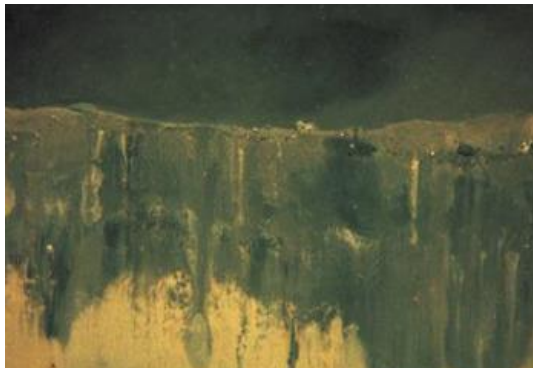
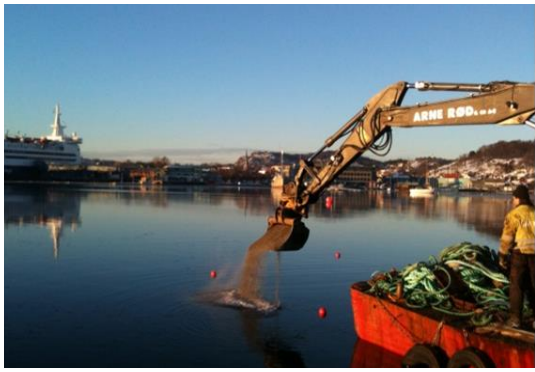
Swedish Geotechnical Institute

In-situ capping of contaminated sediments

Contaminated sediments in Sweden: A preliminary review

Joseph Jersak, Gunnel Göransson, Yvonne Ohlsson, Lennart Larsson, Peter Flyhammar, Per Lindh





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SGI Publication 30-1E, Main text. *In-situ* capping of contaminated sediments. Method overview.

SGI Publication 30-2E. *In-situ* capping of contaminated sediments. Contaminated sediments in Sweden: A preliminary review.

SGI Publication 30-3E. *In-situ* capping of contaminated sediments. Established *ex-situ* and *in-situ* sediment remediation technologies: A general overview.

SGI Publication 30-4E. *In-situ* capping of contaminated sediments. Remedial sediment capping projects, worldwide: A preliminary overview.

SGI Publication 30-5E. *In-situ* capping of contaminated sediments. Capping Sweden's contaminated fiberbank sediments: A unique challenge.

SGI Publication 30-6E. *In-situ* capping of contaminated sediments. An extensive, up-to-date collection of relevant technical and other international references.

SGI Publication 30-7. *In-situ* övertäckning av förorenade sediment. Övergripande sammanfattning. (In Swedish)

SGI Publication 30-7E. *In-situ* capping of contaminated sediments. Overall summary.

Fact sheet. *In-situ* capping of contaminated sediments. Method overview.

1. Introduction

There appears to be no readily available and up-to-date, single document that inventories contaminated sediment sites in Sweden. What is available are summaries of contaminated areas each county publishes and updates at least periodically (regional programs). Also available are documents related to: regional or national environmental monitoring programs; methods for conducting risk assessments, including risk classification of sites; and a mapping of fiberbank deposits and fiber-rich sediments in selected counties.

Conducting a detailed review of the above (and additional) documentation to create a complete list of contaminated sediment sites in Sweden was beyond the scope of this capping overview project. Nevertheless, conducting a preliminary review of readily available information was necessary to place focus of the capping overview project into more of a national context.

To underscore: This is only a preliminary review of contaminated sediment sites in Sweden. There is considerable merit, for a number of reasons, in conducting a follow-up review of such sites that is more expansive, detailed, up-to-date and which incorporates input from multiple informed parties and perspectives.

2. Results of preliminary review

Results of the preliminary review conducted to obtain a general understanding of the occurrence of contaminated sediments in Swedish waters are summarized in Table 1.

3. Summary

Results of the preliminary review conducted to obtain a general understanding of the occurrence of contaminated sediments in Swedish waters are summarized in Table 1. Note, the table intends to illustrate there are a significant number of contaminated sediment sites or areas identified throughout Sweden. It is not intended to provide a complete listing of such sites.

- Contaminated sediments of some type are identified to occur at specific sites or in certain areas within at 19 of Sweden's 21 counties.
- Sediment contamination occurs in a wide variety of inland and coastal aquatic environments, including in lakes, ponds, rivers, creeks, harbors, and bays.
- Different types of contaminated sediments occur in Sweden: mineral-based (minerogenic) sediments and cellulose-based (fiberbank) sediments. Fiberbank sediments comprise either more-or-less pure fiberbank deposits or fiber-rich sediments, which are a mix of fiberbank and minerogenic sediment materials.
- Contamination in minerogenic sediments comes from a wide variety of mainly historical point-source releases from past industrial and other operations. The point sources can be decades to centuries old and include shipyards, wood impregnation, glass and battery manufacture, leather tanning, and gas and metal works. Contaminant inputs to surface waters

continue in a number of areas, but they are mainly non-point-source releases, e.g. combined sewer overflows.

- Contamination inherently contained in fiberbank deposits – including the sediments themselves – come exclusively from past discharges from pulp and papermill operations. Contamination in fiber-rich sediments may come from multiple sources.
- Different types of dissolved-phase sediment contamination occurs across the country, including metals (Pb, Cu, Zn, Cd, Ni, Hg, Cr, As, etc.), organics (dioxins, PCBs, PAHs, chlorinated solvents, hydrocarbons, PCDD/PCDF, etc.), and organometallics (including tributyltin [TBT] and methylated Hg). New or "emerging" contaminants, which could include PFOS (perfluorooctane sulfonate) and PFOA (perfluorooctanoic acid), have also been noted in at least one county (Stockholm).
- A broad range of organic, metallic, and/or organometallic contaminants can occur in minerogenic sediments, given the broad range of possible contaminant sources. In contrast, fiberbank deposits, and likely many fiber-rich sediments, are usually contaminated by a smaller list of contaminants (DDTs, PCBs, PAHs, dioxins, and Hg [including methylated Hg]).
- Although apparently less common, sediments at some sites are also or instead contaminated by non-aqueous phase liquids (NAPLs), including oil (in Halland, Södermanland, Västra Götaland, and Östergötland) or creosote (in Jönköping and Örebro).
- Contaminated minerogenic sediments occur more-or-less throughout the entire country. Fiberbank sediments occur mainly (but not only) in Norrland, where forest-industry activities have historically been most concentrated. Contaminated fiberbank sediments occur in at least 10 counties, and may also occur in a number of other counties as well (where papermill operations have occurred).
- Sediment risk assessments and risk classifications are referenced for some contaminated sites or areas (in Dalarna, Jämtland, Jönköping, Uppsala, Västernorrland, and Örebro). Sites at which risks have been classified (in Dalarna, Uppsala, and Örebro) occur at either high (Class 2) or very high (Class 1) levels.
- Ongoing site- and/or area-specific investigations to further characterize the nature and extent of sediment contamination are referenced for some counties (in Jämtland, Västernorrland, and Västra Götaland).
- Implementation of regional and/or national programs for monitoring concentrations of various metallic and organic contaminants in sediments over time is referenced for some counties (in Kalmar, Norrbotten, Skåne, Stockholm, Västerbotten, and Västra Götaland).
- Implementation of programs and related projects for mapping the occurrence of fiberbank deposits and fiber-rich sediments is referenced in some counties, mainly those in Norrland.

It is obvious (even from this preliminary review) many more contaminated sediment sites and/or areas have been identified in some counties than in others. Why is that? Do some counties simply have more sediment contamination than others? Have investigations been more thorough in some counties than in others? Is addressing contaminated sediments a higher priority for some counties than for others? Do some counties have more funding available to address contaminated sediments than others?

In closing, based on results of this preliminary review, it is reasonable to conclude:

- National, regional, and/or local authorities recognize some type of sediment remediation is needed today – if not already being implemented or planned – at a number of sites at which unacceptable sediment-related risks have been documented.
- Sediment remediation will be needed in the near future at an additional number of sites, once sediment risk assessments and classifications have been completed and unacceptable sediment-related risks are documented.
- Additional sites may require sediment remediation in the future, once the nature and occurrence of contamination has been investigated, risk assessments and classifications have been completed, and unacceptable sediment-related risks have been documented.

Note: For all references cited herein, please see SGI Publication 30-6E.

Table 1 Summary of a preliminary review of contaminated sediment sites and areas in Sweden.

County	References	Occurrence of contaminated sediments in Swedish surface waters (selected highlights)
Blekinge	Länsstyrelsen Blekinge 2014.	- General references to: • Program for monitoring environmental contaminants, including in sediments (Länsstyrelsen, Blekinge, no date). • Hg-contaminated discharges from papermill (pappersbruk) factories. - Specific references to: • TBT sediment contamination in three harbors (Karlskrona, Ronneby, and Sölvesborg). Also expected in other harbors. • A copper works site, where sediments in associated surface-water body are contaminated by Cu. • A sawmill site (Backaryd sågverket), where sediments in associated surface-water body (type[s] unclear). • Another sawmill site (Johannishus såg), where sediments in associated surface-water body contaminated by dioxins.
Dalarna	Länsstyrelsen Dalarna, 2011.	- General references to: • Surface sediments in 18 of 77 lakes and ponds show “great” to “very great” impacts from mainly metals (including Cu, Cr, Hg, Zn, and As) and/or some organics (including hexachlorocyclohexane, some PCBs, and some PAHs). • Sediment risk assessments conducted for seven of the 18 lakes/ponds. All seven fall under either risk-class 1 or 2. Note: According to Naturvårdsverket’s MIFO risk classification system (e.g. Naturvårdsverket, 2009b), risk-class 1 represents a “very high risk” whereas risk-class 4 represents “little risk” to human health and/or the environment.
Gotland	Länsstyrelsen, Gotland, 2012.	
Gävleborg	Länsstyrelsen Gävleborg, 2014, 2016.	- General references to: • Sediment contamination by metals (Hg, Pb, Cd, Zn, and Cu) in coastal waters, particularly in Gävle fjärden. • Presence (and systematic inventory) of fiberbank and fiber-rich sediments (north of Dalälven), derived from former pulp/paper mill activities, which are contaminated by Hg, dioxins, and/or organochlorines. • Presence of high levels of dioxin in Baltic herring along the coast line, and that contaminated areas can contribute to this problem. - Specific references to: • Ongoing fiberbank project (i.e. surveying fiberbank deposit and fiber-rich sediment areas) as well as dredging in Gävle Harbor. For reference, see: http://pure.ltu.se/portal/sv/studentthesis/stabilisering-och-solidifiering-av-muddermassor-i-gavle-hamn(4fc31055-4961-4a21-beda-1c4f749a381d).html. • Remediation project in Håstaholmen (risk classification, priority 1, remediation of dioxin-contaminated sediment planned). • Use of new methodology for risk classification of fiber-rich sediments, as developed by Västernorrland’s County Board. For reference, see: Länsstyrelsen www.lansstyrelsen.se/Vasternorrland/Sv/publikationer/2016/Pages/metodik-for-riskklassning-av-fiberhaltiga-sediment.aspx.

Halland	Länsstyrelsen Halland, 2014.	- General references to: • Multiple papermill (pappersbruk) factories operating, past or present. • Sediment contamination in small-boat harbors. Contaminant type(s) unclear. - Specific references to: • A shipyard site (in Ätran), where sediments in associated surface-water body are contaminated by TBT, Cu, Cr, Pb, and PCBs. • A pulp/paper mill site (Oskarströms sulfitfabrik), where sediments in associated surface-water body are contaminated by mainly oil and Hg. • An industrial site (Industri Zink), where sediments in associated surface-water body contaminated by metals and/or chlorinated solvents and/or chlorinated aliphatics. • Another production site (Rydöbruk Sulfit), where sediments in associated surface-water body are contaminated by various metals and/or organics.
Jämtland	Länsstyrelsen, Jämtland 2013.	- General reference to inventory and investigations of fiberbank sediments (associated with old mills), which are likely contaminated by various organic pollutants and metals (including Hg). - Specific references to: • A pulp-mill site (Järpens massafabrik), where sediments in associated river and lake are contaminated by metals. • A charcoal-production site (Tjärfabrik Grötingen), where sediments in associated surface-water body are contaminated by PAHs, aliphatics, and aromatics, as well as some metals. Risk assessments also referenced. • A production site (Ulriksfors sulfitfabrik), where sediments in associated lake are contaminated by Hg.
Jönköping	Länsstyrelsen Jönköping, 2011.	- Specific references to: • A wood-impregnation site (in Grimstorp), where sediments in associated lake (Lillesjön), are contaminated by As. Risk assessments also referenced. • A paper-mill site, where fiber sediments in associated lake (Munksjön) are contaminated by Hg, other metals, hydrocarbons, and organic substances such as PCBs and dioxin. Possible/likely impacts from discharges from municipal water-treatment plant also referenced. Risk assessments also referenced. • Another wood-impregnation site (Banverkets Impregneringsanläggning), where sediments in associated surface-water body are contaminated by As and creosote.
Kalmar	Länsstyrelsen Kalmar, 2014; 2015.	- General reference to characterizing contaminant status in lake sediments, including implementing Naturvårdverket's monitoring program for specifically documenting occurrence of metal contamination. - Specific references to: • Oskarshamn's harbor basin, where sediments are contaminated by dioxins and various metals. • Four glass-factory sites, or glasfabrik (Alsterbro, Åfors, Gullaskruv, and Målerås), where sediments in associated surface-water bodies are contaminated by As, Pb, and/or Cd. • Two battery-factory sites (Batterifabriken, in Hultsfred; Emåns), where sediments in associated surface-water bodies are contaminated by Pb and Cd. Emåns site also previously contained a former paper plant (sediments in associated surface-water body are contaminated by PCBs). • Two sites (Nedsjön and Nötöfjärden), where fiber-rich sediments in associated surface-water bodies are contaminated by Hg. • A site (Vapenbäcksån), where sediments in associated surface-water body contaminated by Pb and As. • A site (Hulingen), where sediments in associated surface-water body contaminated by Hg and Pb. • A site (Skeppsbrofjärden), where sediments in associated surface-water body contaminated by TBT.
Kronoberg	Länsstyrelsen	

	Kronoberg, 2012.	
Norrbotten	Länsstyrelsen Norrbotten, 2014a; 2014b.	- General references to: • Occurrence of contaminated sediments along coast, including the influence long-term land uplift (due to post-glacial rebound) could have on: (1) increased contaminant dispersion due to increased coastal erosion, and (2) significant reductions in pH (due to oxidation of pyrite-bearing clay soils), which may, in turn, affect mobility of some metals. • Characterizing metal-contamination status in marine sediments (compliment to national monitoring program). • The need for study of TBT in harbor areas. • Results from previous surveys of small coastal rivers, which indicated sediment contamination by metals. - Specific references to: • A pulp/paper mill site (Karlshäll), where fiberbank and fiber-rich sediments in associated water body (bay) are contaminated by Hg. • A site (Sjön Ala Lombolo) where ammunition was dumped in a lake and sediments are contaminated by Hg.
Skåne	Länsstyrelsen Skåne, 2013; 2014.	- General references to: • Multiple papermill (pappersbruk) factories operating, past or present. • Monitoring program focused on, among other things, organic and other contaminants in sediments.
Stockholm	Länsstyrelsen Stockholm, 2014a; 2014b; 2014c; 2015.	- General references to: • Contamination of sediments in surface-water bodies in many suburban areas. • Metals-contaminated sediments in urban-area lakes. • Sediments contaminated by metals (e.g. Pb, Cd, Cu, Hg, and Zn) and organics in Stockholm vicinity and in the archipelago. High levels of Hg in fish in Central Stockholm linked to Hg contamination in sediment. • Sediments in Lake Mälaren contaminated by metals and other environmental toxins. • Contaminated sediments in many other lakes occurring adjacent to buildings, roads, and industrial areas. • Monitoring to document/track metal and PAH contamination of surface sediments in the archipelago and Lake Mälaren. • Presence of sediment contamination by new or “emerging” contaminants, which could include PFOS (perfluorooctane sulfonate) and PFOA (perfluorooctanoic acid). - Specific references to: • Two papermill (pappersbruk) sites (on Lakes Turingen and Tollare) at which Hg-contaminated sediments, including fiberbank sediments, have been capped. • A surface-water body (Brunnsviken), where sediments are contaminated by PCBs and PAHs. • Surface-water bodies (Södertälje kanal; Snäckviken), where sediments are contaminated by Hg. • Surface-water bodies (Oxundasjön; Rosersbergsviken), where sediments are contaminated by PCBs and dioxins.
Södermanland	Länsstyrelsen Södermanland, 2014.	- General references to multiple papermill (pappersbruk) factories operating, past or present. - Specific references to: • A gas-works site (Slottsvakten gasverk), where spread of contaminants, including PAHs and cyanide, to associated river (Nyköpingsån) possible. • A metal-works site (Tunaverken, Valhalla), where some spread of metals to associated small creek. • A landfill site (Kungshagens deponi), where sediments in an associated river (Stadsfjärden) are contaminated by PAHs. • A oil-production site (Bränsledepå BP), where spreading of oil-based contaminants to associated river (Nyköpingsån) possible.

		• A site (Ålöfjärden), where sediments contaminated by Pb, Cd, PAHs, and PCBs, and there is high risk for contaminant spreading by boat traffic. • A site (Vårdkasen 5, Båtsliperi), where sediments contaminated by PAHs, and the extent of spreading is unknown.
Uppsala	Länsstyrelsen Uppsala, no date; 2015.	Specific references to: • A mining area (Dannemora gruvområde), where sediments in the associated surface-water body are contaminated by metals, including As. • An industrial site (Skutskärs bruk), where sediments – including fiber sediments – in associated surface-water body are contaminated by Hg, dioxins, Pb, Cu, and Zn. • An industrial area (Österbyverkens industiområde), where sediments in associated surface-water bodies, including a lake (Filmsjön) are contaminated by various metals. • An industrial site (Tärnsjö Ånggarveri), where sediments in associated lake (Tärnsjön) are contaminated by Cr. Result of risk assessments place site in risk-class 1.
Värmland	Länsstyrelsen Värmland, 2011.	General references to multiple paper industries (pappersindustri) operating, past or present.
Västerbotten	Länsstyrelsen Västerbotten, 2010; 2015.	General reference to Umeå University's monitoring program for measuring dioxin contamination in bay sediments.
Västernorrland	Länsstyrelsen Västernorrland, 2014.	General references to: • Investigations in Sundsvall Bay, where contamination of sediments by various pollutants (PAHs, Hg, and organochlorine compounds) is known or suspected. • Occurrence of fiber-rich sediments (in surface-water bodies) outside of Svanö and Hallstanäs, as investigated by SGU. • SGU's fiberbank mapping project, to provide information on occurrence and contamination status of fiberbanks along the coast. Development of methodology for risk classification of fiberbanks and fiber-rich sediments also referenced.
Västmanland	Länsstyrelsen Västmanland, 2014.	- General reference to sediment studies in Hallstahammars bruk delområde; no specifics on contaminant type(s).
Västra Götaland	Länsstyrelsen Västra Götaland, 2013.	- General references to: • Monitoring program for a former industrial area, where past discharges/releases resulted in contamination of sediments in an associated lake (Laxsjön) by multiple pollutants (dioxins, PCP, oil, Hg and other metals, phthalates and more). • Ongoing spread of TBT (as well as Cu and Zn) to the marine environment. • Mapping of TBT contamination in sediments in small-boat harbors in different areas (Vänern, Mjörn, Göta River, and the west coast) indicates continued high concentrations. • Multiple paper industries and mills (pappersindustrier, pappersbruk) operating, past or present. - Specific references to: • Mapping of dioxin-contaminated sediments in Vänern, linked mainly to paper-mill industries. Elevated dioxin levels in fish also referenced. • Multiple contaminants in sediments in Laxsjön, apparently related to – among other possible/likely sources – operations at

		local paper mills (pappersindustrier). • A glass-production site (Ardagh Glass Limmared AB), where contamination of sediments by various metals (Pb, As, and Cd) in an associated surface-water body investigated. • An industrial site (Göta Färgeri Mossgropen), where sediments in an associated pond are contaminated by oil, metals, and nonylphenol. • Investigation of sediment contamination in surface-water bodies associated with two forest-industry sites (Munksjö Paper and Rexcell Tissue).
Örebro	Länsstyrelsen Örebro, 2013.	- General reference to at least one papermill (pappersbruk) factory operating in the past. - Specific references to: • Wood-impregnation sites (Åsbro), where sediments in associated lake (Tisaren) are contaminated by creosote. • A sawmill site (Silverhöjdens sawmill), where sediments in associated lake (Hörken) are contaminated by PCP, dioxins, and chlorophenols. • A shooting-range site (Bofors), where sediments in associated lake (Långssjön) are contaminated by metals, mainly Hg and Pb (but also As; Cu and Ni). Risk assessment results indicate site is risk-class 1. • An industrial site (Sikfors bruk), where sediments in associated surface-water body contaminated. Contaminant type(s) not identified. Risk assessment results indicate site is risk-class 2.
Östergötland	Länsstyrelsen Östergötland, 2014.	- General references to the occurrence of multiple papermills (pappersbruk), both past and present. - Specific references to: • A papermill site (Kisasjön), nearby to which occurs fiberbank sediments contaminated by Hg. • A leather-tanning site (Lundbergs Läder), where sediments in associated surface-water body (Valdemarsviken) are contaminated by Cr. • A sawmill site (Ydrefors träförädling), where sediments in associated lake (Brosjön) are contaminated by dioxins. • Another sawmill site (Bestorp sågverk), where sediments in associated lake (Stora Rängen) are contaminated by dioxins. • A site (Gusumsån) impacted by discharge of untreated industrial wastewater, where sediments in associated river (Gusumsån) are contaminated by PCBs, Cu, Zn, and Pb). • A glass-factory site (Reijmyre glasbruk), where sediments in associated lake (Hunn) are contaminated by As. • An industrial area (Skutbosjön), where sediments contaminated by metals (Cu, Cr, Hg, Ni, and Zn) as well as PAHs, PCBs, and heavy aliphatic hydrocarbons. • An industrial mill site (Qvarnshammars Jernbruk [De Geersfors]), where sediments in associated river (Godegårdsån) are contaminated by metals (Cr, Cu, Pb, Zn, and Cd) and oil. Contamination also detected in crayfish. • A wood-industry site (Per Blomquist AB), where sediments in associated river (Lillån) are contaminated by dioxins.

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