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Integrated classification scheme for sediments

Application to watersheds and SWOT-Analysis

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Interreg
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Sullied Sediments

Sediment Assessment and Clean Up Pilots in Inland Waterways in the North Sea Region

Many of the inland waterways in Europe are under threat due to the introduction of Watch List chemicals that are not currently regulated under the European Water Framework Directive. These chemicals enter our waterways as a result of our day-to-day activities and through industry, and many have been shown to be harmful to wildlife and the wider aquatic environment. Regardless of their source, these pollutants accumulate in the sediments in our rivers and canals over time.

Water regulators and managing authorities do not always know the levels, locations or impacts of these pollutants. Nor do they have the tools to assess sediments confidently and make informed environmental management decisions. To address these issues, the Sullied Sediment project partnership of scientific experts, regulators and water managers is developing and testing new tools that will enable stakeholders to better assess, treat and prevent contamination from these chemicals. This work is being carried out at selected sites in the Elbe, Humber and Scheldt river catchments.

The intention of the Sullied Sediments project is therefore to help regulators and water managers make better decisions with regard to the management, removal and disposal of sediments, thereby reducing economic costs to private and public sector organisations, and the impact of these pollutants on the environment.

The partnership is also working to reduce the extent of chemicals entering the water system by raising awareness about what we, as consumers, are releasing into the environment through the use of common drugs and household products. This includes the involvement of volunteers in a sediment sampling initiative across the North Sea Region, which will inform and empower them as water champions in their local communities.

The Sullied Sediments project has been co-funded by the European Regional Development Fund through the Interreg VB North Sea Region Programme with match funding from the 13 partners involved. The project partnership includes public, private, community and voluntary sector organisations based in the United Kingdom, Germany, Belgium and the Netherlands.

The project has been supported under the Interreg VB North Sea Region Programme's third priority, which is focused on a Sustainable North Sea Region, and is led by the University of Hull (UK).

Website: northsearegion.eu/sullied-sediments

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Introduction for stakeholders

The data that have been compiled in Sullied Sediments and the conclusions drawn from it confirm that sediment assessment and management is not a straightforward process. Decisions on the fate of contaminated sediment (and dredged material) are usually required within a certain time window and cannot wait until science has understood completely how contaminants and the biotic environment interact. Consequently, they have to be based on uncertain data:

Chemical threshold values, even though most often used to guide decisions, are only available for relatively few substances among the many thousands that potentially end up in the environment, and may underestimate the hazardous potential in sediments. Routine analysis of chemicals in sediment does not inform on ageing effects that may reduce the adverse impact, or assess synergistic or antagonistic interactions of the contaminant cocktail in sediments.

Bioassays, on the other hand, react solely to bioavailable substances. They are performed in the laboratory by exposing test organisms (worms, shrimps, bacteria, algae, water fleas etc) to the elutriates of sediments or to sediments directly. Impairment of their physiological functions (e.g. photosynthesis, growth, reproduction, respiration) is assumed to reflect, what could potentially happen to the biological community in the environment. While these ecotoxicological data integrate the effect of contaminant mixtures, it is not easily possible to identify what substances are responsible for this measured effect – also because we are only aware of a tiny fraction of the pollutants that may be present. The transfer of laboratory data to the environment has some deficiencies: Sediments are usually tested only by a few bioassays, due to economic reasons but also because they are partly labour intensive and take time. But can these few test species represent the biological community? It is necessary to understand, that this is not the intention behind biotesting. With a test battery that comprises 10 to 20 biotests, we can say little more about the diverse biological community than with 4 or 5. Biotest data only give us an indication of the hazard that is present in the sediment and which can potentially to impact biota. They do not predict what actually happens in the environment. If adversely affected, biotests show that substances are present in the environment that can inhibit certain essential functions (e.g. photosynthesis) in representatives of important trophic levels (e.g. water fleas). In order to cover a wide spectrum of possible effects, bioassays that are sensitive to different substances, to different exposure pathways and belong to different trophic levels are combined into biotest batteries.

In order to assess in what status the biological community is, we have to look at the **diversity of organisms** in the sediment, but even this does not tell us everything what we need to know. The biological community may not have yet reacted to recently emitted contaminants, or it may have adapted to historic contaminants. A low diversity may be due to available toxicants, but it may also be the result of a recent oxygen deficiency or weather related saltwater intrusion.

So none of the tools that we have available so far – chemical, ecotoxicological and ecological – are perfect. All have their strengths and limitations. Combining the information from all three tools, however, will reduce the uncertainty in decision making and the probability to make a false decision. In a weight of evidence approach, following the best professional judgement of the investigator, the more evidence points towards a specific assessment, the higher the probability, that this assessment is correct (Burton et al. 2002). If a sediment sample shows a high contamination with known substances AND it has a high impact on organisms in bioassays AND the biological community at the site is strongly impaired, chemical pollution is most certainly the reason for the bad environmental quality. On the other site, a "clean", unpolluted sediment should not cause an ecotoxicological effect, should have a diverse biological community. Most sediments in current water systems, however, are neither very strongly polluted, nor are they free of contaminants. A combined assessment of all 3 "lines of evidence" allows a prioritization of sediment sites for management purposes because the likelihood to overlook a potential risk is reduced, while – on the other side – reducing overly protective decisions. The response patterns of the different lines of evidence furthermore inform about the kind of stress on the biological community: If chemical analysis, for example, does not come up with any significant concentrations of contaminants, but the bioassays show toxicity and the biological community diversity is low, there may be other chemicals responsible than the ones that were expected and analysed. This example illustrates the main underlying idea behind the weight of evidence approach to sediment assessment: It is not expected that all three "tools" show the same result unless the sediment quality is extremely bad or extremely good. The inadequacy of each “tool” is ameliorated by considering all three - partially independent - results together and deducing information on the underlying stress factors.

On the basis of the data compiled in the Sullied Sediments Work package 3, those 3 lines of evidence (LoE) are discussed in the light of a weight of evidence approach. As ecotoxicological LoE, hazard classes were used that have been derived by the integrated biological effect based assessment system (See the BEBA-Report). An analysis of weaknesses, opportunities, strengths and threats (SWOT) will be carried out as a simple method to critically assess the developed BEBA approach.

How contaminated were the sampling sites of the Sullied Sediments project?

While the Sullied Sediments Report by Richardson et al. explains and critically discusses the use of Sediment Quality Guidelines (SQG) much more thoroughly, they are presented here to demonstrate chemical contamination of the different sites and potential consequences regarding ecotoxicological effects. SQG help to interpret sediment contaminant concentrations in terms of their toxic potential for sediment dwelling organisms. Consensus based guidelines were set up e.g. by de Deckere et al. (2011) based on a large sediment biomonitoring data set from Flanders on (1) sediment concentrations of priority pollutants, (2) macrozoobenthos and (3) ecotoxicological data. Both, lowest and severe effect levels were defined as threshold effect concentrations (TECs) and probable effect concentrations (PECs). Below the TEC of a certain chemical no toxic effects are expected (effects a not likely). Above the PEC of a certain chemical, toxic effects are very likely.

As an index for the toxic potential of a sediment sample, mean values of SQG-quotients (PEC-Q or TEC-Q = measured concentration/PEC(TEC)) can be calculated over all measured chemicals with an existing SQG. According to MacDonald et al. (2000), a mean PEC-Q of >0.5 accurately predicts a high probability of toxic effects (i.e. ecological impacts). Mean PEC-Qs <0.5 indicate a lower toxic risk, however, toxic effects cannot be excluded. Here, the additional use of TEC-Qs might be helpful to identify sediments where toxic effects are unlikely (mean TEC-Q <1).

The results show that at 6 sites (BE1, BE3, DE1, UK1-3) toxic effects (ecological impacts) can be expected, as the mean PEC-Q is >0.5 (Figure 1). Although at BE2, DE2 and DE3 the mean PEC-Q is <0.5, effects cannot be excluded, as the mean TEC-Q is still clearly above 1 (Figure 2).

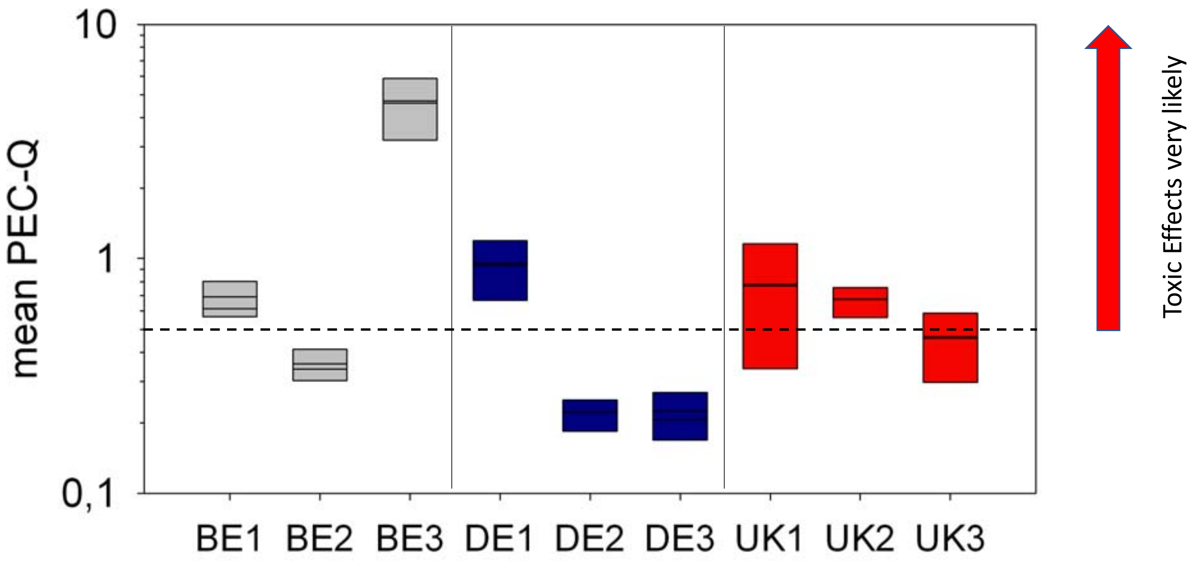

Figure 1: Index based on SQGs for severe effects (mean PEC-Q) describing the toxic potential of the sediments from various sites of the three catchments; boxes represent 25/75 percentiles with mean and median (n = 6 sampling dates); dashed line = threshold above which ecological impacts are likely to occur.

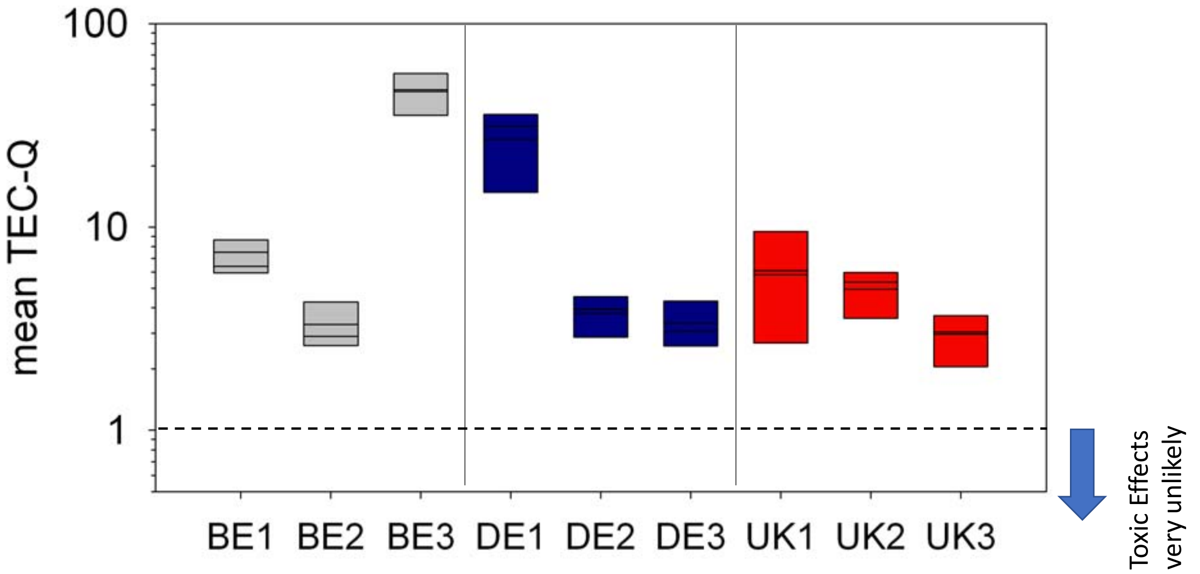

Figure 2: Index based on SQGs for lowest effects (mean TEC-Q) describing the toxic potential of the sediments from various sites of the three catchments; boxes represent 25/75 percentiles with mean and median (n = 6 sampling dates); dashed line = threshold below which ecological impacts are unlikely to occur.

As discussed by Richardson et al (Sullied Sediments report), relatively few data are available to derive ecotoxicological based SQG. So while the comparison with effect levels above show that all sediments from the data base present a high enough contamination to adversely affect the community, most contaminants measured in the project could not be taken into account due to lack of SGQ values. Hence in the following, another comparison between sites was done on the basis of all measured chemical substances, in form of a simply adding up the normalized concentrations of chemicals.

Comparison of BEBA-hazard classes, biotic indices and chemical data

Methodological Approach

For an easy comparison all data were normalized. For chemical data, sums of normalized chemical concentrations were used for simple comparison between sites. These sums again were normalized across all sites to a range of 0 to 100 % in accordance with the other parameters. To facilitate visual inspection, the outcome of the chemical data was then assigned different colours: To indicate the lower 25 percentage of data, >25 to 50 %, >50 to 75 %, and more than 100 %. The indices of the biological community were assigned to categories as indicated in the BEBA-Report, as were hazard classes.

This translates for the different parameters as follows:

Chemical analysis: Data range from the lower contaminated sites (<25 % of the contaminated sites) to the most contaminated sites sampled in this project. Attention should be paid to the fact, that these are relative data, as there was no "clean" site and, as shown in the previous chapter: all sites were polluted to an extent that exceeded the mean TEC-Q.

Belgian sediment index: The BSI is categorized as follows: (7-10): good biological quality (class 1); 5-6: moderate biological quality (class 2); 3-4 poor biological quality (class 3); 0-2: very poor biological quality (class 4)

NemaSPEAR (ecological status and genus level): both indices are categorized as follows: >56: high; 30-56: good; 20-30: moderate; 10-20: poor; 0-10: bad. (Höss et al. 2011; Höss et al. 2017)

Hazard class: The hazard class (HC) had been calculated on the basis of 6 toxicity tests (see BEBA-Report). Ecotoxicological test results were categorized into 4 classes with class 1 indicating no hazard, class 2: potential hazard, class 3: moderate hazard with high certainty, class 4: high hazard with high certainty.

Results and discussion

Chemical contamination of sites is highest in the German Samples ("DE"). No sites fall into the lower contamination range. For all sampling campaigns, the first and most upstream sampling station (Stover Strand) is most contaminated. This fits well with previous studies that showed the chemical quality of the Elbe estuary being impacted mostly by historic contaminants from the upper catchment (Förstner et al. 2004; Heise et al. 2007; Heise et al. 2008). In contrast to the German sites, most of the UK sites are comparatively low contaminated (all in the lower 50% of the contamination range). There is a tendency, that the first UK site is slightly more contaminated than the others within one campaign. The Belgium sites are in between the German and the UK ones, with 1 site in the highest contamination range, but 4 sites in the lowest. The third Belgium site tends to show the highest relative contamination within a sampling campaign.

This simple approach to sediment chemical quality classification shows the same trends as the mean PEC-Q and mean TEC-Q presented in the previous chapter, pointing to BE_3 and DE_1 delivering the most contaminated samples (with possibly highest effects) of each watershed, and UK_1 being, in cases, more contaminated but also more variable than the other sites. PEC and TEC criteria compare substance-specific ecotoxicological effect data to the substances' environmental concentrations. While this provides additional information which could relate to the result of bioassays, the criteria are only known for a limited range of substances. The double-normalized all-contaminant approach followed in this chapter, on the other side, takes most of the measured chemicals into account. The observation, that both methods give the same basic outcome and relative assessment of the sites within a watershed, shows that the chemicals for which TEC and PEC criteria have been derived, are important pollutants. According to PEC and TEC values, however, BE_3 is rated more toxic than DE_1 which deviates from the all-contaminant-concentration approach. This will be due to Elbe-catchment specific contaminants, that are also elevated at DE_1 but for which there are no sediment criteria.

In the following, we will discuss chemical, ecotoxicological and ecological data as different lines of evidence. By integrating the results of the sullied sediments study in a weight of evidence approach, conclusions on the environmental quality and the factors determining it can be drawn. Figure 3 shows exemplarily the principle of interpreting different lines of evidence as part of a sediment assessment scheme.

Components of the Triad			Exemplary Conclusions
Chemical contami-nation?	Inhibitory Responses (bioassays)	Reduced diversity of biological community	*different possibilities that can be concluded are divided by a slash ("/")*
+	+	+	Strong indication of chemical-induced impacts
-	-	-	Probably no adverse effect on the environment / false negative
+	-	-	Contaminants are not bioavailable/contaminants in low concentrations
-	+	-	Effective contaminants have not been detected (not looked for) and the biological community may have adapted or not yet reacted / Bioassays may have reacted to confounding factors (false positive)
-	-	+	Other than contaminants caused a change in the biological community/chronic effects prevail after exposure
+	+	-	Chemical contaminants are present and available, no effect on benthic community due to e.g. due to response delay / acclimation / insufficient stress to cause a community response
-	+	+	Chemicals that have not been detected (not looked for) stress the biological community.
+	-	+	Contaminants are present but not available in the bioassay / bioassay organisms are not sensitive / chronic effects cause changes in the biological communty (not detected in bioassays) / contaminants are not bioavailable and the community has reacted to another kind of stressor.

Figure 3: Examples for a simple weight of evidence approach, combining different lines of evidence of the sediment triad.

SuSe Sample ID	relative index of chemical data	Belgian Sediment Index	NemaSPEAR	Hazard Class
BE_1.1	68	1	21	4
BE_1.2	17	6	21	4
BE_1.3	55	5	23	4
BE_2.1	40	5	26	4
BE_2.2	20		19	4
BE_2.3	45		16	2
BE_3.1	35	7	17	2
BE_3.2	28	7	21	2
BE_3.3	57	8	14	3
BE_4.1	38	8	16	3
BE_4.2	24	6	13	4
BE_4.3	55	4	18	2
BE_5.1	34	8	18	2
BE_5.2	31	8	11	2
BE_5.3	82	8	25	3
BE_6.1	45	8	26	3
BE_6.2	25	7	25	2
BE_6.3	67	5	38	3

Most of the sediments from the Belgian watershed (Figure 4) show moderate to high contaminant concentrations (25 to 75 %) relative to all sampled sites. Accordingly, also hazard classes are elevated and the NemaSPEAR indicate a poor to moderate ecological quality in most samples. The BSI mainly indicated moderate to good ecological quality, which could point to a less exposed macrobenthos community. However, both biotic indices showed a slight amelioration of the quality over time.

Figure 4: Belgian Watershed: Comparison of relative chemical contamination, quality of the biological community (Belgian Sediment index, NemaSPEAR) and Hazard class, derived from the ecotoxicolgical data (see BEBA Report). Colours reflect the severeness of impact from green: low to red: high (for chemical contamination this is done on a relative scale).

SuSe Sample ID	relative index of chemical data	Belgian Sediment Index	NemaSPEAR	Hazard Class
DE_1.1	69	2	15	3
DE_1.2	37	6	29	4
DE_1.3	31		14	4
DE_2.1	90	7	29	4
DE_2.2	27	2	33	3
DE_2.3	25	1	45	3
DE_3.1	86	6	12	4
DE_3.2	36	6	15	4
DE_3.3	28	1	27	3
DE_4.1	88	7	8	3
DE_4.2	31	1	15	4
DE_4.3	28		11	2
DE_5.1	100	6	25	2
DE_5.2	27	1	28	3
DE_5.3	35	0	37	3
DE_6.1	74	6	33	2
DE_6.2	39	1	51	1
DE_6.3	36	0	33	3

The appearance of data from the Elbe Estuary is different (Figure 5). There are a lot of samples that showed a bad ecological quality (BSI). These were, however, not collected from the highly contaminated Stover Strand, but, with one exception, from the port area. It will need to be further investigated, whether this can be due to sedimentation rates which are higher in the harbour area than at the upstream site. All sites were tidal but not saline (<0.1 %), so a salt effect can be excluded. Regarding the ecological quality, the NemaSPEAR index revealed contrary results to the BSI, suggesting different exposure scenarios for meio- and macrobenthic invertebrates.

Figure 5: German Elbe Estuary: Comparison of relative chemical contamination, quality of the biological community (Belgian Sediment Index, NemaSPEAR) and Hazard class, derived from the ecotoxicolgical data (see BEBA Report). Colours reflect the severeness of impact from green: low to red: high (for chemical contamination this is done on a relative scale).

SuSe Sample ID	relative index of chemical data	Belgian Sediment Index	NemaSPEAR	Hazard Class
UK_1.1	44	7	24	3
UK_1.2	22	7	9	2
UK_1.3	12	9	4	4
UK_2.1	28	9	21	2
UK_2.2	34	9	13	1
UK_2.3	12	10	21	2
UK_3.1	25	7	19	1
UK_3.2	22	9	19	2
UK_3.3	19	10	35	4
UK_4.1	35	9	32	4
UK_4.2	27	5	21	4
UK_4.3	17	10	18	4
UK_5.1	29	9	18	1
UK_5.2	20	8	4	1
UK_5.3	21	9	12	1
UK_6.1	19	9	32	4
UK_6.2	24	3	31	2
UK_6.3	25	9	34	1

For UK samples (Figure 6), contamination is relatively low and the BSI mostly indicates a good quality of the macrozoobenthic community. Both NemaSPEAR and HC however indicate adverse effects during the 1st and the 4th sampling campaign, both carried out in autumn. During the 5th campaign (spring), only the NemaSPEAR showed a bad impact on the nematode community while most other data did not show any effect.

Figure 6: Humber watershed: Comparison of relative chemical contamination, quality of the biological community (Belgian Sediment Index, NemaSPEAR) and Hazard class, derived from the ecotoxicolgical data (see BEBA Report). Colours reflect the severeness of impact from green: low to red: high (for chemical contamination this is done on a relative scale).

Comparing all sites and watersheds, a prioritization of sediment management activities would result in the highest priority given to German sites, followed by Belgian sites. The UK sites seem to present the lowest hazard among all sites sampled for this project. There is some indication of a seasonal influence, which should be discussed in the light of local hydrological data.

SWOT Analysis of the assessment scheme

In order to address potential issues arising form the proposed assessment scheme, a SWOT analysis is carried out. The identification of strengths and weaknesses (internal) and opportunities and threats (external) will help communicating with decision makers and stakeholders. Understanding and acceptance by regulatory bodies will be a requirement, before such an assessment scheme can be realized and applied for management purposes:

Strengths What do you do well? What unique resources can you draw on? What do others see as your strengths?	**Weaknesses** What could you improve? Where do you have fewer resources than others? What are others likely to see as weaknesses?
Integrative assessment of bioassay data means: decisions are not based on single bioassay outcomes. The more tests respond in the same way, the higher the certainty, that a hazard exist. In combination with chemical analyses and biotic indices, in can be concluded on e.g. lacking analytes (contaminants, that the organisms respond to but which have not been measured), on changes in bioavailability (e.g. due to seasonal changes), or on non-available contamination.	Understanding complex systems: Highly contaminated sites do not always result in low biological diversity, if chemicals are not available. High Hazard classes may not be reflected by an (adapted) biological community. These complex interrelationsships need to be understood before regulatory bodies will adapt this approach. Expert knowledge will be necessary - either personally provided or the assessment tool will have to be integrated into an expert system which allows automatic results.
Opportunities What opportunities are open to you? What trends could you take advantage of? How can you turn your strengths into opportunities?	**Threats** What threats could harm you? What is your competition doing? What threats do your weaknesses expose you to?
Decision makers can gain understanding of the area that they are working on or with Less chances of false positive or false negative results More environmentally safe, less costly on the long-term.	More ecotoxicological tests need to be carried out Biotic indices would need to be determined more often Decision makers would have to communicate a more complex framework. Not to use the worst case approach may lead to people protesting against decisions that are perceived as less stringent.

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Partners

The Sullied Sediments project partnership comprises 13 project beneficiaries:

Canal and River Trust (UK)

East Riding of Yorkshire Council (UK)

Ecossa (Germany)

Hamburg Port Authority (Germany)

Hamburg University of Applied Sciences (Germany)

Institut Dr Nowak (Germany)

Openbare Vlaamse Afvalstoffenmaatschappij (Belgium)

Radboud University (The Netherlands)

Socotec UK Ltd (UK)

University of Antwerp (Belgium)

University of Hull (UK)

University of Leeds (UK)

Vlaamse Milieumaatschappij (Belgium)

The partnership also receives expert advice from 12 strategic partners who form our Advisory Group:

East and North Yorkshire Waterways Partnership (UK)

Elbe Habitat Foundation (Germany)

Environment Agency (UK)

Federal Institute of Hydrology (Germany)

Foundation for Applied Water Research (Europe)

Hamburg Ministry of the Environment and Energy (Germany)

Northumbrian Water (UK)

River Hull Board (UK)

Sediment European Network Steering Group (European)

Thames Water (UK)

Vlakwa (water research consultancy) (Belgium)

Yorkshire Water (UK)

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