Screening of flotation chemicals

Water sampling downstream Swedish mines

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Summary

This report presents a screening study commissioned by the Swedish Environmental Protection Agency to assess the occurrence and concentration of flotation chemicals downstream of sulfide mining operations in Sweden. Flotation chemicals, particularly xanthates and thiocarbamates, are widely used in ore processing and may pose ecological risks if released into the environment via effluent from tailings ponds.

The project developed and validated a robust analytical method using solid-phase extraction and LC-MS/MS to detect five target compounds at low concentrations. Sampling was conducted at four mining sites during fall 2024 to spring 2025. In total, 85 analyses were made on surface water samples collected under variable hydrological conditions, with 34 analyses showing detectable levels.

Detected concentrations ranged from 0.2 to 250 µg/L, with butyl and amyl xanthate being most frequently observed. Over 70% of detections were below 10 µg/L, which is lower than most reported toxicity data from tests with aquatic organisms. However, the ecotoxicological foundation is scattered, which is reflected in predicted no effect concentrations (PNEC) for aquatic organisms ranging between 1 and 1500 µg/L. Previous studies on synergistic effects between xanthates and metals (e.g., cadmium, copper) showed a substantial increased toxicity, and this should be considered also at low xanthate concentrations.

This screening focused only on snapshot conditions in surface water to ensure robust analysis methods. Xanthate and thiocarbamate occurrence in other environmental media such as sediment and biota remain unclear and surveying their degradation products was not included in the screening project. To gain a better understanding of xanthate and thiocarbamate prevalence and potential ecological risk in downstream water, further seasonal monitoring is needed, as well as additional ecotoxicological studies for sublethal endpoints.

Sammanfattning

Den här rapporten presenterar en screeningstudie som genomförts på uppdrag av Naturvårdsverket för att undersöka förekomst och koncentration av flotationskemikalier i ytvatten nedströms svenska sulfidmalmsgruvor. Flotationskemikalier, särskilt xantater och tiokarbamater, används i stor utsträckning vid malmanrikning och skulle kunna innebära ekologiska risker om de släpps ut i miljön via bräddningsvatten från sandmagasin.

Projektet utvecklade och validerade en robust analysmetod baserad på fastfasextraktion och LC-MS/MS för att kunna detektera fem flotationskemikalier i låga koncentrationer. Provtagning genomfördes vid fyra gruvor under hösten 2024 till våren 2025. Totalt genomfördes 85 analyser på ytvattenprover under varierande hydrologiska förhållanden, varav 34 visade detekterbara halter.

De uppmätta koncentrationerna varierade mellan 0,2 och 250 µg/l, där butyl- och amylxantat var mest förekommande. Över 70 % av detektionerna låg under 10 µg/l, vilket är lägre än majoriteten av rapporterade toxicitetsdata från tester med vattenlevande organismer. Det ekotoxikologiska underlaget visar emellertid stor spridning, vilket också reflekteras i bedömningen av PNEC (predicted no effect concentration) för akvatiska organismer som i litteraturen varierar mellan 1 och 1500 µg/l. Tidigare studier har visat att synergistiska effekter mellan xantater och metaller (t.ex. kadmium och koppar) kan leda till avsevärt högre toxicitet, vilket bör utvärderas även vid låga xantathalter.

Denna screening fokuserade enbart på momentan förekomst i ytvatten för att säkerställa tillförlitliga analysmetoder. Förekomst av xantater och tiokarbamater i andra medier, såsom sediment och biota, är fortfarande oklar, och nedbrytningsprodukter inkluderades inte i den här studien. För att få en bättre förståelse för förekomst och potentiell ekologisk risk krävs fortsatt säsongsövervakning samt ytterligare ekotoxikologiska studier med fokus på subletala effekter.

Table of contents

Summary 3

Sammanfattning 4

1 Introduction 6

2 General toxicity 7

3 Method 10

3.1 Method development 10

3.2 Field sampling 11

3.3 Sample analysis 12

4 Results 12

4.1 Developed analysis method 12

4.2 Water sample results 13

5 Discussion 15

5.1 Toxicity levels and sample results 15

5.2 Remaining knowledge gaps 17

6 Summarizing conclusions 18

7 Reference list 20

Appendix 22

1 Introduction

In 2022, the Swedish Environmental Protection Agency initiated a screening project on flotation chemicals used in mining operations, beginning with a literature review to identify substances currently in use at Swedish mines and assess their potential environmental risks. The resulting report (Fischer and Jarsjö, 2023) compiled information on chemical usage volumes, toxicity, degradation, bioaccumulation, and analytical feasibility. Building on those findings, the present report represents the second phase of the screening project; field sampling to verify the occurrence of priority chemicals downstream of mining facilities. This phase was carried out by IVL Swedish Environmental Research Institute in 2024 and 2025. Although flotation chemicals have been used for a long time with known potential negative effects to aquatic ecosystems (e.g., Bertills et al., 1986), monitoring of downstream levels have been limited by insufficient analysis methods. The primary objective of this project was therefore to 1) develop robust analysis methods for chosen flotation chemicals in low concentration field samples, and 2) to collect and analyze surface water samples downstream Swedish mining sites.

Flotation chemicals are widely used in the mining industry to separate minerals from waste (gangue) materials. A collector reagent is usually added in flotation cells with the purpose of modifying the mineral surface properties into either hydrophobic or hydrophilic. By pumping air into the flotation cells, the modified minerals attach to the air bubble, follow up to the surface, and can there be skimmed off (Figure 1). The discarded material from the flotation cells is instead directed to the tailing ponds for sedimentation. To maintain safe operating conditions in the tailing ponds, excess process water is sometimes released into the surrounding environment. It is in this effluent that any remaining flotation chemicals could reach downstream aquatic environments.

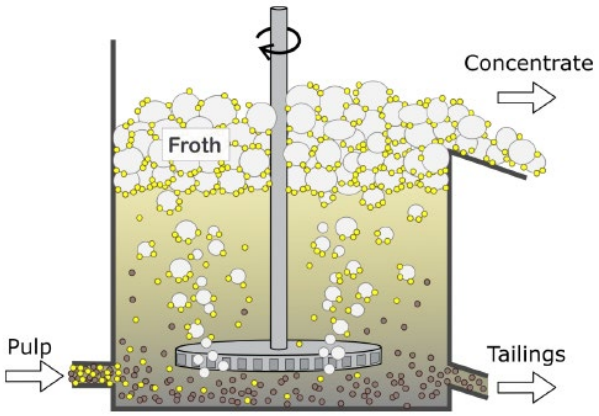


Figure 1. Principle of froth flotation in mining ore separation processes. Taken from Fischer and Jarsjö (2023).

One of the most common groups of flotation collectors for sulfidic minerals are xanthates, which are the main active ingredient in reagent products such as Flomin and Nascol. Xanthates have the general chemical formula $ROCS_2$-M^+, where R is an alkyl group and M^+ is a metal ion (Kemppinen et al., 2015). Another common collector chemical for sulfide ores is O-isopropyl ethyl thiocarbamate (or IPETC, in this report referred to as thiocarbamate), which is one of the active ingredients in products such as Danafloat. Xanthates and thiocarbamates were identified in the review by Fischer and Jarsjö (2023) as being widely used, of environmental concern, and possible to analyze, and were therefore chosen as the target chemicals for this screening project.

2 General toxicity

Ecotoxicological data for xanthates vary greatly; the same xanthate and same test species can yield results that span orders of magnitude in toxicity (Bararunyeretse et al., 2022; Fischer and Jarsjö, 2023). Even among the different xanthate species and among the different test organisms the reported toxicity range is wide and sometimes contradictory. For freshwater organisms, reported no observed effect concentrations (NOEC) range from 300 to 38 000 µg/L, with modelled values reaching up to 90 000 µg/L. At the same time, much lower thresholds have been reported for more severe toxicity measures. For example, algal growth rate inhibition was measured to a short-term EC_{50} of 25 µg/L isopropyl xanthate (Bertills et al., 1986; EC_{50} = the concentration that results in a certain effect in 50% of the test population). Fish mortality have been measured down to a chronic LC_{50} of 30 µg/L of ethyl xanthate (ECHA CAS 140-90-9; LC_{50} = the concentration that kills 50% of the test population). Ethyl xanthate has also shown inhibition in

invertebrate reproduction at 47 µg/L as a chronic EC_{10} (ECHA CAS 140-90-9). Acute toxicity tests, which reflect short-term exposure, generally report LC_{50} values for fish between 120 and 220 000 µg/L (Bertills et al., 1986; Fuerstenau, 1974; Webb et al., 1976); ECHA CAS 140-90-0, 2720-73-2, 13001-46-2, 141-98-0). Chronic tests, designed to simulate continuous exposure, show EC_{50} values for invertebrates in the range of 370-5000 µg/L, while the only reported chronic EC_{50} for fish is 550 µg/L (ECHA CAS 140-90-9, 25306-75-6). Predicted no effect concentrations (PNEC), calculated based on available ecotoxicological data and uncertainty assessment factors, also vary widely. ECHA registers ranges of 1–300 µg/L for ethyl xanthate (CAS 140-90-9, 140-89-6), 4–360 µg/L for amyl xanthate (CAS 2720-73-2, 928-70-1), 20–1500 µg/L for isobutyl xanthate (CAS 25306-75-6, 13001-46-2), and 10 µg/L for isopropyl xanthate (CAS 140-93-2). Taken together, this wide span in toxicity thresholds means that both low and high values should be interpreted with caution.

Xanthates are water soluble and degrade into the toxic carbon disulfide (CS_2) and carbonyl sulfide (COS) depending on pH, temperature, redox potential, and presence of metal ions (Elizondo-Álvarez et al., 2021; Shen et al., 2019). For example, Sun and Forsling (1997) saw that it took more than a month for ethyl xanthate in cold temperatures (5 °C) to degrade to half its concentration at pH 7. CS_2 is volatile and will likely outgas rapidly once formed (NICNAS, 1995).

The combination of xanthates and metals have also shown to greatly increase acute toxicity for bacteria, algae, and fish (Bertills et al., 1986). Figure 2 displays their resulting LC_{50} values for 1-year old salmon being exposed to 4 days of various xanthate-metal mixtures. For example, the LC_{50} for 1-year old salmon for only cadmium (Cd; labeled "Endast Cd" in Figure 2) lies above 500 µg Cd/L. If the salmon was instead exposed to a mixture of xanthate and Cd, the LC_{50} dropped to between 0.8 to 20 µg/L depending on the xanthate species. This was only investigated for high xanthate concentration mixtures (e.g., 1000–10 000 µg/L xanthate), which might not be representative in today's downstream environments, but shows the potential for synergistic effects between metals and xanthates. It should also be noted that LC_{50} represents a severe toxicity endpoint; other measures such as EC_{10} or lowest observed effect concentration (LOEC) would indicate harmful effects at considerably lower concentrations than those shown in Figure 2.

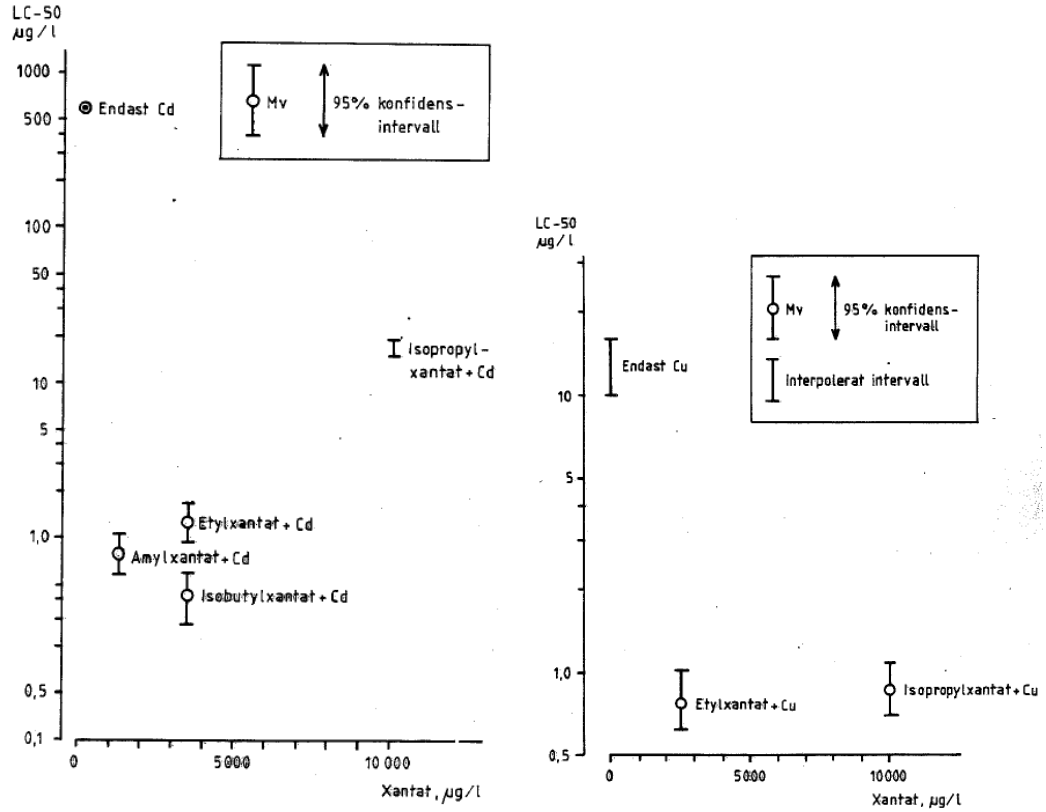


Figure 2. Previous experiments by Bertills et al. (1986) on acute toxicity to metals (LC_{50}, 96h) on 1-year old summer salmon in combination with sublethal concentrations of xanthates.

Much less is known about the thiocarbamate compared to xanthates. According to ECHA (CAS 141-98-0), the PNEC is reported at 20 µg/L. Toxicity data however indicate relatively high thresholds: a short-term NOEC for algal growth rate inhibition of 1000 µg/L, and a long-term NOEC for microbial respiration inhibition of 2200 µg/L. Reported acute LC_{50} values are 40 000–48 000 µg/L for fish (Fuerstenau, 1974) and 63 000 µg/L for invertebrates (ECHA CAS 141-98-0). In addition, thiocarbamates have been shown to degrade relatively slowly, with a reported half-life of 12 days at 25 °C (Chen et al., 2011).

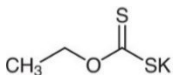
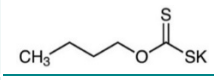
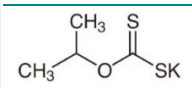
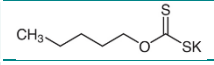
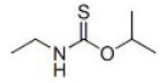
3 Method

3.1 Method development

Our method development was based on previous work by Qiao et al. (2023) and Zhu et al. (2023) using high-performance liquid chromatography (HPLC) and triple quadrupole mass spectrometry (MS/MS) available at the IVL laboratory in Stockholm.

Developing a new analytical method involves several steps, including optimization of mass spectrometer settings, selection of a suitable chromatographic column for effective separation, and establishing a reliable sample preparation procedure to extract the compounds from water samples. In this case, solid-phase extraction (SPE) using a WAX column was identified as the most effective approach for isolating the target substances. Several columns and elution conditions were evaluated to maximize recovery and minimize matrix effects. For compound separation, a BEH C18 column was selected based on its ability to provide sufficient retention. Method validation included assessments of linearity, detection and quantification limits, recovery, matrix effects, and repeatability. In addition, storage stability was systematically tested under different pH and temperatures, confirming that xanthates degrade quicker under acidic conditions and possibly from thawing of frozen samples. Best stability was achieved when samples were refrigerated and buffered to a pH of 10 or higher. The specific xanthate and thiocarbamate species used in the method development are outlined in Table 1.

Table 1. List of analytes included in the screening project.

Chemical	Abbreviations	CAS nr.	Formula	Structure
Potassium ethyl xanthate	EtX, SEX	140-89-6	$C_3H_5OS_2K$	
Potassium butyl xanthate	BuX, IBX	871-58-9	$C_5H_9KOS_2$	
Potassium isopropyl xanthate	IpX, IPX	140-92-1	$C_4H_7KOS_2$	
Potassium amyl xanthate	AmX, KAX, PAX	2720-73-2	$C_6H_{11}KOS_2$	
O-isopropyl ethyl thiocarbamate	Thiocarbamate, IPETC	141-98-0	$C_6H_{13}NOS$	

3.2 Field sampling

Since presence of flotation chemicals downstream mining sites was unknown, we aimed to take water samples under different ambient conditions to maximize chances of detection. For example, xanthates degrade faster under warmer temperatures (see review by Fischer and Jarsjö, 2023) and increased precipitation or snowmelt might dilute effluent concentrations. Samples were consequently taken downstream four different sulfide mining sites (Figure 3) on one or two occasions between fall 2024 and spring 2025 depending on local conditions. For instance, samples were only taken during periods with ongoing effluent discharge. As the Aitik mine did not release any effluents during the screening period, no sampling was carried out there.

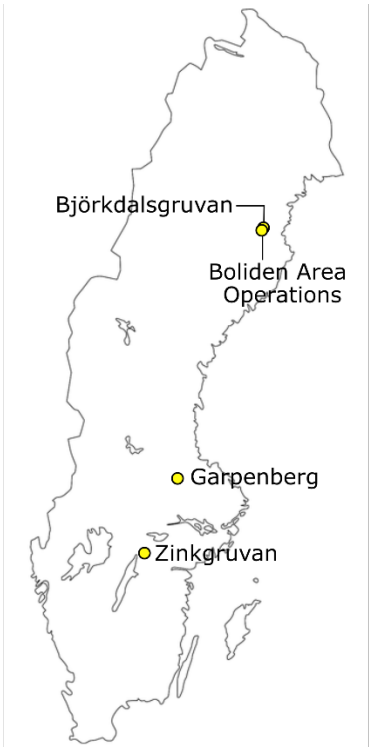


Figure 3.Sampling sites downstream four Swedish sulfide mining operations: Björkdalsgruvan, Boliden Area Operations, Garpenberg and Zinkgruvan.

At each site, samples were taken directly downstream the outlet of sedimentation or clearing ponds, and then along a stretch of 1–7 km downstream, yielding between three to four samples per site and occasion. At some mining facilities, samples were also taken inside the sedimentation pond to aid the verification of the analysis method, but the results of those samples are not included in this report. Sampling was done with a handheld sampler bottle that collected the

streamwater that was then poured into pre-prepared 0.5L bottles in duplicates. The prepared bottles contained carbonate salt to maintain a high pH in order to limit chemical degradation until analysis. Samples were kept cool and dark and directly transported to the IVL laboratories in Stockholm for analysis within 48 hours.

3.3 Sample analysis

Water samples were analyzed for the xanthates and the thiocarbamate using solid-phase extraction (SPE) follow by liquid chromatography-tandem mass spectrometry (LC-MS/MS). A 100 mL sample volume was extracted using Cleanert PWAX SPE cartridges (Agela) and eluted with 5 mL of 5/95 (v/v) ammonia (25%)/methanol. Chromatographic separation was performed on an Acquity UPLC BEH C18 column (2.1x100mm, 1.7 µm; Waters) using a gradient elution with 0.12% ammonia in MQ water and acetonitrile. The analysis was carried out on a Shimadzu LCMS-8050 system equipped with ESI in negative mode for xanthates and positive mode for the thiocarbamate.

4 Results

4.1 Developed analysis method

The repeatability of the analysis method showed satisfactory results with a relative standard deviation (RSD) of instrumental results of 3–13% (Table 2). Method uncertainty was evaluated in relation to matrix effects, i.e., potential disturbance during the analysis from other compounds in typical industrial water. Ethyl xanthate showed the highest uncertainty (44%) if analyzed in typical industrial water. Since the degree of matrix effects in newly collected water samples can be difficult to estimate beforehand, the general method uncertainty is 44% as a worst-case scenario. Detection and quantification limits reached down to 0.1–0.4 µg/L and 0.3–1.3 µg/L, respectively, depending on the substance (Table 2).

Table 2. Uncertainty measures and final detection and quantification limits of the developed method for each of the target flotation chemicals.

Parameters	Thio-carbamate	Ethyl xanthate	Butyl xanthate	Isopropyl xanthate	Amyl xanthate
Instrument repeatability (RSD %)	3	5	4	13	6
Method uncertainty incl. matrix (%)	15	44	21	36	14
Detection limit; LoD (µg/L)	0.1	0.4	0.2	0.3	0.2
Quantification limit; LoQ (µg/L)	0.3	1.3	0.8	0.9	0.6

4.2 Water sample results

Xanthates and thiocarbamates were detected downstream all sampled sites with a general decreasing trend downstream. Figure 4 shows the results for each mine and sampling season, where hollow circles indicate analyses below the quantification limit (see Table A1 in the Appendix for all the analysis results). Because the different mines use different flotation reagents, not all target compounds were analyzed at every site. In addition, the standard for ethyl and isopropyl xanthate became available only after the autumn sampling, so analyses for isopropyl xanthate was analyzed only in the winter and spring samples. Given the developmental nature of both the analytical method and the sampling strategy, which aimed primarily to maximize the likelihood of detection, the resulting dataset is somewhat scattered. Of the 85 sample analyses run, 34 showed detectable levels of flotation chemicals. Butyl and amyl xanthate showed the highest concentrations at the discharge outlet (250 µg/L and 160 µg/L, respectively), and up to 4 km downstream we detected concentrations above 10 µg/L. The presented results do not take dilution effects into account and the downstream distance should therefore only be interpreted as how far downstream the chemical was still detectable. Due to the limited number of samples taken on each occasion and site, no seasonal comparison of the results can be made.

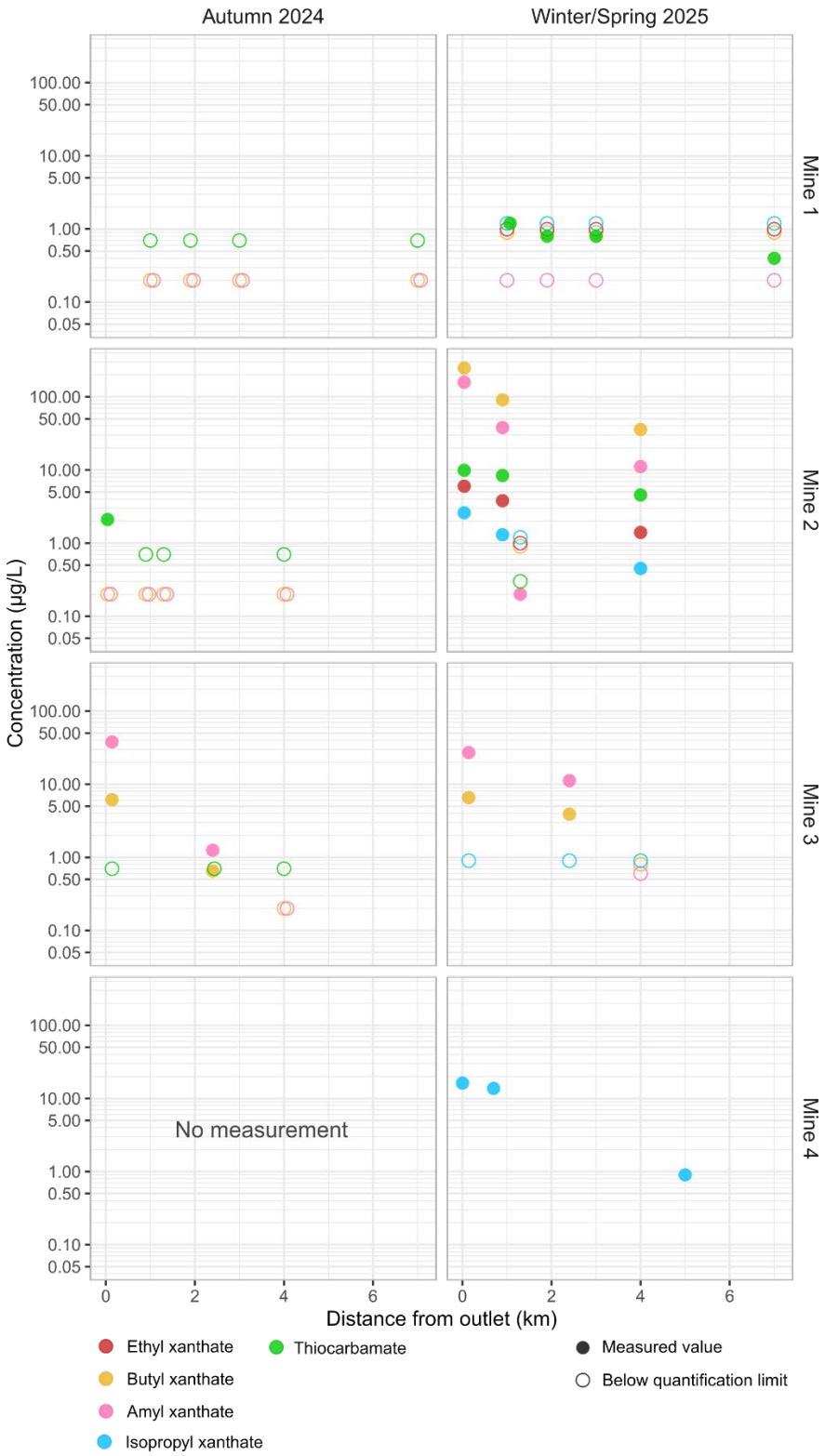


Figure 4. Water sample concentrations of xanthates and thiocarbamate relative to their sampling location downstream the discharge point from the respective mining sedimentation pond. Hollow circles represent samples below the quantification limit of respective analysis for the different chemicals.

5 Discussion

Screening of flotation chemicals in downstream surface water near mining sites presents several challenges. First, the types of chemicals used in flotation processes often change over time due to variations in ore composition or shifts in processing strategies. Consequently, legacy chemicals may still be present in sedimentation ponds and continue to leach into receiving waters years after use has stopped. Second, the environmental fate of these chemicals, including their degradation, persistence, and potential for bioaccumulation, remains poorly characterized in scientific literature. These factors complicate efforts to prioritize which chemicals warrant focused toxicity investigation and long-term monitoring.

5.1 Toxicity levels and sample results

The concentrations of flotation chemicals detected in this screening project (0.2–250 µg/L) are comparable to those reported in the 1980s (2–3000 µg/L; Walterson, 1984) at downstream sites near Swedish mines. Although modern extraction processes likely use lower chemical dosages, detectable levels persist in receiving waters. Detection alone, however, does not imply ecological harm. In our dataset, 24 of 34 samples contained xanthates below 10 µg/L (Figure 4), which is lower than most reported toxicity measures. Figure 5 shows the observed xanthate and thiocarbamate concentrations alongside published toxicity data (primarily based on the review table by Fischer and Jarsjö, 2023). There is some overlap with PNEC values (grey points with a vertical line in Figure 5) being lower than some of the observed data. Another overlap for amyl xanthate was the observed value of 160 µg/L that is higher than the EC_{50}-value of 100 µg/L for algal growth inhibition. However, based on the few numbers of snapshot observation values and a worst-case method uncertainty of 44%, it is difficult to draw any robust conclusions on risk levels for aquatic ecosystems. Available toxicity data is highly irregular in terms of tested species and effect levels, and both long-term observational data and long-term chronic toxicity tests are needed for a more complete assessment.

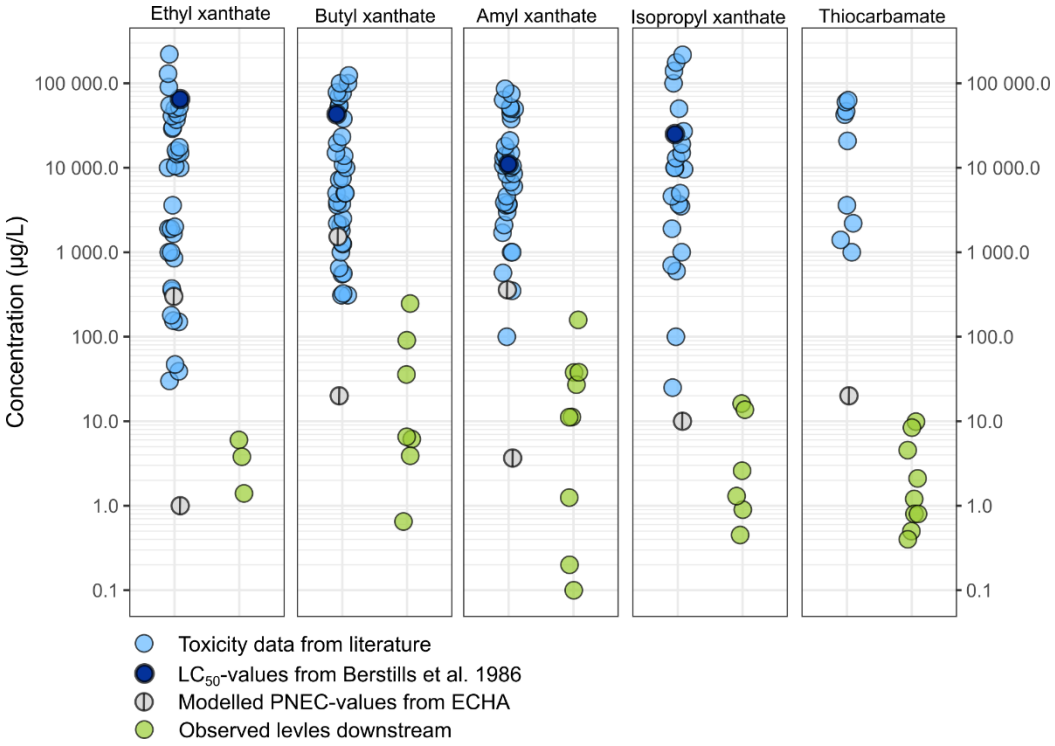


Figure 5. Comparison of reported toxicity data from literature (blue points) with observed chemical concentrations in downstream waters (green points). The toxicity data includes all available toxicity levels (LC_{50}, EC_{50}, NOEC etc.) for all available test organisms. The LC_{50} values used in Bertills et al. (1986) are marked in dark blue, and PNEC values from ECHA are marked in grey with a vertical line.

The potential synergistic effects between xanthates and metals (Figure 2) showed that LC_{50} values can be reduced by 20–500 times for cadmium-xanthate mixtures and about 10 times for copper-xanthate mixtures. These experiments used relatively high xanthate concentrations (dark blue points in Figure 5) compared to the range of toxicity data available today (blue points in Figure 5), and it remains unclear whether similar synergistic effects occur at lower, environmentally relevant xanthate levels. Although modern effluent controls focus on metal concentrations, even low-level xanthate-metal interactions may pose unrecognized risks. To address this, future studies should evaluate synergistic toxicity at sublethal endpoints across a broader range of species beyond fish. Bertills et al. (1986) demonstrated this approach for algal growth inhibition (Figure 6), reporting that just 50 µg/L isobutyl xanthate combined with 5 µg/L cadmium achieved an IC_{50} endpoint (i.e., concentration that results in 50% growth inhibition). These xanthate concentrations fall within the higher range detected in our screening project (blue lines in Figure 6), underscoring the need to consider metal-xanthate synergies in environmental risk assessments.

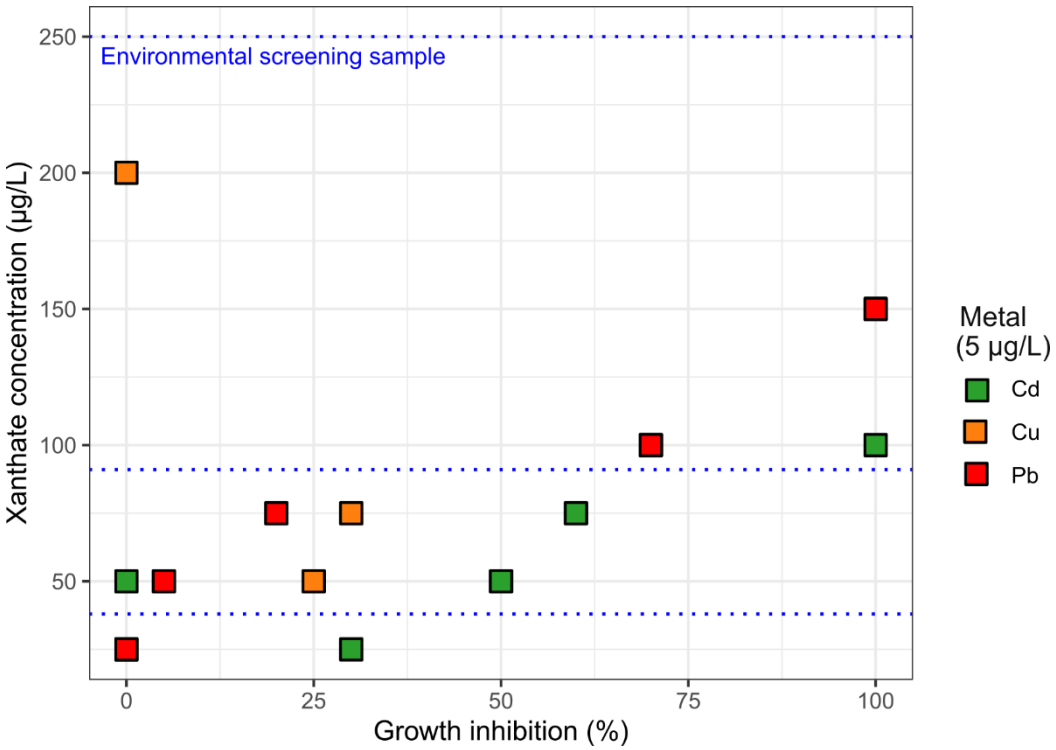


Figure 6. Combined toxicity effects from isobutyl xanthate and 5 µg/L metals on algal growth inhibition by Bertils et al. (1986). The blue horizontal lines mark the three highest measured butyl xanthate concentrations from this project's screening.

5.2 Remaining knowledge gaps

This screening project targeted surface water immediately downstream of mining operations to establish a robust analytical baseline and facilitate comparison with previous measurements and toxicity thresholds in aquatic systems. To screen for these chemicals in other environmental matrices (e.g., sediment, soil, biota) and their degradation products is much more challenging. For instance, xanthates are highly water-soluble and are generally expected to remain in the aqueous phase rather than sorb to sediments or bioaccumulate (NICNAS, 1995). Limited studies have however reported uptake into aquatic organisms: Xu et al. (1988) observed xanthate accumulation in *Daphnia magna*, and Block and Pärt (1986) documented enhanced metal bioaccumulation in the presence of xanthates and thiocarbamates. Still, given the limited data, the role of biota as a potential xanthate sink for further screening remains unclear.

The primary xanthate degradation product, carbon disulfide (CS_2), typically escapes to air and is unlikely to accumulate in water. While headspace analysis of CS_2 in xanthate-containing water samples is possible, it is difficult to distinguish if

the detected CS_2 is the result of xanthate degradation in the sampled environment or degradation induced from sample handling and analysis. Methods to degrade xanthates from mineral wastewater have however become increasingly investigated (e.g. Raj and Tembhurkar, 2024), both for the purpose of increasing reusability of the process water and to ensure safe discharge conditions. However, complete removal is still challenging and no industrial scale method has been implemented yet (Wang et al., 2024).

The thiocarbamate is less water-soluble than xanthates and may therefore persist longer in the aquatic environment. It is still not likely that the thiocarbamate binds to sediments (ECHA CAS 141-98-0), and no studies have been found on bioaccumulation. Information on degradation products are also scarce even though intermediates of the thiocarbamate have been flagged as of potential toxic concern (Wang et al., 2021). While suspect-screening approaches could be employed to detect these intermediates, the absence of toxicity data for aquatic organisms makes it difficult to justify the cost investment.

6 Summarizing conclusions

Within this screening project for flotation chemicals downstream of Swedish mining operations, robust methods were developed and applied to detect target compounds at low environmental concentrations. Surface water samples were collected during fall 2024 and winter/spring 2025 from four Swedish mining sites and analyzed using the developed methods. Key results include:

- A selective SPE–LC-MS/MS method was established for four xanthates and one thiocarbamate, with detection limits of 0.1–0.4 µg/L and quantification limits of 0.3–1.3 µg/L. Stability tests showed that xanthates degrade rapidly under acidic conditions or thawed from frozen conditions. Best results were achieved by refrigerating samples buffered to pH ≥ 10 and analyzing them within 48 hours.

- In total, 85 surface water samples were analyzed, with flotation chemicals detected in 34 samples at concentrations ranging from 0.2 to 250 µg/L. These levels are lower but comparable with those reported in the 1980s (2–3000 µg/L; Walterson, 1984).

- More than 70% of detections were below 10 µg/L, which is lower than most reported toxicity measures. However, available toxicity data is highly scattered with PNEC levels ranging between 1 and 1500 µg/L. Considering

the limited number of snapshot observations of this screening project, robust conclusions on ecological risks are therefore not possible to draw.

Recommendations for further work:

- This study provides a snapshot in time of detected flotation chemicals. To better understand temporal variability and dilution effects—especially in colder climates considering long frozen periods and spring snowmelt dynamics—we need repeated sampling across seasons and mass balance calculations along stream networks.

- Existing toxicity data primarily focus on acute LC_{50} values for fish. Additional studies targeting other trophic levels using sublethal endpoints and chronic effects would improve understanding of potential broader ecosystem responses.

- Synergistic effects between flotation chemicals and metals have previously been shown to increase toxicity. Further testing under environmentally relevant concentrations is needed to evaluate these interactions in current effluent discharges.

- Monitoring of degradation products, e.g., via headspace analysis for CS_2 or suspect screening for thiocarbamate intermediates, should be integrated with detailed water sampling and transport assessments to clarify environmental fate and potential risks.

7 Reference list

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Appendix

Table A1. *Average (of duplicates) chemical concentration from each mine from the sampling campaigns in the fall 2024 and the winter/spring 2025. The ranges of detection limits (DL) come from the individual analysis runs. The order of the sampling locations (Place 1-14) corresponds to the reported IDs at the SGU data repository. NA indicates where no analysis was carried out.*

Sample			Butyl xanthate (µg/L)	Amyl xanthate (µg/L)	Ethyl xanthate (µg/L)	Isopropyl xanthate (µg/L)	Thio-carbamate (µg/L)
Detection limit (DL)			0.1-0.3	0.1-0.4	0.3	0.3-0.4	0.1-0.2
Quantification limit (QL)			0.2-0.9	0.2-0.6	1	0.9-1.2	0.3-0.7
Mine 1	Autumn	Place 4	< DL	< DL	NA	NA	< DL
		Place 5	< DL	< DL	NA	NA	< DL
		Place 6	< DL	< DL	NA	NA	< DL
		Place 7	< DL	< DL	NA	NA	< DL
	Winter	Place 4	< DL	< DL	< DL	< DL	1.2
		Place 5	< DL	< DL	< DL	< DL	0.8
		Place 6	< DL	< DL	< DL	< DL	0.8
		Place 7	< DL	< DL	< DL	< DL	0.4
Mine 2	Autumn	Place 8	< DL	< QL	NA	NA	2.1
		Place 9	< DL	< DL	NA	NA	< QL
		Place 10	< DL	< DL	NA	NA	< DL
		Place 11	< DL	< DL	NA	NA	< DL
	Winter	Place 8	247.5	158.5	6.0	2.6	9.9
		Place 9	91	38	3.8	1.3	8.4
		Place 10	< DL	0.2	< DL	< DL	< DL
		Place 11	35.8	11.2	1.4	0.5	4.6
Mine 3	Autumn	Place 1	6.15	37.8	NA	NA	< DL
		Place 2	0.65	1.25	NA	NA	< DL
		Place 3	< DL	< DL	NA	NA	< DL
	Winter	Place 1	6.6	27.1	NA	< QL	NA
		Place 2	3.9	11.2	NA	< QL	NA
		Place 3	< DL	< DL	NA	< DL	NA
Mine 4	Autumn	Place 12	NA	NA	NA	NA	NA
		Place 13	NA	NA	NA	NA	NA
		Place 14	NA	NA	NA	NA	NA
	Winter	Place 12	NA	NA	NA	16.2	NA
		Place 13	NA	NA	NA	13.7	NA
		Place 14	NA	NA	NA	0.9	NA

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This report has been reviewed and approved in accordance with IVL's audit and approval management system.