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Repurposing Dredged Canal Sediment for Topsoil at Bowling, Scotland

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Abstract: 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. To investigate potential opportunities to reuse dredged sediments as topsoil following phyto-conditioning, a pilot scale operation was undertaken at Bowling, Scotland. As part of normal maintenance, 550 m^3 of wet sediment was removed from the Forth and Clyde Canal at Old Kilpatrick by Scottish Canals using a hydraulic excavator during September 2020, transported by barge, then transferred to a dewatering cell constructed in an old canal basin by lining with a geotextile break-layer and installing engineered drainage. Following initial dewatering, the sediment was sown with three varieties of grass, which each germinated and survived the winter. By March 2021 composite soil samples already met the BS 3882:2015 criteria for topsoil, other than for Zn levels, which reflected the locally elevated baseline values. This allowed the conditioned sediment to be used immediately as topsoil as part of the nearby construction of a long-distance cycle track following an old railway embankment. Following reuse, replicated validations of six grass or wildflower seed mixtures were sown in April 2021 and monitored to verify longer-term suitability as a landscaping soil.

Keywords: circular economy; nature-based solution; net zero; waste recovery dredged sediment

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1. Introduction

Dredged sediment from harbors, canals and waterways is an underutilized resource that could potentially be repurposed for erosion and flood protection. The SURICATES (Sediment Uses as Resources in Circular And Territorial EconomieS) Project was initiated to investigate opportunities for the beneficial reuse of dredged sediment, which is, by definition, classified as waste in the European Union [1]. Whilst laboratory-scale studies are common, they seldom provide insight into the practical considerations of handling and conditioning thousands of tonnes of wet sediment. Consequently, multiple pilot studies were undertaken by SURICATES project partners, including at four sites adjacent to Scottish Canal's waterway network. Scottish Canals has a statutory obligation to maintain agreed navigational depths. As the disposal of dredgings can be expensive and logistically problematic for inland canals, local sustainable reuse solutions are attractive options [2]. Further, a life cycle assessment study showed that soil conditioning has the lowest economic impact amongst disposal options [3].

The suitability of dredged sediment for reuse is determined by several factors. Physical properties, such as particle size distribution and total organic content (TOC), determine its suitability (or otherwise) as an aggregate or additive to concrete after calcination [4]. The typical mix of sand, silt and clay grain sizes, low salinity and relatively higher organic matter contents make inland waterway sediments more attractive targets for use as soil than those from ports or harbors. However, urban canals are susceptible to contamination from vessel emissions and their proximity to former heavy industries and contaminated land [5]. Urban canals typically have low inputs of diluting clean sediment from natural drainage, while local soils are blown in or added by sheetwash during high rainfall events. Consequently, the presence of contaminants, including metals and polyaromatic hydrocarbons (PAHs) may further limit reuse options. Emerging contaminants, such as per- and poly-fluoroalkyl substances (PFAS) [6] and microplastics [7], can also accumulate in urban waterway sediment and may further restrict reuse. Finally, high transportation costs for wet sediment place economic restrictions on any planned use that is distant from the dredging site.

Cortis [8] reported elevated concentrations of As, Cr, Cu, Ni, Pb, Sn, and Zn in a study of Potentially Toxic Elements (PTE) in the Forth and Clyde Canal (F&CC) and concluded that canal sediments had higher values of these elements than local urban soils. Consequently, urban canals can act as sinks for contaminants with elevated PTEs often linked to specific industries adjacent to the canals, such as mercury contamination from a former explosives factory on the Union Canal [9]. There are known issues with tri-butyl tin (TBT) contamination, originating from marine anti-fouling paints, in sediments at Bowling [10].

From a practical consideration, dredged canal sediments can contain up to 85% water which must be reduced before recycling. Staged-dredged sediment will dewater without intervention, but bio-conditioning through the growth of tolerant plants can accelerate this process. Plants remove moisture from the sediment through transpiration and evaporation [11,12], which further promotes the formation of a crust on the sediment top. This crust mitigates the impact of precipitation through runoff. The aim of the Bowling pilot study was to demonstrate the technical, environmental, and practical suitability of using phyto-conditioning as a nature-based solution to promote dewatering, allowing local reuse of dredged canal sediments as restoration topsoil.

2. Materials and Methods

The pilot study was undertaken to evaluate nature-based dewatering on a demonstration scale, to try planting seed on wet sediment, to test the properties as a soil against standards, then to verify the material as a growth medium. The site selected was at Bowling, West Dumbartonshire, which is located on the north bank of the River Clyde Estuary, approximately 20 km west of Glasgow, Scotland, as shown in Figure 1. At Bowling, the Forth and Clyde Canal links to Bowling Harbour on the River Clyde via sea locks at the western end of the canal. The Forth and Clyde Canal was constructed in the early part of the 19th century for moving coal and freight across the Central Belt of Scotland, but steadily declined until it was finally abandoned in the 1960s [13].

Since restoration as a 2000 Millenium Project [14], the canal has become a catalyst for urban regeneration in Glasgow through expanded recreational use [15], with associated benefits to communities for promoting health and well-being [16]. In meeting Scottish Government targets for reducing traffic and associated air emissions [17], canal towpaths are fast, safe, and direct corridors for cyclists commuting into Glasgow from the northern suburbs. Further capital projects are being undertaken by Scottish Canals to improve the connectivity of the towpaths for walkers and cyclists. Based on the characteristics of the sediment in the F&CC, it was determined that the most appropriate sediment reuse was as topsoil, matching a concurrent requirement for landscaping material on the Bowline cycleway project at Bowling.

An abandoned basin adjacent to Bowling Harbour was modified as a dewatering cell for this pilot trial (Figure 2). The basin is a concrete structure that dates to around 1896, when the Lanarkshire and Dumbartonshire Railway viaduct was constructed to cross over the canal [18]. Viaduct construction necessitated the construction of a new canal lock and basin at Bowling. The exact purpose of the abandoned basin is unknown, but it provided a secure and convenient treatment cell for dredged sediment. In preparation for the pilot study, the basin was secured with a metal fence to prevent access, as the surrounding area is used by the public for recreational activities.

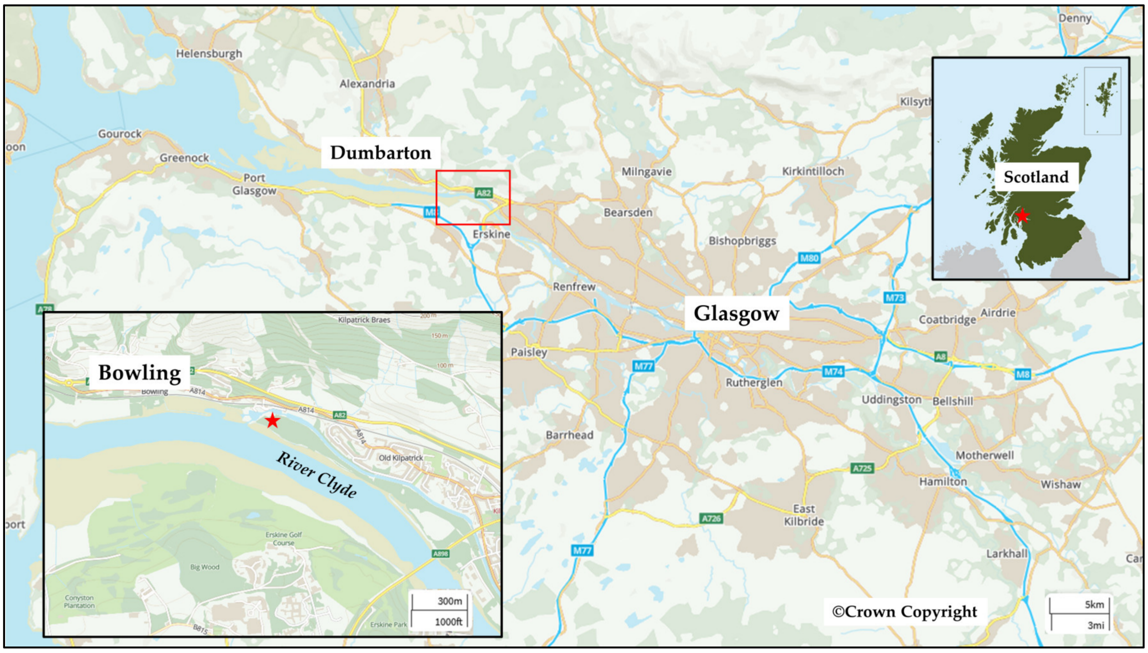

Figure 1. Location of the trial site at Bowling. Base map © Crown copyright and database rights "2023 Ordnance Survey (100025252)".

Figure 2. Treatment basin at Bowling prior to installation of geofabric.

Land use at the site is well documented through several geotechnical and geochemical investigations [19]. The basin was built on previously reclaimed land, dating from when the River Clyde was narrowed at the end of the 18th century to deepen the channel and permit navigation as far upstream as the Broomielaw in Central Glasgow [20]. Based on a study of historical Ordnance Survey maps, this reclaimed area has been steadily eroding since 1850 through the combination of wave, current and tidal action of the River Clyde. Future development and reuse of this land is limited by the potential for further erosion [21]. As the basin was used in the 1940s as a railway depot, the ground has been impacted by the disposal of ash, cinder, and other wastes. Analysis of the soil, consisting of made ground, showed elevated concentrations of polyaromatic hydrocarbons and toxic metals (Pb, As, Zn, Cu) that are consistent with known historical land uses.

Baseline characterization of a potential site is an important management tool for sediment reuse [22]. In advance of sediment emplacement, a comprehensive geochemical survey of the site was undertaken, supplemented by previous ground investigation reports. Samples from the soil underlying the basin were collected in 2018 and characterized on site using portable X-ray fluorescence (pXRF) in the field for PTEs, supplemented by laboratory analysis of the collected soil samples. Site characterization included a groundwater investigation using existing monitoring wells, which showed that the water table was approximately 2.5 m below ground level (bgl) in the basin, but varied by up to 1.4 m under the tidal influence of the estuary. The subsurface of the basin consisted of up to 2 m of cinder and other coarse fill materials which had high permeability and could be utilized to promote the de-watering of the wet sediment. This was confirmed by the Diver© data from piezometers installed below the basin floor level which showed no standing water in the wells during the trial.

The final design for the basin is shown in Figure 3. Earthworks were undertaken during July/August 2020 by Mackenzie Construction Ltd., Glasgow, Scotland, who were Scottish Canal's main contractor on the Bowline cycle pathway upgrades. The floor of the basin was graded to dip towards the river (5% grade) with soil bunds built along the northern edge to create an enclosed dewatering cell with access from the west. Using lessons learned from an earlier project at Falkirk, internal monitoring wells and a drainage sump were installed to monitor dewatering and allow surface water drainage from precipitation. Prior to the emplacement of the sediment, Diver© transducers were installed in each of the three monitoring wells and set to continually record water temperature and pressure (water level) at 30 min intervals. This data collection was supplemented with the installation of plastic sleeves in January 2021 for use with a PR2/4 TDR moisture probe (Delta-T, Cambridge, UK). Because of the known contamination of the sub-surface, a geomembrane was placed on the basin floor to act as a break layer to prevent mixing with the dredged sediment.

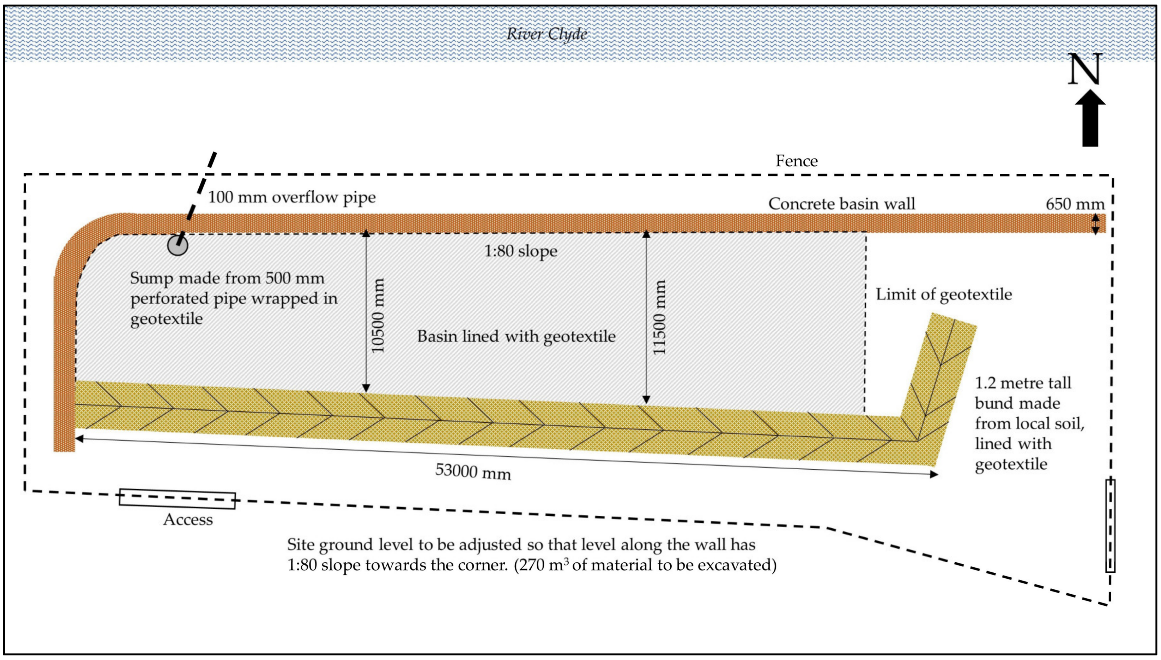

Figure 3. Engineering design of the sediment treatment basin.

Five samples of canal sediment were collected in situ from a boat on 2 September 2020 from a 2 km long section of the Forth and Clyde Canal, using a Petit Ponar grab sampler from an average depth of 20 cm. Samples were sent to Envirolab Ltd., Hyde, United Kingdom (https://www.envlab.co.uk (accessed on 24 May 2021)) for analysis, and the results are shown in Table 1.

Table 1. Analytical data from sediment samples collected from the Forth and Clyde Canal.

Sample ID	SC/090/001	SC/090/002	SC/090/003	SC/090/004	SC/090/005
Grid Ref	NS465 9672578	NS468 5172065	NS472 7971812	NS476 0771480	NS48034 71283
pH	6.99	7.17	7.39	7.30	7.34
Loss on ignition (550 °C) *w*/*w*	20.7%	26.7%	23.8%	18.7%	16.0%
Dry matter at 40 °C *w*/*w*	20.1%	15.5%	14.2%	19.0%	24.5%
As (mg/kg)	72	33	32	39	36
Ba (mg/kg)	315	281	274	274	302
Cd (mg/kg)	3.1	3.1	2.9	2.5	2.6
Cu (mg/kg)	236	157	170	172	161
Total Cr (mg/kg)	100	75	67	61	79
Cr (VI) mg/kg)	<1	<1	<1	<1	<1
Cr (III) (mg/kg)	100	75	67	61	79
Pb (mg/kg)	301	186	193	193	216
Hg (mg/kg)	0.76	1.19	2.32	2.57	2.71
Ni (mg/kg)	61	50	43	39	49
Se (mg/kg)	3	3	3	4	3
Zn (mg/kg)	1460	1180	1310	1040	1090

The sediment samples had an average loss on ignition value of 21% at 550 °C, equivalent to a total organic carbon content of 12% (assuming organic matter (OM) = 1.724 × TOC). Lead (Pb) ranged from 186 mg/kg to 301 mg/kg; zinc (Zn) from 1040 mg/kg to 1460 mg/kg; copper (Cu) from 157 to 236 mg/kg; and nickel(Ni) from 30 to 61 mg/kg. Some aliphatic and aromatic compounds were also reported above the method detection limit. Total aliphatic compounds ranged from 94 to 418 mg/kg. Total aromatic compounds ranged from 208 to 478 mg/kg. No PAH compounds (USEPA-16 PAHs) were reported above the method detection limit (0.01 mg/kg). While Pb and Zn concentrations in the sediment were elevated, they are consistent with the urban location of the canal and its proximity to the A814 road. Further, the grab sampling method that was used to collect sediment samples is biased towards the surface sediment, which is affected by urban dust, leaf litter, and refuse.

Dredging was undertaken by Scottish Canals, beginning on 2 September 2020, on a section of the canal between Old Kilpatrick and Dalmuir, 5 km from the basin at its furthest point. A barge-mounted excavator and hopper barge, with a capacity of 20 cubic meters were used (Figure 4). When full, the hopper barge was towed along the canal to the Canal House Basin, then unloaded into a small dumper truck for the 50 m trip to the treatment site. As no sediment was moved via public highways, this greatly reduced the carbon footprint of the project. In practical terms, the distance that sediment can be economically transported on the Forth and Clyde Canal by barge is limited by the number of locks that must be traversed, due to the time involved in locking up or down.

Over a period of two weeks, approximately 550 cubic meters of wet sediment was placed within the treatment cell at Bowling. Despite urban canals being notorious as convenient dumping grounds, only a small amount of refuse was observed in the dredgings. This included aluminum cans, plastic bottles, and golf balls which were removed. No visible sharps were observed in the sediment, which is an important consideration for topsoil that will be placed in public areas.

Phyto-conditioning was selected as the most suitable treatment option, with the goals of (a) accelerating dewatering of the sediment, (b) improving the texture of the soil, and (c) demonstrating the viability of sediment as topsoil. Phyto-conditioning differs from phyto-remediation and phyto-extraction, in that it addresses the physical and mechanical condition of the sediment, rather than the levels of contaminants. Meanwhile, some degradation of organic pollutants may occur due to changing physical conditions and oxidative states promoted during phyto-conditioning. The goal of phyto-conditioning is therefore to accelerate the ripening of sediment and production of topsoil that is suitable for landscaping, rather than for agriculture, which may be prohibited by levels of contaminants [5] and regulatory considerations.

Figure 4. Barge-mounted excavator in operation on the Forth & Clyde Canal at Old Kilpatrick, September 2020.

As received into the basin, sediment had an average moisture content of around 81%, liquified on handling and behaved as a viscous fluid, following the contours of the basin to form a level surface (Figure 5). Based on previous trials, the optimum time to sow is when a thin-top crust has formed on the top of the sediment, which provides a more conducive environment for seed germination. By 29 September 2020, the surface had sufficiently dried out to permit seeding.

(**a**) (**b**)

Figure 5. Basin at Bowling, September 2020. (**a**) Geotextile-lined basin being filled with wet sediment (**b**) Basin at the end of sediment transportation.

Three seed types were selected to promote dehydration based on our results from a previous trial. This included two single varieties of annual rye grass and one seed mixture, as shown in Table 2, to account for uncertainties in sowing late in the growing season, with a goal of demonstrating that grass could be grown on freshly dredged canal sediment in Scotland. Beginning on 15 March 2021, sediment in the basin was excavated and placed along the verge of a new cycleway being constructed along the length of the former Lanarkshire and Dumbartonshire railway embankment. Sediment was spread by a hydraulic excavator bucket over the embankment to a depth of 30 cm over a linear distance of 200 m, on a sublayer of cinder and crushed rock. Although the average moisture content of sediment at 46.5% was considered higher than was desirable, the sediment rapidly dried out after being placed on the horizontal verge, with desiccation cracks forming within a month, in part, due to a period of unseasonably dry weather. In practice, the elevated moisture content aided the spreading and transportation of the soil from the basin to the cycle verge.

Table 2. Application of seed types to dredged sediment at Bowling.

	GG6 Banks Seed Mix	Italian Rye Grass	Westerwolds Rye Grass
Seed mixture	Chewings Fescue 25% Strong Creeping Red Fescue 60% Flattened Meadow Grass 10% Browntop Bent 5%	Italian Rye Grass 100%	Westerwolds Rye Grass 100%
Application	35 g per m^2	35 g per m^2	35 g per m^2
6-9-6 fertilizer	40 g per m^2	40 g per m^2	40 g per m^2
Germination	Within 3 weeks	Within 3 weeks	Within 3 weeks

To confirm that the treated sediment was a viable topsoil, seven 16 m^2 plots were pegged out on each side of the cycle pathway and sown with varieties of grass, as shown in Table 3. Sowing was performed on 13 April 2021 on two sets of seven plots. Reed canarygrass (*Phalaris arundinacea*) was selected because of its known tolerance to marginal conditions [23]. Plots on the north edge of the cycle path were also treated with 40 g/m^2 of a general 6-9-6 fertilizer in pellet form.

Table 3. Application of seed mixes to trial plots along Bowline cycle pathway.

Plot	Mix	Application
1A	GG6 Banks seed mix	20 g per m^2
2A	Annual (Italian) rye grass	20 g per m^2
3A	Annual (Westerwolds) rye grass	20 g per m^2
4A	Reed canarygrass	20 g per m^2
5A	Perennial rye grass	20 g per m^2
6A	Wildflower mix Pro Flora 8	20 g per m^2
7A	Control plot	20 g per m^2

3. Results

To validate that grass could be grown on wet sediment, an area around the margins of the basin was sown with a proprietary mixture intended for embankment planting (GG6 Banks seed mix), sourced from Watson Seeds (Dunbar, Scotland), while the middle of the basin (between the monitoring wells) was sown with one block each of the two annual rye grass varieties for visual comparison. Quantification of growth could not be undertaken as the sediment would not support the weight of a person until the end of the trial. Despite the late season, all grass types germinated within two weeks and continued to grow until the first frost in late December, after which they remained green all winter (Figure 6). Both rye grass single varieties showed slightly stronger initial growth than the GG6 mix.

Progress of the sediment maturation was monitored by weekly visual inspections and direct measurements of moisture content by TDR at four monitoring locations, MP1, MP2, MP3, and MP., within the basin. By mid-March 2021, the soil water content had decreased to between 30–54% of total mass, as shown in Table 4, through drainage, compaction, evaporation, and phyto-conditioning.

Figure 6. The basin showing the growth of both seed mixtures. February 2021.

Table 4. Moisture variation within sediment basin.

18 January 2021				
	Monitoring location			
Depth bgl *	MP1	MP2	MP3	MP4
10 cm	41.6%	43.2%	41.4%	43.0%
20 cm	47.2%	48.6%	39.3%	31.7%
30 cm	51.7%	49.9%	47.4%	50.7%
40 cm	53.5%	55.2%	45.3%	54.4%
10 March 2021				
Depth bgl	MP1	MP2	MP3	MP4
10 cm	42.6%	43.9%	41.3%	47.3%
20 cm	46.8%	48.0%	39.2%	30.4%
30 cm	52.3%	49.6%	47.4%	49.3%
40 cm	54.2%	54.9%	44.2%	53.9%

* bgl. = below ground level.

Sediment samples were collected from the basin on 12 March 2021, using a gouge auger to recover continuous soil cores from the full depth of the sediment profile (10–50 cm). Thirty such samples were collected from across the basin and homogenized with a trowel in a stainless-steel bucket for a single analytical sample. The soil sample was sent to NRM Laboratories, Bracknall, United Kingdom (https://www.cawoodscientific.uk.com/nrm/ (accessed on 23 May 2021)) for analysis.

Table 5 provides a comparison of the phyto-conditioned soil and the dredged sediment against BS 3882:2015, with out of specification results shown in bold. Due to the slightly too low levels of available phosphorous and potassium, the soil failed to meet BS 3882 for topsoil [24]. However, this deficiency might be readily adjusted with the application of a chemical fertilizer. The concentration of phytotoxic Zn, at 559 mg/kg, was almost three times the permissible limit for a saleable topsoil product leaving the site, but would still be acceptable for urban landscaping on a site-specific basis. For example, the Land Quality Management/Chartered Institute of Environmental Health (LQM/CIEH) Suitable for Use Level (S4UL) for Zn for public open space (park) is 170,000 mg/kg [25].

Table 5. Comparison of dredged sediment and conditioned sediment (topsoil). Values in bold are exceedances of BS 3882.2015.

Characteristic	BS 3882:2015 Acceptable Range or Limits	Conditioned Sediment	In Situ Canal Sediment
Sample Ref	N/A	45032–507869	20/07344
Moisture	Not specified	21%	81.3%
Texture	>2 mm <30% >20 mm <10% >50 mm 0	Clay loam >2 mm 2.4 >20 mm 0 >50 mm 0	N/A
Mass loss on ignition	3 to 20%	6.1% (@430 °C)	**21.2** (@550 °C)
Soil pH	5.5–8.5	8.3	7.2
Conductivity	3300 µS cm^{-1}	2038 µS cm^{-1}	N/A
Total nitrogen (%) m/m	>0.15	0.19	
Extractable PO_4 mg/L	16 to 140	**11.8**	
Extractable K mg/L	121 to 1500	**109**	
Extractable Mg mg/L	51–600	193	
C: N ratio	<20:1	17.8:1	
Zn mg kg^{-1}	<200	**559**	**1216**
Cu mg kg^{-1}	<100	79.8	**152**
Ni mg kg^{-1}	<60	39.6	48

Germination was visible after 14 days; thereafter, the plots were monitored weekly. Within 28 days, growth was observed on all plots, though predominantly concentrated in the desiccation cracks within the sediment. It is postulated that the cracks retained moisture and acted as a nursery for the young plants. The control plot (#7) remained free of vegetation until the end of June, when Himalayan balsam (*Impatiens glandulifera*) and common nettles (*Urtica dioica*) had become established at the edge of the plot.

Over the initial trial period, rainfall was below average which favored the more robust rye grass varieties. As of early July 2021, reed canarygrass (Plot #4) had a similar growth rate. It was noted that by June 2021, rabbits and deer were heavily grazing the unprotected plots, which made quantification problematic. Surprisingly, the plots that were unfertilized were observed to have denser growth than the fertilized plots which were situated on the north side of the cycleway (Figure 7). This may reflect the shaded location of the unfertilized plots on the south side of the trackway, which retained higher moisture during dry spells, rather than nutrient demand. All plots continued to thrive in 2022. By early 2023 it was observed that reed canarygrass had become fully established within and beyond Plot #4.

Figure 7. The completed cycle path, showing grass growth. June 2021.

The reuse of the bio-engineered sediment had some positive impacts on the Bowline cycle path project. As there was no suitable location that would have allowed the sediment to be placed of along the canal side, in accordance with any of activity exemptions provided in the Waste Managing Licensing (Scotland) Regulations, 2011, this material would have been handled as waste and sent to landfill at an estimated cost of £40 per cubic meter. The use of the bio-engineered sediment in place of topsoil saved an estimated 320 cubic meters of topsoil. Collectively, this represents an estimated cost saving of around £30,000.

4. Discussion

4.1. When Should Phyto-Remediation Be Considered for Dredged Sediment?

Sediment managers can consider a range of potential reuse options as an alternative to ocean or landfill disposal [26]. The Bowling trial has demonstrated that dredged sediment from an urban canal can be successfully phyto-conditioned into a viable topsoil, as over 550 cubic meters of sediment was dredged from the Forth and Clyde Canal at Old Kilpatrick and conditioned within the treatment cell by reducing moisture content and total organic carbon of the sediment to BS 3882:2015 levels. There are several grass species that are suitable for accelerating de-watering, including rye grasses and fescue mixtures, that are readily available and cost effective to deploy. As the cost of applying a phyto-conditioning seed to the sediment during de-watering is negligible, it should be considered for all landscaping reuse options.

4.2. Impact of Contaminants

The presence of contaminants in dredged sediment from urban canals should be anticipated and screening for likely PTEs undertaken. Metals will be preferentially sorbed on to the finer particles present in canal sediment [27]. At Bowling, elevated concentrations of Zn in the dredged sediment exceeded the 200 mg/kg threshold of BS 3882:2015. From the in situ sediment analysis, we anticipated that Cu might be a concern, but analysis of the conditioned sediment reported Cu concentrations that were almost 50% less. This difference is likely attributable to sampling bias of the sediment grab. Despite the presence of these phytotoxic metals, the topsoil produced from the F&CC sediment was suitable for landscaping applications in place of imported topsoil.

Although the initial TOC content of the dredged sediment was around 20%, these samples probably included much near-surface, partially decayed vegetation. Moving from an anaerobic environment at the bottom of the canal to the treatment cell would have promoted oxidation of the remaining organic matter within the sediment, allowing the specification of BS 3882:2015 to be met. Moisture reduction was promoted by the drainage characteristics of the cell, especially the high permeability of the cinder subsoil. We observed that dewatering is enhanced by the formation of a top crust on the sediment, as evidenced by the formation of shrinkage cracks. This transition is largely irreversible and assists the runoff of precipitation from the drying sediment.

The economic viability of phyto-conditioning on this scale is largely controlled by the economics of transporting wet sediment from the dredge site to the treatment cell. For this pilot study, sediment was transported by hopper barge on the canal, which both reduced costs and the carbon footprint of the operation.

4.3. Future Work

The concentrations of Zn, Cu, and Ni in the conditioned sediment were approximately half of those measured on samples collected from the canal. It is not fully understood whether this reduction is repeatable, and if so, what is the fate and transportation of these metals during phyto-conditioning. The ability to sample groundwater at the Bowling site would allow for some mass balance calculations to be made during the critical three-month period after emplacement. Similarly, the fate of organic carbon in the sediment requires further study. Work is underway to better account for the carbon storage implications of reusing dredged sediment as a topsoil.

5. Conclusions

The Bowling pilot study has demonstrated the viability of bio-conditioning dredged canal sediment as a topsoil for landscaping on a pilot-study scale. The barriers to reuse are largely economic, related to the cost (distance) of transporting wet sediment. Although the sediment in this study was nutrient poor, this can be readily adjusted by the addition of fertilizer. However, for some landscaping applications, such as grass verges, this can be advantageous in reducing maintenance costs.

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