Deliverable T2.4.1 – Formulation and lab test of eco-solutions to be implemented in Bowling South Falkirk pilot site report

Interreg North-West Europe SURICATES
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ABBREVIATIONS

AOD	Above Ordnance Datum
CBR	California Bearing Ratio
CI	Cone Index
CL	Cable Length
GPS	Global Positioning System
LOI	Loss on Ignition
MEXE	Military Engineering Experimental Establishment
OS	Ordnance Survey
PSD	Particle Size Distribution
PVC	Polyvinyl chloride
RGC	Reed canarygrass (Phalaris arundinacea)
SC	Scottish Canals
SURICATES	Sediment Uses as Resources In Circular And Territorial EconomieS
TDR	Time-domain reflectrometry
TOC	Top of Casing
TOC	Total Organic Carbon
TSP	Triple superphosphate
UNESCO	United Nations Educational, Scientific and Cultural Organization
UoS	University of Strathclyde
WL	Water Level
WP	Work Package

1 INTRODUCTION

1.1 OVERVIEW

The aim of the SURICATES (Sediment Uses as Resources In Circular And Territorial EconomieS) project is to increase sediment reuse for erosion and flood protection through innovative pilot implementation. The University of Strathclyde (UoS) is a Principal Partner in SURICATES and has partnered with Scottish Canals (SC) to undertake pilot studies using sediment dredged during routine maintenance from multiple locations within the canal network.

The Falkirk South was selected as an additional pilot study site because maintenance dredging on the Union Canal coincided with our requirement to test design concepts that would be implemented at future pilot study sites, such as the Bowling Basin. The main goals of the pilot study were therefore to identify and address construction issues related to the cell walls and internal cell bunds, to install gauging equipment, designing effective cell drainage, emplacing the wet sediment in the cells and to trial deployment methods for phytostabilisation of wet dredged sediments. Solutions to issues that arose during the emplacement of the sediment, for example poor drainage, had to be resolved between deliveries of sediment in order to allow dredging to be completed within its allotted timeframe.

The site was prepared and excavated during July 2019 by Scottish Canals (SC), with sediment delivered during July and August. Monitoring of ground conditions continued until January 2020, when material in the cells was removed.

This report fulfils the requirement for work package WP T2 deliverable; T2.4.1 “Formulation and lab test of eco-solutions to be implemented in Bowling site report”.

2 SITE DESCRIPTION

2.1 LOCATION

The site is in Central Scotland, at the southern edge of the town of Falkirk, adjacent to the Union Canal. It accessed from Bonnyhill Road (B816) at OS Grid Reference NS 85374 79580. The grid square is NS87. It was selected based on its proximity to dredging sites on the Union Canal in Linlithgow, approximately 8.5 miles by road. The property belongs to Scottish Canals and is used primarily as a builder’s yard. It is bordered to the north by the westernmost lock on the Union Canal and the main Edinburgh to Glasgow railway line, which runs north and parallel to the Union Canal at this section. The land surrounding the site is largely pastoral with woods.

Figure 1. Plan showing the location of the South Falkirk Site.

2.2 Site history

This section of the Union Canal dates to the reopening of the canal in 2000 which is connected to the Forth & Clyde Canal via a tunnel under the railway line to the Falkirk Wheel. This new stretch of canal replaced a section of the original Union Canal that connected to the Forth & Clyde Canal at Camelon via a series of locks that had been abandoned and filled in by the 1930s. Instead, canal boats are lifted 24 metres from the Forth and Clyde Canal by the innovative Falkirk Wheel.

Previous land use appears to be largely agricultural, based on examination of historical OS maps. However, the Roughcastle open cast coal mine was operated in this area from the mid-1980s until 1996 by Coal Contractors Inc. and was subsequently reclaimed and landscaped. The treatment cells were close to or are within the former pit excavation boundary[1].

Antonine's Wall, begun in AD142 by the Romans, runs within 500 metres of the northern boundary of the site. This is listed by the United Nations Educational, Scientific and Cultural Organization (UNESCO) as a "World Heritage Site", marking the most north-westerly boundary of the Roman Empire and subject to special protection. In addition,

[1] The exact position of the mine excavation boundary has not been established from site plans but can be approximated using oblique aerial photographs, for example, Figure 1.

there are several archaeological sites associated with the wall, including the roman Rough Castle Fort[2], which is immediately west of the site.

Figure 2. 1988 Oblique aerial photograph showing the Roughcastle Open Cast Coal Mine looking northwest. https://canmore.org.uk/collection/1669754 ©RCAHMS

Figure 3. 1993 Photo of Roughcastle mine looking southeast showing the underlying geology. British Geological Survey. P000221.

[2] https://canmore.org.uk/site/124018/antonine-wall-rough-castle

2.3 TOPOGRAPHY AND GEOLOGY

The South Falkirk Site is a fenced area of 1,500 square metres, with access via a single gate along the eastern side. Ground slopes from south to north, with an elevation change of approximately 2 metres. The upper 1 -2 metres of soil is described as silty clays, clays and loams, overlying in-situ glacial clays and compacted sandstone boulder fill, with coal fragments. These are interpreted as waste rock from open cast mining operations that was ultimately used to backfill the mine excavation.

The underlying geology of the site is well documented through boreholes and sub-surface mining, (Cameron, et al., 1998), consisting of gently dipping sequential white sandstones, coal seams and fireclays of Upper Carboniferous age, belonging to the Coal Measures Group, capped with glacial till (British Geological Survey, 1997). Both coal and fireclay were extensively mined in the Falkirk Area, with numerous underground workings and former pits in the area. A large open cast coal mine operated at the site until 1996 which was backfilled using waste rock (Figure 2 &) and re-graded.

3 Construction of Treatment Cells

3.1 Site preparation

The South Falkirk site had been partially excavated in 2017 by SC but additional material was removed within a fenced area to create the cell base at an elevation of approximately 73.7 metres above ordnance datum (AOD). Bunds were constructed at 6 metre intervals using compacted topsoil to create cells that were approximately 5 metres by 20 metres. It was determined that the most efficient method to fill the cells was to have each dump truck empty its load directly into the furthest cell (F1) and progressively fill cells moving towards the site entrance. An excavator was then used to redistribute the slurry within the cell. Additional bunds were constructed as the cells were sequentially filled. Monitoring wells were constructed in each cell in advance of receiving dredged sediment but their placement was constrained by the need for the excavator to manoeuvre in the adjacent empty cell.

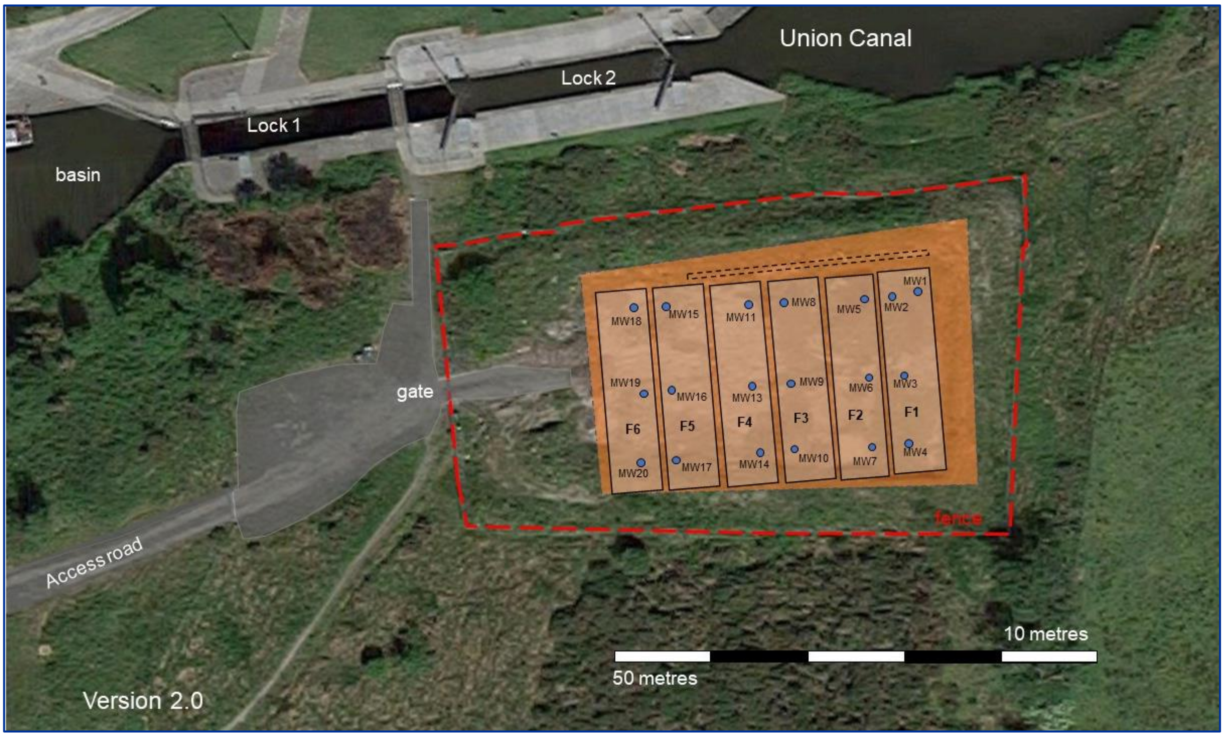

Figure 4. Plan showing the cell boundaries and position of monitoring wells.

3.2 Construction of monitoring wells and piezometers

Groundwater monitoring wells and piezometers[3] were constructed to allow groundwater levels to be measured at different stages of dewatering. The incoming dredged sediment had a water content of 70 – 80% and was observed to behave as a viscous fluid during emplacement in the cell. Consequently, the monitoring wells were constructed in advance of dredged sediment deposition to allow the sediment to flow around the completed well point. Piezometers were constructed from 50mm diameter PVC pipe, cut

[3] Most wells were only used to determine the depth to groundwater and are therefore described as piezometers.

to a length of approximately 140cm. 1.5mm transverse slots were cut into the bottom 50cm of the pipe to allow water to infiltrate the well. The pipe was encased within a 110mm diameter PVC pipe, cut to a length of 110cm, that was perforated for the bottom 50 cm of its length using a hand drill with a 10 mm bit. A 40cm x 60cm sleeve of a construction geo-fabric was installed to cover the perforations and held in place using zip ties (Figure 21).

Monitoring wells for the collection of water samples (MW1 & MW12) were constructed as above but using 40mm white PVC pipe. As a test of alternative methods, MW12 was installed after sediment had been placed in the cell. The well was assembled prior to installation and was pushed into the sediment from the bund. Although successful, this approach is limited to within 0.5 metres of the bund.

Monitoring wells were installed as follows. A 150mm diameter hole was dug in the bottom of the cell by hand to a depth of 150mm or more, depending on ground conditions. In the northern section of the site, the underlying material was compacted sandstone cobbles with clay that was difficult to penetrate. The southern half of the cells were underlain by clay which could be easily cut. The base of the well was supported using coarse gravel and rock ballast scavenged from the excavated topsoil. This provided some protection from the slurry flow which could dislodge the well during filling of the cell. A cap was placed on the top of the well and the well location recorded using a Garmin Oregon 4000 Global Positioning System (GPS) unit. Finally, the elevation of the top of the 50mm PVC well pipe was surveyed using a level and staff, tied into a benchmark beside the canal lock.

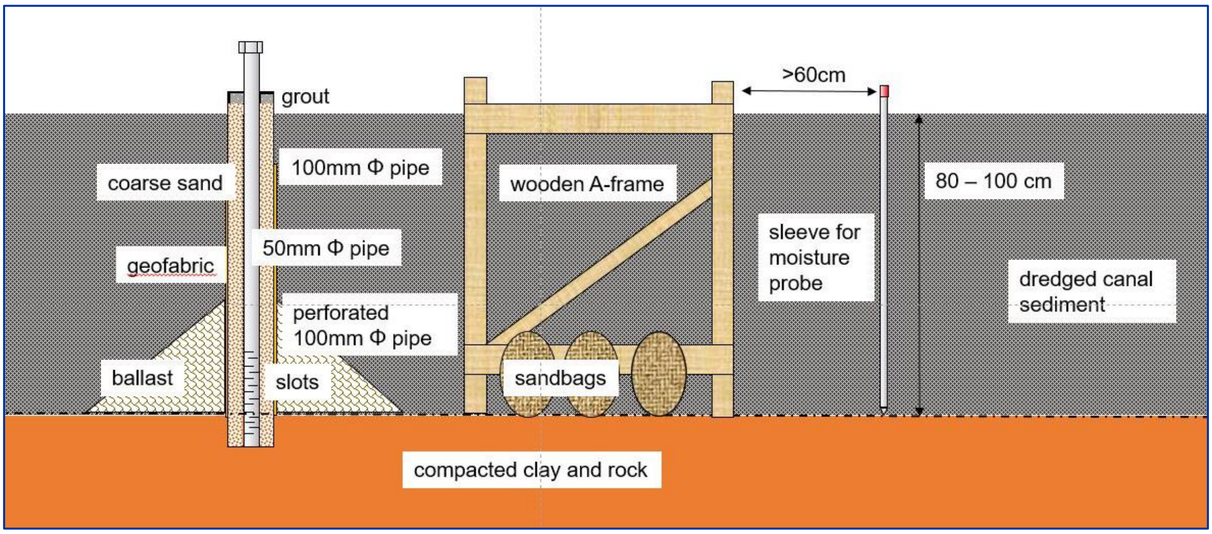

Figure 5. Design of monitoring wells with A-frame to support access board.

As the dredged sediment had the consistency of wet sludge the safety of personnel during measurement was the prime concern. Adjacent to each well point was placed a wooden A-frame (Figure 22) which was constructed using scrap timber. The A-frame protruded above the level of the sediment and was used to support a Youngman® board[4] placed from the bund. This was the only safe way that the wells could be accessed for measurement/sampling, as the dredged material could not support any weight.

TD-Diver© water level data loggers[5] were installed in MW2, MW5 and MW15 at a depth of approximately 1 metre below the top of casing (TOC). The Divers© autonomously recorded groundwater levels and temperature at intervals of 15 minutes. Data was collected from each Diver© by removing it from the well and retrieving the data via an optical interface with a USB connector to a computer loaded with Diver-Office software. Water levels in wells that were not fitted with a Diver© were gauged in the conventional manner using a water level sounder at regular intervals (Figure 38).

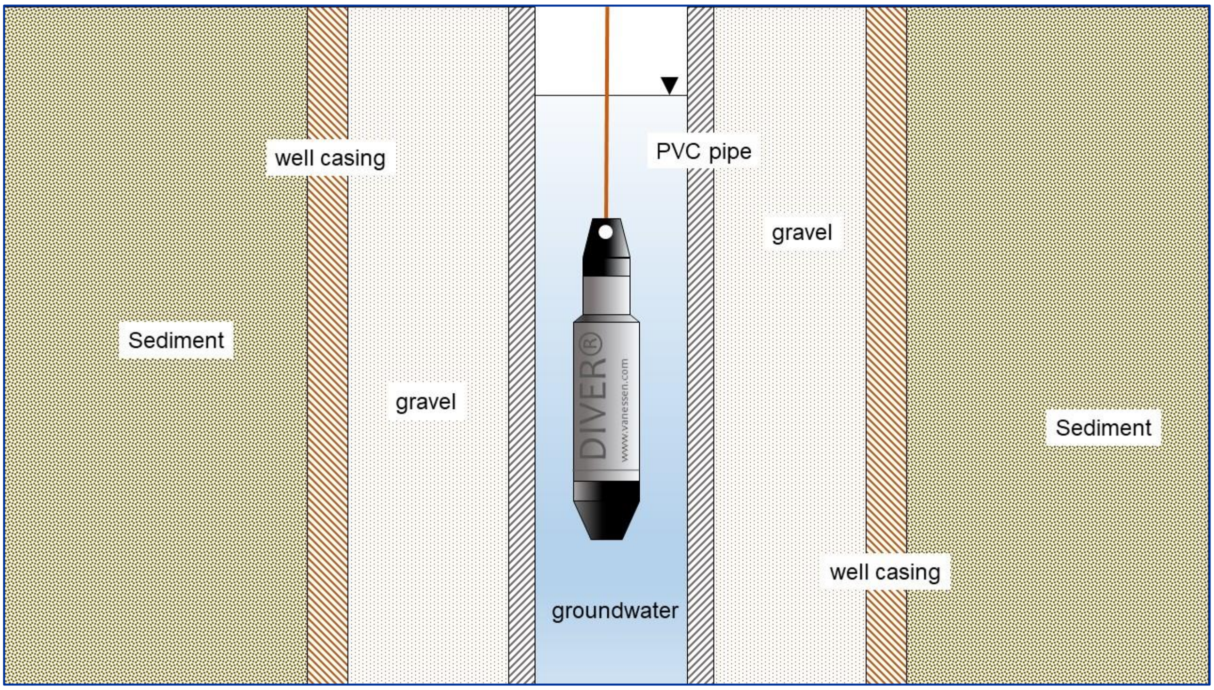

Figure 6. Positioning of Diver© transducer in the well.

3.3 Installation of moisture probe sleeves

Close to each well, a 1-metre long fiberglass sleeve was pushed into the wet sediment, tapped down and capped. This sleeve was designed to accept a one-metre long PR2/6 TDR moisture probe[6] connected to a data logger which measured moisture at six vertical intervals in the sediment. Data were collected using a portable data-logger connected to the moisture probe (Figure 39). In practice, the sleeves couldn't be installed flush with cell surface level so at least two sensors were above ground level. The height of the top of the sleeve was determined by surveying so that the elevation of each sensor was known for all locations.

[4] Youngman Group Limited; https://www.youngmanaccess.com/uk/
[5] Van Essen Instruments B.V.; www.vanessen.com
[6] Supplied by Delta-T Devices, Burwell, Cambridge https://www.delta-t.co.uk/

The combination of the piezometer readings and the moisture probe profile allowed the progress of de-watering to be monitoring in each cell. At the end of the trial the sleeves were recovered to use in future pilot studies.

4 SEDIMENT DE-WATERING

It was anticipated that de-watering of the wet dredged sediments would be achieved through a combination of 1) drainage under gravity, 2) evaporation, and 3) infiltration to deeper aquifers (Figure 7). It was further assumed that transpiration would make an increasing contribution to moisture loss when vegetation became established on the surface of the cells.

A drain was constructed in the north-eastern corner of the site fed by a perforated pipe running along the north edge of the cells. However, it was largely ineffective at promoting additional drainage from the cells due to its elevation above the floor of the cell. As the sediment was emplaced as a watery sludge water initially collected at low spots on the surface. The tops of the cell bunds were 1 – 2 metres below ground level and additional water inputs from the surrounding area were observed as seeps on the southern excavation wall.

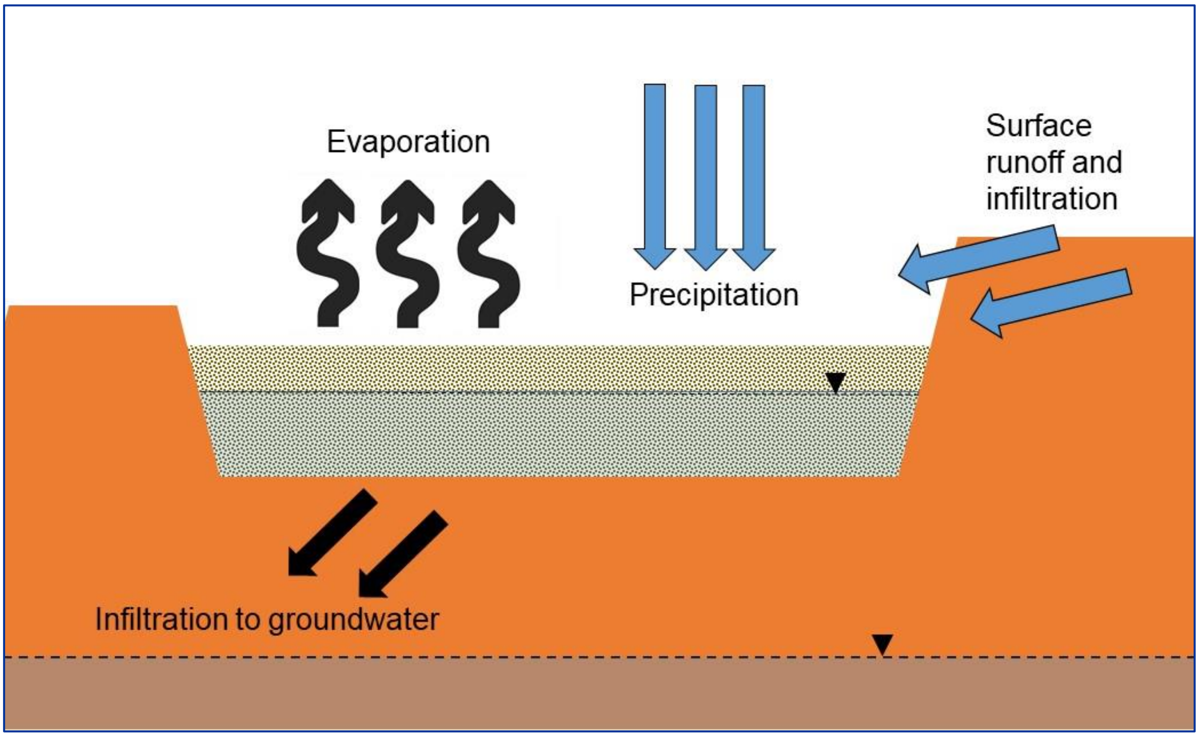

Figure 7. Conceptual model of water balance within the cell.

Water was observed initially in the piezometers at the same level as the surface water, consistent with a completely saturated sediment mass. From boreholes advanced during the construction of the Millennium Canal link, groundwater is reported as being present at a depth of around 52 metres AOD (Beadman & Manning, 2002)(. Consequently, each cell was conceptualised as containing a temporary perched aquifer, bounded by the clay-rich base and the compacted bunds.

The beginning of August 2019 saw exceptionally high precipitation, including two daily recordings of 14.5mm and 20.8mm at the Polmonthill Weather Station[7]. This compares

[7] https://apps.sepa.org.uk/rainfall//data/index/15187 Accessed 12 August 2019.

to the August average rainfall of 61.5mm for this station; total rainfall for August 2019 was 147.2mm. These exceptional rainfall events rapidly inundated the treatment cells and overtopped inter-cell bunds. Consequently, additional measures were taken to improve the surface drainage of the treatment area, including excavating surface drainage channels and overspill notches in berms.

4.1 DREDGED SEDIMENT

Sediment was dredged from three sites in the Union Canal at Linlithgow using a barge-mounted excavator and hopper barges. The barges were unloaded at St. Michaels using a long-reach excavator and sediment transferred to trucks for the road journey to the South Falkirk Site. Transportation of the sediment was unfortunately not possible due to logistical and cost considerations.

Each truck contained approximately 8 cubic metres of dredged sediment, which weighed 10 – 15 tonnes. A total of 48 loads were received for a total weight of 693 tonnes. It took 8 to 11 loads to fill each cell to capacity. The volume of sediment placed in each cell is summarised in Table 1.

Table 1. Summary of Dredged Sediment Volumes Placed in each Cell.

	Cell Width	Length	Area m^2	Truck loads	Emplaced Volume (m^3)	Emplaced weight (tonnes)
Cell F1	8m	21m	168	11	200	138
Cell F2	5m	21m	105	7	166	115
Cell F3	5m	20m	100	9	196	135
Cell F4	5m	20m	100	10	217	150
Cell F5	5m	20m	100	9	196	135
Cell F6	5m	20m	100	2	43	30
Total				**48**	**1018**	**703**

Analytical data for sediment from each dredging location is provided in Appendix A. Sample SC/076/001 had elevated concentrations of lead (136mg/kg, mercury 1.69 mg/kg and zinc (308 mg/g) which may be phytotoxic to some plant species, but otherwise soil metal concentrations were below action levels. Particle size distribution (PSD), moisture content and Loss on Ignition (LOI) measurements were also determined for each sediment sample (Table 2). All of the samples had high concentrations of organic carbon, as shown by the LOI results in Table 2.

Table 2.

Field name	LOI (dry)	Moisture content	%gravel	%clay	%silt	%sand	Soil textural class[8]
SS1	21%	79%	0	2	50	47	Sandy silt loam
SS2	19%	74%	21	0	0	79	Sand
SS3	23%	65%	31	0	0	69	Sand
SS4	8%	51%	10	8	12	70	Sandy loam
SS5	13%	35%	16	0	0	84	Sand
SS6	17%	73%	15	2	32	51	Sandy loam

[8] Soil Survey of England & Wales (see www.landis.org.uk)

Table 3. Representative Sediment Samples from Union Canal Dredging Locations near Linlithgow.

Sample Ref	Colour	Latitude	Longitude	Date collected	Time collected	Water content	LOI*
SC/076/001	Dark brown	55.970176°	-3.611357°	21/05/2019	13:25	79.00%	21.00%
SC/076/002	Dark brown	55.970629°	-3.610024°	21/05/2019	13:15	74.00%	19.00%
SC/076/003	Dark brown	55.976156°	-3.589827°	21/05/2019	14:45	65.00%	23.00%
SC/076/004	Dark brown with chestnut hue	55.976088°	-3.587901°	21/05/2019	15:00	51.00%	8.00%
SC/076/005	Dark brown	55.975939°	-3.586418°	21/05/2019	15:30	35.00%	13.00%
26082019SS6	Dark brown	55.975948	-3.557458	26/08/2019	11:00	73.00%	17.00%

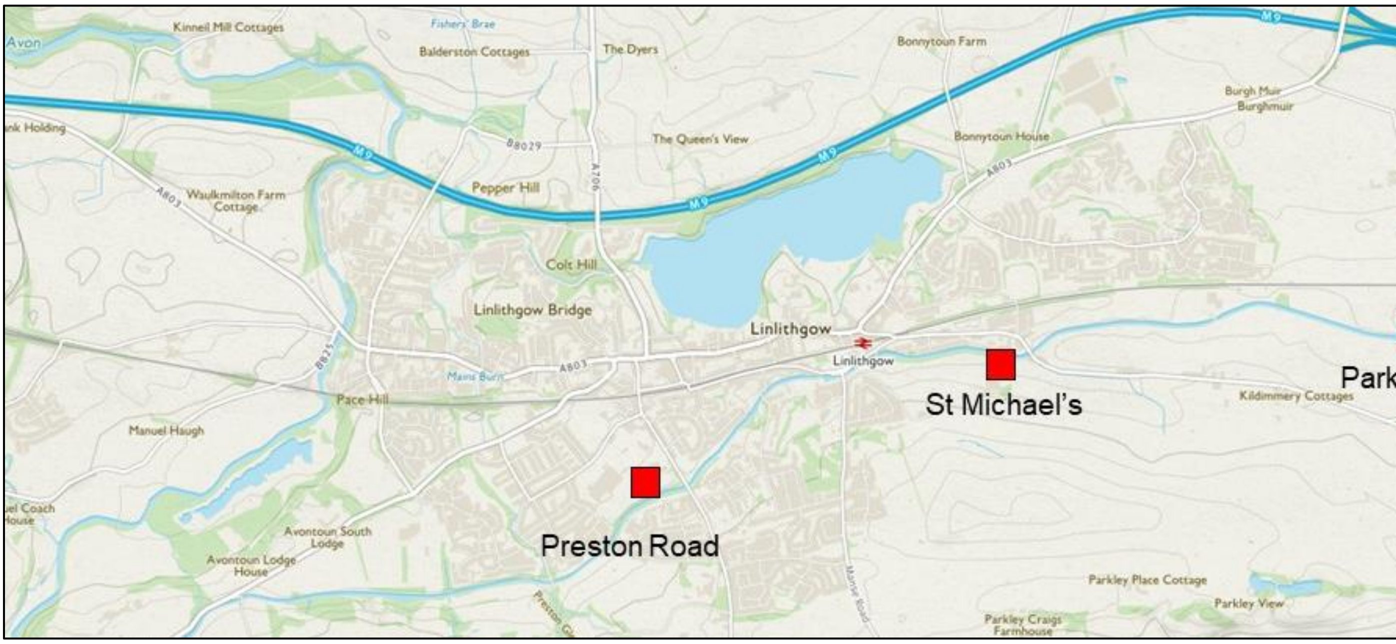

Figure 8. Areas dredged within the Union Canal during July 2019 (Google Maps).

Each load was discharged directly to the centre of the cell in a single operation (Figure 23). The large loader was then used to re-distribute the sediment to the ends of the cell, taking care not to disturb the wells. During the filling of cell F1 there was some movement of both the wells and the A-frames. Subsequently, sand bags were used to anchor the A-frames and additional ballast placed around the base of the wells to reduce any movement of the well assembly from the vertical (Figure 32). No further issues with well movement were experienced. The depth of sediment in cells F1 to F5 varied from 0.7 metres to 1.0 metres. Cell F6 was filled to less than 20% of capacity but may be used for future excavations. The monitoring wells in this cell were not used.

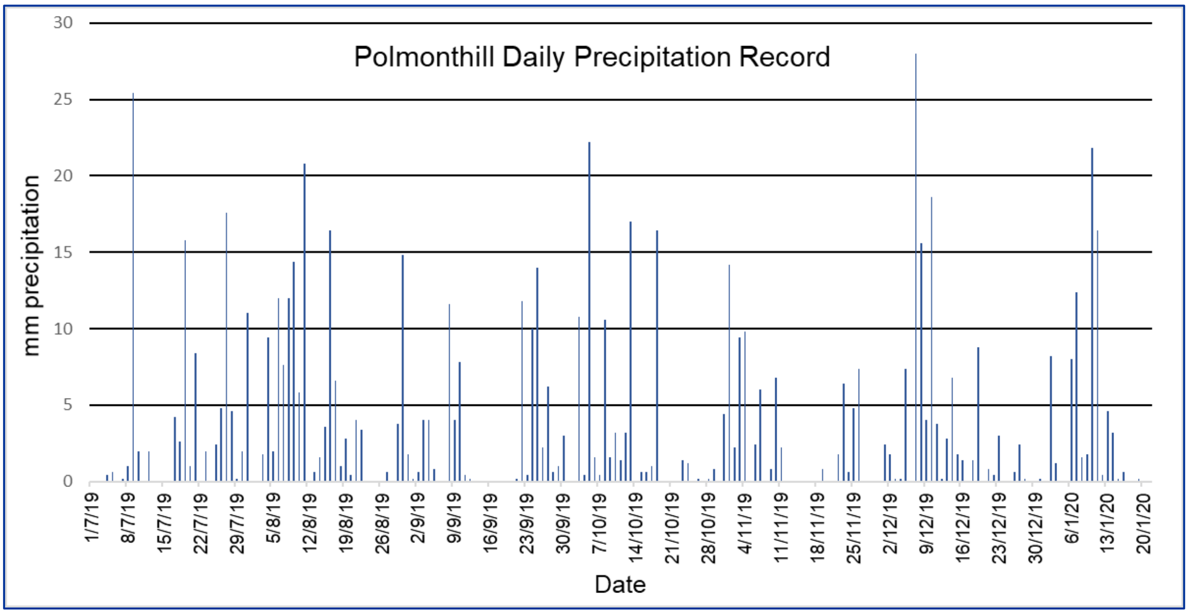

Figure 9. Daily precipitation record for Polmonthill Weather Station, downloaded 22/1/20.

It was noted that the surface within each cell was irregular with low spots that filled with water draining from the surrounding land and augmented by precipitation. During August 2019, 147.2mm of precipitation was recorded at the nearest weather station, Polmonthill, which is 239% of the average precipitation for August. (Scottish Environmental Protection Agency, 2019). For comparison, only 51.4mm precipitation was recorded in August 2018. Consequently, surface drainage ditches were manually installed in some cells to help the surface of the cell to dry out.

4.2 PHYTO-CONDITIONING

To study the effect of phyto-conditioning on de-watering rates, three cells were sown with Reed Canary Grass (RCG) *Phalaris arundinacea*. RCG has been successfully used on brownfield sites as it is tolerant of toxic metals in the soil ((Lord, 2015). As a consequence of the heavy rainfall in August 2019, sowing was not undertaken until September 11th and September 23, when most surface water had drained from the cells. 180 grams of RCG seed[9] were mixed with approximately 1,000 grams of sand that was spray-painted fluorescent pink and manually spread over the surface of the each cell from the bund, using a plastic trowel. This mass of seed equates to an application rate of 20kg.ha^{-1}. Triple superphosphate (TSP) fertilizer[10] (46% P_2O_5 by weight) was then applied at a rate of 391 grams per cell, as previous work had indicated that the sediment would be deficient in available phosphorous nutrient. This amount of TSP provides 15 kg.ha^{-1} of P, in an available form, which is rate recommended for establishment years (Lewandowski et al., 2003). The sand assisted in the even distribution and visualisation of the fine seed. The surface was raked using a rake attached to a telescopic handle[11] to protect the seed during germination.

Prior to seeding, many native plant species had become established on the surface of the cell. These included species such as Cotton thistle (*Onopordum acanthium*), Creeping buttercup (*Ranunculus repens*), Coltsfoot (*Tussilago farfara*), Amphibious bistort *(Persicaria amphibian*); Greater plantain (*Plantago major*), Bugle (*Ajuga reptans*) Rosebay willowherb, (*Chamaenerion angustifolium*), Reed canarygrass (*Phalaris arundinacea*) and Common reed, (*Phragmites australis).* Many of these plant species (e.g., Common Reed, Reed Canarygrass) are likely present as seeds or viable cuttings within the dredged sediment.

By the end of the pilot trial in January 2020 there was considerable plant growth (Figure 49), including isolated clumps of RCG. However, there was no discernible new growth RCG from the seeds that were planted in September. This may be due to the late autumn planting, competition with established plant species or poor seed stock quality. Appendix C provides a visual record of changes to the appearance of each cell through from de-watering and vegetation growth.

[9] Bright Seeds Ltd, Wilton, Wiltshire; RCG variety 'Pedja' www.brightseeds.co.uk
[10] 'Amvista' purchased from ProGreen Weed Solutions Ltd., Bourne, Lincolnshire www.progreen.co.uk
[11] Gardena combisystem

5 Lessons Learned

5.1 Cell construction

A stated in the introduction, the main goal of the Falkirk South pilot study was to evaluate cell construction methods and to resolve implementation issues in advance of the Bowling Pilot study. Table 3 summarises some of the issues encountered during construction and the lessons that will be applied to the design of future pilot studies.

Table 4. Summary of problems and solutions during cell construction

Issue	Impact	Lesson for future pilot trials
The depth of excavation for each cell was uncontrolled as no elevation measurements were taken during construction.	• Cells 3 & 4 drained in the opposite direction to cells 1 & 2. • Unnecessary excavation and cost	• Create proper plan of cell and work to this plan. • Check elevations during earthworks.
Bunds between cells were unstable and did not hydrologically isolate individual cells.	• Impossible to compare results from different cell experiments	• Bunds must be adequately constructed and compacted to be watertight, and must be higher that the level of sediment in the cell.
Not enough consideration given to basal drainage. The main drainage pipe was above the elevation of the base of the cells.	• Cells did not readily drain from the base of the cell	• Drainage ditch must be below the base of the treatment cell and properly engineered.
No provision for the drainage of surface water from the top of the cells	• Dredged sediment in the cells remained saturated until some crude drainage ditches were dug into the surface	• Use weir box/staunch to allow excess water to be drained from the surface
Access to monitoring wells required support frames and duck boards – potentially hazardous.	• Safety concerns limited the frequency of water level measurements.	• Install transducers in the wells to collect data and eliminate the need for access.

Pre-installed monitoring wells moved due to the force of the wet sediment during emplacement.	• Wells had to be re-installed or modified before they could be used.	• Additional ballast needed to keep the well packs stable.
Surface water delayed planting of RCG, which was sown too late in the season	• RCG had no impact on sediment conditioning	• Sow cells with RCG as soon as surface is dry, ideally in Spring so that it does not have to compete with other plants.

5.2 Cell drainage

Adequate drainage of water from both the surface of the cell and from the base of the cells are critical for effective sediment de-watering. The original design of the pilot cells did not include adequate drainage provision which was exacerbated by higher than average rainfall during the pilot trial and the excavation of the cells below ground level. These deficiencies will be remedied in the design of future pilot studies at Bowling.

5.3 Data collection

A secondary goal of the pilot study was to assess procedures and equipment for the in-situ collection of data on soil condition. One of the challenges was to safely access the monitoring wells after wet sediment had been emplaced. While the wooden A-frames and bunds allowed satisfactory access to the wells, we demonstrated that automatic logging of well levels, using the TD-Divers, is both viable and preferable.

5.3.1 Monitoring well levels

Water level measurements from the piezometers collected from July 2019 until January 2020 is provided in Table 6. As expected, water levels in the wells fell over time but water remained in all wells. The transducer data shows that water levels responded rapidly to periods of heavy rainfall, for example around Jan 10, 2020. Raw data from the transducer is provided in Appendix D. Water level (WL) can be calculated as shown in Figure 10 (Van Essen Instruments, 2018).

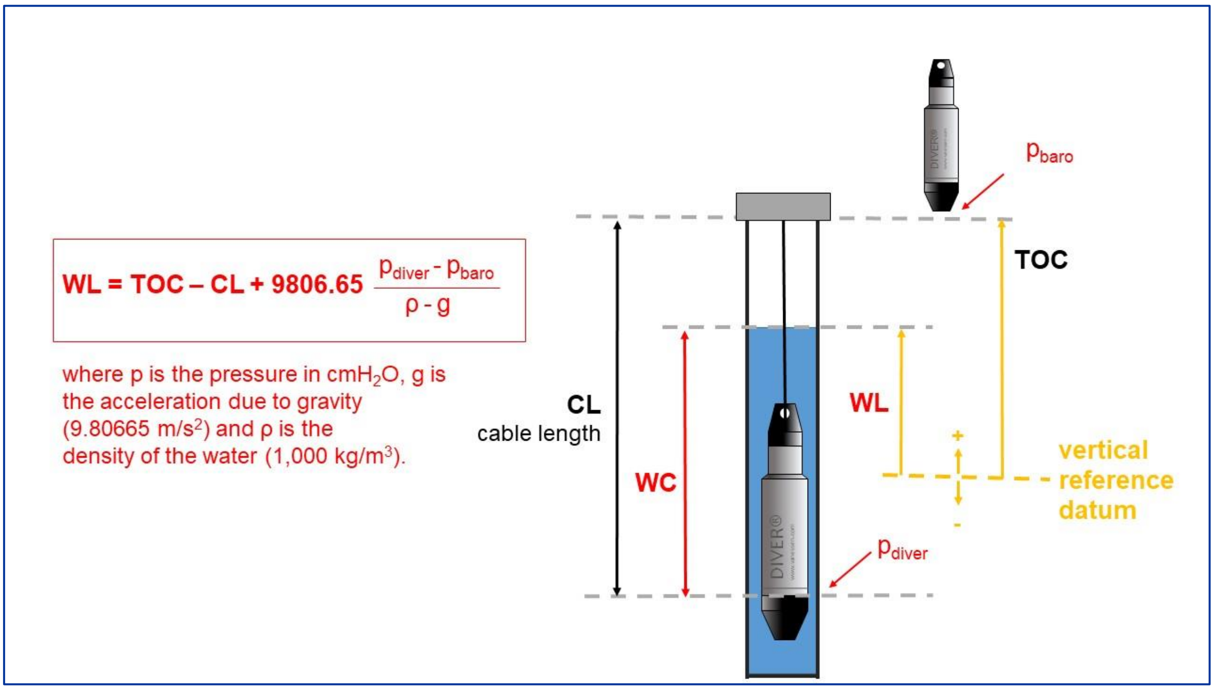

Figure 10. Determination of water level (WL) from Diver© pressure data (Van Essen Instruments).

5.3.2 Moisture probe measurements

Moisture data was collected from accessible monitoring sleeves from August 2019 until 2010. Data from the PR2/6 moisture probe is included in Appendix B.

5.3.3 Measurement of soil geotechnical properties

A MEXE Soil Assessment Cone Penetrometer, Model SL 137[12] was used for in-situ soil testing at the end of the trial (Figure 48). This instrument is designed for assessing fine-grained soils. A 20mm diameter cone attached to the device was pushed into the ground and the resistance noted. This reading can be used to estimate the California Bearing Ratio (CBR) of the subsurface, which is a measure of its compressive strength. Results are shown in Table 5. For comparison, a typical target strength for a road subgrade is 2 (200%) CBR (Cook & Dobie, 2016). CBR values of 5-80% can be expected for different types of natural soils, with improvement from 30% to 50% for marine sediments amended with lime or cement for road construction (Wang et al. 2012).

Cell F5 had the highest CBR values, which is reflective of the lower moisture content of the sediments in this cell. De-watering of cell F5 was aided by being adjacent to the empty cell F6 which acted as an effective sump.

[12] Impact Test Equipment Ltd www.impact-test.co.uk . Originally developed by the Military Engineering Experimental Establishment (MEXE), Christchurch, Dorset.

Table 5. Summary of Cone Penetration Measurements

Location	Cone Index	CBR	Comments
Cell F1			
MW1	35	0.9%	
MW2	20	0.5%	
MW3	23	0.6%	
MW4	40	1.1%	
Cell F2			
MW5	35	0.9%	
MW6	15	0.3%	
MW7	20	0.5%	
Cell F3			
MW8	-		Not accessible
MW9	15	0.3%	
MW10	35	0.9%	
Cell F4			
MW11	55	1.5%	
MW12	15	0.3%	
MW13	10	0.2%	
MW14	15	0.3%	
Cell F5			
MW15	45	1.2%	
MW16	45	1.2%	
MW17	50	1.4%	

6 DISCUSSION

The Falkirk South pilot study was a valuable learning exercise that uncovered many potential design and construction issues for future dredged sediment treatment cells and phyto-management. De-watering of sediment is dependent on the incorporation of effective drainage for both the base of the cells and the surface of the cells. A combination of inadequate basal drainage and heavier than normal rainfall made it difficult to assess the success of the pilot study.

Dredged sediment from the Union Canal was typically silty sands or sandy silts, with various gravel size fractions of anthropogenic origin. The Total organic carbon (TOC) content of the sediments ranged up to 23% dry weight as received, which appears from the observed colour change (black to brown) to slowly oxidised as water level in the cells dropped. The role that organic carbon plays in the maturation of the sediment and is poorly understood and is compounded by limited methods to measure in-situ TOC content in wet sediment.

Although methods for seeding wet sediment were developed, RCG germination was unsuccessful. However, adventitious revegetation was rapid from the seed bank and rhizomes present. Growth of vegetation and greening-up is likely to be an important criterion in determining the point of recovery of sediment placed as soil.

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Table 6. Elevation measurements of water levels within monitoring wells (metres AOD).

Well	Cell	TOC	02/08/19	07/08/19	21/08/19	3/09/19	11/09/19	19/09/19	26/09/19	8/10/19	2
MW2	F1	74.77	74.541	74.48	74.487	74.48	74.46	74.45	74.43	74.429	7
MW3	F1	74.955	74.513	74.53	74.506	74.505	74.498	74.466		74.498	7
MW4	F1	75.01	74.233	74.489	74.1	74.455	74.469	73.969	73.555	74.455	7
MW5	F2	74.81	74.477	74.49	74.461	74.435	74.43	74.42	74.42	74.42	7
MW6	F2	74.91	74.465	74.493	74.392	74.405	74.411	74.36	74.34	74.335	7
MW7	F2	75.005	74.338	74.43	74.17	74.405	74.415	73.982	73.525	74.4	7
MW8	F3	75.035						74.303	74.396	74.4	7
MW9	F3	74.96						74.42	74.42	74.4	7
MW10	F3	75.115							74.4	74.39	7
MW11	F4	74.88						74.379	74.47	74.47	7
MW13	F4	74.93							74.39	74.38	7
MW14	F4	74.755							73.885	74.025	7
MW15	F5	75.155				74.183	74.231	74.20	74.20	74.22	7
MW16	F5	75.235				74.723	74.702	74.54	74.675	74.675	7
MW17	F5	75.125				74.70	74.698	74.75	74.70	74.685	7

PHOTO LOG

Figure 11. Treatment cell area prior to excavation, looking east from gate. (June 2019).

Figure 12. Treatment cell area looking north towards the Union Canal. (May 2019).

Figure 13. Photograph showing placement of dredged sediments in 2017.

Figure 14. June 2019 view of the site prior to excavation, looking northeast.

Figure 15. Dredging on the Union Canal at Linlithgow.

Figure 16. Long-reach excavator used to unload sediment from the barge at Linlithgow.

Figure 17. Excavation of the cells prior to sediment deposition.

Figure 18. Construction of earthen bund along the northern side of the treatment cells.

Figure 19. Cell F1 after construction of the bund separating it from cell F2.

Figure 20. Cell F1 with monitoring wells in position ready for sediment.

Figure 21. Construction of monitoring well/piezometers.

Figure 22. MW01 and MW02 in cell F2 showing A-frame in position.

Figure 23. Dredged sediment being dumped into Cell F1.

Figure 24. Cell F1 at around 50% of capacity.

Figure 25. Loader redistributing sediment within cell F1.

Figure 26. Texture of sediment surface after emplacement.

Figure 27. Deployment of Youngman board to access MW5 in cell F2.

Figure 28. Cell F2 after first load of dredged sediment.

Figure 29. Tipper lorry being cleaned using a power washer after sediment delivery.

Figure 30. Cells F1 and F2 showing surface water on top of sediment.

Figure 31. Onset of de-watering with desiccation cracks on top layer of sediment around the edges of cell F1.

Figure 32. Well MW7 with A-frame anchored using sand bags.

Figure 33. Cells F3 and F4 after heavy rain shower.

Figure 34. Cells F1 and F2 with canal barge.

Figure 35. Cell F3 prior to sediment addition.

Figure 36. Sediment slurry being emplaced by tipper lorry.

Figure 37. Site on August 12, 2019 after heavy rain during the previous weekend.

Figure 38. Measuring depth to water at MW7 in Cell F2 using water level meter.

Figure 39. Moisture probe (PR2/6) prior to insertion into pre-installed fiberglass sleeve.

Figure 40. In-situ measurement of soil moisture at six horizons using soil moisture probe and moisture meter.

Figure 41. PR2/6 soil moisture probe with HH2 moisture meter.

Figure 42. Evidence for the ingress of soil water from the up gradient part of the site.

Figure 43. Growth of new vegetation on the cell surface prior to seeding.

Figure 44. TD-Diver© water level logger being installed in MW5.

Figure 45. Sowing of Reed canarygrass in cell F5 on September 2019.

Figure 46. Surface of cell after application of Reed canarygrass seed.

Figure 47. Sowing of Cell F3 with Reed canarygrass on September 23, 2019.

Figure 48. Using the MEXE cone penetrometer to determine soil strength in cell F6.

Figure 49. View of the site on January 17th 2020 showing the degree of re-vegetation within the cells.

Figure 50. Excavation of material from cell F3 and F4, January 2020.

APPENDIX A ANALYTICAL DATA

envirolab
Units 7 & 8 Sandpits Business Park
Mottram Road, Hyde, Cheshire, SK14 3AR

FINAL ANALYTICAL TEST REPORT

Envirolab Job Number:	19/05004	
Issue Number:	1	Date: 11 June, 2019

Client: British Waterways Scotland
Canal House
1 Applecross Street
Glasgow
G4 9SP

Project Manager:	Julia Johnstone
Project Name:	Linlithgow Dredging Sites
Project Ref:	SC/076
Order No:	PO00013829
Date Samples Received:	23/05/19
Date Instructions Received:	24/05/19
Date Analysis Completed:	11/06/19

Prepared by:

M Marshall

Melanie Marshall
Laboratory Coordinator

Approved by:

Richard Wong
Client Manager

MCERTS

UKAS TESTING 2247

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Envirolab Job Number: 19/05004

Client Project Name: Linlithgow Dredging Sites

Client Project Ref: SC/076

Lab Sample ID	19/05004/1	19/05004/2	19/05004/3	19/05004/4	19/05004/5			Units	Limit of Detection	Method ref
Client Sample No	SC/076/001	SC/076/002	SC/076/003	SC/076/004	SC/076/005					
Client Sample ID	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5					
Depth to Top										
Depth To Bottom										
Date Sampled	21-May-19	21-May-19	21-May-19	21-May-19	21-May-19					
Sample Type	Soil	Soil	Soil	Soil	Soil					
Sample Matrix Code	4E	4E	4E	4E	4E					
% Moisture at <40C$_A$	77.1	71.0	73.1	33.1	58.3			% w/w	0.1	A-T-044
% Stones >10mm$_A$	<0.1	<0.1	<0.1	4.1	2.9			% w/w	0.1	A-T-044
pH$_D^{M\#}$	6.64	6.83	7.07	7.88	7.02			pH	0.01	A-T-031s
Sulphide$_A$	<5	<5	<5	<5	<5			mg/kg	5	A-T-S2-s
Arsenic$_D^{M\#}$	12	6	11	<1	8			mg/kg	1	A-T-024s
Barium$_D$	185	175	181	82	123			mg/kg	1	A-T-024s
Boron (water soluble)$_D^{M\#}$	3.7	3.6	2.4	<1.0	1.8			mg/kg	1	A-T-027s
Cadmium$_D^{M\#}$	1.1	1.1	1.0	0.8	0.7			mg/kg	0.5	A-T-024s
Copper$_D^{M\#}$	71	52	80	19	37			mg/kg	1	A-T-024s
Chromium$_D^{M\#}$	50	47	48	30	35			mg/kg	1	A-T-024s
Chromium (hexavalent)$_D$	<1	<1	<1	<1	<1			mg/kg	1	A-T-040s
Chromium (trivalent)	50	47	48	30	35			mg/kg	1	Calc
Lead$_D^{M\#}$	138	97	94	20	60			mg/kg	1	A-T-024s
Mercury$_D$	1.89	1.03	1.00	<0.17	0.58			mg/kg	0.17	A-T-024s
Nickel$_D^{M\#}$	89	76	81	37	56			mg/kg	1	A-T-024s
Zinc$_D^{M\#}$	308	249	237	71	161			mg/kg	5	A-T-024s
Dry Matter (Dry Solids) at 40C	22.9	29.0	26.9	66.9	41.7			% w/w	0.1	Calc-no stones

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Envirolab Job Number: 19/05004

Client Project Name: Linlithgow Dredging Sites

Client Project Ref: SC/076

Lab Sample ID	19/05004/1	19/05004/2	19/05004/3	19/05004/4	19/05004/5			Units	Limit of Detection	Method ref
Client Sample No	SC/076/001	SC/076/002	SC/076/003	SC/076/004	SC/076/005					
Client Sample ID	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5					
Depth to Top										
Depth To Bottom										
Date Sampled	21-May-19	21-May-19	21-May-19	21-May-19	21-May-19					
Sample Type	Soil	Soil	Soil	Soil	Soil					
Sample Matrix Code	4E	4E	4E	4E	4E					
Asbestos in Soil (inc. matrix)										
Asbestos in soil$_S$#	NAD	NAD	NAD	NAD	NAD					[illegible]
Asbestos ACM - Suitable for Water Absorption Test?	N/A	N/A	N/A	N/A	N/A					

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Envirolab Job Number: 19/05004

Client Project Name: Linlithgow Dredging Sites

Client Project Ref: SC/076

Lab Sample ID	19/05004/1	19/05004/2	19/05004/3	19/05004/4	19/05004/5			Units	Limit of Detection	Method ref
Client Sample No	SC/076/001	SC/076/002	SC/076/003	SC/076/004	SC/076/005					
Client Sample ID	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5					
Depth to Top										
Depth To Bottom										
Date Sampled	21-May-19	21-May-19	21-May-19	21-May-19	21-May-19					
Sample Type	Soil	Soil	Soil	Soil	Soil					
Sample Matrix Code	4E	4E	4E	4E	4E					
PAH-16MS										
Acenaphthene$_{A}^{M\#}$	<0.01	<0.01	<0.01	<0.01	0.02			mg/kg	0.01	A-T-019s
Acenaphthylene$_{A}^{M\#}$	<0.01	<0.01	<0.01	<0.01	<0.01			mg/kg	0.01	A-T-019s
Anthracene$_{A}^{M\#}$	<0.02	<0.02	<0.02	<0.02	<0.02			mg/kg	0.02	A-T-019s
Benzo(a)anthracene$_{A}^{M\#}$	0.52	0.31	0.19	0.06	0.16			mg/kg	0.04	A-T-019s
Benzo(a)pyrene$_{A}^{M\#}$	0.57	0.28	0.19	<0.04	0.14			mg/kg	0.04	A-T-019s
Benzo(b)fluoranthene$_{A}^{M\#}$	0.74	0.34	0.22	<0.05	0.21			mg/kg	0.05	A-T-019s
Benzo(ghi)perylene$_{A}^{M\#}$	0.57	0.28	0.22	0.07	0.16			mg/kg	0.05	A-T-019s
Benzo(k)fluoranthene$_{A}^{M\#}$	<0.07	<0.07	<0.07	<0.07	<0.07			mg/kg	0.07	A-T-019s
Chrysene$_{A}^{M\#}$	0.61	0.34	0.22	<0.06	0.19			mg/kg	0.06	A-T-019s
Dibenzo(ah)anthracene$_{A}^{M\#}$	<0.04	<0.04	<0.04	<0.04	<0.04			mg/kg	0.04	A-T-019s
Fluoranthene$_{A}^{M\#}$	0.92	0.48	0.33	<0.08	0.30			mg/kg	0.08	A-T-019s
Fluorene$_{A}^{M\#}$	0.04	<0.01	<0.01	<0.01	0.02			mg/kg	0.01	A-T-019s
Indeno(123-cd)pyrene$_{A}^{M\#}$	0.61	0.31	0.22	0.06	0.16			mg/kg	0.03	A-T-019s
Naphthalene $_{A}^{M\#}$	<0.03	<0.03	<0.03	<0.03	<0.03			mg/kg	0.03	A-T-019s
Phenanthrene$_{A}^{M\#}$	0.22	0.14	<0.03	0.06	0.09			mg/kg	0.03	A-T-019s
Pyrene$_{A}^{M\#}$	0.74	0.41	0.26	<0.07	0.26			mg/kg	0.07	A-T-019s
Total PAH-16MS$_{A}^{M\#}$	5.54	2.89	1.85	0.25	1.71			mg/kg	0.01	A-T-019s
TPH Banded 2										
>C8-C10$_{A}^{M\#}$	<5	<5	<5	<5	<5			mg/kg	5	A-T-007s
>C10-C25$_{A}^{M\#}$	240	210	145	56	107			mg/kg	5	A-T-007s
>C25-C40$_{A}^{M\#}$	585	562	316	129	217			mg/kg	5	A-T-007s
Total TPH Banded 2$_{A}^{M\#}$	825	772	461	185	324			mg/kg	5	A-T-007s

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Envirolab Job Number: 19/05004

Client Project Name: Linlithgow Dredging Sites

Client Project Ref: SC/076

Lab Sample ID	19/05004/1	19/05004/2	19/05004/3	19/05004/4	19/05004/5			Units	Limit of Detection	Method ref
Client Sample No	SC/076/001	SC/076/002	SC/076/003	SC/076/004	SC/076/005					
Client Sample ID	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5					
Depth to Top										
Depth To Bottom										
Date Sampled	21-May-19	21-May-19	21-May-19	21-May-19	21-May-19					
Sample Type	Soil	Soil	Soil	Soil	Soil					
Sample Matrix Code	4E	4E	4E	4E	4E					
TPH UKCWG										
Ali >C5-C6A#	0.26	<0.01	<0.05	<0.05	<0.05			mg/kg	0.01	A-T-022s
Ali >C6-C8A#	0.22	<0.01	0.33	<0.05	0.21			mg/kg	0.01	A-T-022s
Ali >C8-C10A#	<0.05	<0.01	<0.05	<0.05	<0.05			mg/kg	0.01	A-T-022s
Ali >C10-C12A#	<0.1	<0.1	<0.1	<0.1	<0.1			mg/kg	0.1	A-T-022s
Ali >C12-C16A#	<0.1	<0.1	<0.1	<0.1	<0.1			mg/kg	0.1	A-T-022s
Ali >C16-C21A#	<0.1	<0.1	<0.1	<0.1	<0.1			mg/kg	0.1	A-T-022s
Ali >C21-C35A#	<0.1	<0.1	<0.1	<0.1	<0.1			mg/kg	0.1	A-T-022s
Ali >C35-C44A	<0.1	<0.1	<0.1	<0.1	<0.1			mg/kg	0.1	A-T-022s
Total AliphaticsA	0.9	<0.1	0.7	<0.1	0.5			mg/kg	0.1	A-T-022s
Aro >C5-C7A#	<0.05	<0.01	<0.05	<0.05	<0.05			mg/kg	0.01	A-T-022s
Aro >C7-C8A#	<0.05	<0.01	<0.05	<0.05	<0.05			mg/kg	0.01	A-T-022s
Aro >C8-C9A#	<0.05	<0.01	<0.05	<0.05	<0.05			mg/kg	0.01	A-T-022s
Aro >C9-C10A#	<0.05	<0.01	<0.05	<0.05	<0.05			mg/kg	0.01	A-T-022s
Aro >C10-C12A#	<0.1	<0.1	<0.1	<0.1	<0.1			mg/kg	0.1	A-T-022s
Aro >C12-C16A#	<0.1	<0.1	<0.1	<0.1	<0.1			mg/kg	0.1	A-T-022s
Aro >C16-C21A#	<0.1	<0.1	<0.1	<0.1	<0.1			mg/kg	0.1	A-T-022s
Aro >C21-C35A#	<0.1	<0.1	<0.1	<0.1	<0.1			mg/kg	0.1	A-T-022s
Aro >C35-C44A	<0.1	<0.1	<0.1	<0.1	<0.1			mg/kg	0.1	A-T-022s
Total AromaticsA	<0.1	<0.1	<0.1	<0.1	<0.1			mg/kg	0.1	A-T-022s
TPH (Ali & Aro)A	0.9	<0.1	0.7	<0.1	0.5			mg/kg	0.1	A-T-022s
BTEX - BenzeneA#	<0.05	<0.01	<0.05	<0.05	<0.05			mg/kg	0.01	A-T-022s
BTEX - TolueneA#	<0.05	<0.01	<0.05	<0.05	<0.05			mg/kg	0.01	A-T-022s
BTEX - Ethyl BenzeneA#	<0.05	<0.01	<0.05	<0.05	<0.05			mg/kg	0.01	A-T-022s
BTEX - m & p XyleneA#	<0.05	<0.01	<0.05	<0.05	<0.05			mg/kg	0.01	A-T-022s
BTEX - o XyleneA#	<0.05	<0.01	<0.05	<0.05	<0.05			mg/kg	0.01	A-T-022s
MTBEA#	<0.05	<0.01	<0.05	<0.05	<0.05			mg/kg	0.01	A-T-022s

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REPORT NOTES

General
This report shall not be reproduced, except in full, without written approval from Envirolab.
The results reported herein relate only to the material supplied to the laboratory.
The residue of any samples contained within this report, and any received with the same delivery, will be disposed of six weeks after initial scheduling. For samples tested for Asbestos we will retain a portion of the dried sample for a minimum of six months after the initial Asbestos testing is completed.
Analytical results reflect the quality of the sample at the time of analysis only.
Opinions and interpretations expressed are outside the scope of our accreditation.
If results are in italic font they are associated with an AQC failure, these are not accredited and are unreliable.
A deviating samples report is appended and will indicate if samples or tests have been found to be deviating. Any test results affected may not be an accurate record of the concentration at the time of sampling and, as a result, may be invalid.

Soil chemical analysis:
All results are reported as dry weight (<40°C).
For samples with Matrix Codes 1 - 6 natural stones, brick and concrete fragments >10mm and any extraneous material (visible glass, metal or twigs) are removed and excluded from the sample prior to analysis and reported results corrected to a whole sample basis. This is reported as '% stones >10mm'.
For samples with Matrix Code 7 the whole sample is dried and crushed prior to analysis and this supersedes any "A" subscripts
All analysis is performed on the sample as received for soil samples which are positive for asbestos or the client has informed asbestos may be present and/or if they are from outside the European Union and this supersedes any "D" subscripts.

TPH analysis of water by method A-T-007:
Free and visible oils are excluded from the sample used for analysis so that the reported result represents the dissolved phase only.

Electrical Conductivity of water by Method A-T-037:
Results greater than 12900µS/cm @ 25°C / 11550µS/cm @ 20°C fall outside the calibration range and as such are unaccredited.

Asbestos:
Asbestos in soil analysis is performed on a dried aliquot of the submitted sample and cannot guarantee to identify asbestos if only present in small numbers as discrete fibres/fragments in the original sample.
Stones etc. are not removed from the sample prior to analysis.
Quantification of asbestos is a 3 stage process including visual identification, hand picking and weighing and fibre counting by sedimentation/phase contrast optical microscopy if required. If asbestos is identified as being present but is not in a form that is suitable for analysis by hand picking and weighing (normally if the asbestos is present as free fibres) quantification by sedimentation is performed.
Where ACMs are found a percentage asbestos is assigned to each with reference to 'HSG264, Asbestos: The survey guide' and the calculated asbestos content is expressed as a percentage of the dried soil sample aliquot used.

Predominant Matrix Codes:
1 = SAND, 2 = LOAM, 3 = CLAY, 4 = LOAM/SAND, 5 = SAND/CLAY, 6 = CLAY/LOAM, 7 = OTHER, 8 = Asbestos bulk ID sample.
Samples with Matrix Code 7 & 8 are not predominantly a SAND/LOAM/CLAY mix and are not covered by our BSEN 17025 or MCERTS accreditations, with the exception of bulk asbestos which are BSEN 17025 accredited.
Secondary Matrix Codes:
A = contains stones, B = contains construction rubble, C = contains visible hydrocarbons, D = contains glass/metal, E = contains roots/twigs.

Key:
IS indicates Insufficient Sample for analysis.
US indicates Unsuitable Sample for analysis.
NDP indicates No Determination Possible.
NAD indicates No Asbestos Detected.
N/A indicates Not Applicable.
Superscript # indicates method accredited to ISO 17025.
Superscript "M" indicates method accredited to MCERTS.
Subscript "A" indicates analysis performed on the sample as received.
Subscript "D" indicates analysis performed on the dried sample, crushed to pass a 2mm sieve

Please contact us if you need any further information.

envirolab

Envirolab Deviating Samples Report

Units 7&8 Sandpits Business Park, Mottram Road, Hyde, SK14 3AR
Tel. 0161 368 4921 email. ask@envlab.co.uk

Client: British Waterways Scotland, Canal House, 1 Applecross Street, Glasgow, G4 9SP
Project No: 19/05004
Date Received: 24/05/2019 (am)
Cool Box Temperatures (°C): 14.3, 14.9

Project: Linlithgow Dredging Sites
Clients Project No: SC/076

Lab Sample ID	19/05004/1	19/05004/2	19/05004/3	19/05004/4	19/05004/5
Client Sample No	SC/076/001	SC/076/002	SC/076/003	SC/076/004	SC/076/005
Client Sample ID/Depth	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Date Sampled	21/05/19	21/05/19	21/05/19	21/05/19	21/05/19
Deviation Code					
F	✓	✓	✓	✓	✓

Key
F *Maximum holding time exceeded between sampling date and analysis for analytes listed below*

HOLDING TIME EXCEEDANCES

Lab Sample ID	19/05004/1	19/05004/2	19/05004/3	19/05004/4	19/05004/5
Client Sample No	SC/076/001	SC/076/002	SC/076/003	SC/076/004	SC/076/005
Client Sample ID/Depth	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Date Sampled	21/05/19	21/05/19	21/05/19	21/05/19	21/05/19
Sulphide	✓	✓	✓	✓	✓
VPH CWG			✓	✓	✓

If, at any point before reaching the laboratory, the temperature of the samples has breached those set in published standards, e.g. BS-EN 5667-3, ISO 18400-102:2017, then the concentration of any affected analytes may differ from that at the time of sampling.

APPENDIX B MOISTURE PROBE DATA

MW2	Elev. (m)	07/8/19	14/8/19	21/8/19	03/09/19	11/9/19	19/9/19	26/09/19	08/10/19	29/19
0	74.794									
0.1	74.694									
0.2	74.594									
0.3	74.494			32.3	48.9	33.1	5.2	24.9	21.5	
0.4	74.394			70.4	78.7	73.6	66.1	69.9	73	
0.6	74.194			69.9	77.1	70.2	73.9	65.9	67.7	
1	73.794			57.3	63.4	60.1	62.3	55	50	

MW3	Elev. (m)	07/8/19	14/8/19	21/8/19	03/09/19	11/9/19	19/9/19	26/09/19	08/10/19	29/19
0	74.855									
0.1	74.755									
0.2	74.655									
0.3	74.555							2.5		
0.4	74.455			66.6	67.7		81.2	66		
0.6	74.255			66.5	68.7		86.4	79.3		
1	73.855			62.5	62.9					

MW4	Elev. (m)	07/8/19	14/8/19	21/8/19	03/09/19	11/9/19	19/9/19	26/09/19	08/10/19	29/1
0	74.645									
0.1	74.845									
0.2	74.745									
0.3	74.645	15.00	15.00	3.61	48.90	6.80	10.40	15.80	31.00	19.9
0.4	74.545	48.90	60.10	53.10	78.70	56.60	65.30	56.20	55.10	45.5
0.6	74.345	53.00	64.80	55.10	77.10	54.90	63.30	55.40	56.20	45.1
1	73.945	59.20	69.50	63.00	63.40	67.40	80.50	65.00	65.00	54.5
MW5	Elev. (m)	07/8/19	14/8/19	21/8/19	03/09/19	11/9/19	19/9/19	26/09/19	08/10/19	29/1
0	74.795									
0.1	74.695									
0.2	74.595									
0.3	74.495									
0.4	74.395			69.6	82.1	72.5	64		38.40	22.3
0.6	74.195			79	94.5	80.6	78.7		43.10	61.9
1	73.795			76.6	91.8	78	77.3		error	62.5

MW6	Elev. (m)	07/8/19	14/8/19	21/8/19	03/09/19	11/9/19	19/9/19	26/09/19	08/10/19	29/1
0	74.645									
0.1	74.545									
0.2	74.445									
0.3	74.345			65.3	79.4	67.5	67.5		43.30	54.8
0.4	74.245			66.4	88.4	68.7	67.1		60.80	53.1
0.6	74.045			73.5	88.3	74	69.5		66.70	55.5
1	73.645			77.6	93.8	78.3	76.9		error	60.7

MW7	Elev. (m)	07/8/19	14/8/19	21/8/19	03/09/19	11/9/19	19/9/19	26/09/19	08/10/19	29/1
0	74.825									
0.1	74.725									
0.2	74.625									
0.3	74.525								0.2	
0.4	74.425	60.1		65.6	77.2	65.8	46.6		69.40	48.2
0.6	74.225	64.8		73.1	80	71	77		69.90	56.0
1	73.825	69.5		75.1	83.5	71.6	79.3		error	57.9

MW8	Elev. (m)	07/8/19	14/8/19	21/8/19	03/09/19	11/9/19	19/9/19	26/09/19	08/10/19	29/1
0	74.79									
0.1	74.69									
0.2	74.59									
0.3	74.49									
0.4	74.39							57.5	41.3	14
0.6	74.19						88.5	85.8	85.6	64
1	73.79						67.7	error	error	54.6

MW9	Elev. (m)	07/8/19	14/8/19	21/8/19	03/09/19	11/9/19	19/9/19	26/09/19	08/10/19	29/19
0	74.675									
0.1	74.575									
0.2	74.475							29	49.2	44.2
0.3	74.375						30.2	66.3	61.5	53.3
0.4	74.275						59.8	73.5	64.9	54.8
0.6	74.075						94.1	86.2	71.2	58.6
1	73.675						84.3	error	error	58.2

MW10	Elev. (m)	07/8/19	14/8/19	21/8/19	03/09/19	11/9/19	19/9/19	26/09/19	08/10/19	29/9
0	74.647									
0.1	74.547									
0.2	74.447									
0.3	74.347							74.4	65.3	57.3
0.4	74.247							81.7	70.6	58.6
0.6	74.047							79.2	67.4	53.7
1	73.647							error	error	41.4
MW11	Elev. (m)	07/8/19	14/8/19	21/8/19	03/09/19	11/9/19	19/9/19	26/09/19	08/10/19	29/9
0	74.955									
0.1	74.855									
0.2	74.755									
0.3	74.655									
0.4	74.555						3.1	23	24.8	20
0.6	74.355						54.5	70.1	62	40.8
1	73.955						56.8	error	error	44.6

MW13	Elev. (m)	07/8/19	14/8/19	21/8/19	03/09/19	11/9/19	19/9/19	26/09/19	08/10/19	29/ 9
0	74.62									
0.1	74.52									
0.2	74.42								36	15.4
0.3	74.32						86.8	5.7	66.5	57.8
0.4	74.22						93	73.8	69.9	59.2
0.6	74.02						80.4	79.5	67.8	58.4
1	73.62							error	error	53.9

MW14	Elev. (m)	07/8/19	14/8/19	21/8/19	03/09/19	11/9/19	19/9/19	26/09/19	08/10/19	29/ 9
0	74.845									
0.1	74.745									
0.2	74.645							59.3	52.7	45.6
0.3	74.545							63.1	54.5	46.7
0.4	74.445							75.1	62.5	52.8
0.6	74.245							79.6	69	55.8
1	73.845							error	error	50.2

MW15	Elev. (m)	07/8/19	14/8/1 9	21/8/19	03/09/1 9	11/9/19	19/9/19	26/09/1 9	08/10/1 9	29/ 9
0	75.055									
0.1	74.955									
0.2	74.855									
0.3	74.755									
0.4	74.655				33.5	35	16.2	17.9	22.7	16.
0.6	74.455				94.8	87.6	83.6	83.9	73.6	57.
1	74.055				83.1	72.3	74.7	error	error	54.

MW16	Elev. (m)	07/8/19	14/8/1 9	21/8/19	03/09/1 9	11/9/19	19/9/19	26/09/1 9	08/10/1 9	29/ 9
0	74.95									
0.1	74.85									
0.2	74.75									
0.3	74.65				49.5	55.7	19.1	19.5	27.6	24.
0.4	74.55				85.6	76.9	75.2	75.7	70.8	56.
0.6	74.35				100	87.6	88.6	84.1	78.1	59.
1	73.95				90.6	82.7	90	error	error	63.

MW17	Elev. (m)	07/8/19	14/8/19	21/8/19	03/09/19	11/9/19	19/9/19	26/09/19	08/10/19	29/ 9
0	74.94									
0.1	74.84									
0.2	74.74									
0.3	74.64							18.6	69.8	60
0.4	74.54							71.2	73.9	60.6
0.6	74.34							79.1	74.4	63.3
1	73.94							error	error	48.5

APPENDIX C. VISUAL CHANGES IN CELLS


F1 29rd Aug 2019
F2 29rd Aug 2019
F3 29rd Aug 2019
F4 29rd Aug 2019
F5 29rd Aug 2019
F1 12th Aug 2019
F2 12th Aug 2019
F3 12th Aug 2019
F4 12th Aug 2019
F5 12th Aug 2019


F1 11th Sept 2019
F2 11th Sept 2019
F3 11th Sept 2019
F4 11th Sept 2019
F5 11th Sept 2019
F1 3rd Sept 2019
F2 3rd Sept 2019
F3 3rd Sept 2019
F4 3rd Sept 2019
F5 3rd Sept 2019

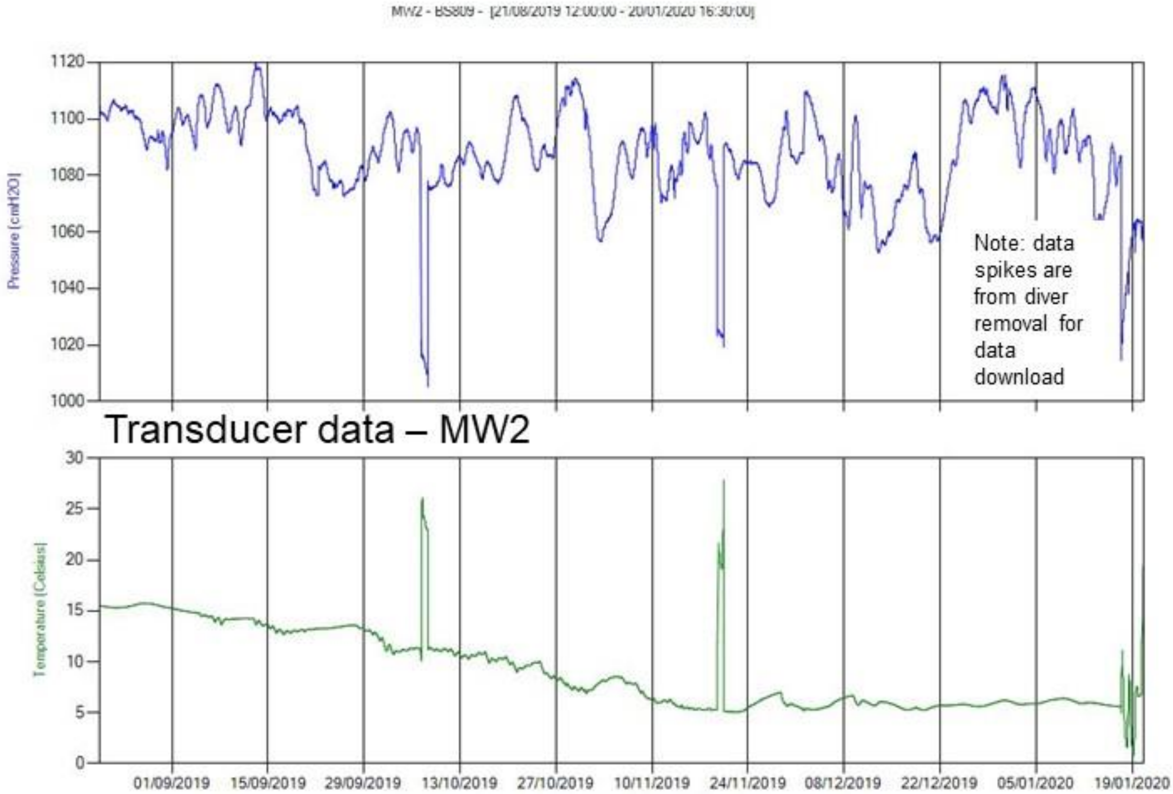

F1 8th Oct 2019
F2 8th Oct 2019
F3 8th Oct 2019
F4 8th Oct 2019
F5 8th Oct 2019
F1 26rd Sept 2019
F2 26rd Sept 2019
F3 26rd Sept 2019
F4 26rd Sept 2019
F5 23rd Sept 2019

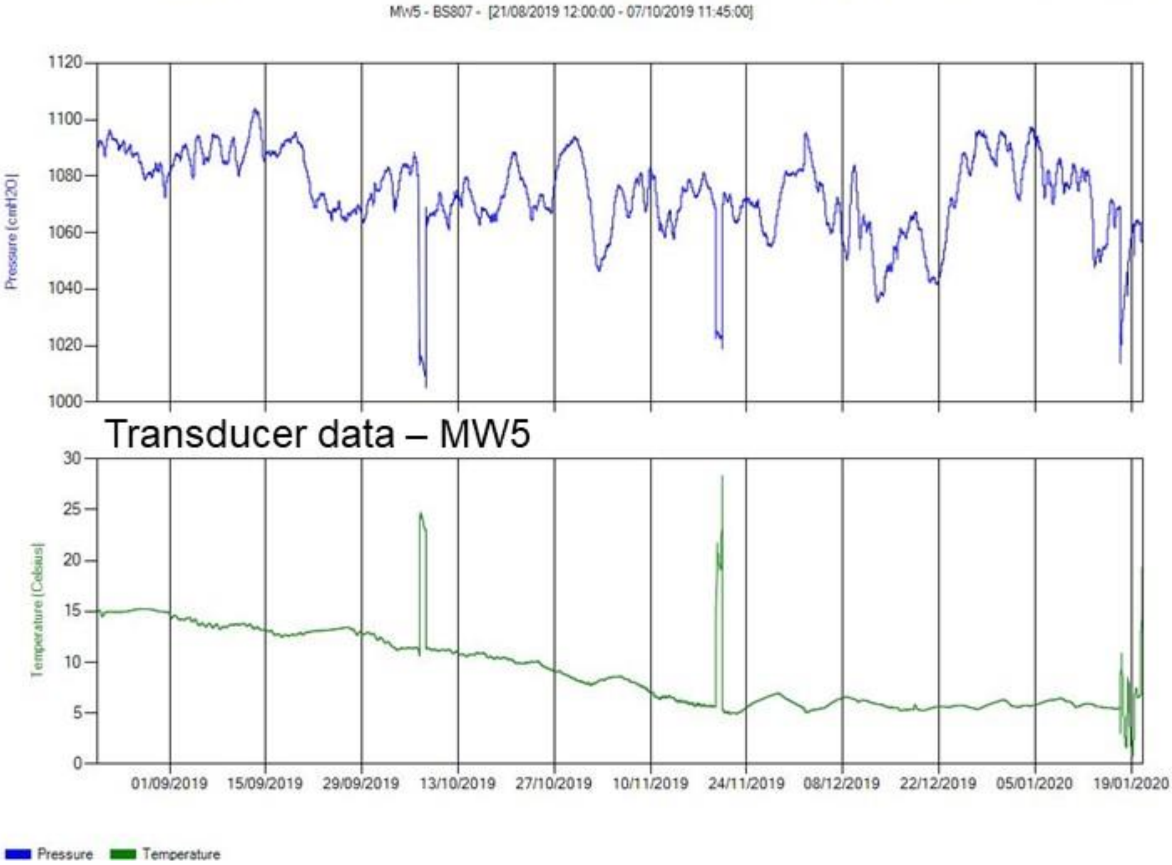

F1 29th Oct 2019
F2 29th Oct 2019
F3 29th Oct 2019
F4 29th Oct 2019
F5 29th Oct 2019
F1 19th Nov 2019
F2 19th Nov 2019
F3 19th Nov 2019
F4 19th Nov 2019
F5 19th Nov 2019

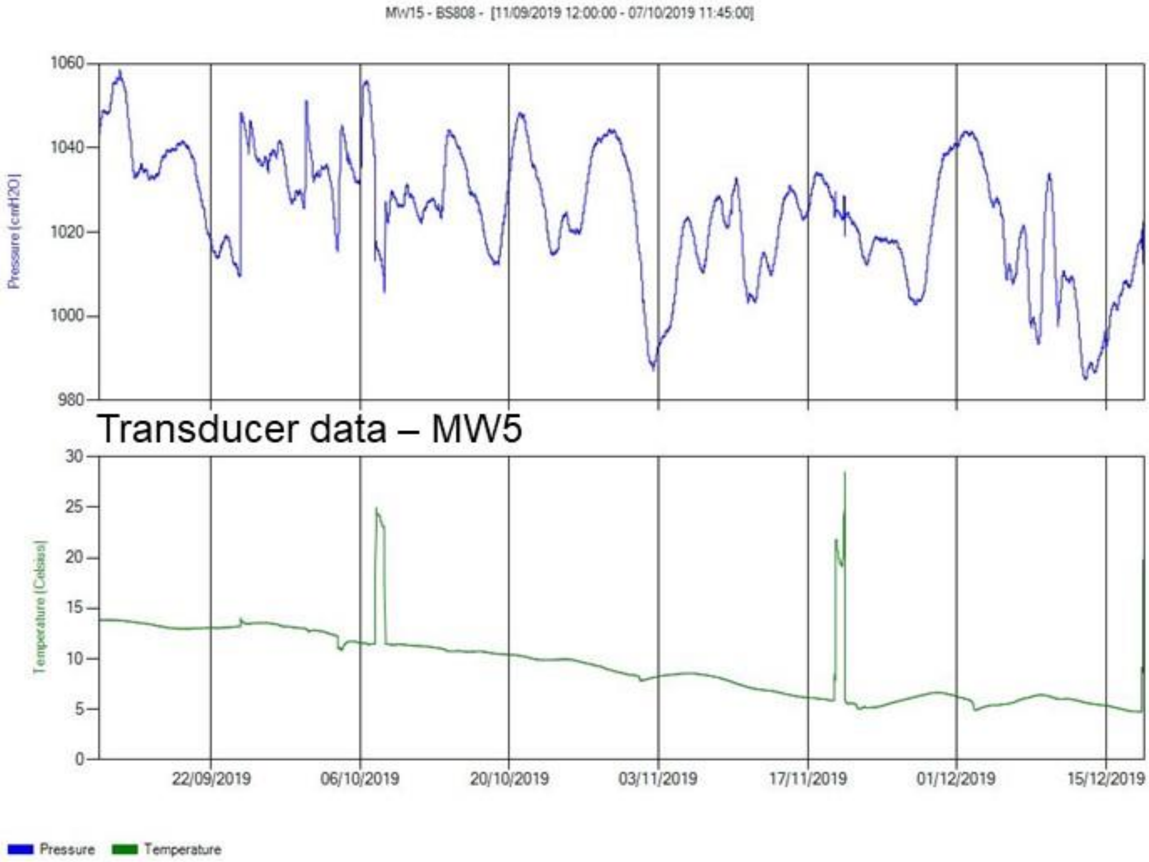

F1 18th Dec 2019
F2 18th Dec 2019
F3 18th Dec 2019
F4 18th Dec 2019
F5 18th Dec 2019
F1 19th Nov 2019
F2 19th Nov 2019
F3 19th Nov 2019
F4 19th Nov 2019
F5 19th Nov 2019


F1 17th Jan 2020
F2 17th Jan 2020
F3 17th Jan 2020
F4 17th Jan 2020
F5 17th Jan 2020
F1 18th Dec 2019
F2 18th Dec 2019
F3 18th Dec 2019
F4 18th Dec 2019
F5 18th Dec 2019

APPENDIX D TRANSDUCER DATA


MW2 - BS809 - [21/08/2019 12:00:00 - 20/01/2020 16:30:00]
Pressure [cmH2O]
Transducer data – MW2
Temperature [Celsius]
Note: data spikes are from diver removal for data download
01/09/2019
15/09/2019
29/09/2019
13/10/2019
27/10/2019
10/11/2019
24/11/2019
08/12/2019
22/12/2019
05/01/2020
19/01/2020


MW5 - BS807 - [21/08/2019 12:00:00 - 07/10/2019 11:45:00]
Pressure [cmH2O]
Transducer data – MW5
Temperature [Celsius]
01/09/2019
15/09/2019
29/09/2019
13/10/2019
27/10/2019
10/11/2019
24/11/2019
08/12/2019
22/12/2019
05/01/2020
19/01/2020
Pressure
Temperature


MW15 - BS808 - [11/09/2019 12:00:00 - 07/10/2019 11:45:00]
1060
1040
1020
1000
980
Pressure (cmH2O)
Transducer data – MW5
30
25
20
15
10
5
0
Temperature (Celsius)
22/09/2019
06/10/2019
20/10/2019
03/11/2019
17/11/2019
01/12/2019
15/12/2019
Pressure
Temperature