Does remediation save lives?

On the cost of cleaning up arsenic-contaminated sites in Sweden

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KONJUNKTURINSTITUTET, KUNGSGATAN 12-14, BOX 3116, SE-103 62 STOCKHOLM

TEL: +46 8 453 59 00 FAX: +46 8 453 59 80

E-MAIL: KI@KONJ.SE HOMEPAGE: WWW.KONJ.SE

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Sammanfattning

I politiken betonas ofta vikten av att samhällsmål nås med kostnadseffektiva åtgärder. För åtgärder som sparar liv innebär det att resurser fördelas till åtgärder med lägst kostnad per sparat liv oavsett politikområde. Ett styrmedel av stor ekonomisk omfattning som syftar till att minska hälso- och miljöriskerna är Naturvårdsverkets sakanslag för sanering av förorenade områden. I den här rapporten analyserar Konjunkturinstitutet vad det kostar att spara liv genom sanering. Analysen av kostnaderna visar att livräddande insatser inom saneringsarbetet värderas implicit många gånger högre än åtgärder för att spara liv inom till exempel trafiken. Mot bakgrund av dessa resultat anser vi det angeläget att det förs en allmän diskussion om hur samhällets resurser ska användas för att rädda liv.

BAKGRUND

Regeringen har beslutat att sexton miljömål med tillhörande delmål ska vara vägledande för Sveriges utveckling i riktning mot ett hållbart samhälle. Miljömålet ”Giftfri miljö” har två delmål som rör sanering av förorenade områden. Enligt dessa delmål ska samtliga förorenade områden som innebär akuta risker vid direktexponering vara utredda, och vid behov åtgärdade, till 2010. Dessutom ska åtgärder ha genomförts i så stor andel av de prioriterade områdena att miljömålet i sin helhet ska vara uppnått senast år 2050.

I dag finns drygt 80 000 förorenade områden i Sverige. Av dessa tillhör ca 1 500 områden risk klass 1, vilka utgör störst risk för hälsa och miljö. Hittills har sanering av förorenade områden kostat drygt tre miljarder kronor. Att sanera de mest förorenade områdena beräknas kosta ytterligare 60 miljarder kronor. Naturvårdsverket leder arbetet med efterbehandling av förorenade områden i Sverige. Via ett statligt sakanslag, planerar och genomför de efterbehandlingsåtgärder i samarbete med berörda länsstyrelser och kommuner. Sakanslaget uppgår till ca 0,5 miljarder kronor per år vilket motsvarar ca 10 procent av miljöpolitikens årliga utgifter.

RISKBEDÖMNING

För att göra det möjligt att prioritera mellan förorenade områden har Naturvårdsverket utvecklat en metodik för riskbedömning. Naturvårdsverkets riskbedömning tar sällan hänsyn till den verkliga exponeringen vid ett förorenat område utan stannar ofta vid att mäta halten i marken och jämföra med ett visst riktvärde. Principiellt innebär det att ett område kan saneras utan att någon människa faktiskt exponeras. Det sker således ingen kvantifiering av saneringens förväntade riskreduktion, vilket eliminerar möjligheten att göra ekonomiska värderingar av riskminskningen som sedan skulle kunna vägas mot saneringskostnaden. Den här rapporten analyserar hur hälsoeffekter från förorenade områden värderas implicit i efterbehandlingsarbetet, genom att utgå från en miljömedicinsk ansats som tar hänsyn till faktisk exponering. I en sådan ansats beaktas huvudsakliga exponeringsvägar med traditionell toxikologisk metodik. Exponerings-responssamband från den vetenskapliga litteraturen används för att kvantifiera de olika föroreningarnas hälsoeffekter.

FOKUS PÅ ARSENIK I ANALYSEN

Av de 1 500 områdena som tillhör risk klass 1 har ca 80 områden pågående eller avslutad sanering som är finansierad med statliga bidragsmedel. Även om områdena har förorenats av flera föroreningar kan man i många fall definiera en så kallad primär förorening. Den primära föroreningen är ofta den förorening som är farligast, förekommer i störst mängd och är vägledande för ambitionsnivån på efterbehandlingsinsatserna. Bland de högst prioriterade objekten utgör arsenik den enskilt vanligaste föroreningen. Arsenikföroreningarna härstammar från tidigare industriella aktiviteter i form av exempelvis träimpregneringsanläggningar och gruvor. Arsenik sprids från förorenade områden huvudsakligen med grundvatten, men luftburen spridning förekommer också. För arsenik är hälsoriskerna (inte miljöriskerna) vägledande för saneringsarbetet. Eftersom riskerna kan vara många är det endast de risker som förväntas vara styrande för resultaten som behöver kvantifieras. Arsenik är cancerframkallande och det är endast för cancerogena ämnen som risken kan uppskattas kvantitativt, det vill säga uttryckas i antal extra cancerfall under en livstid.

Det finns 23 arsenikområden i riskklass 1 med pågående eller avslutad sanering. För att kvantifiera den extra cancerrisk som orsakas av arsenikexponering används exponerings-responsfunktioner för de huvudsakliga exponeringsvägarna: inandning av luft, intag av jord och hudkontakt. Vi utgår från markanvändningen som indikerar vistelsetiden för att omvandla antal exponerade individer till antal heltidsexponerade individer som vistas på området. Sedan används medelhalten på området för att beräkna koncentrationen för varje exponeringsväg. Slutligen appliceras exponeringsresponsfunktioner för att beräkna saneringens riskreduktion. Därefter används saneringskostnaden för att beräkna kostnaden per sparat liv i saneringsarbetet.

RESULTAT

Resultaten visar på förvånande små hälsoeffekter från saneringsarbetet. Som mest sparas det 0,03 liv genom sanering av ett av områdena. Totalt sparas på arsenikområdena 0,12 liv till en förväntad kostnad på 881 miljoner kronor. Kostnaden per sparat liv varierar mellan 287 miljoner kronor och 1 835 miljarder kronor. Det överstiger vida värdet av ett statistiskt liv som uppgår till 21 miljoner kronor. Även om vi fördubblar värdet av ett statistiskt liv (vilket föreslagits i riskvärderingslitteraturen för att ta hänsyn till att värderingen av riskreduktionen från miljörelaterad dödlighet skiljer sig från värderingen av riskreduktionen från trafikrelaterad dödlighet) så är skillnaden mycket stor. Detta trots att vi i våra antaganden har varit konservativa, det vill säga sannolikt överskattat exponeringen och därmed hälsoeffekten och således underskattat kostnaden per sparat liv. Intressant att notera är att 72 procent av de beräknade hälsoeffekterna åstadkoms på tre områden vilka har sanerats till 13 procent av de totala kostnaderna för arsenikområdena. Det understryker vikten av rätt prioriteringar i saneringsarbetet. Vi har även räknat på hur många exponerade som krävs för att spara ett liv på varje område. Resultaten visar att antal exponerade måste i vissa fall öka så mycket att de överstiger antalet invånare i kommunen. Trots osäkerheten i analysens antaganden illustrerar det här att ambitionsnivån i saneringsarbetet är hög och i vissa fall kanske orimligt hög.

Baserat på våra resultat anser vi det därför angeläget att det förs en allmän diskussion om hur samhällets resurser ska användas för att rädda liv inom olika politikområden. Vilken hälsorisk är acceptabel vid förorenade områden och hur och varför skiljer den sig jämfört med andra hälsorisker? Som jämförelse kan nämnas att bostadsradon varje år beräknas orsaka 400 nya fall av lungcancer, och luftföroreningar utomhus flera tusen förtida dödsfall per år. Om miljörelaterade hälsorisker ska förebyggas finns det sannolikt områden där ekonomiska insatser kan göra mer nytta.

Tabell 1 Antal sparade liv, kostnader och resultatjämförelser

Område	Total kostnad (kr)	Antal sparade liv**	Kostnad per sparat liv (miljoner kr)	Antal exponerade individer	Antal exponerade som krävs för att spara 1 liv
Akterspegeln*	23 185 000	0,0098	2 357	100-1 000	104 000
Robertsfors	59 433 934	0,0010	60 785	10-100	103 000
Burträskbygden	7 620 350	0,0008	9 341	1-10	12 500
Tvärån*	15 494 619	0,0219	707	10-100	4 600
Svartbyn*	2 122 176	0,0015	1 427	1-10	6 700
Sjösa	32 748 762	0,0013	25 884	10-100	79 000
Lyshälla*	1 227 383	0,0035	348	1-10	2 850
Mjölby	2 703 250	0,0000	121 505	1-10	450 000
Rimforsa	9 820 099	0,0001	76 520	1-10	78 000
Hjulsbro	1 219 711	0,0005	2 613	10-100	215 000
Glasbrukstomten	88 000 000	0,0344	2 559	100-1 000	35 000
Grimstorp	126 910 779	0,0015	82 672	1-10	6 500
Elnaryd	84 834 848	0,0003	254 208	1-10	30 000
Högsby–Ruda*	75 400 000	0,0047	16 049	10-100	47 000
Tröingeberg	9 350 919	0,0026	3 653	10-100	39 000
Oxhult*	2 853 000	0,0018	1 580	1-10	5 500
Gudarp	73 666 537	0,0002	419 213	10-100	570 000
Konsterud*	9 087 563	0,0317	287	10-100	3 200
Kramfors*	15 072 604	0,0018	8 373	1-10	5 600
Svanö*	34 080 000	0,0019	18 169	10-100	53 500
Svartvik	84 932 698	0,0000	1 834 629	1-10	215 000
Forsmo*	24 658 432	0,0005	53 126	1-10	21 500
Fagervik	96 539 845	0,0002	601 087	10-100	620 000
Total	880 962 509	0,1219	7 227		

Anm.* Indikerar att saneringen är avslutad. För de pågående saneringsområdena är den totala kostnaden uppskattad. Kostnaden är hämtad från kvartalsrapporter från länstyrelserna till Naturvårdsverket (kvartal 4, 2007).** Avrundat till fyra decimaler.

Contents

1. Introduction

Swedish environmental policy is based on 16 environmental quality objectives (Gov. Bill 2000/01:130 and Gov.Bill 2004/05:150).[1] One of the most challenging objectives, 'A non toxic environment', has two interim targets that concern remediation of contaminated sites. In sum, they state that the highest priority should be given to sites posing the highest risks to human health and the environment.[2] By eliminating pollutants in soil, groundwater and sediment, the interim targets aim to reduce risks to human health and the environment. In Sweden, 83,000 sites are potentially contaminated due to previous industrial activities. According to the Swedish Environmental Protection Agency (EPA), the administrator of the governmental funds for remediation, approximately 1500 of these sites contain contaminant concentrations that could seriously harm human health and the environment (Swedish EPA, 2008a). To reach the interim targets, all these sites need to be remediated by 2050. Remediation of contaminated sites has so far cost more than SEK 3,000 million.[3] The approximated cost to mitigate the potential risks at the most harmful sites is estimated at SEK 60,000 million.[4] The Swedish government's funding for remediation presently comes in the form of a directed grant (*sakanslag*). The directed grant, administrated by the Swedish EPA, subsidises remediation of contaminated sites that were contaminated prior to modern environmental legislation (in 1969) or for which no liable party can be found. The directed grant amounts to approximately 455 millions annually, which corresponds to about 10 percent of the annual national funds for environmental protection (Gov. Bill 2007/08:1). To make it possible to prioritise among contaminated sites, the Swedish EPA has developed a method for risk assessment called the 'MIFO' (i.e. the Method for Inventory of Contaminated Sites). The risk assessment does not take into account the actual exposure at a contaminated site. Risk is instead assessed based on divergence from guideline values for acceptable concentrations given a standardised (i.e. worst case) exposure situation on an individual level. This means that a site can be remediated without any individuals actually being exposed. The expected risk reduction is consequently not quantified. This eliminates the possibility of valuing the risk reduction, which should be weighed against the remediation cost.

The purpose of this paper is to analyse how health effects, in the form of cancer risks, from sites contaminated by arsenic are valued implicitly in remediation. By using an environmental medicine approach that takes exposure into account, and without underestimating the potential health consequences of arsenic exposure, our purpose is to place arsenic risk management in the overall picture of live-saving interventions. In the case of cancer prevention, it is necessary to recognise that focus on an environmental carcinogen like arsenic may draw public attention – and funding – away from

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[1] The environmental quality objectives are: Reduced Climate Impact; Clean Air; Natural Acidification Only; A Non-Toxic Environment; A Protective Ozone Layer; A Safe Radiation Environment; Zero Eutrophication; Flourishing Lakes and Streams; Good-Quality Groundwater; A Balanced Marine Environment, Flourishing Coastal Areas and Archipelagos; Thriving Wetlands; Sustainable Forests; A Varied Agricultural Landscape; A Magnificent Mountain Landscape; A Good Built Environment; and A Rich Diversity of Plant and Animal Life.

[2] Interim target 6: Studies will have been carried out and, where necessary, appropriate action will have been taken by the end of 2010 at all contaminated sites that pose an acute risk on direct exposure, and at contaminated sites that threaten important water sources or valuable natural environments, today or in the future. Interim target 7: From 2005 to 2010, measures will be implemented at a sufficiently large proportion of the prioritised contaminated sites to ensure that the environmental problem as a whole can be solved by 2050 at the latest.

[3] On average, 1 Euro=SEK 9.61 and 1 USD=SEK 6.58 in 2008.

[4] Based on the sites' average remediation cost of SEK 40 million (Swedish EPA, 2008b).

more important causal factors like tobacco, dietary habits and exercise, and environmental health risks like ambient air pollution and indoor radon. Although environmental pollution accounts for less than ten percent of all cancer cases (Harvard Centre for Cancer Prevention, 1996; Saracci and Vineis, 2007), environmental factors are important to recognize since they may be preventable. We emphasise, however, the inefficiency in becoming overly concerned about small risks while, at the same time, losing sight of the large risks. If society's spending on lifesaving measures with small effects (i.e. a small number of lives saved) crowds out spending on lifesaving measures with large effects, then remediation can, in fact, even be said to *waste* lives.

By using data on 23 arsenic-contaminated sites in Sweden, we estimate the site-specific cancer risks and calculate the cost per life saved by using the sites' remediation costs. Our results show that the cost per life saved through remediation is much higher than that associated with other primary prevention measures, indicating that the ambition level of Swedish remediation may be too high.

2. The cost per life saved in primary prevention

Although valuation of life is difficult, uncertainty-laden and filled with ethical considerations, we do not have a choice between doing it and not doing it. All decisions made by society about lifesaving interventions implicitly reflect the decision makers' valuations. The resulting 'implicit' values of lives can be calculated from the costs of risk-reducing interventions, given the number of lives saved. In contrast, an 'explicit' value of life is a pre-determined value used in e.g. cost-benefit calculations. Thus, implicit values of lives are *ex post* values, i.e. values resulting from measures taken, whereas explicit values are *ex ante* values, i.e. calculation values used before a measure is taken.

Ramsberg and Sjöberg (1997) investigate the cost-effectiveness of 165 lifesaving interventions in Sweden and show that the average *cost per life-year saved* varies from USD 470 to USD 1,245,000 (in 1993 prices). The least costly way of saving life-years was found to be in the 'lifestyle risk' category. That is, by e.g. raising the age on tobacco use and using campaigns against smoking, life-years can be saved at a low cost (conditional on the interventions leading to fewer smokers). Burström (1999) uses Ramsberg and Sjöberg's results to calculate the *cost per life saved* for a subgroup of the interventions, i.e. the primary prevention interventions (see Table 1).

As shown in Table 1, the implicit cost per life saved is, on average, SEK 66.6 million, with a large variation among different sectors from SEK 68,000 to SEK 675 million. The median cost per life saved is approximately SEK 12 million. Rosén et al. (2006) compare the Swedish guideline values for contaminated sites to other risks and find that in some cases, 100-1,000 times higher health risks are accepted in working and housing environments compared to risks from contaminated sites.

From a societal perspective, a cost efficient allocation of resources occurs when the marginal cost of saving one life is equal in all interventions, given the same risk preferences. If the marginal costs differ, resources should be reallocated to the sector with the lowest marginal costs. Departure from this principle implies that fever lives are saved at a given cost.[5]

The literature gives ample evidence on differences in the valuations of different types of risk reductions. Except socioeconomic factors, the character of the risk, the type of consequences, the baseline risk, and the magnitude of the risk reduction may also matter (Rosén et al., 2006). The public's (and therefore the politicians') risk perceptions differ quite substantially from those of experts (Slovic et al., 1981; Chess et al., 2004). Differences in cost per life saved among different sectors can therefore partly be explained by differences in risk perceptions, even if very large differences can hardly be justified (Sjöberg, 2003).

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[5] Tengs and Graham (1996) show that it would be possible in the US to save an additional 60,000 lives per year through a more cost efficient allocation.

Table 1 The cost per life saved for primary prevention measures (SEK 2007 prices)

Type of measure	Number of measures	Average cost (SEK)	Median cost (SEK)
Medicine	20	25,411,000	6,331,000
Radiation	10	13,307,000	1,075,000
Traffic safety	31	78,778,000	22,457,000
Lifestyle risks (smoking)	3	68,000	47,000
Fire protection	6	41,012,000	3,166,000
Electrical safety	2	674,910,000	674 ,910,000
Accidents	1	170,340,000	170,340,000
Environmental pollution	5	80,655,000	23,174,000
Crime	1	5,614,000	5,614,000
Total	79	66,566,000	11,587,000

Sources: Own calculations based on Ramsberg and Sjöberg (1997) and Burström (1999).

3. Data

Of the 1,500 sites with highest priority, about 80 have been remediated or have on-going remediation financed by government funds. Even if a site has been contaminated by several pollutants, it is often possible to identify a so-called primary contaminant. The primary contaminant is often the most hazardous and is present in the largest quantity, and hence guides the ambition level of the remediation work. Among the most prioritised sites metals (30 percent) and arsenic (26 percent) are the most common primary contaminants (Swedish EPA, 2008b). Since metals can, in turn, be divided into mercury, lead, chromium, copper and cadmium, the single most common primary contaminant is arsenic which motivates the focus of the analysis. Table 2 lists the 23 arsenic-contaminated sites with either completed (10) or on-going measures (13).

Table 2 Site-specific characteristics

Site	Arsenic concentration[a] (mg/kg)		Exposed individuals[b]	Accessibility	Land use[b]
	Pre	Post			
Akterspegeln*	163	15	100-1,000	Open	Recreation
Robertsfors	250	15	10-100	Enclosed	Recreation
Burträskbygden	260	40	1-10	Open	Industry
Tvärån*	608	17	10-100	Open	Industry
Svartbyn*	80	15	1-10	Open	Housing
Sjösa	30	6	10-100	Enclosed	Industry
Lyshälla*	170	15	1-10	Open	Housing
Mjölby	46	40	1-10	Enclosed	Industry
Rimforsa	49	15	1-10	Open	Industry
Hjulsbro	87	15	10-100	Open	Recreation
Glasbrukstomten	102	20	100-1,000	Open	Industry Recreation
Grimstorp	424	10	1-10	Open	Industry
Elnaryd	130	40	1-10	Enclosed	Industry
Högsby–Ruda*	55	5	10-100	Open	Housing Industry Recreation
Tröingeberg	23	15	10-100	Open	Housing
Oxhult*	94	15	1-10	Open	Housing
Gudarp	119	80	10-100	Enclosed	Recreation
Konsterud*	119	15	10-100	Open	Housing
Kramfors*	500	15	1-10	Open	Industry
Svanö*	418	100	10-100	Open	Recreation
Svartvik	150	40	1-10	Open	Recreation
Forsmo*	1,128	10	1-10	Enclosed	Recreation
Fagervik	65	40	10-100	Open	Recreation

Note: *Remediation has been completed (based on the quarterly report [Quarter 4, 2007] provided by the county administrative boards by order of the Swedish EPA). (a) The arsenic concentrations before remediation are derived from site-specific investigation reports or from involved consultants. (b) The land use data is derived from agent officials.

Arsenic contaminants result from previous industrial activities such as wood impregnation, and from sawmill, glasswork and sulphate and metal industries. Arsenic is mainly transported from contaminated sites through groundwater, but also through the air. Remediation work for arsenic is guided by health effects and not environmental effects (Swedish EPA, 2008c). Since there can be several risks involved, only the primary risks need to be quantified (Swedish EPA, 2008d). Both acute health risks and long-term risks can be important for arsenic-contaminated sites. Arsenic is classified as carcinogenic to humans (IARC, International Agency for Research on Cancer, 2004; 2008).[6] That is, arsenic exposure is scientifically proven to increase the risk of developing cancer, primarily in the lungs, urinary bladder and skin, but probably also in the liver and kidneys (U.S. Department of Health and Human Services, US-HHS, 2007). At long-term low-level exposure to inorganic arsenic, cancer is the most important proven health risk, since blood vessel disease and skin changes (other than cancer) do not occur below a certain exposure level.

ARSENIC CONCENTRATIONS

To estimate the risk reduction associated with arsenic mitigation, the average arsenic concentrations *pre remediation* have been collected. A reason for estimating risk based on an average concentration is that, over time, an individual will be exposed to an average concentration rather than to exceptionally high or low concentrations (US-EPA, 1992; Swedish EPA 2008d).[7,8] As illustrated in Table 2, the average *pre remediation* arsenic concentrations show a range from 23 to 1,128 mg/kg.[9] The arsenic concentrations *post remediation* refer to the sites' quantitative remediation objectives. As illustrated in Table 2, a majority of the sampled sites have remediation objectives that correspond to the Swedish EPA's guideline values for either *sensitive*, i.e. 15 mg/kg, or *less sensitive*, i.e. 40 mg/kg, land use. As shown, some of the sites' remediation objectives have, however, been adjusted in regard to the site-specific background concentrations of arsenic.

EXPOSURE

To be able to take actual exposure into account, we collected data from agent officials (i.e. municipality or county administrative board personnel) by asking them to approximate the number of individuals on or adjacent to (i.e. within 500 metres of) a particular site. To simplify the approximation for the respondents, the following intervals were given: 1-10, 10-100 and 100-1,000. In addition, the respondents were asked to address the current and planned land use as well as the prevalence of children on or adjacent to the site. In order to take children who put fingers and occasionally soil in their mouth into account, we used the municipality's share of children aged 0-3 years provided by Statistics Sweden.

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[6] The IARC is part of the World Health Organization. IARC is the publisher of the Monograph series (1972-2002), which contains evaluations and classifications of environmental agents and exposures linked to the development of human cancer. The categories are: Group 1: Carcinogenic to humans ; Group 2A: Probably carcinogenic to humans ; Group 2B: Possibly carcinogenic to humans ; Group 3: Not classifiable as to carcinogenicity to humans ; and Group 4: Probably not carcinogenic to humans.

[7] Commonly applied concentration values in risk assessments of contaminated sites are: average concentration; Upper Confidence Limit (UCL) of the mean (based on t-statistics); a specific percentile (e.g. the 50th percentile or the 95th percentile); and maximum measured concentration (Swedish EPA, 2008d).

[8] A conservative average concentration (i.e. called UCL_{95}) would, if available, be preferred (US-EPA, 2002; Swedish EPA, 2008d) as the average site concentration depends on the depth and range of the investigated area, number of samples, purpose of sampling (i.e. to define the contaminated area or to determine the average concentration), and the distribution of concentrations (e.g. many samples with low concentrations and few with very high concentrations).

[9] The natural background concentrations of arsenic vary. Depending on geographical location, concentrations from 3 to 15 mg/kg are found. Notably, for almost half of the sample sites the investigation reports do not provide information on background concentrations. Thus, these are not included in the subsequent quantifications.

ACCESSIBILITY AND LAND USE

Accessibility indicates whether a site is open or fenced. Land use refers to pre remediation use. The data on land use is relevant for approximating exposure times. The daily exposure times applied in subsequent quantifications (see the next section) is 24 hours for individuals residing on or adjacent to a site, 1 hour for recreational activities, and 5.7 hours for occupational activities. If pertinent, 5.7 hours also applies to day-care/school. We assume that both land use and the numbers of exposed individuals are unchanged post remediation, although it is plausible that both these factors increase post remediation. By assuming that these factors are unchanged we may hence underestimate the population at risk post remediation, overestimate the number of lives saved and, therefore, underestimate the cost per life saved.

4. From exposure to lives saved

RISK ASSESSMENT

Since arsenic occurs naturally in the environment, humans are exposed by merely eating, drinking and breathing. The scientific task is to determine the levels of arsenic exposure and their effects on human health and the environment when *additional* contaminant sources, like a contaminated site, are present. According to the MIFO risk assessment developed by the Swedish EPA, risk classification is based on an overall evaluation of the hazardousness and migration potential of site-specific contaminants, contamination level, and a site's environmental sensitivity and protection value (Swedish EPA, 2007a). To be able to make lucid risk assessments of all contaminated sites, the Swedish EPA has compiled general guideline values for contaminants in the soil for different types of land use. The guideline values are in turn based on conservative assumptions about toxicological data and human exposure that often overestimate the risk posed by a site. These are national values and mark the levels that should not be exceeded. Occasionally, health risk assessments are supplemented with formal opinions from environmental medicine experts. In contrast to the conventional procedure for health risk assessment, environmental medicine personnel make use of their qualifications in exposure assessment, toxicology and medicine to answer questions regarding e.g. what the actual exposure is at a specific site and what human health risks arise at a specific level of exposure.

The major aim of the Swedish EPA's risk assessment is to compare site-specific contaminant levels with the general guideline values. For health risk assessments, the starting point is, in general, the tolerable daily intake (TDI) that the World Health Organization (WHO) or other international organisations have recommended.[10] For carcinogenic substances without thresholds, the general guideline value in Sweden is the value that is expected to result in one extra cancer case per 100,000 lifetime exposed individuals.[11] It is then calculated how much an individual may actually be exposed to in total through aggregation of different exposure pathways at a certain contaminant level. For sites with less sensitive land use (i.e. offices, industries, roads etc.), the exposure pathways are: direct intake of contaminated soil, dermal contact with contaminated soil and inhalation of dust from the contaminated site. For sites with sensitive land use (i.e. residential areas and playgrounds), all relevant exposure pathways are considered (direct intake of soil, dermal contact, inhalation, intake of groundwater and intake of vegetables and fish). The Swedish EPA then makes standardised assumptions and uses models to estimate dissemination from soil to air, drinking water, vegetables etc. (Swedish EPA, 1997, 2007b). Under the assumption that humans are exposed through all possible pathways (a so-called 'worst case'), exposures through all pathways are added together. Then a general guideline value for the soil contaminant is calculated, which should protect humans from exceeding the TDI. The Swedish EPA does not make any judgment on the probability of exposure through a certain pathway. The precautionary principle is used for handling all uncertainties in the risk assessment, implying that in order to not underestimate the risks: (i) the contaminant levels should represent a 'bad but possible scenario; (ii) possible but

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[10] The TDI is the amount of intake per kilo body weight per day of a chemical that can be ingested over a lifetime without posing a significant risk to health.

[11] This is a low risk to the individual. Since the lifetime risk of cancer in Sweden is around 40 percent, it implies that the risk increases to 40.001 percent (Liljelind and Barregård, 2008).

less probable circumstances that could increase the risks are considered; and (iii) conservative values should be chosen for the parameters in the risk assessment (Swedish EPA, 2007b).

Important to note is that the guideline values are national and that the risk is calculated at the individual level. It does not matter how many individuals reside at or close to a contaminated site. The relation between the guideline value and the adverse effect is also unclear, which makes it difficult to relate a reduction in a contaminant level to a risk reduction (Rosén et al., 2006). To be able to make risk valuations, the risk before and after remediation needs to be quantified e.g. in the number of cancer cases avoided. Since the expected risk reduction is not quantified by the Swedish EPA, it is difficult to make socioeconomic priorities in remediation.

The model for generic guideline values can simplify the decision process in the early stages of risk assessment. One of the significant limitations is however that site-specific circumstances are only taken into account to a certain extent. The model is therefore indirect, mechanical and not directly applicable to calculate actual health risks. An environmental medicine assessment, on the other hand, aims to a larger extent to assess the health risks associated with actual exposure. In such an analysis, the main exposure pathways are considered through toxicological methods. Exposure-response relationships from scientific studies are used to quantify health effects of different contaminants. An important difference between the two approaches is the time perspective. The Swedish EPA strives for long-term sustainability and argues that 100-1000 years should be considered. The environmental medicine approach strives to a larger extent to describe the actual exposure and does not usually analyse periods longer than a couple of decades (Liljelind and Barregård, 2008). Another difference is that environmental medicine treats high concentrations of contaminants on the surface more seriously than contaminants deeper down that humans normally do not risk being exposed to, except for the case of ingestion of ground water.

On a European level there are large differences between different models for guideline values. A comparison between European guideline value models is made by Carlon (2007) in order to analyse differences among methods and reasons behind these differences in order to identify possibilities for harmonisation. The differences in some cases depend on sociocultural factors. In other cases the differences mirror different national strategies for environmental policies. Additionally, national differences can reflect lack of scientific consensus. In other cases there are no obvious reasons for the disparities and random factors seem to dominate, such as personal experience or historical aspects. For carcinogenic substances, the acceptable risk is expressed in extra cancer risk during a lifetime and varies between one per 10,000 and one per million in EU member states. The importance of this risk level should be evaluated in relation to the conservative assumptions made in the risk assessment, and then compared to the risks associated with other sources, such as air pollutants and smoking.

The consequences of exceeding guideline values vary according to national legislation. The strength in the execution of a sanction can also vary (Carlon, 2007). In the US, remediation started in the 1980s, and the focus has, as in Sweden, been placed on potential individual specific cancer risks rather than actual exposure. This has made the remediation programme much more expensive than planned. The annual cost of the US remediation programme 'Superfund' is now around USD 1,000 million. To remediate the remaining sites is estimated to take 30 years and to cost USD 30,000 million in total (US EPA, 2004).

CALCULATING THE NUMBER OF CANCER CASES AVOIDED

Exposure-response functions for different exposure pathways are used to calculate the extra cancer risk due to arsenic contamination. The main exposure pathways for cancer risks due to arsenic-contaminated sites are: inhalation of air, ingestion of soil and skin contact.[12] We depart from land use to estimate the exposure time for the site. The contaminant average concentration levels are then used to calculate the exposure for every pathway. For inhalation of air, the arsenic exposure is calculated based on assumptions of how the character of the soil affects the amount of particles in the air and that fine particles may contain higher concentrations of arsenic (see Appendix for an illustration). For ingestion of soil, the arsenic exposure is calculated based on assumptions of the amount of intake during the exposure time. For skin contact, the arsenic exposure is calculated based on assumptions of amount of soil on skin and percentage of skin absorption. These assumptions are all made in a manner that is customary for environmental medicine analyses. Uncertainties are indicated with an interval for certain factors (for example amount of soil on skin and bioavailability of arsenic contaminants). In the cases where such intervals are used, we have in the following calculations used the values of the intervals that lead to the highest exposure, resulting in the highest possible numbers of lives saved.[13] Hence, the calculations are conservative. If we instead would have used mid-interval estimates, the calculated risk and the number of saved cancer cases would have been several times lower. Thereafter, exposure-response functions are applied to calculate the risk reduction caused by the remediation. Table 3 lists the exposure-response functions used in the calculations. First we calculate the number of cancer cases that may occur during a 30 year period if the site is not remediated. Then we calculate the risk that remains following remediation, according to the Swedish EPA's guideline values.[14,15] The risk reduction therefore consists of the difference between the risk pre remediation and the remaining risk post remediation. However, since not all cancer cases lead to death, the numbers must be adjusted when estimating the numbers of lives saved.[16] The future cancer cases have not been discounted, since we do not know when in time they will occur.[17] This implies that we underestimate the cost per life saved. It should be noted that we used a more updated risk assessment than the one used by the Swedish EPA. The number of cancer cases in our calculations becomes several times higher than if we had used the Swedish EPA's exposure-response function. The reason is that not only do we take skin cancer into account, but also the risk for lung and bladder cancer.

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[12] In some cases the exposure-pathways ingestion of groundwater and intake of vegetables could be relevant. Exposure through intake of vegetables has not been relevant for the sites included in this analysis. Exposure through ingestion of groundwater implies that the wells are used for drinkingwater and that the water contains contaminant levels that exceed drinkingwater guidelines for arsenic. There is risk for exposure through ingestion of groundwater on two of the sites. In addition there is risk for migration to groundwater on a third site. Our analysis is, however, limited to the exposure-pathways inhalation of air, ingestion of soil and skin contact.

[13] That is, the numbers of exposed individuals are based on the upper bound of the applied intervals, and the exposure times in regard to for instance residential activities are assumed to be as high as 24 h a day.

[14] To use a 30 year period is consistent with the US EPA's calculations (Viscusi, Hamilton and Dockins, 1997).

[15] For more information about the data, see Forslund and Barregård (2008).

[16] For lung cancer, mortality is more than 90 percent, but we have also calculated the risk for skin cancer and bladder cancer, which have lower mortality (around 20 and 30 percent respectively). We therefore use 50 percent mortality in the calculations (see also Rosén et al., 2006, and Tallbäck et al., 2004).

[17] This is consistent with US EPA (Hamilton and Viscusi, 1999).

Table 3 Quantified cancer risks, descriptions and sources.

Exposure pathway	Cancer risk (Concentration)	Description	Source
Inhalation of air	1.5×10^{-3} (1 μg/m^3)	At an air concentration of 1 μg/m^3 an estimate of excess lifetime risk for cancer is 1.5×10^{-3}.	WHO (2000)
Ingestion of groundwater ; Skin contact* ; Ingestion of soil*	a) 6×10^{-4} (0.01 mg/litre)	At a concentration of 0.01 mg/litre an estimate of excess lifetime skin cancer risk is 6×10^{-4}.	WHO (1993)
	b) 2.5×10^{-3} (0.01 mg/litre)	At a concentration of 0.01 mg/litre an estimate of excess lifetime risk for cancer in lung and urinary bladder is 2.5×10^{-3}.	Modified for Sweden from US-NAS (2001)

Note:* The Cancer risk was estimated assuming the same risk per unit of absorbed dose for exposure by ingestion of soil or skin absorption as for drinking water.

5. The cost per life saved at arsenic sites

Table 4 shows that at most 0.03 lives will be saved through remediation of the site 'Glasbrukstomten'. In total 0.12 lives can be expected to be saved on the arsenic sites at a cost of SEK 881 million. The cost per life saved on the arsenic sites varies from SEK 287 million to SEK 1,834,000 million. This widely exceeds the value of a statistical life (VSL), which in Sweden is considered to be about SEK 21 million (SIKA, 2008). Even if we double the VSL, which has been suggested (SIKA, 2005) in order to take into account that valuations of reductions in risks of environmentally related mortality differ from valuations of reductions in risks of traffic related mortality, the difference is enormous. It is interesting to note that 72 percent of the health effects occur at three sites (Tväråan, Glasbrukstomten, Konsterud), where remediation costs amount to 13 percent of the total remediation costs. This underlines the importance of making the right priorities in the remediation work. The cost per life saved can be compared to similar estimates from an analysis of 150 contaminated sites financed by the US remediation program 'Superfund'; there the average cost of an *avoided cancer case* amounted to USD 3 million (SEK 20 million), ranging from USD 20,000 (SEK 131,000) to USD 1,000 million (SEK 6,600,000 million) and with a median of USD 388 million (SEK 2553 million) (Hamilton and Viscusi, 1999), which can be compared to our average cost of one *life saved* of SEK 7,200 million and our median of SEK 16,000 million.[18] The average Swedish cost is hence much higher than the U.S. average cost. If we are less conservative in our calculations on exposure, the cost per life saved becomes several times higher. We also calculated how many individuals need to be exposed at each site in order for one life to be saved. The results show that the number of exposed must increase from 10-1,000 to 2,850-620,000 individuals. These figures in some cases exceed the number of inhabitants in the municipality. Despite the uncertainties involved in our assumptions, the calculations illustrate that the ambition level in remediation is high, and in some cases unreasonably high.

[18] The average cost is calculated as the quotient between the total remediation cost and the total number of cancer cases avoided (or lives saved). If we instead use the average of the site-specific costs per cancer case avoided (or life saved), the average would be higher.

Table 4 Number of saved lives, costs and comparisons

Site	Total cost (SEK)	Number of lives saved**	Cost per life saved (million SEK)	Number of exposed individuals	Number of exposed individuals to save one life
Akterspegeln*	23,185,000	0.0098	2,357	100-1,000	104,000
Robertsfors	59,433,934	0.0010	60,785	10-100	103,000
Burträskbygden	7,620,350	0.0008	9,341	1-10	12,500
Tvärån*	15,494,619	0.0219	707	10-100	4,600
Svartbyn*	2,122,176	0.0015	1,427	1-10	6,700
Sjösa	32,748,762	0.0013	25,884	10-100	79,000
Lyshälla*	1,227,383	0.0035	348	1-10	2,850
Mjölby	2,703,250	0.0000	121,505	1-10	450,000
Rimforsa	9,820,099	0.0001	76,520	1-10	78,000
Hjulsbro	1,219,711	0.0005	2,613	10-100	215,000
Glasbrukstomten	88,000,000	0.0344	2,559	100-1,000	35,000
Grimstorp	126,910,779	0.0015	82,672	1-10	6500
Elnaryd	84,834,848	0.0003	254,208	1-10	30,000
Högsby–Ruda*	75,400,000	0.0047	16,049	10-100	47,000
Tröingeberg	9,350,919	0.0026	3,653	10-100	39,000
Oxhult*	2,853,000	0.0018	1,580	1-10	5500
Gudarp	73,666,537	0.0002	419,213	10-100	570,000
Konsterud*	9,087,563	0.0317	287	10-100	3200
Kramfors*	15,072,604	0.0018	8,373	1-10	5600
Svanö*	34,080,000	0.0019	18,169	10-100	53,500
Svartvik	84,932,698	0.0000	1,834,629	1-10	215,000
Forsmo*	24,658,432	0.0005	53,126	1-10	21,500
Fagervik	96,539,845	0.0002	601,087	10-100	620,000
Total	880,962,509	0.1219	7,227		

Note:* Indicates that remediation has been completed. For the sites with ongoing remediation the total cost is estimated. The cost is derived from the quarterly reports.** Rounded to four decimals.

The analysis has not taken into account acute health risks, other health risks than cancer and environmental risks. The acute risks are mostly associated with children's pica-behaviour, i.e. the risk that children to a high extent put fingers and contaminated soil in their mouths. However, the risk that children eat soil at the arsenic-contaminated sites in our sample is considered to be very small. It is also questionable whether such small contributions to a human's normal arsenic exposure are able to increase the risk of contracting any chronic disease other than cancer. The environmental risks differ among sites and are very difficult to estimate and value. As discussed earlier, it is the primary risks that should be valued, and in arsenic remediation health risks are considered to be primary.

6. Discussion

Remediation of contaminated sites is one of the most challenging Swedish environmental quality objectives in terms of reaching it on time. In addition, its cost amounts to as much as 10 percent of the total environmental budget. Sweden is only in the beginning of the remediation work, which until now has cost more than SEK 3,000 million, but is estimated to reach SEK 60,000 million after remediating the most hazardous sites. Internationally, the US Superfund has been criticised due to remediations having become much more expensive than estimated. In order for the Swedish objectives to be reached, remediation must prioritise the right sites and use an appropriate level of ambition.

Our results show that the level of ambition is high, maybe even too high. The cost per life saved under a 30 year period amounts to between SEK 287 million and SEK 1,835,000 million in the 23 sites examined, despite conservative calculations that probably underestimate the cost. The average cost per life saved amounts to SEK 7,200 million. This widely exceeds the explicit value of a statistical life, which in Sweden amounts to SEK 21 million (SIKA, 2008). Even if differences in risk preferences can motivate differences in marginal cost of saving lives, very large differences can hardly be justified. Based on our results we believe it is important to start a general discussion on how society's resources should be spent in different sectors to save lives. What level of health risk is acceptable at contaminated sites, and how and why does this level differ from what is acceptable in terms of other health risk? Our results indicate that no more than 0.12 lives will be saved during a 30 year period at a cost of SEK 880 million. Compare this to the estimated 400 new lung cancer cases in Sweden each year (12,000 in 30 years) due to residential radon, and the several thousand premature deaths every year due to air pollutants. If environmental health risks are to be reduced, there are probably other areas where economic resources can do more good.

A societal decision criterion is that measures can be defensible as long as the benefit of the risk reduction is larger than the cost. The benefits consist mainly of reduced health and environmental risks. How come realistic quantifications of risk reductions at contaminated sites, which are a prerequisite for economic risk valuations, are so rare? While the Swedish EPA's risk assessment starts from a guideline value and then assesses whether the contaminant concentrations exceed this value, it does not take actual exposure at the contaminated site into account. In Sweden, there is no estimation of a remediation's risk reduction and therefore no valuation of the remediation benefit. To be able to make risk valuations, a new working method is needed. Of course we believe it is important that Sweden decreases the pressure put on the environment, both nationally and globally. However, it is equally important that it is done in a manner that takes costs into account and weighs possible environmental benefits from different measures against each other. It simply seems reasonable to perform socioeconomic analyses when considering costly environmental policy measures.

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Appendix

Calculation of the extra cancer risk posed by arsenic-contaminated air on the basis of soil concentration.

This exercise is based on the assumption that a site's average arsenic concentration is 163 mg/kg. The site and its surroundings are used for recreational purposes and the number of individuals visiting the site is 100 per day.

Relevant parameters for approximating air exposure: (1) mass concentration of *soil particles in inhaled air*, (2) *respirable particle fraction*, and (3) *exposure time* (Swedish EPA, 1997).

The excess inhalable particle concentration tells how much of the total dust in the air that originates from the contaminated site. That is, the parameter depends on the soil characteristic (i.e. grass, sand, soil) and is assumed to vary from 1 to 5 μg/m³.

To control for the fact that fine particles in the air may contain higher concentrations than a sample of soil with a larger average particle size, a concentration factor of 1-5 is applied to the arsenic concentration in soil.

The exposure time is based on land use. Approximating recreational activities to one hour a day, the population exposure is equivalent to a number of individuals exposed 24 hours/day given by $(1\,h \div 24\,h) \times 100 = 4.16 \approx 4\,individuals$.

Given the information above, the arsenic concentration in inhaled air can be calculated as:

$$1 - 25\,mg/m^3 \times 0.163\,ng/mg = 0.163 - 4.075\,ng/m^3 \approx 0.16 - 4.1\,ng/m^3 .$$

As emphasised, the exposure-response function applied to quantify the number of cancer cases from air inhalation over a lifetime at or adjacent to the site is 1.5×10^{-6} per ng/m³. The effect (cancer risk) is given by:

$$0.16 - 4.1\,ng/m^3 \times 4\ individuals \times (1.5 \times 10^{-6}\ ng/m^3) = 0.96 \times 10^{-6} - 24.6 \times 10^{-6} \approx 1 - 25 \times 10^{-6} .$$

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