First pilot study on the use of thin-layer capping with activated carbon and polonite to remediate polluted sediments in the Viskan River, Sweden

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Abstract

The accumulation of contaminants in sediments poses a major environmental challenge for freshwater ecosystems in Sweden. The Viskan River near Borås been heavily polluted from historic emissions from earlier textile industries and sediment contaminant concentrations are exceeding threshold values set by national and EU guidelines. This pilot study examines the potential of thin layer capping as an alternative *in situ* remediation technique to conventional dredging. A new thin layer capping technique, using a composite sorbent made of activated carbon and polonite was tested in sediment cores collected from the river. In addition toxicity tests with the crustaceans *Hyalella azteca* and *Daphnia magna* were cinducteds on sediment and water from the river, collected at Guttasjön, subarea G3 in the Viskan remediation project area. Complementary sedimentation experiments were conducted to determine the settling behaviour and applicability. Preliminary results indicate that thin layer capping with activated carbon and polonite is physically stable and potentially effective in reducing contaminant bioavailability, supporting its relevance as a sustainable remediation option for historically contaminated freshwater systems.

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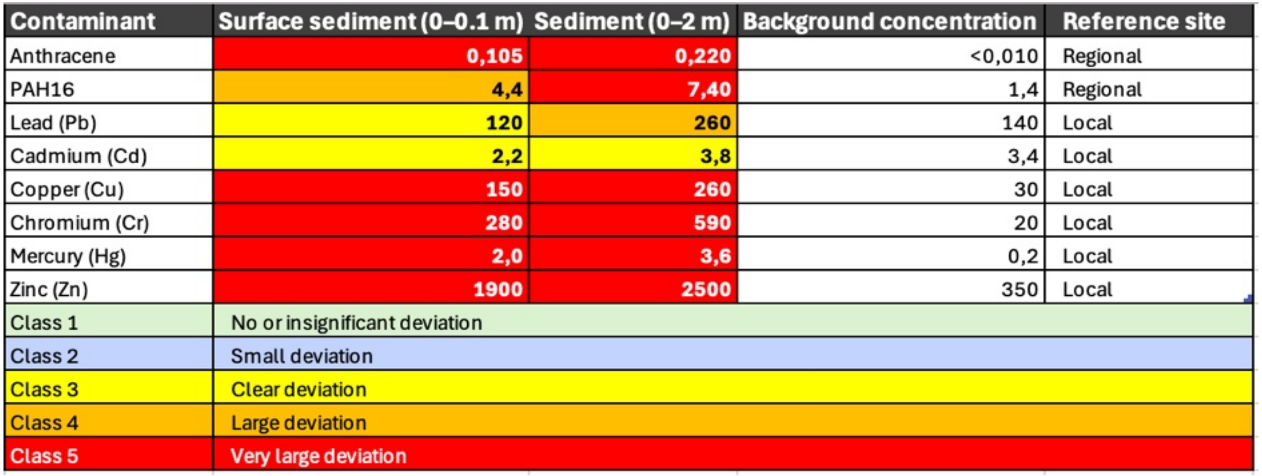
1. Introduction

Contaminants are ubiquitous in all ecosystems on Earth and include a variety of substances such as metals and organic pollutants like PAHs and dioxins. Metals can occur as dissolved cations or be bound to particles, where their sorption to sediments is influenced by pH and oxygen conditions. PAHs are hydrophobic, persistent organic pollutants primarily formed during incomplete combustion of organic matter. Likewise, dioxins are undesirable by-products generated during incomplete combustion processes; however, they differ from the PAHs in that they are chlorinated compounds and generally far more toxic. Due to their hydrophobic properties, both PAHs and dioxins tend to accumulate in sediments. Through evaporation and condensation, water run-offs and direct losses, these contaminants end up in the water (Reichelt-Brushett, 2023). Human populations have historically preferred to settle near riverbanks and lake shores (Zou *et al.,* 2022). As a result, freshwater bodies and coastal areas have been exposed to sewage discharge, urban runoff and industrial wastewater. All these factors, even though some are monitored and controlled today, have led to a high concentration of contaminants and associated loss in biodiversity in many freshwater bodies across Sweden. For example, the Viskan river in Borås is particularly contaminated. The Viskan river running through Borås was a prerequisite for the boom of industries in the area, as the factories were powered with water mills. Borås used to be a particularly developed region in the textile industry, thereby releasing large amounts of metals, dioxins and PAHs in the environment (Sweco, 2025). Previous sampling in Viskan, carried out by Sweco, has reported concerning levels of many contaminants as presented in *Table 1*.

Table 1. Mean concentration of metals and polycyclic aromatic hydrocarbons (PAHs) in sediment from subarea G3, compared with local and regional background levels. All values are based on 2023 sampling and reported in *mg/kg* (dry weight). The data are taken from Sweco´s updated main study for remediation (2025), project no. 30078815, *Table* 6 & 11. Concentrations are coloured according to deviation classification for limnic systems (Swedish EPA,1991)



Contaminant	Surface sediment (0–0.1 m)	Sediment (0–2 m)	Background concentration	Reference site
Anthracene	0,105	0,220	<0,010	Regional
PAH16	4,4	7,40	1,4	Regional
Lead (Pb)	120	260	140	Local
Cadmium (Cd)	2,2	3,8	3,4	Local
Copper (Cu)	150	260	30	Local
Chromium (Cr)	280	590	20	Local
Mercury (Hg)	2,0	3,6	0,2	Local
Zinc (Zn)	1900	2500	350	Local
Class 1	No or insignificant deviation			
Class 2	Small deviation			
Class 3	Clear deviation			
Class 4	Large deviation			
Class 5	Very large deviation			

Many of the contaminates shown in *Table 1* exceed both Swedish and EU regulations on environmental contaminant concentrations. Consequently, the municipality of Borås is in the process of initiating a remediation process. Until now, the municipality has planned to use dredging and conventional capping as the remediation method for the Viskan river. However, they are now considering thin layer capping as an alternative approach. Therefore, we are conducting a pre-study to assist the municipality of Borås for the upcoming remediation. By binding to organic matter and other particles in the water column, contaminants are usually found at significantly higher concentration in the sediment. That is why, in remediation, the most used technique is dredging. Nonetheless, it requires a significant amount of money and resources, and the pollutants are transferred to landfills, where they remain a long-term environmental concern (Reichelt-Brushett, 2023; Sweco 2025). Therefore, the municipality is interested in examining alternative remediation methods for the Viskan river.

In recent years, research has been conducted to develop *in situ* methods for neutralizing contaminants, rather than relocating them. An interesting new method is capping the sediment with activated carbon (AC), a technique known as thin layer capping. Activated carbon is widely recognized as one of the most effective sorbents for both organic and inorganic pollutants. Its high sorption capacity is primarily attributed to its extensive surface area, microporous structure, and chemically active surface sites. These characteristics allow AC to adsorb hydrophobic organic contaminants such as PAHs, PCBs, and dioxins, as well as certain dissolved metals, thereby reducing their bioavailability in the sediment and overlying water (Bhatnagar et al., 2012). In sediment remediation, AC capping is often used to immobilize contaminants *in situ*, limiting their bioavailability and uptake by benthic organisms (Abel and Akkanen, 2019; Patmont *et al.,* 2014; Gunnarsson *et al.,* 2024; Ring *et al.,* 2023; Wikström *et al.*, 2021). Polonite is a calcium- and silicate-rich material that is derived from natural limestone. It is primarily used in water treatment applications to remove phosphorus and metals through adsorption processes. Due to its alkaline nature, it is known to increase pH levels in aquatic environments, which may influence sediment chemistry and biological processes (Cucarella et al., 2009). When combined with activated carbon, polonite may also improve the physical stability of the capping layer by increasing particle density and enhancing sediment settling. The combined functionality of chemical immobilization and physical stabilization makes polonite a particularly promising complement to AC in sediment remediation strategies. (Lindner and Revelj, 2023; Sanders *et al.,* 2021; Wikström *et al.*, 2024a; Wikström, 2024b). With this study, we aim to expand the knowledge on these new remediation methods and provide a foundation for developing a new remediation plan for the Viskan river.

With that in mind, the first aim of our experiment is to determine whether the sediment is compact enough, meaning that the capping will not be displaced by the currents of the river. Secondly, it is to assess the settling of AC capping in stagnant freshwater conditions. Our third objective is to evaluate the mitigation of the toxicity of the contaminants in the sediment of the Viskan river on the survival and growth of *Hyalella azteca*. Finally, we want to determine if the association of AC and polonite has a different effect on the two parameters stated above. According to a previous study (Lindner and Revelj, 2023) we expect the combination of AC and polonite to be more efficient in toxicity mitigation and in settling capacities.

This experiment is conducted in parallel with another group working with *D. magna*. They are monitoring *D. magna* exposed to Viskan river water (without any sediment) to evaluate whether their response to the contaminated water is comparable to that of *H. azteca.* Additionally, we aim to assess if eutrophication may pose an ecological risk using LOI analysis of the collected sediment. However, according to measurements presented by Sweco (Sweco, 2025), eutrophication has not been identified as a significant stressor in the Viskan system.

2. Materials and Methods

To evaluate the effectiveness of capping materials in reducing sediment toxicity and improving settling stability, a laboratory experiment was conducted at Stockholm University. Sediment samples were collected from the Viskan river in Borås and subsequently used in toxicity tests with *Hyalella azteca* and supporting analyses.

Sampling was conducted on September 30, 2025, to collect sediment cores from subarea G3 in Lake Guttasjön located within the Viskan project area (see *Figure 1*). Previous investigations have identified elevated concentrations of contaminants, including metals, dioxins and PAHs (polycyclic aromatic hydrocarbons), in this subarea (Sweco, 2025). The sampling was carried out at Lake Guttasjön in Borås, at GPS coordinates 57°40'23.0"N 12°54'05.4"E, which corresponded to site G3_23_212 in *Figure 2*. This site was chosen because it is relatively isolated within the lake, based on earlier investigations by Sweco (Sweco, 2025). In contrast, nearby subarea G1 has been reported to be affected by historical ammunition-related contamination, making G3 a more suitable site for sampling within the project region. Within G3, the sampling was performed in a small, sheltered bay to minimize the influence of sediment erosion and external disturbance. The sampling site G3 was accessed by rowboat. A buoy was deployed at the site, and sediment cores were collected within a 2-meters radius of the buoy at a depth of approximately 3 to 4 meters. In total, 18 sediment cores were obtained using a kayak corer. After being collected, the cores were transported to Stockholm and stored in a climate-controlled room at 5°C, until October 16, 2025, when the experimental work commenced.

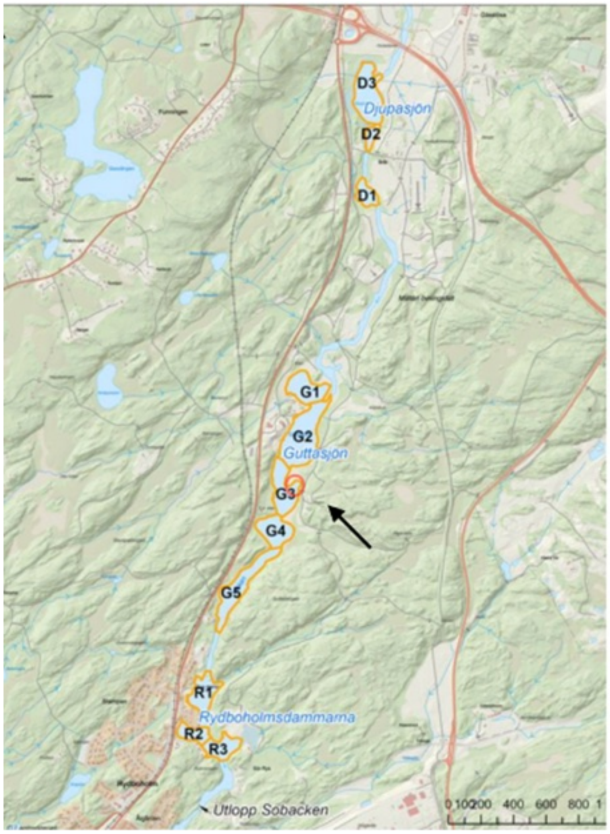


Figure 1. Overview of the areas in the Viskan remediation project. The marked area represents the sampling site. © Lantmäteriet (SWECO, 2025)

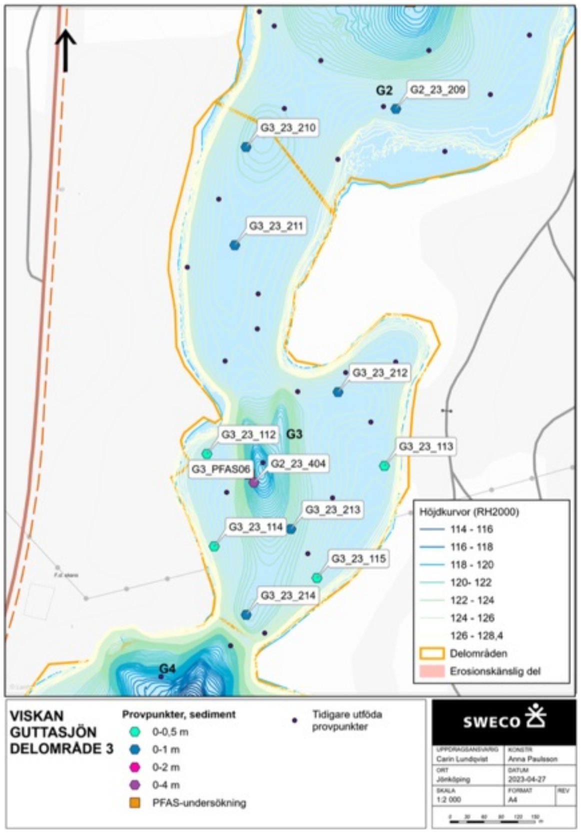


Figure 2. Location G3_23_212, used as a reference point for data collection and the site where sampling for this study was conducted (SWECO)

2.1 Water quality monitoring

The monitored water quality parameters in this test included pH, O_2, temperature, salinity, NH_4 and nitrates. Nitrates and NH_4 will be analysed at a Chemistry Laboratory at Stockholm University (Kemlab) and reported in upcoming reports. The pH and oxygen levels were measured using (insert model and calibration). During the experiment, pH was measured on day 0, 3 and 10 to make sure that conditions for the Hyalella were stable.

2.2 Sedimentation kinetics

Two sedimentation experiments were conducted to evaluate the physical settling behaviour of the capping materials, activated carbon (AC), polonite (P), and their combination (AC + P), since these materials differ in density and particle size.

The initial test was carried out with AC and P in a 2 m high transparent polyester tube filled with stagnant tap water. The tube was filled with water to a level of 1,63 m from the bottom stopper, representing the total water column. The capping materials were pre-mixed with water before application to the tubes. After application, water was collected using syringes placed at five depths:

7 cm, 38 cm, 69c m, 100 cm and 131 cm, where 7 cm was the closest to the bottom of the tube, and 131 cm was the closest to the water-air interface. Water samples were collected manually every five minutes at each depth using syringes. The aim was to collect water simultaneously. The turbidity of the water was analysed using a turbidity-meter (Thermo Scinetific Eutech ECTN100IR Portable Turbidity Meter.

Subsequently, a second experiment was conducted with AC, P and their combination. Reference height markers were placed at 10 cm, 81 cm, and 158 cm from the surface to monitor particle descent at different sampling depths. In this setup, 10 cm represented the shallowest depth, and 158 cm was the deepest. The settling velocity of particles was recorded using two smartphones, one for timing and one for video documentation. The objective was to compare the settling velocity by identifying the lowest front of the descending particles under controlled conditions. Complementary to this, turbidity was measured similarly to the first set-up. However, samples were taken at the three marked depths after different times and not simultaneously. The samples were scheduled to be taken two minutes after application followed by two samples with five minutes between sample. The real time intervals were noted due to manual limitations.

In the two experiments, each treatment was tested in a separate but identical tube, and each treatment had one replicate per experiment. Capping materials were applied as follows:

- 3,0 g activated carbon (AC)
- 3,0 g Polonite (P)
- 3,0 g AC + 1,5 g Polonite (AC + P)

2.3 Toxicity test with *Hyalella azteca*

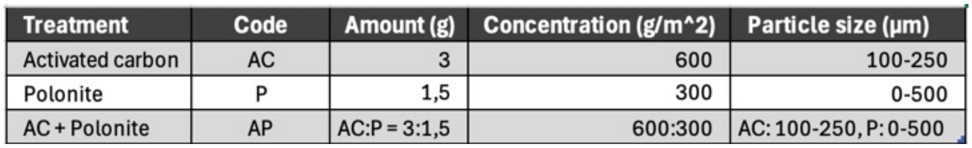
Following the collection of sediment from the Viskan river, toxicity tests were conducted at Stockholm University to evaluate the effects of contaminants in the sediments and overlying water. Toxicity was assessed using the freshwater amphipod *Hyalella azteca*, a benthic crustacean commonly used as a bioindicator of sediment quality (Environment and Climate Change Canada, 2017).

A total of 16 sediment samples were prepared and divided into four treatment types, one of which was an untreated control. Each treatment was replicated four times to ensure statistical reliability. The experimental treatments included:

1. Untreated Viskan sediment (control)
2. Viskan sediment capped with activated carbon (AC)
3. Viskan sediment capped with Polonite (P)
4. Viskan sediment capped with a combination of activated carbon and Polonite (AC + P)

Ten *Hyalella azteca* individuals were introduced to each sediment core and exposed for a 10-day period under controlled laboratory conditions. Mortality and reproduction were monitored as endpoints of sediment toxicity, reflecting negative and positive effects of contaminant exposure.

Table 3. Treatments added to sediment tube cores.



Treatment	Code	Amount (g)	Concentration (g/m^2)	Particle size (µm)
Activated carbon	AC	3	600	100-250
Polonite	P	1,5	300	0-500
AC + Polonite	AP	AC:P = 3:1,5	600:300	AC: 100-250, P: 0-500

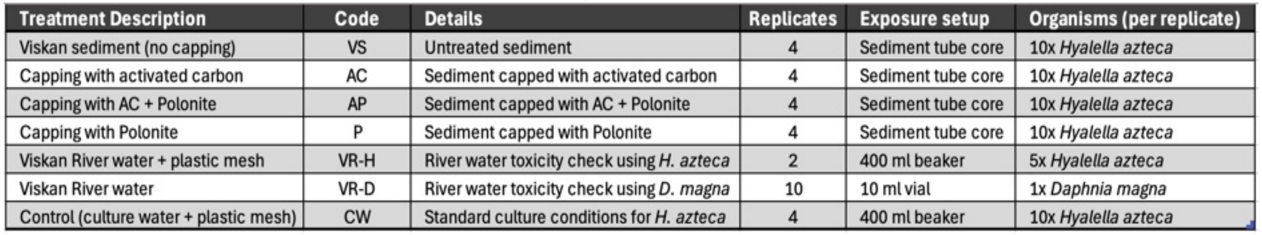
The setup was in a temperature-controlled room with a green light for 12 hours per day, imitating the conditions at the bottom of the Viskan river. In addition to the treatments, two control treatments were setup. One consisted of four replicates with 10 individuals, culture water and plastic mesh in 400 ml beakers, imitating the conditions in which *H. azteca* are reared. The other control had two replicates of water from Viskan, five *H. azteca individuals* and plastic mesh. The amphipods were fed *1 mg* fish food (TetraMin) per individual on day 0 and 4. However, the *H. azteca* living in beakers (VR-H, VR-D and CW) were exempt from feeding on day 4 due to excess food accumulating at the bottom of the beakers and a smaller volume of water, which could alter water parameters and impact the well-being of the *H. azteca.*

The initial endpoint was mortality after a 10-day period. However, as no acute toxicity was detected after 10 days, the trials were extended to assess chronic toxicity. Thus, one core per treatment was sampled for mortality on day 10. The *H. azteca* in the controls were counted, placed in fresh water and fed 1 mg fish food per individual. The remaining three replicate sediment cores will be assessed sequentially for mortality. These results will be presented in upcoming reports. To determine growth, 20 individuals were taken from the original culture on the first day of the test and frozen at -20 °C. After freezing they were thawed, blotted to remove excess water and weighed to determine wet weight. Later, they were dried and weighed to obtain the dry weight of the animals. These values are to be used for comparison of growth with the *H. azteca* that survived the different treatments after the end of the experiment.

2.4 Toxicity test with *Daphnia magna*

In addition to the mortality test with *H. azteca*, the toxicity of water from the Viskan river was assessed in a toxicity test with the parthenogenetic crustacean *Daphnia magna.* A mix of 100 ml water collected in Viskan, and 2,5 ml algal solution was prepared and distributed evenly across 10 vials, each containing one individual. Mortality and reproduction were assessed after a 10-day period, *Table 4* provides an overview of the experimental setup with *H. azteca* and *D. magna*.

Table 4. Experimental setup with *H. azteca and D. magna.*



Treatment Description	Code	Details	Replicates	Exposure setup	Organisms (per replicate)
Viskan sediment (no capping)	VS	Untreated sediment	4	Sediment tube core	10x *Hyalella azteca*
Capping with activated carbon	AC	Sediment capped with activated carbon	4	Sediment tube core	10x *Hyalella azteca*
Capping with AC + Polonite	AP	Sediment capped with AC + Polonite	4	Sediment tube core	10x *Hyalella azteca*
Capping with Polonite	P	Sediment capped with Polonite	4	Sediment tube core	10x *Hyalella azteca*
Viskan River water + plastic mesh	VR-H	River water toxicity check using *H. azteca*	2	400 ml beaker	5x *Hyalella azteca*
Viskan River water	VR-D	River water toxicity check using *D. magna*	10	10 ml vial	1x *Daphnia magna*
Control (culture water + plastic mesh)	CW	Standard culture conditions for *H. azteca*	4	400 ml beaker	10x *Hyalella azteca*

2.5 Tier 1- Risk Assessment

To evaluate the potential risk from chronic exposure to contaminated sediment, a Tier 1 risk assessment was contacted. This first-level assessment works as a screening tool, where the measured sediment concentration is compered with established sediment quality criteria (SQR).

The risk quotient (RQ) was calculated using the following formula: $\frac{\text{MECsed}}{\text{SQC}} \rightarrow \frac{< 1 \text{ no risk}}{\geq 1 \text{ potential risk}}$

3. Results

3.1 Water quality monitoring

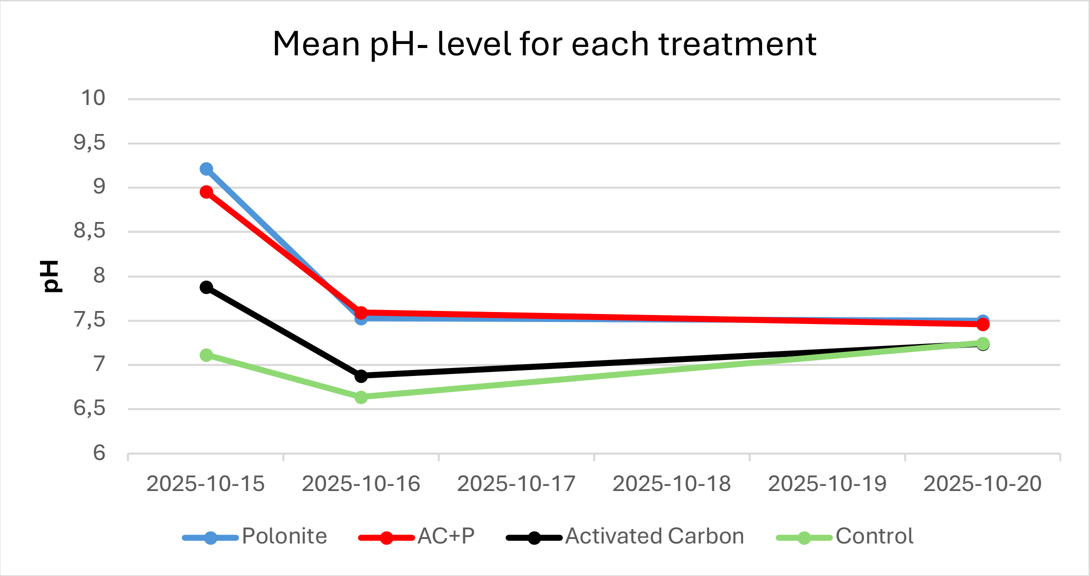


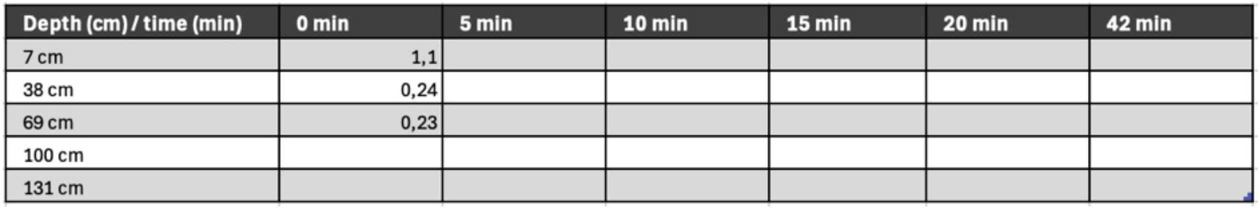
Figure 3. Mean pH-values for three measurement points.

Mean pH values of the water in the sediment cores. The colors represent the three capping tratments and the sediment control. Points represent sampling dates and the 16th of October marks the stating date of the toxicity test. The three pH measurements span over six days of the experiment.

3.2 Sedimentation kinetics

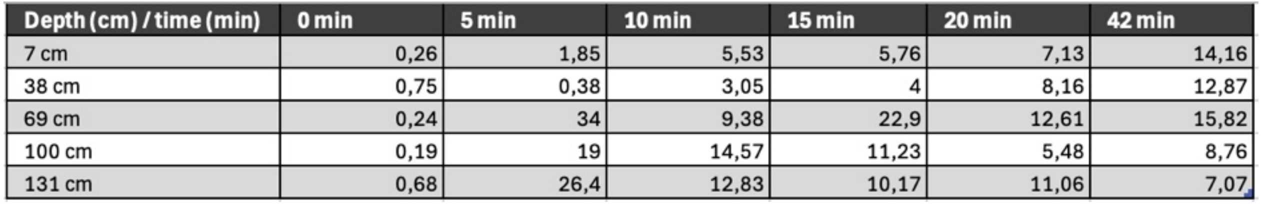
Our first experiment (*Table 7 & 8*) provided results only for the polonite. This is due to the fact our turbidity measurement device used light diffraction coming from the side of the sample. Because all the AC sank to the bottom of the sample in seconds, the values were going to represent only the water, not the AC that it contains as well. We can see in *Table 8* that at 131 cm, which is the shallowest, we have a big value at the beginning that decreases with time. The most impressive gap is between 5 and 10 min. At 100 cm we observe the same tendency but the gap between 5 min and 10 min is lower than at 131 cm. At 69 cm we observe the higher value at 5 min. After that it drops severely before going up again quite high. Finally, it seems to stay constant around 12-15. At 38 cm the values go up along with time, ending at 12,87. At the deepest we measured a similar evolution than just above, the more we wait, the more turbidity we will find. In *Figure 2*, the tendency curves (mobile means) show that the turbidity at the bottom tends to increase over time in opposition to the top of the tube where the turbidity tends to go down.

Table 7. Measurement of the turbidity of tap water in the settling of activated carbon. Values taken at each depth simultaneously via syringes at different times. Time 0 is the start of the experiment.



Depth (cm) / time (min)	0 min	5 min	10 min	15 min	20 min	42 min
7 cm	1,1					
38 cm	0,24					
69 cm	0,23					
100 cm						
131 cm						

Table 8. Measurement of the turbidity of tap water in the settling of polonite. Values taken at each depth simultaneously via syringes at different times. Time 0 is the start of the experiment.



Depth (cm) / time (min)	0 min	5 min	10 min	15 min	20 min	42 min
7 cm	0,26	1,85	5,53	5,76	7,13	14,16
38 cm	0,75	0,38	3,05	4	8,16	12,87
69 cm	0,24	34	9,38	22,9	12,61	15,82
100 cm	0,19	19	14,57	11,23	5,48	8,76
131 cm	0,68	26,4	12,83	10,17	11,06	7,07

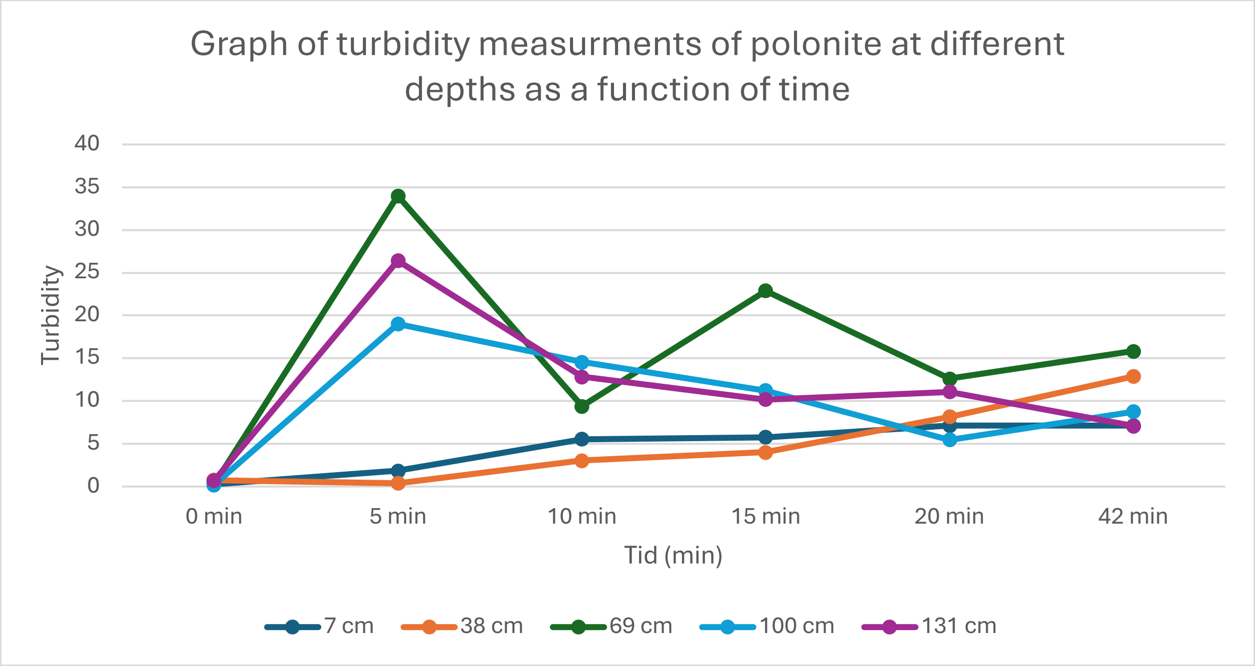


Figure 4. Graph of the turbidity measurements of tap water in the settling of Polonite as a function of time. Values were taken at each depth simultaneously via syringes at different times. The mobile means represent the general tendency of the evolution of the turbidity over time at the different depths.

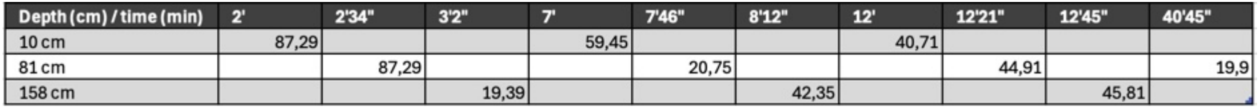
In our second experiment, we obtained results for the three treatments AC, P, and AC + P. First, the AC (*Table 9*) gives very low values of turbidity compared to the P (*Table 10*) and AC + P (*Table 11)*. We see that the AC, at 10 cm (the shallowest here), decreases rapidly between 2 min and 5 min, the values being 2,57 and 0,61 respectively. then it increases a little after 12 min. At 81 cm depth, we have the same pattern but with lower values. At 158 cm, however, the higher value is after 5 min (3,25), which is also the highest value for the AC alone. Between 2 and 13 min the values are quite the same.

Table 9. Measurement of the turbidity of tap water in the settling of activated carbon. Values taken one after the other at different depths starting with the shallower ones, at different timeframes.

Depth (cm) / time (min)	2'	2'20"	2'40"	5'1"	5'26"	5'41"	12'35"	13'04"	13'40"
10 cm	2,57			0,61			1,03		
81 cm		1,05			0,43			0,69	
158 cm			0,66			3,25			0,55

The P shows a constant decrease of turbidity at 10 cm, from 87,29 to 40,71. Whereas, at 81 cm we observe a significant drop from 87,29 to 20,75 between 2’34’’ and 7’46’’ respectively. After 12’21’’ the value is closer to the value at 10 cm again (44,91). But after 40’45’’, the value went down again around 20 (19,9). At 158 cm, finally, there is an increase in turbidity during the measurements, and it stops at 45,81 after 12’45’’.

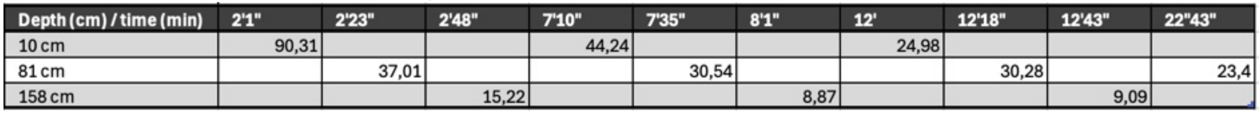
Table 10. Measurement of the turbidity of tap water in the settling of polonite. Values taken one after the other at different depths starting with the shallower ones, at different timeframes.



Depth (cm) / time (min)	2'	2'34"	3'2"	7'	7'46"	8'12"	12'	12'21"	12'45"	40'45"
10 cm	87,29			59,45			40,71			
81 cm		87,29			20,75			44,91		19,9
158 cm			19,39			42,35			45,81	

The AC + P at 10 cm depicts a great decrease from 90,31 to 24,98, with the largest leap between 2’1’’ (90,31) and 7’10’’ (44,24). A little bit deeper, at 81 cm, we notice that the values are constant during the experiment. We only observe a little decrease after the first value (~7) and after 22’43’’ (~7 as well). At 158 cm, we see a similar pattern. A slight decrease of ~7 after the first value and then constant values.

Table 11. Measurement of the turbidity of tap water in the settling of activated carbon and polonite. Values taken one after the other at different depths starting with the shallower ones, at different timeframes.



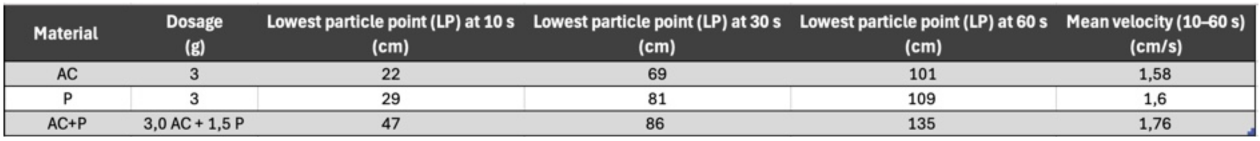
Depth (cm) / time (min)	2'1"	2'23"	2'48"	7'10"	7'35"	8'1"	12'	12'18"	12'43"	22"43"
10 cm	90,31			44,24			24,98			
81 cm		37,01			30,54			30,28		23,4
158 cm			15,22			8,87			9,09	

3.2.1 Results sedimentation behaviour

The settling behaviour of three materials, activated carbon (AC), Polonite (P), and a combination of the two (AC + P), was assessed in a transparent water column, with results summarized in *Table 13*. Both the lowest particle point (LP) and the mean settling velocity over the observation period were measured to quantify sedimentation efficiency.

The AC + P combination exhibited the highest mean settling velocity (1,76 cm/s), reflecting the fastest overall sinking behaviour. Individual materials showed slightly lower velocities, with AC and P reaching 1,58 and 1,60 cm/s, respectively. By the end of the observation period, particles in the AC + P treatment had reached the greatest depth in the column (135 cm), followed by P (109 cm) and AC (101 cm). Polonite alone settled rapidly, with most particles reaching the bottom within minutes, leaving only the finest fraction suspended. In contrast, activated carbon (AC) sank more slowly, likely due to its specific physical properties.

Table 13. Sedimentation behaviour of capping materials (AC, P, AC + P) in a 1,63 m high water column. Observed settling depths (lowest particle point) at specific time intervals with the mean settling velocity between 10 and 60 seconds. AC = activated carbon P = Polonite.



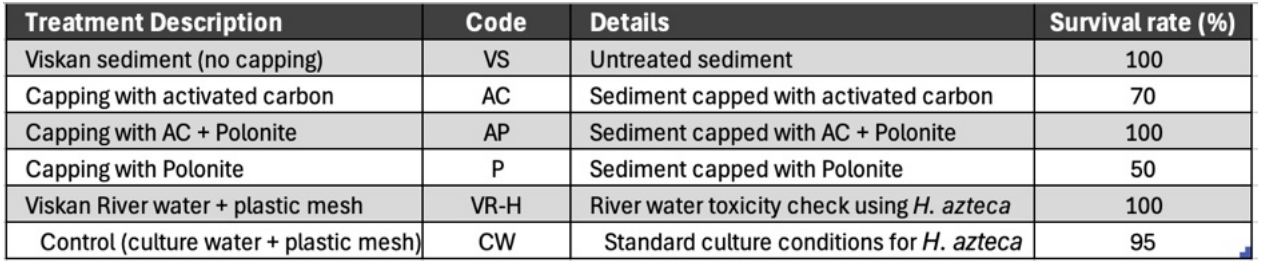
Material	Dosage (g)	Lowest particle point (LP) at 10 s (cm)	Lowest particle point (LP) at 30 s (cm)	Lowest particle point (LP) at 60 s (cm)	Mean velocity (10–60 s) (cm/s)
AC	3	22	69	101	1,58
P	3	29	81	109	1,6
AC+P	3,0 AC + 1,5 P	47	86	135	1,76

3.3 Toxicity test with *Hyalella azteca*

After analysing one core of each treatment, we can see in *Table 5* that the Viskan sediment without capping allowed all the *H. azteca* to survive, as well as the capping with AC and Polonite, and Viskan water without sediment. In the culture water 95 % of the animals were alive after ten days. In the treatment with the carbon only the survival rate reached 70 %. Finally, in the polonite capping cores only 50% of the organisms survived.

It is not yet possible to make a relevant interpretation of the mitigation effect of the treatments, as all subjects from the VS core survived. Thus, we decided not to disturb the other cores and turn this acute toxicity experiment into a chronic toxicity experiment. Additional chronic data points are planned for day 18, 26 and 34.

Table 5. Survival rate (%) of *H. azteca* after an acute 10-days test.



Treatment Description	**Code**	**Details**	**Survival rate (%)**
Viskan sediment (no capping)	VS	Untreated sediment	100
Capping with activated carbon	AC	Sediment capped with activated carbon	70
Capping with AC + Polonite	AP	Sediment capped with AC + Polonite	100
Capping with Polonite	P	Sediment capped with Polonite	50
Viskan River water + plastic mesh	VR-H	River water toxicity check using *H. azteca*	100
Control (culture water + plastic mesh)	CW	Standard culture conditions for *H. azteca*	95

3.4 Toxicity test with *Daphnia magna*

The toxicity test of water from the Viskan river shows, in *Table 6*, a 90 % survival rate of *D. magna*. No offspring were produced in the 10-day timeframe.

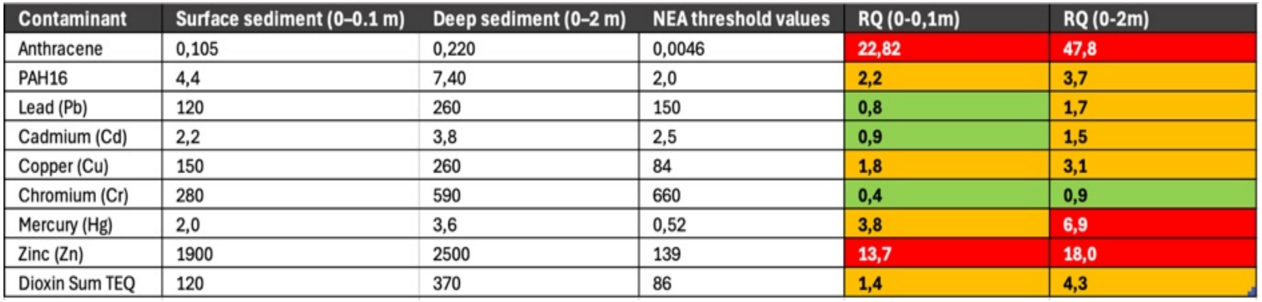
Table 6. Survival rate (%) of *Daphnia magna* after a 10-day period.

Treatment Description	**Code**	**Details**	**Survival rate (%)**
Viskan River water	VR-D	River water toxicity check using *D. magna*	90

3.5 Tier 1- Risk Assessment

The measured environmental concentration in sediment (MECsed) was taken from Sweco's updated main study (Sweco, 2025). In the RQ calculation, SQC (sediment quality criterion; threshold value) was taken from the Norwegian Environment Agency (2018). The RQ quotient is classified by colour according to risk: values 5,0 represents high risk (red), values between 1,0 - 4,9 represent intermediate risk (orange), and values < 1,0 represent a low risk of toxicity (green). A Tier 1 screening of subarea G3 provides a clear overview of which contaminants could pose an ecological risk. *Table 14* shows that all the concentrations and RQ values are higher in the deeper sediment than surface sediment. Anthracene and zinc have the largest threshold exceedance and the RQ values indicate a severe potential risk.

Table 14. Mean concentration of metals, polycyclic aromatic hydrocarbons (PAHs) and Sum TEQ of the mean concentration of dioxins in sediment from subarea G3, compared with threshold values from the Norwegian Environment Agency (NEA). All values are based on 2023 sampling and reported in *mg/kg* (dry weight), except from the Dioxin Sum TEQ, which is presented in *ng/kg.* The measured environmental concentration was collected from Sweco´s updated main study for remediation (2025), project no. 30078815, *Table 6, 11 & 17.* Threshold values are taken from "Box 3 Threshold values for level 1 (ecological risk only)" in Norwegian Environment Agency (NEA)



Contaminant	Surface sediment (0–0.1 m)	Deep sediment (0–2 m)	NEA threshold values	RQ (0-0,1m)	RQ (0-2m)
Anthracene	0,105	0,220	0,0046	22,82	47,8
PAH16	4,4	7,40	2,0	2,2	3,7
Lead (Pb)	120	260	150	0,8	1,7
Cadmium (Cd)	2,2	3,8	2,5	0,9	1,5
Copper (Cu)	150	260	84	1,8	3,1
Chromium (Cr)	280	590	660	0,4	0,9
Mercury (Hg)	2,0	3,6	0,52	3,8	6,9
Zinc (Zn)	1900	2500	139	13,7	18,0
Dioxin Sum TEQ	120	370	86	1,4	4,3

4. Discussion

4.1 Water quality monitoring

As shown in Figure 3, the pH values were initially higher with levels around 9 in the treatments with Polonite. This can be attributed to Polonite being a calcareous material and the fact that our experiments were conducted in 1L stagnant water. These experimental conditions would likely be negligible to field applications in the Viskan river which is a comparably large body of water with sufficient water exchange. These values were detected prior to the introduction of *H. azteca,* which prefers pH levels ranging from 6,5 – 8,5. Therefore, all the water was replaced with new water from the Viskan river in each sediment core. The following day, pH levels were stabilized around a pH values ranging from about 6,5 - 8 and the toxicity test was initiated, followed by regular monitoring. This approach minimized the likelihood that sub-optimal pH had a significant effect on the survival rate and/or growth rate of the test organism.

4.2 Sedimentation kinetics

In our first trial of assessing the behaviour of the capping treatments in the water, we chose to measure the turbidity of samples taken from the water column at certain depths and at certain times. However, the turbidity measurement device was analysing the sample by sending light in the middle of it. For P, this method gave interesting results. But when we started to measure AC, we noticed that all the treatment sank to the bottom of the sample, hence not increasing the turbidity. We decided to change the setup and even though we took samples for turbidity measurement again, we relied more on the lowest particle point at a given time, and the mean velocity.

Then, we can see that at each observed timing, the lowest particle point of AC is higher than the P, which is higher than AC + P. The mean velocity shows the same pattern. P is slightly faster than AC, whereas AC + P is faster than both. These results correlate with the expectations we had that the Polonite helps the AC to settle faster. This part of our experiment supplies more documentation for the association of Polonite to Activated Carbon to improve its settling capacities. It is important to keep in mind that we conducted this experiment in a monitored and protected environment. The water in the cores used in the toxicity test was in complete isolation, provided with food and oxygen, but without any movement or switch of water. To represent more precisely the reality of a river, further studies must be effectuated.

4.3 Toxicity test with *Hyalella azteca*

In CW, 38 of 40 *H. azteca* were alive at the end of our experiment. In VR-H, all individuals were found alive. To say that the water from Viskan is toxic, we would have needed higher mortality in VR-H than in CW. As it is not the case, we can not say that Viskan water is toxic for *H. azteca.*

As we have controls for the toxicity of the water, the results below are linked to the sediment toxicity. In VS, we observed no mortality. As explained in the introduction, contaminants bind to organic matter and particles to settle in the sediment. This may reduce their bioavailability. The oxygen level also affects the bioavailability of metals and since our system was well oxygenated during the entire experiment. The sorption and oxygenation might explain why we obtained results that indicate no acute toxicity despite the high levels of previously measured contaminant concentrations.

In polonite, half of the individuals died. Even though polonite is usually used in addition to the activated carbon, the treatment is supposed to mitigate the effect of the contaminants. Hence, we expected the survival to be slightly improved or like VS. However, we found a higher mortality rate. This can be explained by the fact that, during the breaking of the experiment, we found a Chironomidae larva in the sediment. This could have led to competition or predation of the *H. azteca*. This is supported by the fact that we did not find the dead individuals. There is still a possibility that the dead ones degraded before our analysis and that the larva is not involved. In the beginning of the experiment, when we added the polonite capping, the pH increased significantly, and we had to change the water. After that, the pH was decreased but remained higher compared to the other treatments. This might therefore be another factor affecting the survival-rate of the animals.

The core with AC has a survival rate of 70 %. Because it is the main mitigation treatment, we expected the mortality to be lower or at least at the level of VS. After observing the P core, we know that there are some naturally occurring biota in the sediment potentially threatening to our experimental organisms. All *H. azteca* individuals survived in AP. This is what we expected from the other cores and this one after VS analysis. But, as all animals survived in VS as well, it is not yet possible to affirm if it is useful or not. This is the reason why we decided to spare all the other cores to conduct, instead of an acute, a chronic toxicity test. New interpretations will be drawn from these future results. In addition to that, it is possible that at the end of the chronic test, the water turns out to be toxic, that is why we put all the individuals back in the water only treatments.

4.4 Toxicity test with *Daphnia magna*

In the toxicity test with Daphnia magna, a survival rate of 90% was observed. This indicates that the water from the Viskan river does not pose an acute toxic risk to aquatic organisms. Together with the results from the *H. azteca* test, this provides additional support for the conclusion that the water itself is not a significant source of toxicity. This, in turn, simplifies the evaluation of sediment toxicity by allowing potential effects to be more confidently attributed to the sediment rather than the overlying water.

4.5 Tier 1- Risk Assessment

Tier 1 is the first screening step in the risk assessment and identifies where potential environmental risks occur. The RQ values in *Table 14* indicate a potential risk for most contaminants measured further steps in the risk assessment should therefore be conducted. Higher RQ values in deeper sediments reflect historical contamination from older industries. The less toxic surface sediment indicates that the emissions have declined. Borås municipality is working consistently to reduce contaminant input while investigating the best remediation options. Sweco has proposed dredging, but it is not necessarily the best choice when contamination is mainly in deeper sediments. Direct dredging of deeper layers can cause extensive resuspensions and mixing of contaminants, increasing the exposure and ecological impact. A Tier 1 assessment does not account for bioavailability and in Sweco's report concentration of bioavailable contaminants are only presented for Copper and Zinc (Sweco, 2025).

5. Conclusion

Our initial aim was to assess whether the sediment in the G3 area of the Viskan river was compact enough to allow for capping without being displaced by water currents. Sediment sampling indicated that the riverbed is sufficiently firm to support capping. This was further confirmed by sedimentation kinetic experiments, which validated our hypothesis. The association of Polonite to Activated Carbon enhances the sinking, and then settling, of the capping layer. Thus, allowing this technique to be more reliable in a flowing water environment. The mitigation effects of the thin layer capping, however, were not observed after a ten-day period. Neither were the effects of the association of Activated Carbon and Polonite. Therefore, we decided to turn this acute toxicity test into a chronic toxicity test. Through this switch, we aim to expand the knowledge on these new remediation methods and provide a foundation for developing a new remediation plan for the Viskan river. The test with the *D. magna* brought some weight to the fact that the water is not toxic, even though it might turn out to be toxic at the end of the chronic test. It is still awaited that the toxicity comes from the sediments.

Since the highest contaminant levels are found in deeper sediment layers, and surface sediments show lower toxicity, capping may be a more suitable remediation option than dredging. Our aim is to show that a cap can effectively isolate contaminants, limit their mobility and reduce bioavailability. This will be evaluated further as the experiment extends in time to assess the chronic effect of Viskan sediments and capping materials. Thin layer capping, in this case, may turn out to be particularly relevant when the contamination is historical and concentrated in deeper layers. Dredging in such cases may do more harm than good.

6. Acknowledgements

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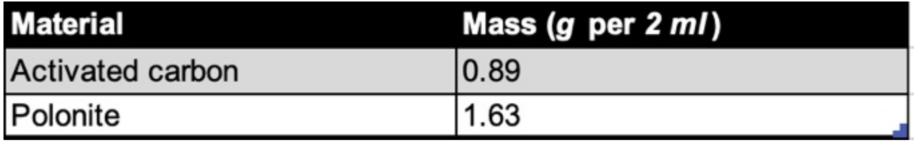
Appendix

Bulk density test

To determine the amount of capping material required for each treatment, bulk density and pH effects were tested for both Polonite and activated carbon (AC). The ratio between Polonite and AC was based on their respective mass and volume. Activated carbon was selected for its strong sorption capacity toward hydrophobic contaminants.

For each material, 2 ml cylinders were filled to the brim with powdered AC or Polonite, and the mass was measured as follows:

Table 14. Bulk density of Activated carbon and Polonite.



Material	**Mass (*g* per 2 *ml*)**
Activated carbon	0.89
Polonite	1.63

Polonite therefore has a higher bulk density compared to AC. The cylinder volume (V) was calculated using:

$$V = \pi r^2 h$$

where, r = radius and h = height (cm)

Cylinder 1(AC): $V = \pi(0{,}57)^2 \times\ 2{,}00\ cm = 2.0414\ cm^3$

Cylinder 2(Polonite): $V = \pi(0{,}56)^2 \times\ 2{,}00\ cm = 1{,}9704\ cm^3$

Bulk density, pH test

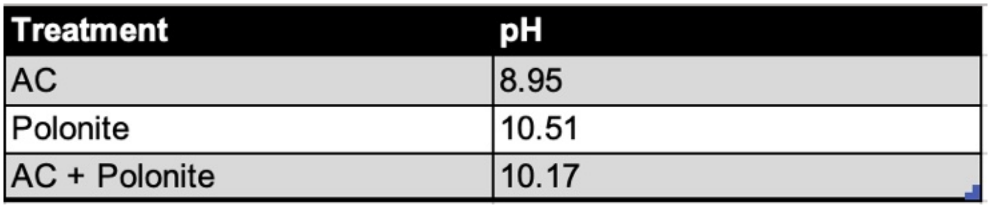
Three small glass cylinders were prepared, each containing 10 ml of water and one of the following treatments:

1. 0,5 g of AC
2. 0,5 g of polonite

3. 0,25 g of AC + 0,25 g of polonite

Polonite is alkaline and increases pH, whereas AC tends to lower pH slightly. The measured pH values were:

Table 15. Measured pH values for 5g of Activated carbon, 5g of Polonite and a combination of 0,25 of both in 10ml water.



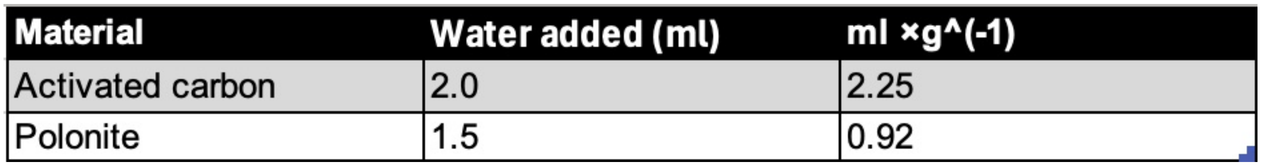
Treatment	pH
AC	8.95
Polonite	10.51
AC + Polonite	10.17

Pore/water volume (partitioning coefficient)

The partitioning coefficient (Kd) describes how a compound distributes between solid and liquid phases, such as sediment and pore water, and helps predict environmental mobility.

To determine water retention, 0.89 g of AC and 1.63 g of Polonite were placed in separate cylinders. The volume of water required to saturate each material was measured:

Table 16. *The amount of water added for each material in ml and the amount of water per gram for Activated carbon and Polonite.*



Material	Water added (ml)	ml ×g^(-1)
Activated carbon	2.0	2.25
Polonite	1.5	0.92

This indicates that AC holds more water per gram than Polonite due to its porous structure.

LOI (loss-on-ignition) and conaminant analyses

Method: Contaminant measurements

Sediment pore water was extracted from twenty 50 ml tubes filled with sediment through centrifugation at 3800 RPM for 10 minutes. The pore water was collected in pre-cleaned jars from ALS. One of the jars was sent to ALS for chemical analysis of metals and POPs. The three remaining jars were sent to TOXICON for toxicity testing using *Nitocra spinipes* under standardized pore water tests.

The organic matter (OM) in the sediments was measured by drying at 60°C to constant weight, followed by combustion at 450°C to obtain loss-on-ignition (LOI) values. Additional sediment was dried, ground and sent to Kemlab for analysis of total organic carbon (TOC), total carbon (TC) and total nitrogen (TN).

LOI values (OM %) were calculated using the following formula:

$$LOI\ (\%) = ((dry\ weight - ash\ weight)/dry\ weight) \times 100$$

The TOC can be derived from the LOI (%) by dividing the mean value with a conversion factor. Ideally, one would derive their own conversion relationship between % TOC and % LOI from their specific system. However, due to time constraints a conversion factor of 0,5 was used to obtain an estimation of % TOC (Lindborg et al., 2020).

Total organic carbon (TOC) was estimated in our report by dividing the OM by two:

$$TOC = OM / 2$$

Result: LOI determination

According to our organic matter analysis, our sediment cores have an LOI ranging from 28,68% to 29,5% (*Table 12*). Two samples (C9 and C10) have been sent to the Kemlab for Total Carbon and Nitrogen analysis, that is why we do not have any results for the ash weight and the LOI.

The mean of our LOI values is 29,08%, and the standard deviation of our samples is 0,3359. From this, the percentage of Total Organic Carbon (TOC) could be estimated to 15 %.

The % of total organic carbon (TOC) is estimated by dividing the OM by two:

$$TOC = 29{,}08 / 2 = 15\ \%$$

Table 12. Weight of sediment samples from the Viskan river. Wet weight is the original sediment mass. Dry weight is the sediment mass after heating. Ash weight is the sediment mass after burning the dry sediment. LOI is the amount of organic matter in the sediment. C9 and C10 have been sent to the lab for further analysis.

Sample	Wet weight (g)	Dry weight (g)	Ash weight (g)	LOI (%)
C7	1,1854	0,1818	0,1289	29,1
C8	1,3458	0,2064	0,1472	28,68
C9	1,1965	0,1837	/	/
C10	1,2657	0,1937	/	/
C11	1,4986	0,2297	0,163	29,04
C12	1,0969	0,1685	0,1188	29,5

Discussion: LOI determination

An LOI of ~40% is a high percentage. Our values having a mean of 29,08% let us think that the organic matter content of the sediment is average. This implies that we would not describe the system as eutrophicated. However, it is not the most direct and reliable method to assess the eutrophication of a system. The N:P ratio or the oxygen levels, for instance, are more precise. On that account, you must be careful with the interpretations of the results.

We defined, with the LOI determination, that the Viskan river is not a eutrophicated system, and we supported the TOC that Sweco measured in 2023. The TOC estimate of our samples is 15%, which corresponds to Sweco´s 2023 TOC measurements of 15%.