reactive Barriers and Soil Mix Technology) holds great potential to provide both public and private sectors with a highly sustainable and economic tool to both contain and treat (in-situ) contaminated groundwater.

Currently, both technologies are still in early stages of evolution and development. Soil Mix Technology is more commonly being recognised by the UK construction industry as viable and more sustainable engineering alternative to many standard deployed solutions to soft or problematic ground conditions (e.g. used to replace pile foundations by providing increased bearing capacity and reduced settlement potential in soft ground or provide sufficient strength to allow open cut excavations instead of costly temporary retention, etc.). Ongoing research is constantly developing new add mixtures, many of which are waste by-products for use as PRBs.

The combination of both technologies, culminating in a 'funnel' and 'gate' construction, provides many advantages over other common remedial options to meet requirements:

As with all new technologies, the proposed remedial solution defined in this application suffers from a proven track record in application and, by association, lacks stakeholder confidence. The opportunity to successfully apply this solution to a high-profile site, such as the Mobuoy Waste Site, will provide the publicity required to highlight its benefits to a wide range of potential users.

Given that both PRB Technology and Soil Mix Technology are established as existing processes, it is believed that there is not existing IP or restrictions associated with the combination of these technologies. Accordingly, no IP has arisen as part of this investigation.

To fully realise the commercial potential of this remedial solution, the applicants plan to utilise the following marketing tools to increase publicity - however only where this is deemed satisfactory to stakeholders:

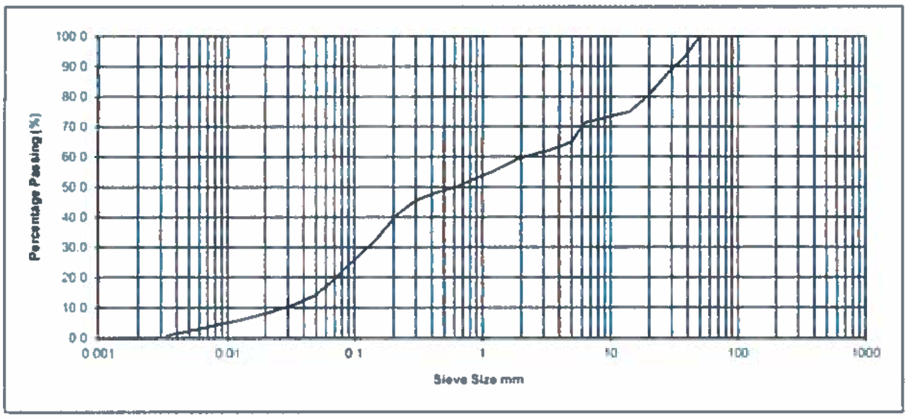
- Feature the project (Phase 1, Phase 2 and Construction) on our company websites and through social media outlets (LinkedIn, Twitter, etc).
- Incorporate Soil Mix PBRs and 'Funnel' and 'Gate' remedial solutions within the current advertised scope of possible Soil Mix applications already advertised. Include this application within already commonly given industrial talks and seminars provided to industry (e.g. CPD accredited lunch time talks to professional bodies).
- Produce a number of research/technical papers on the outcomes of the Phase 1, Phase 2 and construction assessment.
- Publish this innovation technique and successful construction outcome at relevant industry seminars/conferences via poster presentations and expert talks.
- Encourage and undertake further university funded research into Permeable Reactive Barriers and 'funnel and gate'.

APPENDIX A – Figures and Tables

QUB

Determination of Particle Size Distribution
BS 1377 : 1990 : Part 2 : Clauses 9.2 & 9.5

Sieve Size mm	% Passing
125.000	100.0
75.000	100.0
63.000	100.0
50.000	100.0
37.500	93.0
28.000	87.7
20.000	80.6
14.000	74.8
10.000	73.4
6.300	71.3
5.000	65.0
3.350	62.1
2.000	59.6
1.180	54.9
0.600	49.8
0.425	48.1
0.300	45.5
0.212	40.7
0.150	32.8
0.063	17.8
0.048	13.9
0.035	11.3
0.022	8.6
0.013	6.0
0.009	4.6
0.007	3.3
0.005	2.0
0.003	0.7



Percentage Particle Size

Clay	Fine	Medium	Coarse	Fine	Medium	Coarse	Fine	Medium	Coarse	Cobbles	Boulder
	Silt			Sand			Gravel				
	50.6			31.1			18.3			0.0	0.0

Sample Description	Gravelly sandy SILT	Project No	Mobuoy Road landfi
		BH/TP No	Natural
Project	Mobuoy Road landfill	Sample No	

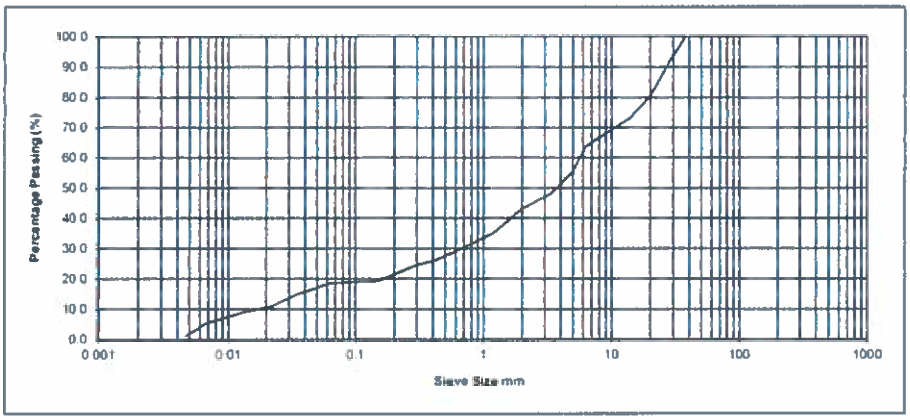
Operator	SS	Checked	VS	Approved	VS	Date sample tested	25/03/2017	Depth	NA

Figure 1 – Particle Size Distribution of NATURAL Ground type

QUB

Determination of Particle Size Distribution
BS 1377 : 1990 : Part 2 : Clauses 9.2 & 9.5

Sieve Size mm	% Passing
125.000	100.0
75.000	100.0
63.000	100.0
50.000	100.0
37.500	100.0
28.000	91.7
20.000	80.6
14.000	73.3
10.000	69.3
6.300	63.7
5.000	55.4
3.350	48.1
2.000	43.2
1.180	35.0
0.600	29.0
0.425	26.2
0.300	24.4
0.212	21.9
0.150	19.3
0.063	18.5
0.049	16.9
0.035	14.9
0.022	10.9
0.013	8.9
0.009	6.9
0.007	5.0
0.005	1.0



Percentage Particle Size

Clay	Fine	Medium	Coarse	Fine	Medium	Coarse	Fine	Medium	Coarse	Cobbles	Boulder
	Silt			Sand			Gravel				
	50.6			31.1			18.3			0.0	0.0

Sample Description	Gravelly sandy SILT (containing organic)	Project No	Mobuoy Road landfi
		BH/TP No	Waste
Project	Mobuoy Road landfill	Sample No	

Operator	SS	Checked	VS	Approved	VS	Date sample tested	25/03/2017	Depth	NA

Figure 2 – Particle Size Distribution of WASTE Ground type

Groundwater Results					
		Ground Water Type		1	2
Determinant	LOD/LOR	Units			
	Sample ID	GW Type 1			
Dissolved Aluminium	<20	ug/l		<20	<20
Dissolved Arsenic	<2.5	ug/l		6.7	9.8
Dissolved Cadmium	<0.5	ug/l		<0.5	<0.5
Total Dissolved Chromium	<1.5	ug/l		7.3	1.5
Dissolved Copper	<7	ug/l		7	7
Total Dissolved Iron	<20	ug/l		23	3036
Dissolved Lead	<5	ug/l		<5	<5
Dissolved Nickel	<2	ug/l		29	24
Dissolved Selenium	<3	ug/l		<3	<3
Dissolved Zinc	<3	ug/l		9	<3
Mercury Dissolved by CVAF	<0.01	ug/l		<0.01	<0.01
PAH MS					
Naphthalene	<0.1	ug/l		<0.1B	0.3B
Acenaphthylene	<0.013	ug/l		0.016	0.053
Acenaphthene	<0.013	ug/l		0.013	0.013
Fluorene	<0.014	ug/l		0.014	0.014
Phenanthrene	<0.011	ug/l		0.011	0.011
Anthracene	<0.013	ug/l		0.013	0.013
Fluoranthene	<0.012	ug/l		0.012	0.012
Pyrene	<0.013	ug/l		0.013	0.013
Benzo(a)anthracene	<0.015	ug/l		0.015	0.015
Chrysene	<0.011	ug/l		0.011	0.011
Benzo(bk)fluoranthene	<0.018	ug/l		0.018	0.018
Benzo(a)pyrene	<0.016	ug/l		0.016	0.016
Indeno(123cd)pyrene	<0.011	ug/l		0.011	0.011
Dibenzo(ah)anthracene	<0.01	ug/l		0.01	0.01
Benzo(ghi)perylene	<0.011	ug/l		0.011	0.011
PAH 16 Total	<0.195	ug/l		0.195	0.353
Benzo(b)fluoranthene	<0.01	ug/l		<0.01	<0.01
Benzo(k)fluoranthene	<0.01	ug/l		<0.01	<0.01
PAH Surrogate % Recovery	<0	%		90	82
Sulphate as SO4	<0.5	mg/l		39.4	0.5
Chloride	<0.3	mg/l		133.1	213.2
Nitrate as N	<0.05	mg/l		5.13	0.05
Nitrite as N	<0.006	mg/l		0.134	0.006
Ammoniacal Nitrogen as N	<0.03	mg/l		18.19	9.28
pH	<0.01	pH units		7.59	7.53

Table 1 - The water quality chemistry of composite GW samples.

Assessment for Column Tests (PRB Gates):

Binder Mix type ID (Test ID Abreviation)	Consituients of Binder Agents *(% mix by dry mass)*	Optimum Dry Binder to Water Mix	% Dry Binder Mix to Dry parent Soil Mix
A	No Binder	To be mixed with sufficent water to saturate column sample	
B	EHC *(100%)*	1(b):4(w)	30%
C	Mulch *(100%)*	1(b):4(w)	
D	Zeolite *(33%)* & Mulch *(67%)*	1(b):3(w)	
E	EHC *(33%)* & Mulch *(67%)*	1(b):3(w)	

Table 2: Binders composition used within the column experiments.

Parent Soil Type	Binder Proportions			Binder %	Test ID	Permeability (m/s)
	Cement	Bentonite	PFA			
Natural	10%	10	80	30	NX	4.50E-10
Waste	10%	10	80	30	WX	6.60E-09
Natural	10%	20	70	30	NY	2.30E-09
Waste	10%	20	70	30	WY	3.30E-09
Natural	10%	30	60	30	NZ	2.30E-09
Waste	10%	30	60	30	WZ	2.20E-09

Table 3: Binders composition and permeability results of low permeability gate assessment.

APPENDIX B – Results of PRB Column Test Assessment

Exova Jones Environmental

Client Name: Byrne Looby
Reference: N1006.1
Location: Mobuoy Road
Contact: Chris Anderson
JE Job No.: 17/5852

Groundwater Results and Column Results — Parent Material Type: Natural Soil (Clays, Sand and Gravels); Ground Water Type 1

Determinand	LOD/LOR	Units	Method No.	GW Type 1	GW Type 2	NA (No Binder)	NB (EHC)	NC (Mulch)	ND (Zeolite & Mulch)	NE (EHC & Mulch)
Dissolved Aluminium [#]	<20	ug/l	TM30/PM14	<20	<20	<20	<20	<20	<20	<20
Dissolved Arsenic [#]	<2.5	ug/l	TM30/PM14	6.7	9.8	3.4	2.5	26.8	17.0	2.5
Dissolved Cadmium [#]	<0.5	ug/l	TM30/PM14	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Total Dissolved Chromium [#]	<1.5	ug/l	TM30/PM14	7.3	1.5	5.2	1.5	1.5	1.5	1.5
Dissolved Copper [#]	<7	ug/l	TM30/PM14	7	7	<7	729	<7	<7	55
Total Dissolved Iron [#]	<20	ug/l	TM30/PM14	23	3036	68	4860000	11430	1378	357600
Dissolved Lead [#]	<5	ug/l	TM30/PM14	<5	<5	<5	<5	<5	<5	<5
Dissolved Nickel [#]	<2	ug/l	TM30/PM14	29	24	68	138	38	35	17
Dissolved Selenium [#]	<3	ug/l	TM30/PM14	<3	<3	30	<3	<3	<3	<3
Dissolved Zinc [#]	<3	ug/l	TM30/PM14	9	<3	3	1339	3	3	95
Mercury Dissolved by CVAF [#]	<0.01	ug/l	TM61/PM38	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
PAH MS										
Naphthalene [#]	<0.1	ug/l	TM4/PM30	<0.1[B]	0.3[B]	<0.1[B]	<0.1[SV]	<0.1[B]	<0.1[B]	<0.1[SV]
Acenaphthylene [#]	<0.013	ug/l	TM4/PM30	0.016	0.053	0.013	0.013	0.013	0.013	0.013
Acenaphthene [#]	<0.013	ug/l	TM4/PM30	0.013	0.013	<0.013	<0.013[SV]	<0.013	<0.013	<0.013[SV]
Fluorene [#]	<0.014	ug/l	TM4/PM30	0.014	0.014	<0.014	<0.014[SV]	<0.014	<0.014	<0.014[SV]
Phenanthrene [#]	<0.011	ug/l	TM4/PM30	0.011	0.011	<0.011	0.011[SV]	<0.011	<0.011	<0.011[SV]
Anthracene [#]	<0.013	ug/l	TM4/PM30	0.013	0.013	<0.013	<0.013[SV]	<0.013	<0.013	<0.013[SV]
Fluoranthene [#]	<0.012	ug/l	TM4/PM30	0.012	0.012	<0.012	<0.012[SV]	<0.012	<0.012	<0.012[SV]
Pyrene [#]	<0.013	ug/l	TM4/PM30	0.013	0.013	<0.013	<0.013[SV]	<0.013	<0.013	<0.013[SV]
Benzo(a)anthracene [#]	<0.015	ug/l	TM4/PM30	0.015	0.015	<0.015	<0.015[SV]	<0.015	<0.015	<0.015[SV]
Chrysene [#]	<0.011	ug/l	TM4/PM30	0.011	0.011	<0.011	<0.011[SV]	<0.011	<0.011	<0.011[SV]
Benzo(bk)fluoranthene [#]	<0.018	ug/l	TM4/PM30	0.018	0.018	<0.018	<0.018[SV]	<0.018	<0.018	<0.018[SV]
Benzo(a)pyrene [#]	<0.016	ug/l	TM4/PM30	0.016	0.016	<0.016	<0.016[SV]	<0.016	<0.016	<0.016[SV]
Indeno(123cd)pyrene [#]	<0.011	ug/l	TM4/PM30	0.011	0.011	<0.011	<0.011[SV]	<0.011	<0.011	<0.011[SV]
Dibenzo(ah)anthracene [#]	<0.01	ug/l	TM4/PM30	0.01	0.01	<0.01	<0.01[SV]	<0.01	<0.01	<0.01[SV]
Benzo(ghi)perylene [#]	<0.011	ug/l	TM4/PM30	0.011	0.011	<0.011	<0.011[SV]	<0.011	<0.011	<0.011[SV]
PAH 16 Total [#]	<0.195	ug/l	TM4/PM30	0.195	0.353	<0.195	<0.195[SV]	<0.195	<0.195	<0.195[SV]
Benzo(b)fluoranthene	<0.01	ug/l	TM4/PM30	<0.01	<0.01	<0.01	<0.01[SV]	<0.01	<0.01	<0.01[SV]
Benzo(k)fluoranthene	<0.01	ug/l	TM4/PM30	<0.01	<0.01	<0.01	<0.01[SV]	<0.01	<0.01	<0.01[SV]
PAH Surrogate % Recovery	<0	%	TM4/PM30	90	82	98	28	77	78	36
Sulphate as SO4 [#]	<0.5	mg/l	TM38/PM0	39.4	0.5	134.1	81.3	0.5	0.5	14.0
Chloride [#]	<0.3	mg/l	TM38/PM0	133.1	213.2	64.5	163.2	276.0	192.5	127.7
Nitrate as N [#]	<0.05	mg/l	TM38/PM0	5.13	0.05	0.05	0.59	0.05	0.05	0.05
Nitrite as N [#]	<0.006	mg/l	TM38/PM0	0.134	0.006	0.016	0.606	0.008	0.006	0.006
Ammoniacal Nitrogen as N [#]	<0.03	mg/l	TM38/PM0	18.19	9.28	8.12	9.26	4.43	0.08	138.34
pH [#]	<0.01	pH units	TM73/PM0	7.59	7.53	7.68	4.90	7.50	7.63	5.35

Column Results — Natural Soil (Clays, Sand and Gravels), Ground Water Type 2; Waste and Natural Soil Mix, Ground Water Type 1

Determinand	N2A (No Binder)	N2B (EHC)	N2C (Mulch)	N2D (Zeolite & Mulch)	N2E (EHC & Mulch)	WA (No Binder)	WB (EHC)	WC (Mulch)	WD (Zeolite & Mulch)	WE (EHC & Mulch)
Dissolved Aluminium [#]	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20
Dissolved Arsenic [#]	3.7	2.5	21.5	15.9	4.8	15.4	23.0	46.5	37.2	2.5
Dissolved Cadmium [#]	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Total Dissolved Chromium [#]	5.8	1.5	1.5	1.5	1.5	1.5	1.5	3.1	4.3	1.5
Dissolved Copper [#]	<7	875	<7	<7	<7	13	574	<7	<7	485
Total Dissolved Iron [#]	52	7021000	2202	8236	27990	286	6537000	797	802	4389000
Dissolved Lead [#]	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Dissolved Nickel [#]	35	126	45	36	42	34	244	39	42	84
Dissolved Selenium [#]	34	<3	<3	<3	<3	<3	<3	<3	<3	<3
Dissolved Zinc [#]	16	2129	3	3	5	44	2108	3	3	656
Mercury Dissolved by CVAF [#]	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
PAH MS										
Naphthalene [#]	<0.1[B]	<0.1[SV]	0.1[B]	<0.1[B]	<0.1[SV]	0.1[B]	<0.1[SV]	0.2[B]	0.1[B]	<0.1[SV]
Acenaphthylene [#]	0.013	0.013	0.013	0.038	0.082	0.030	0.013	0.019	0.019	0.013
Acenaphthene [#]	<0.013	<0.013[SV]	<0.013	<0.013	<0.013[SV]	0.015	<0.013[SV]	<0.013	<0.013	<0.013[SV]
Fluorene [#]	<0.014	<0.014[SV]	<0.014	<0.014	<0.014[SV]	0.014	<0.014[SV]	<0.014	0.015	<0.014[SV]
Phenanthrene [#]	<0.011	0.011[SV]	0.015	<0.011	<0.011[SV]	0.037	<0.011[SV]	0.035	0.021	<0.011[SV]
Anthracene [#]	<0.013	<0.013[SV]	<0.013	<0.013	<0.013[SV]	<0.013	<0.013[SV]	<0.013	0.014	<0.013[SV]
Fluoranthene [#]	<0.012	<0.012[SV]	<0.012	<0.012	0.015[SV]	0.019	<0.012[SV]	<0.012	<0.012	<0.012[SV]
Pyrene [#]	<0.013	<0.013[SV]	<0.013	<0.013	<0.013[SV]	0.015	<0.013[SV]	<0.013	<0.013	<0.013[SV]
Benzo(a)anthracene [#]	<0.015	<0.015[SV]	<0.015	<0.015	<0.015[SV]	<0.015	<0.015[SV]	<0.015	<0.015	<0.015[SV]
Chrysene [#]	<0.011	<0.011[SV]	<0.011	<0.011	<0.011[SV]	<0.011	<0.011[SV]	<0.011	<0.011	<0.011[SV]
Benzo(bk)fluoranthene [#]	<0.018	<0.018[SV]	<0.018	<0.018	<0.018[SV]	<0.018	<0.018[SV]	<0.018	<0.018	<0.018[SV]
Benzo(a)pyrene [#]	<0.016	<0.016[SV]	<0.016	<0.016	<0.016[SV]	<0.016	<0.016[SV]	<0.016	<0.016	<0.016[SV]
Indeno(123cd)pyrene [#]	<0.011	<0.011[SV]	<0.011	<0.011	<0.011[SV]	<0.011	<0.011[SV]	<0.011	<0.011	<0.011[SV]
Dibenzo(ah)anthracene [#]	<0.01	<0.01[SV]	<0.01	<0.01	<0.01[SV]	<0.01	<0.01[SV]	<0.01	<0.01	<0.01[SV]
Benzo(ghi)perylene [#]	<0.011	<0.011[SV]	<0.011	<0.011	<0.011[SV]	<0.011	<0.011[SV]	<0.011	<0.011	<0.011[SV]
PAH 16 Total [#]	<0.195	<0.195[SV]	<0.195	<0.195	<0.195[SV]	0.230	<0.195[SV]	0.254	<0.195	<0.195[SV]
Benzo(b)fluoranthene	<0.01	<0.01[SV]	<0.01	<0.01	<0.01[SV]	<0.01	<0.01[SV]	<0.01	<0.01	<0.01[SV]
Benzo(k)fluoranthene	<0.01	<0.01[SV]	<0.01	<0.01	<0.01[SV]	<0.01	<0.01[SV]	<0.01	<0.01	<0.01[SV]
PAH Surrogate % Recovery	80	23	76	88	143	85	59	89	86	23
Sulphate as SO4 [#]	146.0	153.7	0.5	0.5	0.5	875.7	3128.8	8.7	24.2	2481.6
Chloride [#]	83.4	236.8	313.2	227.0	212.5	579.2	902.8	838.3	750.8	750.0
Nitrate as N [#]	<0.05	1.06	<0.05	<0.05	<0.05	6.02	<0.05	<0.05	<0.05	<0.05
Nitrite as N [#]	<0.006	0.507	<0.006	<0.006	<0.006	0.217	1.565	0.008	0.006	0.356
Ammoniacal Nitrogen as N [#]	7.52	5.82	0.21	23.23	140.69	137.83	4.87	173.42	29.45	18.94
pH [#]	7.26	5.70	7.44	7.42	6.82	7.53	5.74	7.30	7.23	5.99

Column Results — Waste and Natural Soil Mix, Ground Water Type 2

Determinand	W2A (No Binder)	W2B (EHC)	W2C (Mulch)	W2D (Zeolite & Mulch)	W2E (EHC & Mulch)
Dissolved Aluminium [#]	<20	<20	<20	<20	<20
Dissolved Arsenic [#]	30.9	19.5	46.9	43	14.2
Dissolved Cadmium [#]	<0.5	<0.5	<0.5	<0.5	<0.5
Total Dissolved Chromium [#]	1.5	<1.5	4.3	4.4	<1.5
Dissolved Copper [#]	<7	615	<7	<7	568
Total Dissolved Iron [#]	735	7215000	1137	2924	6519000
Dissolved Lead [#]	<5	<5	<5	<5	<5
Dissolved Nickel [#]	37	85	49	52	85
Dissolved Selenium [#]	<3	<3	<3	<3	<3
Dissolved Zinc [#]	<3	2687	<3	<3	872
Mercury Dissolved by CVAF [#]	<0.01	0.02	<0.01	<0.01	<0.01
PAH MS					
Naphthalene [#]	<0.1[B]	0.1[SV]	0.2[B]	0.2[B]	<0.1[SV]
Acenaphthylene [#]	0.033	0.022	0.013	0.018	0.018
Acenaphthene [#]	<0.013	<0.013[SV]	<0.013	<0.013	<0.013[SV]
Fluorene [#]	<0.014	<0.014[SV]	<0.014	0.018	<0.014[SV]
Phenanthrene [#]	0.024	0.044	0.011	0.018	0.034
Anthracene [#]	<0.013	<0.013[SV]	<0.013	<0.013	<0.013[SV]
Fluoranthene [#]	<0.012	0.030[SV]	<0.012	<0.012	<0.012[SV]
Pyrene [#]	<0.013	0.033[SV]	<0.013	<0.013	<0.013[SV]
Benzo(a)anthracene [#]	<0.015	<0.015[SV]	<0.015	<0.015	<0.015[SV]
Chrysene [#]	<0.011	0.011[SV]	<0.011	<0.011	<0.011[SV]
Benzo(bk)fluoranthene [#]	<0.018	<0.018[SV]	<0.018	<0.018	<0.018[SV]
Benzo(a)pyrene [#]	<0.016	<0.016[SV]	<0.016	<0.016	<0.016[SV]
Indeno(123cd)pyrene [#]	<0.011	<0.011[SV]	<0.011	<0.011	<0.011[SV]
Dibenzo(ah)anthracene [#]	<0.01	<0.01[SV]	<0.01	<0.01	<0.01[SV]
Benzo(ghi)perylene [#]	<0.011	<0.011[SV]	<0.011	<0.011	<0.011[SV]
PAH 16 Total [#]	0.195	0.24	0.2	0.25	0.195
Benzo(b)fluoranthene	<0.01	<0.01[SV]	<0.01	<0.01	<0.01[SV]
Benzo(k)fluoranthene	<0.01	<0.01[SV]	<0.01	<0.01	<0.01[SV]
PAH Surrogate % Recovery	79	28	87	83	29
Sulphate as SO4 [#]	1284.4	2965.7	0.5	1.2	2950.2
Chloride [#]	851.8	821	1132.7	1033.2	981.9
Nitrate as N [#]	<0.05	<0.05	<0.05	<0.05	<0.05
Nitrite as N [#]	0.006	0.861	0.346	0.171	1.208
Ammoniacal Nitrogen as N [#]	218.8	105.73	188.81	44.32	12.66
pH [#]	7.55	5.74	7.25	7.13	5.89

Column Results (NORMAILISED against Groundwater results)

Parent Material Type	Natural Soil (Clayey Sand and Gravel)					Natural Soil (Clayey Sand and Gravel)				
Ground Water Type	Ground Water Type 1					Ground Water Type 2				
Binder Agent	No Binder	EHC	Mulch	Zeolite & Mulch	EHC & Mulch	No Binder	EHC	Mulch	Zeolite & Mulch	EHC & Mulch
Sample ID	N1A	N1B	N1C	N1D	N1E	N2A	N2B	N2C	N2D	N2E
Dissolved Aluminium*	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Dissolved Arsenic*	0.507463	0.373134	4	2.5373134	0.373134	0.377551	0.255102	2.193878	1.62244898	0.48979592
Dissolved Cadmium*	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Total Dissolved Chromium*	0.712329	0.205479	0.205479	0.2054795	0.205479	3.866667	<LOD	<LOD	<LOD	<LOD
Dissolved Copper*	<LOD	104.1429	<LOD	<LOD	7.857143	<LOD	125	<LOD	<LOD	<LOD
Total Dissolved Iron*	2.956522	211304.3	496.9565	59.913043	15547.83	0.017128	2312.582	0.725296	2.71277997	9.21936759
Dissolved Lead*	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Dissolved Nickel*	2.344828	4.758621	1.310345	1.2068966	0.586207	1.458333	5.25	1.875	1.5	1.75
Dissolved Selenium*	10	<LOD	<LOD	<LOD	<LOD	11.33333	<LOD	<LOD	<LOD	<LOD
Dissolved Zinc*	0.333333	148.7778	0.333333	0.3333333	10.55556	5.333333	709.6667	<LOD	<LOD	1.66666667
Mercury Dissolved by CVAF*	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	2	<LOD	<LOD	<LOD
PAH MS										
Naphthalene*	<LOD	<LOD	<LOD	<LOD	<LOD	0.333333	0.333333	0.666667	0.33333333	0.33333333
Acenaphthylene*	0.8125	0.8125	0.8125	0.8125	0.8125	0.245283	0.245283	0.245283	0.71698113	1.16981132
Acenaphthene*	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Fluorene*	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Phenanthrene*	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	1.153846	<LOD	<LOD
Anthracene*	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Fluoranthene*	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Pyrene*	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Benzo(a)anthracene*	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Chrysene*	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Benzo(bk)fluoranthene*	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Benzo(a)pyrene*	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Indeno(123cd)pyrene*	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Dibenzo(ah)anthracene*	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Benzo(ghi)perylene*	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
PAH 16 Total*	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Benzo(b)fluoranthene	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Benzo(k)fluoranthene	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
PAH Surrogate % Recovery	0.955556	0.288889	0.855556	0.8666667	0.4	0.97561	0.280488	0.926829	1.07317073	1.74390244
Sulphate as SO4*	3.403553	2.063452	0.01269	0.0126904	0.35533	292	307.4	<LOD	<LOD	<LOD
Chloride*	0.484598	1.226146	2.073629	1.446281	0.959429	0.391182	1.110694	1.469043	1.06472795	0.9967167
Nitrate as N*	0.009747	0.11501	0.009747	0.0097466	0.009747	<LOD	21.2	<LOD	<LOD	<LOD
Nitrite as N*	0.119403	4.537313	0.044776	0.0447761	0.044776	<LOD	84.5	<LOD	<LOD	<LOD
Ammoniacal Nitrogen as N*	0.446399	0.509071	0.24354	0.0032985	7.605278	0.810345	0.627155	0.022629	2.50323276	15.1605603
pH*	1.011858	0.645586	0.988142	1.0052701	0.704875	0.964143	0.756972	0.988048	0.98539177	0.90571049

Parent Material Type	Waste and Natural Soil Mix					Waste and Natural Soil Mix				
Ground Water Type	Ground Water Type 1					Ground Water Type 2				
Binder Agent	No Binder	EHC	Mulch	Zeolite & Mulch	EHC & Mulch	No Binder	EHC	Mulch	Zeolite & Mulch	EHC & Mulch
Sample ID	W1A	W1B	W1C	W1D	W1E	W2A	W2B	W2C	W2D	W2E
Dissolved Aluminium*	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Dissolved Arsenic*	2.298507	3.432836	6.940299	5.55223881	0.373134	3.153061	1.989796	4.785714	4.3877551	1.44898
Dissolved Cadmium*	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Total Dissolved Chromium*	0.205479	0.205479	0.424658	0.5890411	0.205479	<LOD	<LOD	2.866667	2.9333333	<LOD
Dissolved Copper*	1.857143	82	<LOD	<LOD	69.28571	<LOD	87.85714	<LOD	<LOD	81.14286
Total Dissolved Iron*	12.43478	284217.4	34.65217	34.8695652	190826.1	0.242095	2376.482	0.374506	0.9631094	2147.233
Dissolved Lead*	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Dissolved Nickel*	1.172414	8.413793	1.344828	1.44827586	3.241379	1.541667	3.541667	2.041667	2.1666667	3.541667
Dissolved Selenium*	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Dissolved Zinc*	4.888889	234.3333	0.333333	0.33333333	72.88889	<LOD	899	<LOD	<LOD	290
Mercury Dissolved by CVAF*	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	2	<LOD	<LOD	<LOD
PAH MS										
Naphthalene*	<LOD	<LOD	2	<LOD	<LOD	0.333333	0.333333	0.666667	0.6666667	0.333333
Acenaphthylene*	1.875	0.8125	1.1875	1.1875	0.8125	0.622642	0.415094	0.245283	0.3396226	0.301887
Acenaphthene*	1.153846	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Fluorene*	1	<LOD	<LOD	1.07142857	<LOD	<LOD	<LOD	<LOD	1.1428571	<LOD
Phenanthrene*	3.363636	<LOD	3.181818	1.90909091	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Anthracene*	<LOD	<LOD	<LOD	1.07692308	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Fluoranthene*	1.583333	<LOD	<LOD	<LOD	<LOD	<LOD	2.5	<LOD	<LOD	<LOD
Pyrene*	1.153846	<LOD	<LOD	<LOD	<LOD	<LOD	2.538462	<LOD	<LOD	<LOD
Benzo(a)anthracene*	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Chrysene*	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Benzo(bk)fluoranthene*	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Benzo(a)pyrene*	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Indeno(123cd)pyrene*	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Dibenzo(ah)anthracene*	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Benzo(ghi)perylene*	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
PAH 16 Total*	1.179487	<LOD	1.302564	<LOD	<LOD	0.552408	0.679887	0.566572	0.7082153	0.552408
Benzo(b)fluoranthene	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Benzo(k)fluoranthene	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
PAH Surrogate % Recovery	0.944444	0.655556	0.988889	0.95555556	0.255556	0.963415	0.341463	1.060976	1.0121951	0.353659
Sulphate as SO4*	22.22589	79.41117	0.220812	0.6142132	62.98477	2568.8	5931.4	<LOD	2.4	5900.4
Chloride*	4.351615	6.78287	7.049587	5.64087153	5.694966	3.994371	4.319887	5.312852	4.8461538	4.605535
Nitrate as N*	1.173489	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Nitrite as N*	1.619403	11.6791	<LOD	<LOD	2.656716	<LOD	143.5	57.66667	28.5	201.3333
Ammoniacal Nitrogen as N*	7.57724	0.26773	9.53381	1.61902144	1.041231	23.58836	11.39332	20.45366	4.7758621	1.364224
pH*	0.992095	0.761528	0.961792	0.95256917	0.789196	1.002656	0.762284	0.962815	0.9468792	0.782205

Parent Soil Type	GW Type	Binder Agent	Sample ID	Permeability (m/s)	Average Permeability (for Analogous Soil Binder Mixes) (m/s)	Average Permeability Normalised against no binder results	Remarks
Natural Soil (Clayey Sand and Gravel)	GW1	No Binder	N1A	2.00E-07	1.75E-07	-	
	GW2		N2A	1.50E-07			
	GW1	EHC	N1B	3.00E-07	3.15E-07	1.8	Minor Improvement in Permeability
	GW2		N2B	3.30E-07			
	GW1	Mulch	N1C	1.10E-06	1.90E-06	10.86	Significant improvement in Permeability
	GW2		N2C	2.70E-06			
	GW1	Zeolite & Mulch	N1D	1.90E-06	1.85E-06	10.57	Significant improvement in Permeability
	GW2		N2D	1.80E-06			
	GW1	EHC & Mulch	N1E	6.70E-07	5.35E-07	3.06	Minor Improvement in Permeability
	GW2		N2E	4.00E-07			
Waste and Natural Soil Mix	GW1	No Binder	W1A	6.10E-06	3.80E-06	-	
	GW2		W2A	1.50E-06			
	GW1	EHC	W1B	8.50E-08	2.58E-07	0.07	Significant reduction in permeability
	GW2		W2B	4.30E-07			
	GW1	Mulch	W1C	3.20E-07	2.15E-07	0.06	
	GW2		W2C	1.10E-07			
	GW1	Zeolite & Mulch	W1D	1.70E-07	9.75E-08	0.03	
	GW2		W2D	2.50E-08			
	GW1	EHC & Mulch	W1E	5.40E-08	4.15E-08	0.01	
	GW2		W2E	2.90E-08			

Permeability Assessment from Column Tests