CL:AIRE

CON 08
(November 2023)

Concawe bulletin

CL:AIRE's Concawe bulletins describe the deployment of sustainable remediation techniques and technologies on sites in Europe. Each bulletin includes a description of the project context and conceptual site model along with a sustainability assessment. This bulletin describes a novel and sustainable sediment remedy for mitigating sheens.

Sheen Mitigation Using an Oleophilic Bio Barrier - A New and Sustainable Remediation Technique

1. INTRODUCTION

This case study discusses a remediation project undertaken at a site, where historical hydrocarbon contamination was resulting in Light Non-Aqueous Phase Liquid (LNAPL) sheens appearing on the foreshore of the adjacent river. The works involved the application of a new sediment remedy for mitigating sheens through the innovative use of oleophilic geo-composites, which utilised the Arcadis developed and patented Oleophilic Bio Barrier (OBB) technology.

Herein, the project background is discussed, the Conceptual Site Model (CSM) is considered and the design and implementation of the OBB technology is described. Also included is a discussion on sustainability, project highlights, lessons learned, and conclusions. Sustainable remediation is further discussed within the UK Sustainable Remediation Forum (SuRF-UK) framework (CL:AIRE, 2010) and its Supplementary Report 1 (CL:AIRE, 2020).

2. PROJECT CONTEXT AND SITE DESCRIPTION

A "sheen" is a film with iridescent appearance, which can occur on the surface of water. Sheens can occur as a result of natural processes, such as decaying organic matter or bacterial processes, or from manmade pollution events. Petroleum sheens (Figure 1) can be encountered on the surface of water bodies adjacent or near to facilities where historical subsurface petroleum releases have occurred.

The industrial revolution led to the development of coastal and river transportation routes and the surrounding land. The historical development and associated industrial activities have, in some cases, resulted in land contamination. Where sites are contaminated with hydrocarbons, this can impact the adjacent water bodies. In these instances, many traditional forms of remediation are frequently found to be unsuitable solutions, being both unsustainable and costly. Traditional methods are often limited by such factors as:

- Access restrictions due to location of sheen instances (on water bodies);
- On-going active industrial practices restricting access;
- High costs associated with immediate solution of removal of source material; and
- Stringent remediation compliance criteria due to LNAPL impact on water bodies being unacceptable even at low levels, particularly due to visual impacts.

Figure 1: Photograph of sheening.

The site is planned to be remediated as part of a complex wider scheme, however the client required a separate remedial solution to address localised sheening events on the river. Arcadis worked closely with the client to understand the potential sources of the contamination and the mechanisms by which this sheen was being created in order to develop and design a robust solution.

3. CONCEPTUAL SITE MODEL

A detailed data review was conducted to develop a CSM to understand the potential source of the sheens, the mechanisms by which the sheens were being generated, and quantify the contaminant mass flux. Details of some of the information obtained and reviewed are included below.

For further information please contact the authors:
Natasha Shade, Arcadis UK, natasha.shade@arcadis.com
Tom Pickett, Arcadis UK, tom.pickett@arcadis.com
Dr Christopher Piddington, Arcadis UK, chris.piddington@arcadis.com

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Site generated data

- Time lapse photography
- Tidal observations
- Sediment sampling on the foreshore
- Directional drilling site investigation to gather data from beneath the inaccessible foreshore area

External sources of data

- National River Flow Archive (NRFA) Records
- Digital Marine Chart Published by GPS Nautical Charts
- Historical Weather Data (Figure 2)

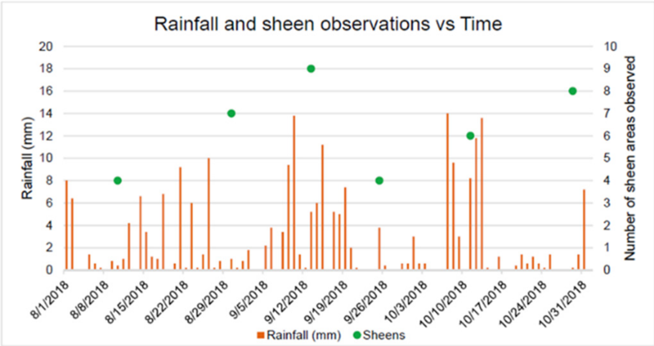

Figure 2: Weather data used with sheen observations prior to remedial works.

The data review concluded that the sheens were generated due to both seepage and ebullition (the release of LNAPL bubbles from sediments into overlying water), observed during rising and falling tides with increased prevalence around mid-tide levels.

The Bonn Agreement Oil Appearance Code (BAOAC; IPIECA-OGP 2015), which identifies categories of sheen appearance that have been correlated to sheen thickness, was used to characterise the observed sheen events. BAOAC ranges from silver (thinnest) to dark (thickest) sheen. Historical observations of sheens were primarily described as "slight", which were interpreted as BAOAC silver sheen, and were occasionally described as "widespread," which were interpreted as BAOAC dark sheen.

4. ASSESSMENT FUNCTION

Understanding the sources of the contamination and the mechanisms by which the sheen was being created was a key component in developing and designing a robust solution.

4.1 Oleophilic Bio Barrier concept

Arcadis developed a concept design for the installation of its patented OBB technology (Figure 3). This is a novel sediment remedy for mitigating sheens through the innovative application of oleophilic geo-composites (Figure 4).

The OBB is comprised of layers of Reactive Core Matting® (RCM®, as manufactured and trademarked by CETCO), and geo-composite mats (in this case manufactured by SKAPS).

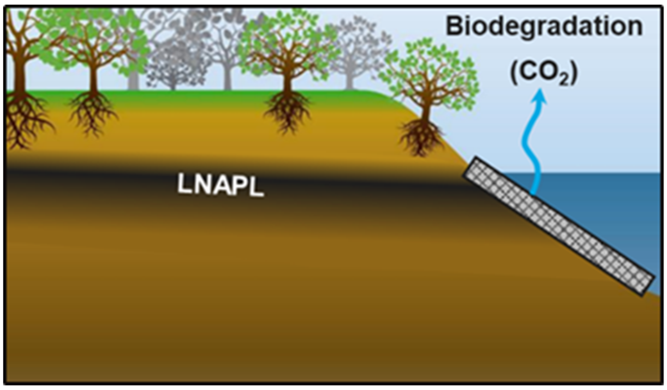

Figure 3: Concept design for OBB technology.

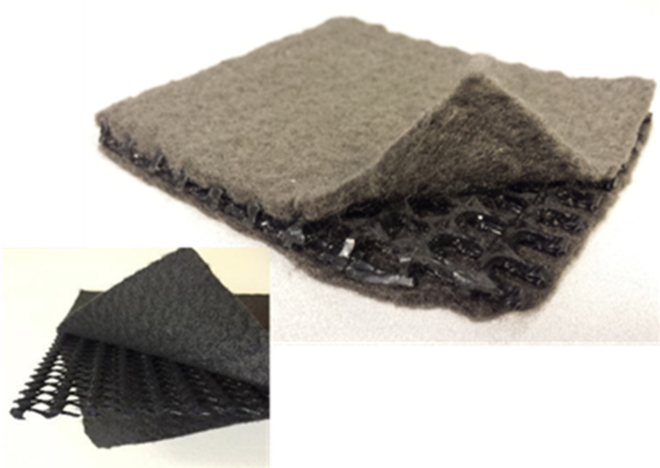

Figure 4: Geo-composite mats.

The RCM® contains an organophilic clay material that binds strongly with oils that flow into the mat without impacting water flow. These organophilic clays are manufactured using an ion exchange process that replaces sodium, calcium and magnesium ions of bentonite clay with quaternary amine compounds (Alther, 2010). This ion exchange process transforms bentonite clay from hydrophilic to oleophilic (meaning that instead of swelling / absorbing water, it absorbs oils). The RCM® also spreads, or wicks[1], the oils across its surfaces, which are constructed of polypropylene geotextiles that are also oleophilic in nature.

If the capacity of the RCM® is exceeded, the oils that pass through the mats are spread to a larger surface area, where they contact the geo-composite product. This product retains oils on its polypropylene geotextiles, while delivering oxygen and nutrients through its high density polyethylene core to microbial communities that populate the mat and degrade the retained oils.

4.2 Design of the barrier

The site-specific design of the OBB is included below and shown in Figure 5:

- Three layers of RCM®;
- One layer of geo-composite;
- Layer of 60 mm x 40 mm aggregate filter material; and
- Layer of 300 mm x 200 mm stone armour.

[1] Drawing up and spreading of oil across the surface via capillary action.

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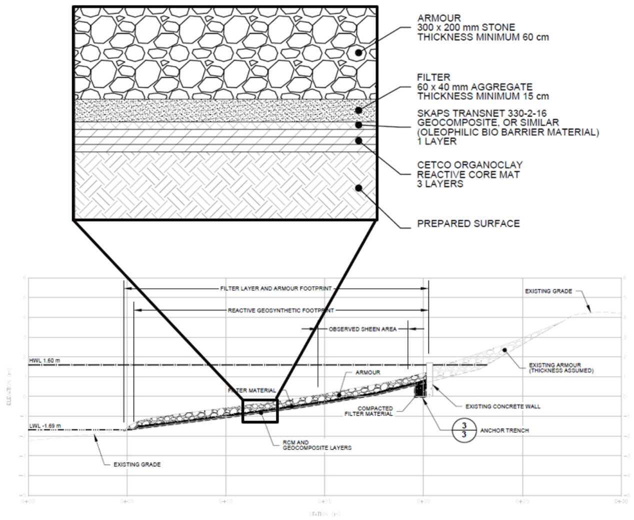

Figure 5: Layering and design of OBB.

The initial design details incorporated a number of assumptions such as rock armour thickness, construction make-up of the existing concrete wall structure, and the source of LNAPL, sheening mechanisms and flux estimates which were based on the previously developed CSM.

4.3 Installation process

The installation process took 5 weeks to complete on site and is outlined in the following sections.

4.3.1 Protection of the environment

During the installation of the OBB a number of environmental protection measures were deployed including:

- A floating containment barrier anchored to the foreshore (black and orange floating structure, Figure 6);
- Absorbents tied to the containment barrier to absorb any liberated LNAPL or sheen (white booms, Figure 6);
- Silt curtain deployed to riverbed to prevent turbidity generated by the works being released to the wider river environment (not visible in Figure 6);
- Ecologist Supervision – a trained and independently accredited individual deployed to observe the works and ensure protected birds and mammals in the area were not disturbed due to the works (this was also a permit requirement).

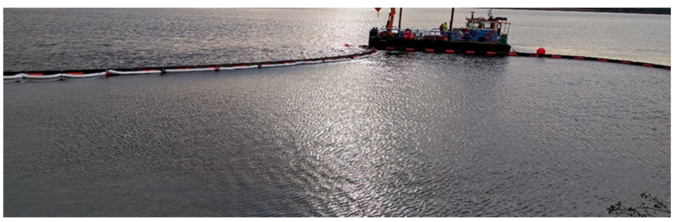

Figure 6: Floating containment and absorbents.

4.3.2 Rock armour removal and surface preparation

The rocky foreshore area was first prepared by removing the rock armour and exposing the contaminated sediments using a terrestrial-based long reach excavator, supported by marine-based plant situated on a 'spud legs' pontoon vessel. Rock armour removal was undertaken in a staged approach to allow assessment of the materials for potential reuse. Preparation of the sediment surface was undertaken to ensure that it was free of debris, protrusions and / or other potentially harmful materials that could otherwise damage the barrier during installation.

Following rock armour material removal, a number of trial pits were excavated to characterise the materials and environmental conditions. This revealed not a single point of sheen generation, but a layer of LNAPL impacted materials beneath the rock armour. Environmental samples were also taken to demonstrate baseline conditions present at the time of OBB installation.

4.3.3 OBB cutting and laying

RCM® and OBB geo-composite were rolled out (Figure 7) and cut to size into individual segments or panels and numbered, adjacent to the installation area. Cut panels were re-rolled onto plastic tube cores to allow a lifting bar and straps to be used for the installation works (Figure 8).

Figure 7: Rolled out RCM® and OBB geo-composite.

Figure 8: Cut and rolled up segments or panels.

The area of the OBB installation was within a significant tidal range of the river, dramatically limiting the working window on the foreshore to only a few hours per day around the low tide event. Individual panels (with plastic roll core) were lifted into position using lifting straps and a long reach excavator. The roll out of individual panels was positioned by hand, with pre-designed amounts of lateral and medial overlap.

4.3.4 Placement of anchor trench and filter stone

The strips of matting were lapped into trenches at the top and bottom of the barrier area, and concrete blocks were placed into the trenches to anchor the mats in place. At the low tide mark, this involved lowering concrete blocks using a HIAB crane installed on a specialist Multicat vessel, working alongside a diver to guide placement and disconnect the lifting tackle.

Following the deployment and installation of the OBB materials a layer of filter stone (Figure 9), followed by a layer of rip rap or rock armour was installed over the barrier area to complete the installation works and ensure the barrier was both secured in place and protected from the frequent storms that occur in the area.

4.4 Post-installation monitoring

Post-installation condition is shown in Figure 10. Observations were made during the demobilisation period to assess the initial conditions around the OBB. Notes were made at near low tide, high tide and during falling and rising tidal conditions, and no hydrocarbon-based sheen or olfactory evidence was noted.

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Figure 9: Area of filter stone placement.

Figure 10: Post-installation condition.

A period of regular (minimum weekly) sheen and odour monitoring was undertaken by the client immediately following the installation, after which monitoring was undertaken on a less regular basis, but no less than twice per month. In the three-year period since the installation was completed no sheening events or olfactory evidence of hydrocarbon contamination have been noted at any of the tidal stages observed.

5. SUSTAINABILITY ASSESSMENT

5.1 Methodology

A retrospective, qualitative assessment of the sustainability of the remediation options considered as part of this project was undertaken in line with guidance outlined in the UK Sustainable Remediation Forum (SuRF-UK) framework (CL:AIRE, 2010) and its Supplementary Report 1 (CL:AIRE, 2020).

The SuRF-UK framework identifies six key principles of sustainable remediation, summarised below:

- Principle 1: Protection of human health and the wider environment
- Principle 2: Safe working practices (for workers and local communities)
- Principle 3: Consistent, clear and reproducible evidence-based decision-making
- Principle 4: Record keeping and transparent reporting (including assumptions and uncertainties)
- Principle 5: Good governance and stakeholder involvement
- Principle 6: Sound science

The sustainability assessment was completed using the Tier 1 Sustainability Assessment Spreadsheet Tool provided by SuRF-UK which enables assessment of the remediation project in accordance with SuRF-UK's guidance.

5.2 Framing of the sustainability assessment

The SuRF-UK framework recognises that in many circumstances, a practitioner does not have an opportunity to influence the design work. They are only asked to implement the remediation solution to deliver the design requirement. This represents a Stage B framework process. At this stage the remediation options appraisal can only seek to identify the technologies or techniques to achieve risk-based remedial objectives and also optimise the net (social, environmental and economic) benefit provided by the remediation.

This is the case for the project discussed herein in which the project goals required a solution to directly address and mitigate the sheening problem. Common options to address this issue were explored and are presented within the sustainability assessment below, alongside the technology implemented (i.e. OBB). The options were:

- Groundwater pumping and treatment of LNAPL (pump and treat);
- Sheen capture via installation of temporary sorbent booms;
- OBB technology to capture, retain and degrade sheen;
- *In Situ* Stabilisation and Solidification of impacted soils (ISS);
- Excavation and disposal of impacted soils ("dig and dump").

The main constraints of this project were as follows:

- Technology needed to address the sheening problem directly, as the site was planned to be remediated as part of a complex wider scheme.
- The location of the site, on a tidal riverbank, created space and access constraints.
- Sensitive environmental area, therefore, works required detailed planning and regulatory discussions to ensure that appropriate control and mitigation measures were in place.
- The site must be restored to a similar physical profile following works.

5.3 Evaluation of options and scoring

The sustainability assessment considered the potential environmental, social and economic costs and benefits in order to select the optimum remediation solution in terms of sustainable remediation. In the Tier 1 assessment, each indicator or criterion is unweighted (all indicators are perceived of equal importance).

Scoring was undertaken proportionately, with options being assigned equal scores where differences between them were marginal. A ranking scale ('0' denoting "worst" to '3' denoting "best") was applied to each sustainability indicator and the results aggregated.

5.4 Tier 1 sustainability assessment results

The output of the SuRF-UK Tier 1 Sustainability Assessment Tool is presented in Table 1. Justifications of assigned scores are discussed in Section 5.5.

Table 1: Tier 1 Sustainability Assessment Indicators and Scoring (Output of the SuRF-UK Tier 1 Sustainability Assessment Tool).

Technology		Sheen Mitigation - Remediation Technologies				
		Groundwater pumping and treatment of LNAPL	Sheen capture (installation of temporary sorbent booms	OBB to capture, retain and degrade sheen	ISS	Excavation and disposal of impacted soils
Social Indicators						
Human Health and Safety	Long Term	No Risk to Human Health Receptors based on existing Conceptual Site Model				
	Short Term, e.g. site workers	2	2	2	1	1
Ethics and Equity		1	2	3	1	2
Neighbourhood and Locality		2	2	3	2	1
Communities and Community Involvement		2	2	2	2	2
Uncertainty and Evidence		2	2	2	2	3
Social Score		**9**	**10**	**12**	**8**	**9**
Economic Indicators						
Direct Economic Costs and Benefits		1	2	2	1	1
Indirect Economic Costs and Benefits		1	1	3	3	3
Employment & Employment Capital		3	2	3	3	3
Project Lifespan		2	2	2	3	3
Project Flexibility		2	3	3	2	3
Economic Score		**9**	**10**	**13**	**12**	**13**
Environmental Indicators						
Air Quality / Climate Change		2	3	3	3	2
Soil and Ground Conditions		1	1	2	2	3
Groundwater and Surface Water		3	2	3	2	2
Ecology		2	2	2	1	1
Natural Resources and Waste		2	3	3	1	0
Environmental Score		**10**	**11**	**13**	**9**	**8**
Overall Summary						
Overall Score		**28**	**31**	**38**	**29**	**30**

5.5 Rationale of individual indicator scores

Social Indicators

Human Health and Safety (H&S)
Technologies scored higher where the technology effectively manages risks in the project (short term) in terms of delivery of mitigation of unacceptable human health risks to site workers, neighbouring residents and the public. ISS and excavation and disposal approaches both scored lower for social H&S elements due to the scale of earthworks plant and site works required in relation to the potential risks and increased H&S concerns.

Ethics and Equity
The OBB had the highest score as the remediation technology and timescales for remediation are more than proportionate to the level of improvement required, as it will directly target the sheening with long term effect.

Neighbourhood and Locality

Excavation of the impacted soils scored lowest due to the high impact expected with this technique in terms of impact to neighbourhood (e.g., dust, noise, light).

Communities and Community Involvement

All technologies scored similarly, whereby the implementation of all the considered remediation technologies would have a minor impact to the local community.

Uncertainty and Evidence

Excavation scored highest, due to the certainty that removal of the impacted soils would in turn reduce the likelihood of further sheening events. All other technologies considered would reduce or prevent sheening events, but with a lower level of certainty.

Economic Indicators

Direct Economic Costs and Benefits

Pumping and treatment of groundwater, ISS and excavation scored lower due to high costs associated with large scale plant and works (as noted above), operation and maintenance costs and waste disposal. The sheen capture would be low cost, however, would require regular maintenance. The OBB operation would incur moderate capital and low maintenance costs.

Further to the low maintenance costs, specific to the OBB, economic benefits would arise due to estimated design life for the OBB being at least 17 years. This is based on current site conditions, an infinite source mass, the retention capacity of the barrier components, and the estimated sheen flux. Once the planned wider remediation scheme is underway there will be a reduction in the up-stream source of the LNAPL with a corresponding reduction in the sheen flux at the OBB area. Therefore, resulting in an extension of operational barrier lifetime. The design of the rock armour installed over the barrier area also helps to ensure the barrier is both secured in place and protected from the frequent storms that occur in the area.

Indirect Economic Costs and Benefits

Pumping and treatment of groundwater and sheen capture scored lowest, as they may not enable site regeneration in the short term and would usually be used as a temporary or ongoing management solution. All other technologies scored highly due to the active treatment and / or removal of the affected soils / water allowing for regeneration and therefore indirect cost reduction in the short term.

Employment & Employment Capital

When considering this factor for job creation, employment levels (short and long term), skill levels before and after, opportunities for education and training, innovation and new skills - all technologies scored highly (and similarly) for this due to the need for 'employment' of specialists – either in active treatment and / or removal of the affected soils / waters. Sheen capture scored lowest as it is a short-term solution and may not enable site regeneration in the short term.

Whilst traditional bioremediation schemes are often seen to be a slower form of remediation, the OBB remediation scheme was developed to immediately address the sheening events on the adjacent river whilst creating an ideal environment for the microbial communities to establish and populate the mat to degrade the retained oils, allowing for site regeneration in the short term.

Project Lifespan

Excavation and ISS are well proven with stable timescales for application, so scored highly. The other technologies have timescales for implementation which can be reasonably estimated.

Project Flexibility

The technologies assessed can all be adaptable to changing conditions (on site, regulatory / local needs), however ISS can be adaptable at design phase only, so scored moderately along with groundwater pumping and treatment. The sheen capture, OBB and excavation and disposal scored highly as they are readily adaptable to changing conditions.

Environmental Indicators

Air Quality / Climate Change

Pumping and treatment of groundwater scored lowest due to the possible need to treat any vapour phase contamination associated with pumping of contaminated groundwater. Excavation and disposal scored moderately due to the associated emissions of plant and vehicles required for the works as well as the release of hydrocarbon vapour into the atmosphere during excavation works. The rest of the technologies scored highly as there would likely be negligible air emissions which do not require treatment.

Soil and Ground Conditions

Pumping and treatment of groundwater, as well as sheen capture, scored lowest due to limited positive impact on soil quality. Excavation scored highest, due to removal of impacted soils. The OBB and ISS would have an overall positive impact on soil quality due to removing or stabilising some of the impacted soils.

Groundwater and Surface Water

Pumping and treatment of groundwater, as well as the OBB, scored highest as these would have the most significant positive impact on groundwater quality or local surface water features. Other technologies would likely have an overall positive effect.

Ecology

The site is designated as ecologically sensitive. All technologies scored moderately or lower as the works could potentially impact ecology, and a management plan would be required. Excavation and disposal as well as ISS scored lowest due to the high impact of the works, which would likely require active mitigation. For the OBB, due to the ability to visually integrate the barrier into the surrounding area there was, and still is, a negligible disruption to the ecology in the vicinity with no visual impact as the works included restoring the disturbed foreshore to match the existing surroundings.

Natural Resources and Waste

Often, traditional remediation technologies will use higher levels of energy and create multiple waste streams, particularly with excavation and disposal, which scored the lowest. Sheen capture would be a low energy technique with negligible waste streams, so scored highly. The OBB also scored highly due to being low energy and able to minimise waste streams. The application of an OBB, in preference to a number of traditional sheen mitigation schemes that would require the wholesale or large-scale removal of impacted materials, minimises waste being generated on site and subsequent disposal to off-site sources.

5.6 Sustainability assessment conclusion

The sustainability assessment indicated that the OBB technology selected would provide the optimum remediation approach based on the assessment where potential social, economic and environmental impacts are considered of equal importance.

The selected remediation technology employed methods which minimised potential environmental, social and economic impacts at every stage throughout the project design and delivery, where possible and practicable to do so.

6. PROJECT HIGHLIGHTS

This project produced a number of highlights, including:

- Overcoming the challenging significant tidal range of the river, by working with a commercial diving team for in-water work and underwater excavation of trenches. Without the commercial diving team, the tidal range would have limited the working window to a few hours around the low tide event.
- Proactively managing the environmental challenges of working within an ecologically sensitive area through detailed planning and regulatory discussions, ensuring that appropriate control and mitigation measures were in place to prevent detrimental impact on the local environment and ecology.
- The implementation and installation works of the OBB representing a European first application. They were undertaken in highly challenging conditions, as referenced above, with no incidents or accidents.

7. LESSONS LEARNED

As would be anticipated from one of the first applications of a new remedial solution, there were lessons learned from the project identified in the design phase, pre-works and installation phases, with the main lessons learned summarised below:

Conceptual Site Model Uncertainty and Design Flexibility
The OBB design provided a barrier area and panel layout configuration. This required that each barrier panel be constructed from a continuous piece of fabric, reducing the ability to cut and reuse excess material. During installation works site conditions were found to be slightly different to those anticipated at the design stage and the coverage required for the OBB had to be increased to accommodate this variation. Allowing placement of excess cut materials (and specifying how to overlap these cut materials) could be added to the design to allow more flexibility during construction and minimise material wastage.

While the OBB design is inherently flexible and barrier coverage can be readily increased if required, this can lead to delays during the site works. As such it is desirable to undertake as much direct investigation of the target area as possible to aid the design process and ensure the area in question is as robustly understood as possible. While this would add expense to the design phase, it would add more certainty to the installation programme and potentially save on construction downtime costs, should it be necessary to increase the barrier area. However, it should be noted that typical locations for OBB installations can often mean that complete access is not possible in every instance (as was the case for this particular site) and as such the ability to flex the design to accommodate site specific variables encountered during installation works is a highly beneficial aspect of the OBB concept.

Licensing, Permitting and Technical Understanding of Stakeholders
Design and technical documents presented to stakeholders and non-technical consultees should be modified to account for variations in knowledge and understanding. Separation of interpretive or indicative drawings from technical design drawings would also help facilitate understanding by various stakeholders.

8. CONCLUSIONS

This design and build project represented the first application in Europe of the Arcadis patented OBB technology, with over 1,300 m^2 of oleophilic geo-composite and reactive core material installed during the project.

The installation works were successfully undertaken in highly challenging conditions and the project was completed safely, with no incidents or accidents and with no detrimental impact to the area.

It was notable with respect to working in an ecologically sensitive area within the marine environment that during discussions with key project stakeholders (e.g., local environmental protection and marine licencing authorities) many of the key sustainable attributes of the solution, when compared to alternative approaches, were integral to attaining timely approvals for the proposed works. For example, being able to limit or minimise disturbance and environmental impact in the area during the installation works, as well as the ability to integrate the barrier into the surrounding area with no visual impact or change to the foreshore area once completed, were important factors during the regulatory review period.

Following completion of the project initial evidence and observations indicate that the works have successfully mitigated the occurrence of sheen in the foreshore area and ongoing visual monitoring is continuing to ensure the demonstrable success of this OBB project. No sheens or olfactory evidence of hydrocarbon contamination have been observed in the three years of monitoring since installation.

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