CL:AIRE

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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 the application of a reactive mat to protect a surface water resource.

Reactive Mat in Canal Catches Groundwater Contaminants

1. INTRODUCTION

This bulletin describes the application of a nature-based system variant of permeable reactive barriers for protecting a surface water resource called a "reactive mat". This installation was part of an EU-funded Interreg project called RESANAT (residual contamination remediation with nature-based techniques). The bulletin describes the design, implementation and the functioning of the reactive mat and provides a retrospective (*post hoc*) sustainability assessment comparing the reactive mat approach with alternatives that might have potentially been deployed.

2. PROJECT CONTEXT AND SITE DESCRIPTION

There are many European locations where a long-term inflow of contaminated groundwater reduces the quality of receiving (draining) surface waters. These inputs may lead to ecological and human impacts which breach the Water Framework Directive. In general, this also leads to environmental liabilities, reputational damage and a lower marketability of sites.

This case study is an example of this situation. It concerns a canal (the Lieve) that has been affected by an adjacent historically contaminated site. It is located near to the harbour of Ghent in Belgium. The contamination results from industrial production of tar and carbon black. Contaminants include aliphatic and aromatic hydrocarbons, in particular benzene, toluene, ethylbenzene, xylenes (BTEX), C6-C10 hydrocarbons and several polycyclic aromatic hydrocarbons (PAH). Contaminated groundwater from this site drains into the Lieve, causing surface water concentrations 70 to 300 times Flanders environmental quality standards for several PAH-components (e.g. acenaphthene: measured 18 µg/l; environmental quality standard 0.06 µg/l). In 2006 the site was partially remediated by excavation and removal of shallow soil, which allowed redevelopment of the site for two car dealerships. However significant residual soil and groundwater contamination remains. In 2019, at the start of the RESANAT-project, the site included the two car dealerships and a vacant plot. Figure 1 shows an aerial photo of the site in 2020. The vacant plot has since been redeveloped.

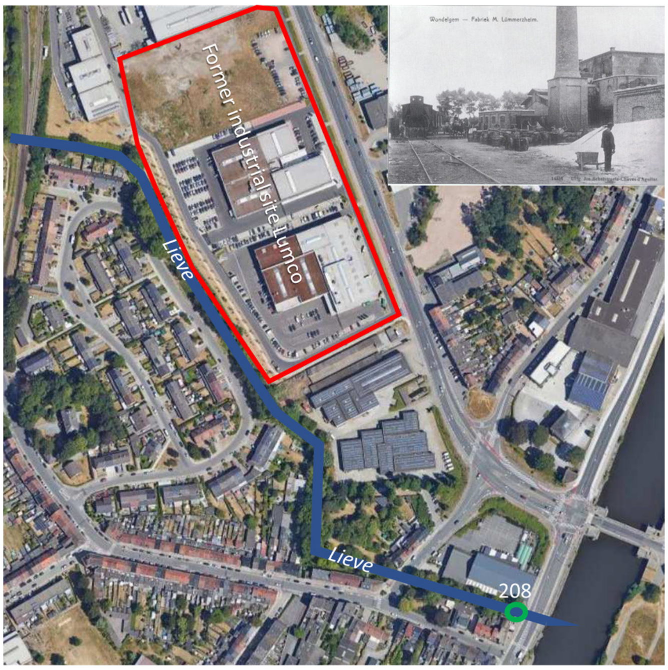

Figure 1: Aerial photo of the Lieve Canal and the former Lumco industrial site in 2020 (red outline). In 2021, a new car company was established at the bare land at the top of the picture. Inset photo is a factory in Ghent circa 1918.

Over many decades, the Lieve became clogged by a thick contaminated sediment layer. This layer was dredged and removed in 2019 as a climate adaptation measure by the water manager. As a result of dredging the draining capacity of the canal increased. In turn this increased flow has led to a higher influx of contaminated groundwater and so a further increase in the concentration of contaminants in the canal (surface) water. Moreover, following removal of the sediment, residual free product is locally (still) present in the current waterbed and thin 'rainbow' layers have been observed on the water surface.

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TAUW proposed the concept of using natural materials as an adsorbent in a permeable barrier. It designed a mat structure which is placed on the bed of a surface water body to intercept the contaminated groundwater that drains into it. TAUW has named this technology 'Natural Catch' and it received the 2013 NICOLE Technology Award. The functioning of this reactive mat exploits three nature-based processes:

1. The natural drainage capacity of the canal, so no pump is needed;
2. The use of a naturally occurring renewable adsorbent in the mat that is inert and has a high adsorption capacity; and
3. A biologically active interface at the mat surface that provides aerobic biodegradation.

The RESANAT project (2019-2022) supported a full-scale proof of concept for the Natural Catch[TAUW] technology for the Lieve canal. The project was part funded by the EU, the Dutch Ministry of Economic Affairs and the project partners OVAM, Envisan, TAUW, iFlux, TTE and Witteveen+Bos. The project was led by TAUW. OVAM, the Flemish governmental agency responsible for waste policy and soil remediation, was closely engaged as initiator of RESANAT and its responsibility for the site. The City of Ghent was involved because it is regulator for the Lieve and its banks. The duration of the project was 3.5 years, and it is planned that the reactive mat will remain in place after the project.

3. CONCEPTUAL SITE MODEL

The soil east of the Lieve, at and near the former industrial site, consists of a fine silty sand to a depth of about 5 to 6 m below ground level (bgl) and below that of moderate sand alternated with loamy layers. The groundwater level is present at a depth of 1.5-2.5 m bgl, depending on seasonal fluctuation. The contaminated groundwater from the former industrial site to a depth of about 6 m bgl is drained by the canal (see Figure 2). The deeper groundwater contamination below 6 m bgl flows in the opposite direction. Representative groundwater concentrations on the east bank of the Lieve for some relevant contaminants are presented in Table 1 (measured March 2020). Initial surface water concentrations in the Lieve, after dredging the sediment layer, are presented in Table 2 (NB: measuring point 208 is depicted in Figure 1).

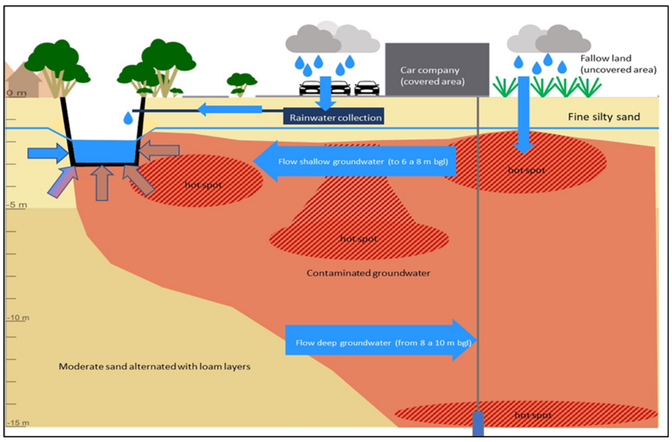


Figure 2: Conceptual site model.

Table 1: Measured groundwater concentrations (µg/l).

March 2020	Well 20 (3.2-5.2 m bgl)	Well 50 (3.15-5.15 m bgl)	Well 90 (3.2-5.2 m bgl)	Well 100 (2.4-4.4 m bgl)
Benzene (µg/l)	15	38,000	100	< 0.2
Toluene (µg/l)	15	11,000	1.2	< 0.5
Ethylbenzene (µg/l)	5.5	1,100	8	< 0.5
Xylenes (µg/l)	9.9	4,600	3.9	< 0.5
Naphthalene (µg/l)	240 / 270	6,100 / 7,200	13 / 16	0.14 / 0.2
Acenaphthene (µg/l)	1.1	280	41	0.1
C6-C10 (µg/l)	99	60,000	130	< 10

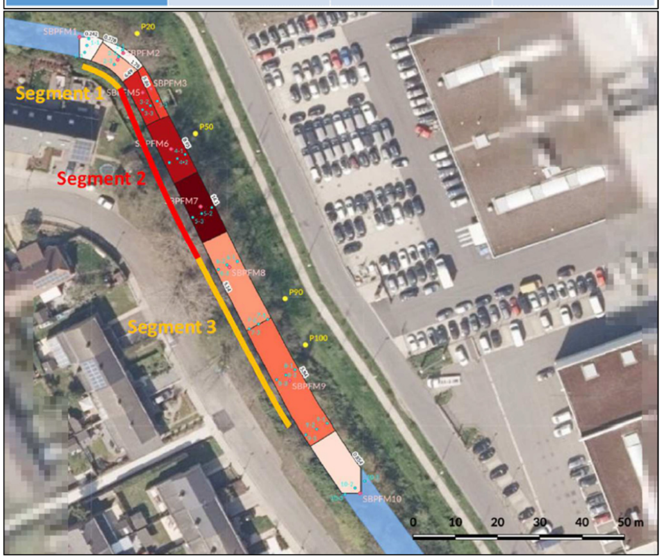
Table 2: Measured surface water concentrations (µg/l).

	201	202	203	204	205	206	207	208
Benzene	< 0.2	<0.2	180	140	100	83	75	3.5
Toluene	< 0.5	<0.5	56	30	20	16	16	8.2
Ethylbenzene	< 0.5	1	6.1	6.9	7	5.9	5.4	3.2
Xylenes	< 0.5	1.7	27	23	21	17	16	9.3
Naphthalene	0.2	12	46	57	60	54	53	26
PAH (16 EPA)	0.66	25	57	77	86	80	93	79
Acenaphthene	0.12	3.9	3.2	6.3	7.5	9.4	10	15
C6-C10	< 10	<10	280	210	160	130	120	61

iFlux used sediment bed passive flux meters to give an indication of the vertical influx of contaminants from the sediment to the surface water (Table 3). These measurements have led to an important insight into the contaminant loads that the canal receives daily, the distribution of influxes over the canal length and the influence of degradation and dilution downstream. The majority of flux to the canal was found at measuring points 202/203 to 204/205 through the bed (see image under Table 2).

Table 3: Measured influx of contamination from groundwater to surface water (mg/m²/day).

	Segment 1	Segment 2	Segment 3
Benzene	0,00	11.8	0.00
Xylenes (sum)	0.17	20.2	0.04
Naphthalene	2.36	28.4	0.35
Phenanthrene	7.93	17.8	5.17
Pyrene	2.21	4.59	4.83
Acenaphthene	4.98	7.24	2.24
C6-C10	0.00	3.02	0.00



Based on these findings the reactive mat needed to be installed at a 110 m long canal section with a total surface area of 660 m^2. The hydraulic head of the groundwater in the bank is about 1.5 to 2.2 m bgl (wells at 5 m bgl). The difference in the hydraulic head of this groundwater and the surface water level is 0.2 to 0.3 m, which supports the data of the vertical flux measurements that indicate a flow from groundwater towards the surface water as well. The implication is that shallow groundwater contamination flows from the former industrial site (source zone) into the Lieve (receptor). The draining depth of the Lieve is believed to be approximately 6 m bgl; below this the groundwater flows in the opposite direction.

4. PROCESS DESIGN AND INSTALLATION

The process of selecting absorbent material was based on a short-list identified following a literature study. Six materials were identified:

- Hazelnut shells (milled);
- Biogranulate (thermally treated sewage sludge);
- Carbon sludge (used pulverised activated carbon from drinking water treatment);
- Biochar (carbon from pyrolysed waste wood);
- Pine bark (shredded); and
- White peat (sieved).

These were tested in laboratory batch experiments using contaminated groundwater from the site to determine physical parameters and their adsorption capacity for key contaminants. The laboratory data were used to model the technical life expectancies of materials in a reactive mat for the Lieve canal. Biochar and peat were found to be the optimum materials: biochar recorded the highest adsorption capacity; peat had the second best adsorption capacity and is lower in cost.

To keep the adsorption material in place on the waterbed in the Lieve, a special geotextile construction was designed and produced (by TenCate Geosynthetics) to provide a replaceable system. It consists of a double fabric: a strong woven outer part and a fine non-woven inner part that keeps the fine adsorbent particles inside. Each mat element consists of several compartments to guarantee that the adsorption material is homogeneously distributed.

In September 2020 empty geotextile mat elements were transported to the site and filled with the adsorption material (either biochar or peat) and ballast (gravel) by the contractor Envisan (Jan de Nul Group). They were then hoisted into the canal and fixed to the banks (Figure 3). Biochar mats were placed at the canal section with the highest influx over a length of 65 m (segments 1 and 2, see image under Table 3), with peat mats used where the canal receives the lowest influx over a length of 45 m (segment 3). The mats were primarily deployed on the canal bed, with a small vertical fold part on the banks.

In January 2021 environmental monitoring of surface water quality and several other indicators began. The first three monitoring rounds after installation found that the surface water quality had improved substantially, particularly for the biochar section of the mats, where the highest influx of contaminants was measured. A high efficiency on the reduction of concentrations in the surface water was observed: 85-99% for PAH, 84-97% for benzene, 90-97% for xylenes and 92-100% for C6-C10.

Figure 3: Construction of reactive mat in the Lieve.

At the end of the fourth round of monitoring (September 2021), there was an unexpected increase in contaminant concentrations at the three measuring points furthest downstream. Vertical flux measurements taken in December 2021 demonstrated that the biochar mats were far from saturated with contaminants. On further investigation a visible gap was found between two mat elements and these were adjusted to close the gap. At the next monitoring round in January 2022, the contaminant concentrations had fallen back to earlier levels (Figure 4).

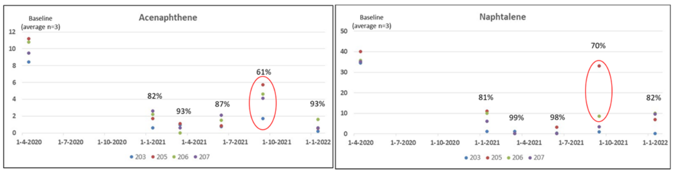


Figure 4: Concentration (µg/l) in surface water as function of time (Biochar mat - 203 & 205; Peat mat - 206 & 207).

Aerobic biodegradation is a key part of the Natural Catch^{TAUW} concept and is being tracked in the Lieve Canal project. For this, in January 2021 the water at the mat surface was analysed by a qPCR-test to identify the presence of specific micro-organisms (Figure 5). In addition to anaerobic biodegraders, aerobic biodegraders of BTEX, PAH and alkanes were present at the interface in low to moderate numbers (10^1–10^4 cells/ml), which means aerobic biological degradation is taking place of residual contaminants that pass the adsorbent.

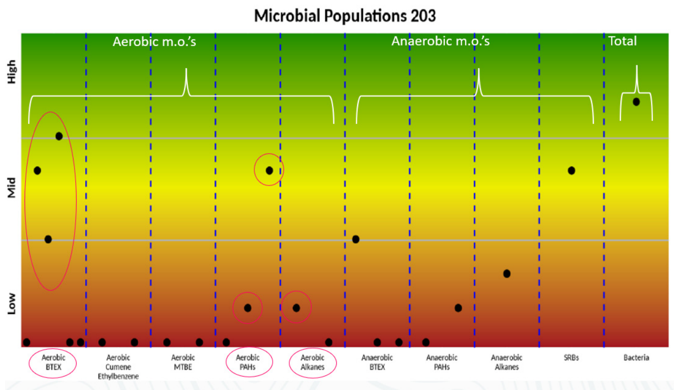


Figure 5: Overview of the microbial aerobic and anaerobic populations in sample 203, based on the quantified genes.

Monitoring continued until the end of the project in December 2022, including a further qPCR-test on micro-organisms on the mat surface and an analysis of the adsorption material in the mat to find out about the load of contaminants.

5. SUSTAINABILITY ASSESSMENT

5.1 Method and score

TAUW has developed an in-house tool for assessing the sustainability of remediation options by assigning weights and scores to sustainability indicators across the three dimensions of People, Planet and Prosperity (Society, Environment & Economy). The indicators are listed in TAUW's internal Guidance Document on Sustainable Remediation (2020) and the TAUW methodology is based on ISO 18504, the UN Sustainable Development Goals, SuRF-UK documents, other relevant literature resources and in-house experience. TAUW has already used the assessment tool at several commercial projects.

All sustainability indicators were given an initial weighting for perceived importance from 1 to 3. The maximum weight of 3 was given to the following indicators:

- 'Health and safety risks' and 'Nuisance' (dimension People);
- 'Uplift in soil and groundwater quality', 'Uplift in surface water quality' and 'CO_2 footprint' (dimension Planet); and
- 'Cost of remediation' and 'Uplift in land values' (dimension Prosperity).

These weightings were given because the ideal remediation alternative should be effective in tackling the soil and groundwater contamination and entail at least as low as possible health and safety risks, nuisance and costs (relatively). Other sustainability indicators have a weight of 1 or 2.

The individual score for each sustainability indicator can take a value from 0 to 5. The lowest individual score is 0, the best individual score is 5. A score of 0 means either no added value at all or a negative burden. The higher the score, the lower the burden or the higher the benefit in terms of sustainability.

The product of individual score and weight delivers a final value for each individual sustainability indicator. These values are summed to a give a total for each of the three dimensions. These totals are then used as a basis to compare remediation alternatives.

5.2 Remediation alternatives and assessment

The sustainability assessment for this case study of the Lieve was completed *post hoc*. It supports the project's secondary objective which is to validate, on the basis of practical data, this technology is sustainable in relation to remediation alternatives.

For the purposes of the sustainability assessment pump & treat (P&T) and excavation were considered as the alternative remediation approaches to using the reactive mat. P&T is the technically most obvious remediation alternative for the specific site circumstances. Excavation is prevented by ongoing businesses on top of the source zone. However, as excavation and removal of contaminated soil could be a potential effective option in other contexts (e.g. after demolition of a factory) it has been included as an additional comparator in the sustainability assessment.

The two comparators are based on the following designs:

1. The P&T alternative is considered to consist of three extraction wells to 5 m bgl (reaching groundwater to a depth of at least 6 m bgl by extraction), a groundwater extraction flow rate of 40 m^3/d (taking into account the natural flow rate) using an extraction pump and a treatment unit with an oil-water separator and water purification filters with activated carbon. Subsequently, the purified water is discharged directly into the Lieve. Replacement of system components takes place after 10 to 15 years and it takes at least 30 years for the contaminant concentrations to decrease to an acceptable level with regard to surface water quality protection.
2. The excavation alternative consists of soil excavation at a surface area of approximately 7,500 m^2 to an average depth of approximately 5 m bgl; an area that is supposed to be present within the radius of influence of the draining canal. Groundwater needs to be extracted in order to make soil excavation possible in the saturated zone and so a water treatment unit with the same components as for the P&T alternative is necessary. Sheet piles are necessary to be able to create a dry environment and for stability. The contaminated part of the soil, expected to be approximately 22,500 m^3, needs to be transported off site for thermal treatment, especially with regard to the presence of PAH and free phase product. Clean soil is needed for the backfill.

The reactive mat has a length of 110 m and is 5 m wide. A length of 65 m is filled with biochar (about 110 m^3) and the other part is filled with sieved peat (about 70 m^3). Every 10 years the adsorbent needs to be replaced, assuming that no biodegradation takes place (conservative assumption). The charged adsorbent is transported off site for thermal treatment. The geotextile and the ballast material are re-used and every 10 years the geotextile is refilled with fresh adsorbent and replaced. It takes at least 30 years for the contaminant concentrations to decrease to an acceptable level with regard to surface water quality protection.

Table 4 (overleaf) shows TAUW's scoring of the sustainability assessment for the three options, along with supporting rationales. If the assessment had been part of an advance decision-making process at a site, it would also have needed input from other stakeholders, such as the problem owner and local residents. As stakeholders may judge (weigh and score) sustainability indicators differently this would make a more robust assessment. This is particularly true for criteria which are not directly or fully measurable, such as 'Nuisance', 'Community involvement' and 'Aesthetic impact'.

The outcome of the assessment is as follows:

- On the 'People' dimension, both P&T and reactive mat have similar scores and better than excavation, due to the indicators 'Health and safety' and 'Nuisance'.
- On the 'Planet' dimension, the reactive mat scores best and excavation worst. This is mainly due to the indicators 'Impact on air quality', 'Use of energy', 'CO_2 footprint' and 'Use of virgin soil'.
- On the 'Prosperity' dimension, the reactive mat scores best and excavation worst. This is mainly due to the indicators 'Costs of remediation', 'Business interruption' and 'Financial project risks'.

Table 4: Sustainability assessment of reactive mat and two alternatives – excavation and pump & treat.

Assessment tool TAUW on sustainability indicators S&G remediation

Dimension	Sustainability Indicator	Assessment score Excavation	Assessment score Pump&Treat	Assessent score Reactive Mat	Weight	Final score Excavation	Final score Pump&Treat	Final score Reactive Mat
People	Health & safety risks (regarding execution remediation)	2	5	4	3	6	15	12
	Nuisance (odor, noise, dust, movements, vibrations, light, road closure)	1	4	4	3	3	12	12
	Community involvement	2	2	3	1	2	2	3
	Aesthetic impact of works (permanent)	3	2	2	1	3	2	2
	Uplift in public value of site (leisure, cultural historic, etc)	0	0	0	1	0	0	0
	Subscore dimension People					**14**	**31**	**29**
Planet	Uplift in soil & groundwater quality	5	0	0	3	15	0	0
	Uplift in surface water quality	5	5	5	3	15	15	15
	Impact on air quality (fine particles (PM10) and NOx)	0	5	5	1	0	5	5
	Physical landscape disturbance (permanent)	3	3	3	1	3	3	3
	Biodiversity impact (macro and micro)	1	3	4	1	1	3	4
	Climate adaptation impact (incl extraction of groundwater resources)	1	3	3	1	1	3	3
	Use of energy (fossil or green fuel and electricity)	0	4	5	1	0	4	5
	CO2 footprint (energy, materials, chemicals, redox)	0	4	4	3	0	12	12
	Use of virgin soil (sand mining)	0	5	5	1	0	5	5
	Production of waste	2	3	4	2	4	6	8
	Subscore dimension Planet					**39**	**56**	**60**
Prosperity	Cost of remediation	0	3	5	3	0	9	15
	Land use restrictions (with respect to excavation and extraction)	5	2	2	1	5	2	2
	Business interruption	0	5	5	2	0	10	10
	Financial project risks	0	5	4	1	0	5	4
	Impact on brand value	1	1	4	2	2	2	8
	Time span (from start to end of remediation work)	5	0	0	1	5	0	0
	Uplift in land values (reclaim of land, marketability, etc)	4	3	3	3	12	9	9
	Subscore dimension Prosperity					**24**	**37**	**48**
© TAUW	**Total score**					**77**	**124**	**137**

Overall, the reactive mat has the best record on sustainability across the three dimensions. A brief explanation of the assessment of each indicator is given below:

People dimension

Health and safety risks
Due to the substantial excavation and backfill activities, the transport movements and the evaporation of volatiles, the excavation alternative has the lowest score.

Nuisance (for neighbourhood)
With regard to all transport movements on and off site and the accompanying noise, dust, movements, vibrations, light and road closure, the excavation alternative has the lowest score.

Community involvement
The community has not actively been involved in the realisation of the remediation. The neighbourhood was informed of the progress by periodic newsletters. What distinguishes the reactive mat is that because of its visibility and its innovative character, an information board for the public will be installed next to the Lieve to give information on the history of the site and the innovative approach.

Aesthetic impact of works (permanent)
The excavation alternative will not negatively influence the view of the site permanently. The other two alternatives will have some visible parts for the longer term.

Uplift in public value of site (leisure, cultural historic, etc)
The public value of the site does not increase as a result of the works.

Planet dimension

Uplift in soil & groundwater quality
In the short and medium term, the soil & groundwater quality will not (or hardly) increase by the P&T and reactive mat alternatives: neither are focused on the source, only on the path and receptor. The excavation is the only alternative that scores on this indicator.

Uplift in surface water quality
All alternatives equally score on this indicator, because they all positively contribute to the surface water quality (after all, this the purpose of the remediation).

Impact on air quality (fine particles (PM10) and NOx)
All the vehicles needed for excavation, transport and backfilling still use fossil fuels. This causes exhaust emissions such as fine particles and NOx. For the two other alternatives this is negligible in relation to the excavation alternative.

Physical landscape disturbance (permanent)
The landscape will not permanently be disturbed by any of the alternatives in a positive or negative way. The sand mining might disturb the landscape, but this is already dealt with under another indicator: 'Use of virgin soil'.

Biodiversity impact (macro and micro)
The excavation will cause loss of the current vegetation and biodiversity in the current soil. The P&T variant does not have any impact on biodiversity. The reactive mat has a slight positive impact on biodiversity in the water body as it forms a breeding ground for micro-organisms and some aquatic plants (N.B. periodically plants need to be removed to ensure the integrity of the mat).

Climate adaptation impact (including extraction of groundwater resources)
In all alternatives the removal of contaminated sludge and the increase of drainage capacity of the Lieve is incorporated, with which the surroundings can be dewatered in case of heavy rainfall. Nevertheless, for the excavation option a large active extraction of groundwater during a certain period of time is necessary. This leads to a temporary depletion of groundwater resources and local desiccation, which is an increasing issue in Flanders and The Netherlands.

(direct) Use of energy
The excavation alternative uses a lot of energy (green or fossil fuel or electricity) because of the use of excavators, trucks for transport of contaminated soil and clean sand, and machines for levelling after backfilling. For the P&T alternative extraction and purification pumps are necessary during a long period. The use of energy in the case of the reactive mat is negligible in relation to the other alternatives.

CO_2 footprint (energy, materials, chemicals, redox)
All the vehicles needed for excavation, transport and backfilling still use fossil fuels. This causes net CO_2 emission. The thermal treatment of the soil does not only need a lot of energy, but also causes oxidation of organic matter in the soil, leading to CO_2 emission. The production of sheetpiles, though reused at other locations (but not endlessly), causes a large part of the CO_2 emission as well. The final significant emission in the case of excavation is via the production of activated carbon and the regeneration of spent activated carbon used for water treatment.

In case of P&T green energy can be used for the pumps, which is almost CO_2-neutral. The largest CO_2 emission for P&T is via the production of activated carbon and the regeneration of spent activated carbon used for water treatment.

In case of the reactive mat, both biochar and peat are used. The biochar needs production energy, but less than activated carbon. The largest CO_2 emission in the case of the reactive mat is via the thermal treatment of spent biochar and peat after about 10 years (N.B. in practice there might be an alternative solution for thermal treatment of the spent biochar and peat by using white rot fungi for biological treatment). The CO_2 emission as a consequence of the production of the geotextile is negligible and the geotextile is reused as much as possible.

Use of virgin soil (sand mining)
For backfilling, the excavation alternative needs a large amount of clean soil, which is assumed to originate from a sand mine.

Production of waste
In the cases of excavation and P&T, waste in the form of piping material used for extraction of groundwater is produced, as well as free product from the oil-water separator. In the case of excavation, geotextile is used for temporary storage of soil piles, which needs to be destroyed afterwards.

In case of the reactive mats, the geotextile 'jacket' will eventually become waste (though in the first decades it can be reused by emptying and refilling).

Prosperity dimension

Cost of remediation
The costs of the excavation will be about EUR 3 million within a timeframe of a few months. The costs of the P&T alternative and the reactive mat alternative for 30 years will be about EUR 1 million and EUR 0.7 million respectively.

Land use restrictions (with respect to excavation and extraction)
Excavation scores best on land use restrictions, simply because almost all soil and groundwater contamination has been removed, at least above a depth of 5 to 6 m bgl to avoid the inflow of contaminants into the canal. In the case of both P&T and the reactive mat the current land use restrictions stay the same (under which the establishment of production and storage halls is still possible).

Business interruption
In the case of excavation, activities on site should be stopped for a couple of months. Business activities can proceed when P&T and the reactive mat are installed and operational.

Financial project risks
The financial impact of deviations in the dimensioning of excavation are much larger than for the other alternatives.

Impact on brand value
Any soil and groundwater remediation that is successfully executed contributes to the brand value of the problem owner. More impact can be generated when projects are carried out in an innovative and visible way, in combination with the link to their nature-based character. The latter is the case for the reactive mat, especially by communicating to the public by using an information board and a link to an online animation.

Time span (from start to end of remediation work)
The excavation alternative scores best on the time span of the works: months versus decades.

Uplift in land values (reclaim of land, marketability, etc)
For all alternatives there will be an uplift in economic land value, because of a reduction of the liability with regard to the contamination. In addition, the marketability is higher when all soil and groundwater contamination has been removed to a depth of 5 m bgl. Hence, excavation scores best.

6. PROJECT HIGHLIGHTS

- Laboratory results on the adsorption capacity of green adsorbents matched well with field scale measurements.
- Direct measurements were made of vertical fluxes of individual contaminants through the waterbed, which assisted the design of the mat.
- The ease of on-site deployment and customisation.
- The significant improvement of the surface water quality compared to the initial situation.
- A *post hoc* sustainability assessment found that the reactive mat was the most sustainable alternative.
- The international cooperation of several professional partners under the flag of EU Interreg that was initiated and facilitated by the Flemish OVAM.

7. LESSONS LEARNED

- Close consultation between environmental consultant, contractor and producer are essential for the design of an innovative construction.
- Design and construction of a reactive mat cannot be done without knowing the site characteristics (history, scale, environmental risks), flux measurements and adsorption characteristics (the chemical side), nor without reflection on the pros and cons of several potential construction types (the technical side) that should fit the specific situation.
- The connections between the mat elements are key: the watertight sheets on top of these connections should overlap both mat elements and be kept in place to prevent preferential flow paths of contaminated groundwater and/or free product. Otherwise, preferential flow paths would cause a reduction in surface water quality.
- Accumulation of gas in the construction (gas clogging) can occur, especially in shallow water applications. This might cause a decrease in the adsorption capacity of the mat and a decrease in residence time of groundwater contaminants. Initially encapsulated atmospheric air can be easily removed by temporary pressure on top of the mats. Gas formation (methane) as a result of anaerobic degradation of organic material in the aquatic soil underneath the reactive mat can be minimised by removing more sludge from the waterbed prior to installation.

8. CONCLUSIONS

- The use of a reactive mat filled with green adsorbents like biochar and peat can significantly improve the quality of a surface waterbody that receives groundwater contaminated with PAH, BTEX and C6-C10.
- Preliminary measurements on influx of contaminants and adsorption capacity of green adsorbents are of great value for the design and operation of a Natural Catch^{TAUW} construction.
- Following the ISO 18504 procedure for sustainable remediation assessment, the reactive mat was compared with two remediation alternatives: excavation and P&T. On this basis, the reactive mat had the best record on sustainability in the case of the Lieve.
- For similar situations with surface waters threatened by contaminated groundwater with oil-related components, the Natural Catch^{TAUW} construction can be a sustainable solution. Depending on the site-specific circumstances like depth and width of the surface water, the construction can be adapted (e.g. the installation technique and the type of ballasting).