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THE METAL LOAD ON THE GULF OF BOTHNIA

Emelie Enckell-Sarkola[1], Heikki Pitkänen[1]
and Hans Wrådhe[2]

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Vuosikymmenien aikana mm. teollisuus, kaivokset, yhdyskunnat sekä maa- ja metsätalous ovat kuormittaneet Pohjanlahtea merkittävästi. Julkaisu antaa kuvan merialueiden metallipitoisuuksista, metallien päästölähteistä ja niiden suuruudesta 1980-luvulla, suunnitelluista ja toteutuneista vesiensuojelutoimenpiteistä, jokien aiheuttamasta kuormituksesta sekä ilman kautta tulevasta laskeumasta. Jo nyt on erittäin suuria määriä arsenikkia, sinkkiä, lyijyä, kuparia ja rautaa, sekä suhteessa niiden toksisuuteen myös elohopeaa ja kadmiumia varastoitunut Pohjanlahteen. 1970-luvulta lähtien päästöt ovat vähentyneet oleellisesti, mutta vielä on jäljellä monta ongelmaa. Vaaditaan mm. lisätoimenpiteitä teollisuuspäästöjen sekä kaivos- ja kaatopaikka-alueilta peräisin olevien päästöjen vähentämiseksi. Lisäksi asetetaan vaatimuksia Suomen ja Ruotsin päästötarkkailun sekä jokikuormituksen mittaamisen tehostamiseksi.

Asiasanat (avainsanat)

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Abstract

The Gulf of Bothnia has been subjected for decades to a heavy load from industry, mines, municipalities, agriculture and forestry. In the present report a descpription is given on metal concentration in the sea area, sources of metal discharges and their magnitude during the 1980's, water protection measures that are planned and have been taken, river transportation and deposition from the atmosphere. Very large quantities of arsenic, zinc, lead, copper and iron and, in relation to their toxicity, also mercury and cadmium have already been deposited and stored in the Gulf of Bothnia. The effluent discharges have decreased substantially since the 1970's, but there are still several problems to be solved. Among other things further measures are required to reduce industrial discharges and leakage from mines and refuse dumps as well as make the effluent control and river transportation control more efficient and uniform in the both countries.

Keywords

Metals, water pollution, water quality, sea water, river transportation, water protection, the Gulf of Bothnia

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1. INTRODUCTION

The Gulf of Bothnia has been subjected for decades to a heavy load from industry, mines, municipalities, agriculture and forestry. Environmental poisons, above all chlorinated organic substances from the pulp and paper industry and metals from the metal industry, the chemical industry and mines constitute a serious threat to the sea area. The Committee for the Gulf of Bothnia carried out a cooperation project round the pulp and paper industry's water protection questions in 1985-1988 and initiated a new metal load project at its annual meeting in February, 1988. This report summarizes the studies carried out on the metal load and its effects.

In 1988 the Committee for the Gulf of Bothnia also arranged for the planning of a major research project entitled "The Gulf of Bothnia Year". The plans include an inventory of the supply of what from the aspect of marine biology are production-stimulating substances and environmental poisons. This report on the metal load, and any continued work on the subject, might also be of use to the research project.

In the autumn of 1988 the Scandinavian environmental ministers decided "that a working group which included representatives of Sweden and Finland should be appointed to study the pollution load on the Gulf of Bothnia more closely and propose suitable measures to reduce it". According to a joint decision of the Swedish and Finnish ministers, the National Board of Waters and Environment and the National Environmental Protection Board should, with the activities of the Committee of the Gulf of Bothnia as a point of departure, "illuminate the load situation in the Bothnian Bay and propose a plan of action to reduce the discharge of pollutants in the area". This report on the metal load should be viewed as an interim report for the ministers of the environment also.

An account of the load on the Gulf of Bothnia during the period 1972-1982, including metal discharges from industry and certain river-borne metals, has been given in the theme chapter in the in the annual report 11 (1983) of the Committee for the Gulf of Bothnia. The load during the two following years is summarized in the Committee's report "The Gulf of Bothnia - discharges from land and air, 1982-1984". Corresponding reports for later years will also be published.

In the present report on the metal load, a brief description is given of the established occurrence of metals in the Gulf of Bothnia and the significance of the metal load, the source and magnitude of the metal discharges, measures that are planned and have been taken, river transport and deposition from the atmosphere. Extensive literature and unpublished records on the subject already exist in both Sweden and Finland. Only a few references to central and directly quoted sources are given here. Special importance has been attached in the report to the discharge forecast up to 1995 and the need for additional measures in the future.

2. THE EFFECTS OF THE METAL LOAD TO THE GULF OF BOTHNIA

Metals are supplied to the Gulf of Bothnia in various ways. Rivers carry along metals which have been leached out in the course of natural disintegrating processes, metals which have been discharged from industrial processes and metals which have been deposited from the air in the run-off areas. Overdrainage of forest land and acidification of the soil probably contribute to the increased release and subsequent transport of metals. Several industrial manufacturing plants and communities also discharge water with a metal content directly into the sea. The metals deposited from the air stem for the most part from industrial processes, motor traffic, etc. but to some extent also from natural processes.

The natural contribution of metals transported with river water to the Gulf of Bothnia occur chiefly in bonded inaccessible form while the industrial effluents largely occur in dissolved form. Zinc and cadmium are also transported to a large extent in dissolved form in rivers. The dissolved metals are more easily accessible to aquatic organisms.

Different metals are differently mobile. Lead and chromium are bonded comparatively heavily to the bottom sediment, copper assumes an intermediate position while arsenic, cadmium, nickel and zinc are more highly mobile metals. A certain proportion of the mobile metals is also bonded to the sediment near a point source but a large proportion is spread over wider areas. Mobility is also affected by the pH of the water.

As a rule, water of low salinity makes the metals more toxic and more easily accessible to living organisms. The Gulf of Bothnia, with a salinity of only 0.3-0.6 % is therefore more sensitive to metal pollutants than sea-water with a higher salinity.

An account of the Gulf of Bothnia's content of some metals is given below.

Mercury

A remarkably high mercury content in sediment, 2-5 mg/kg dry matter (background level 0.05 mg/kg dry matter), has been measured in the deep areas in the southern part of the Gulf of Bothnia. A high content is also present in the vicinity of older pulp and paper plants where the water is polluted by fibre sediment containing mercury. The fibre banks are a potential source of methyl mercury emission. Higher mercury concentrations are also present in the sediment outside Rönnskär in the Bothnian Bay.

The mercury content in animal plankton and Baltic herring has gone down since the mid-1970s and the early 1980s. Outside Gävle Bay the mercury content in Baltic herring muscle decreased from 0.23 mg/kg in 1980 to 0.025 mg/kg in 1985.

At the mouth of the River Oulujoki, below a chloralkali and pulp and paper plant, the concentration of mercury in the upper layer of sediment (0-2 cm) was 0.4-1.3 mg/kg. Owing to earlier large-scale discharges, the concentration in the lower layers was as a rule higher than 3 mg/kg. It is calculated that the sediment in this area may contain up to 6,000 kg of mercury. The mercury concentration in pike in this area declined from 1.2-1.4 mg/kg to 0.66-0.94 mg/kg in 1980.

Elevated mercury concentrations of 0.57-5.2 mg/kg, 0.10-0.77 mg/kg and 1.62-3.00 mg/kg respectively have also been measured in the sediment outside Kokkola, Pori and the mouth of the River Kokemäenjoki.

Cadmium

Cadmium concentrations of about 1 mg/kg dry matter (background level approx. 0.3 mg/kg dry matter) have been measured outside Rönnskär. A cadmium concentration in Baltic herring liver of 1-2 mg/kg has been measured, which is higher than in the Kattegat, for example.

Cadmium concentrations of 0.81-2.9 and 0.40-2.0 mg/kg have been found in the sediment outside Kokkola and Taalintehdas. Elevated concentrations in the biota (*Mesidotea* and *Macoma*) have also been found at the same places and outside Pori.

Lead

The lead content of the sediment in the Gulf of Bothnia is roughly 60 mg/kg dry matter (background level 20-40 mg/kg dry matter). Outside Rönnskär, local concentrations are higher, between 200 and 2,700 mg/kg dry matter.

At the mouth of the River Kokemäenjoki and outside Taalintehdas, lead concentrations of 59-75 and 43-610 mg/kg respectively have been found in the sediment. The content of lead in the biota (*Macoma*) is also elevated.

Arsenic

Round the primary smelter in Rönnskär, the arsenic content of the sediment is several times higher than the background level (approx. 10 mg/kg dry matter). Arsenic concentrations of between 400 and 1,400 mg/kg dry matter have been measured outside Rönnskär. Elevated concentrations of arsenic have been found in the sediment throughout the entire Gulf of Bothnia. Since arsenic is a readily mobile metal, old sediment constitutes a potential source of continued dispersion. Its extremely low phosphate content makes the Gulf of Bothnia especially sensitive to arsenic pollution. The arsenic content in animal plankton in 1979 and 1987 is shown in Fig. 1.

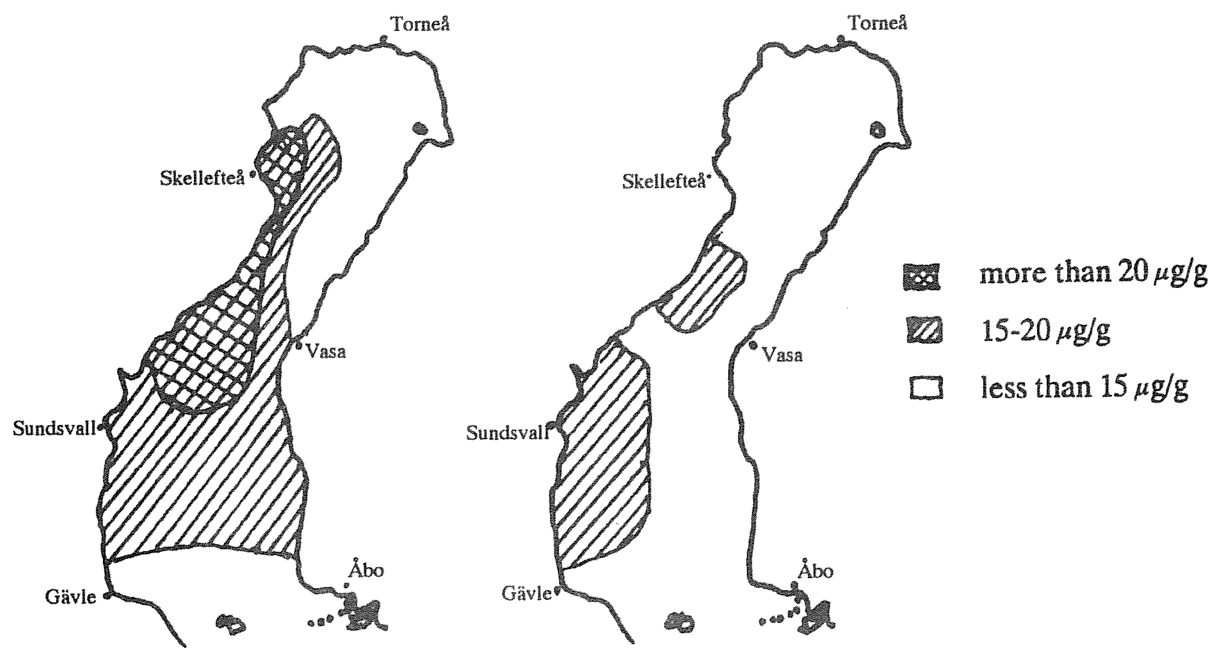


Fig. 1. Arsenic concentration in animal plankton, May-June, 1979 (µg/g dry matter).

Copper

High copper concentrations, 60-1,600 mg/kg dry matter, occur in the sediment outside Rönnskär but elsewhere the copper content does not appreciably exceed the background level (approx. 40 mg/kg dry matter). In certain cases, copper may constitute a limiting factor to life on account of the high toxicity of copper ions.

High concentrations of copper have also been found in the sediment outside Kokkola, the mouth of the River Kokemäenjoki, Pori and Taalintehdas, where the copper content varied between 36 and 430, 77 and 145, 19 and 100, and 36 and 180 mg/kg respectively. Elevated concentrations have been found in the biota (*Mesidotea*) and Baltic herring outside Kokkola.

Zinc

The zinc content of the sediment is greatly elevated round Rönnskär, where measurements show concentrations of between 300 and 1,400 mg/kg dry matter. Otherwise, it does not differ much from the background level (approx. 125 mg/kg dry matter).

Along the Finnish coast the highest zinc concentration in the sediment, 190-795 mg/kg, has been found outside Kokkola. Zinc concentrations are also somewhat elevated locally in the areas previously mentioned and at the mouth of the River Kyrönjoki. The zinc content in the biota and Baltic herring have also been studied, but only *Mesidotea* samples from Kokkola and *Macoma* samples from Taalintehdas show definite elevations by a factor of about two.

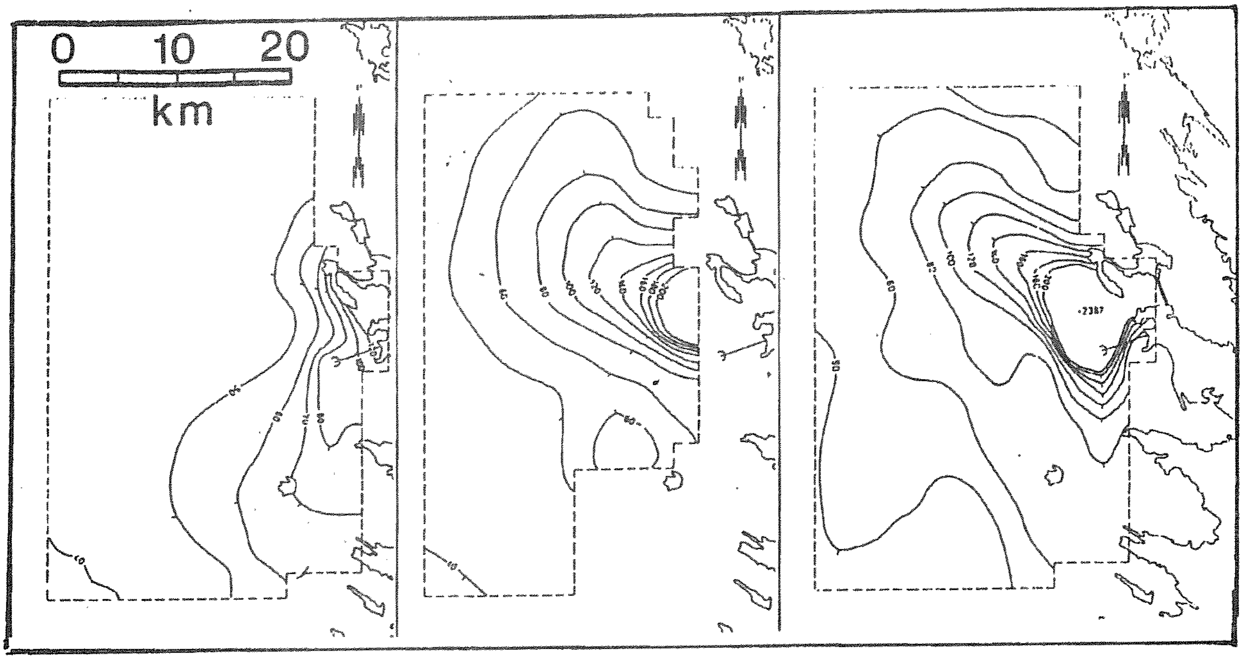
Chromium

The sediment in the Bothnian Bay along the Swedish coast has a chromium content of 12-45 mg/kg dry matter, which is of the same magnitude as the background level. Higher concentrations, 240 mg/kg dry matter, have been measured in Gävle Bay. The concentration of chromium in the liver of *Cottus quadricornis* and whitefish, and in the muscle of Baltic herring, has been measured at 0.1-2 mg/kg dry matter, which is the same as in the rest of the Baltic.

Outside Tornio and Taalintehdas, chromium concentrations of 40-166 and 41-230 mg/kg respectively have been found in the sediment. Somewhat elevated concentrations have also been found at Kokkola, the mouth of the River Kokemäenjoki and Pori. Elevated concentrations of chromium have also been found in the biota (*Macoma*) outside Pori, Taalintehdas and the mouth of the River Kokemäenjoki.

Iron

The concentration of iron in the sediment of the Gulf of Bothnia is roughly twice as high as in the central parts of the Baltic (approx. 40,000 mg/kg dry matter). This high concentration of iron probably reflects the metal load received via the rivers and the ferrous sulphate effluent discharged from the titanium dioxide factory outside Pori. Measurements show that the sediment near the discharge point has an iron content of 50,000-170,000 mg/kg. Concentrations nearly as high have also been found outside Taalintehdas. In the biota (*Macoma*), the iron content has been elevated by a factor of about three. The iron content of the water layers close to the bottom outside the titanium dioxide factory are also clearly elevated within a radius of 20-30 km from the discharge point (Fig. 2). The average concentration of iron in the southern part of the Bothnian Sea is 20-30 μg/l.



Surface layer (0-8 m) Intermediate layer (16-20 m) Bottom layer

Fig. 2. Iron content of the water in the southern part of the Gulf of Bothnia outside Kemira Oy Vuorikemia factories in the summer of 1986 (µg/g).

Vanadium and titanium

Elevated concentrations of titanium in the sediment along a 70 km stretch of coastline have been discovered outside the titanium dioxide factory. The highest concentrations found are about 5-10 times higher than in the reference area (Pyhämaa). The vanadium content is also elevated, although not to the same extent. The biota has an elevated titanium content.

Effects of the metal load on living organisms

Bottom layers with no living animals can be found outside manufacturing plants. The bottom fauna are completely eliminated or heavily reduced in an area of about 200 sq.km. outside the heavy metal smelter in Rönnskär and outside the titanium oxide factory in Pori an area of 8-20 sq.km is entirely without water organisms or with a seriously disturbed ecological system.

A strongly increased frequency of vertebral column defects in *Cottus quadricornis* has been found in the Bothnian Bay, particularly in the vicinity of Rönnskär, Kokkola, the mouth of the River Kyrönjoki and Tornio. Other types of disease or injury related to the effects of metal have also been noted in different species of fish. Eye defects in Baltic herring have been found outside Pori as well as the flight of fish from the area. The coastal zones play a central role as reproduction areas for many species of fish. Sensitivity to the effect of metals is particularly high during the reproduction phase.

A key map showing the occurrence of environmental poisons in Finnish coastal waters is given in Fig. 3.

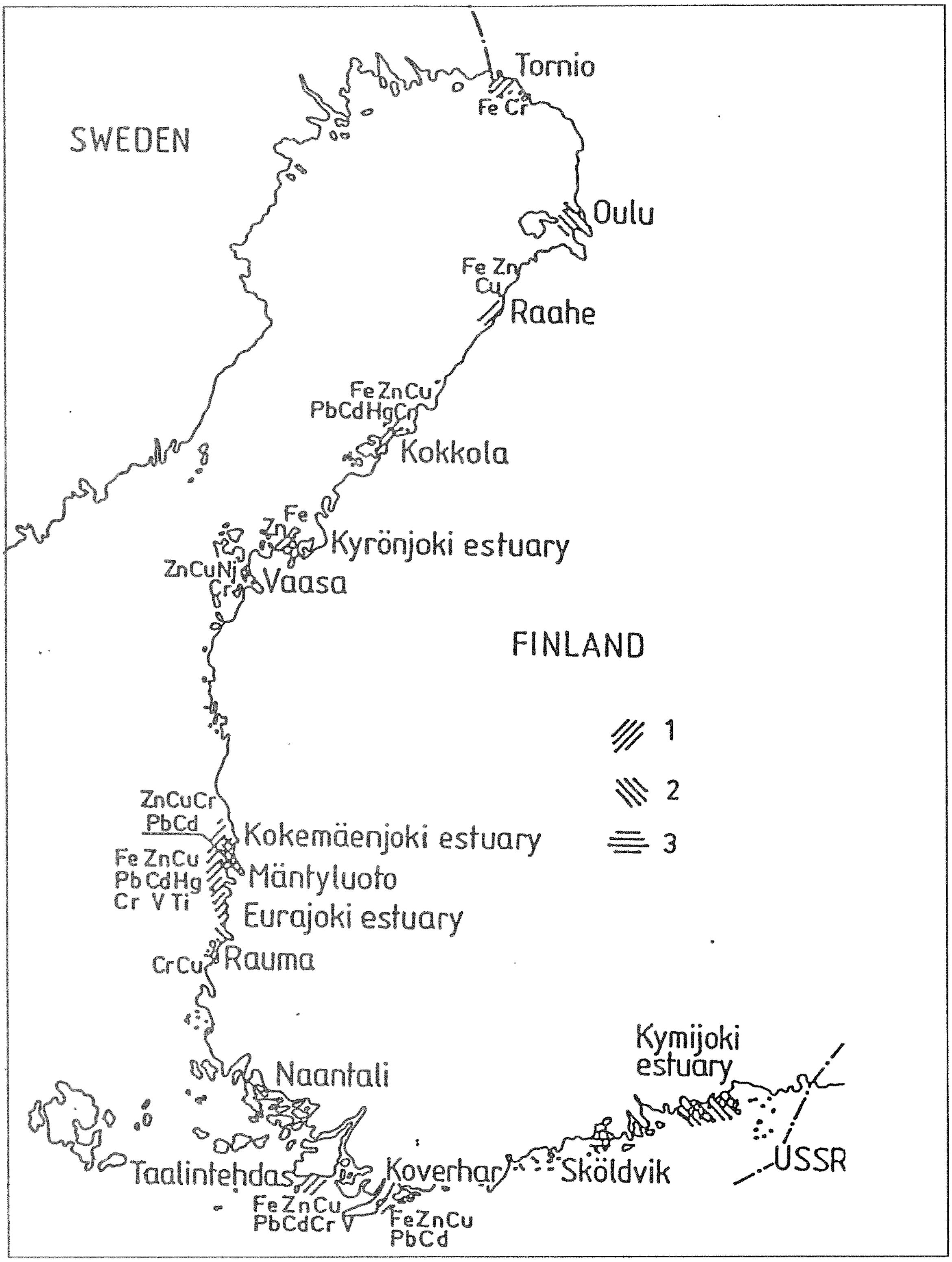


Fig. 3. The areas loaded with iron and heavy metals (1), the areas where mercury concentrations in pike are clearly elevated (2), and the areas loaded with oil and other organic micropollutants (3). Metals present in higher concentrations in the sediment or biota than in the reference area are indicated.

Conclusions

The situation in the Gulf of Bothnia is more serious than in other parts of the Baltic owing to the high metal load from present and earlier discharges of effluent and its low salinity, which makes the metals more toxic and easily available to aquatic organisms.

Owing to the slow water turnover, the harmful effects may remain long after the supply of metals has been minimized.

Special importance should be attached to reducing the load - and studying the effects - of arsenic, mercury, cadmium, copper, lead, chromium, zinc and iron.

3. ANTHROPOGENIC SOURCES, MEASURES TAKEN AND MEASURES PLANNED

3.1 INDUSTRY

Sweden

The industrial plants which discharge effluent directly into the Gulf of Bothnia or which make sizeable contributions via the rivers and/or are situated on the shores of the Gulf of Bothnia, and where emissions of metal to the atmosphere are considerable, are presented below. Recent analyses of the wastewater from some pulp and paper plants in Sweden indicate that they may be responsible for substantial metal discharges. Sufficient data on which to calculate the metal discharged by the pulp and paper industry into the Gulf of Bothnia is not available, however.

Sweden has presented to the Helsinki Commission a series of measures which it is possible to take with the application of the best available technology in several different branches of industry. (Report on Sweden's plans and activities and the results achieved concerning the Declaration which relates to the 50 % reduction of certain discharges, 1989.)

The geographical location of the sources presented below will be evident from the map (Fig. 4). The magnitude of the discharges is shown in tables 1-5.

The primary steel plant in Luleå. The plant includes coke plant, 2 blast furnaces, 2 basic oxygen furnaces, 3 continuous casting machines and rolling mills. About 1.6 million tonnes of commercial steel is produced annually. The steelworks also has a unit for surface treating sheet metal and plate.

Seventy per cent of the cooling water for hot rolling and continuous casting is recirculated. The waste water undergoes sedimentation and is filtered in sand filters before discharge. A higher degree of circulation would probably result in reducing the content of suspended substances to less than 50 g/tonne for the rolling mills and 10 g/tonne for continuous casting process.

Nearly all the water from wet scrubbers for basic oxygen furnace flue gases is cleaned and recirculated. The blast furnaces comprise the principal source of Pb and Zn discharges into water. The blast furnace gases are wet scrubbed and the water undergoes sedimentation before recirculation. The discharges would be reduced if the degree of circulation could be increased.

Large quantities of Zn leak out into the northern part of the Gulf of Bothnia from blast furnace dust deposition. Through a more sealed deposition or other processing of the waste, it would be possible to reduce Zn leakage from about 12 tonnes per year to an estimated 2 tonnes per year.

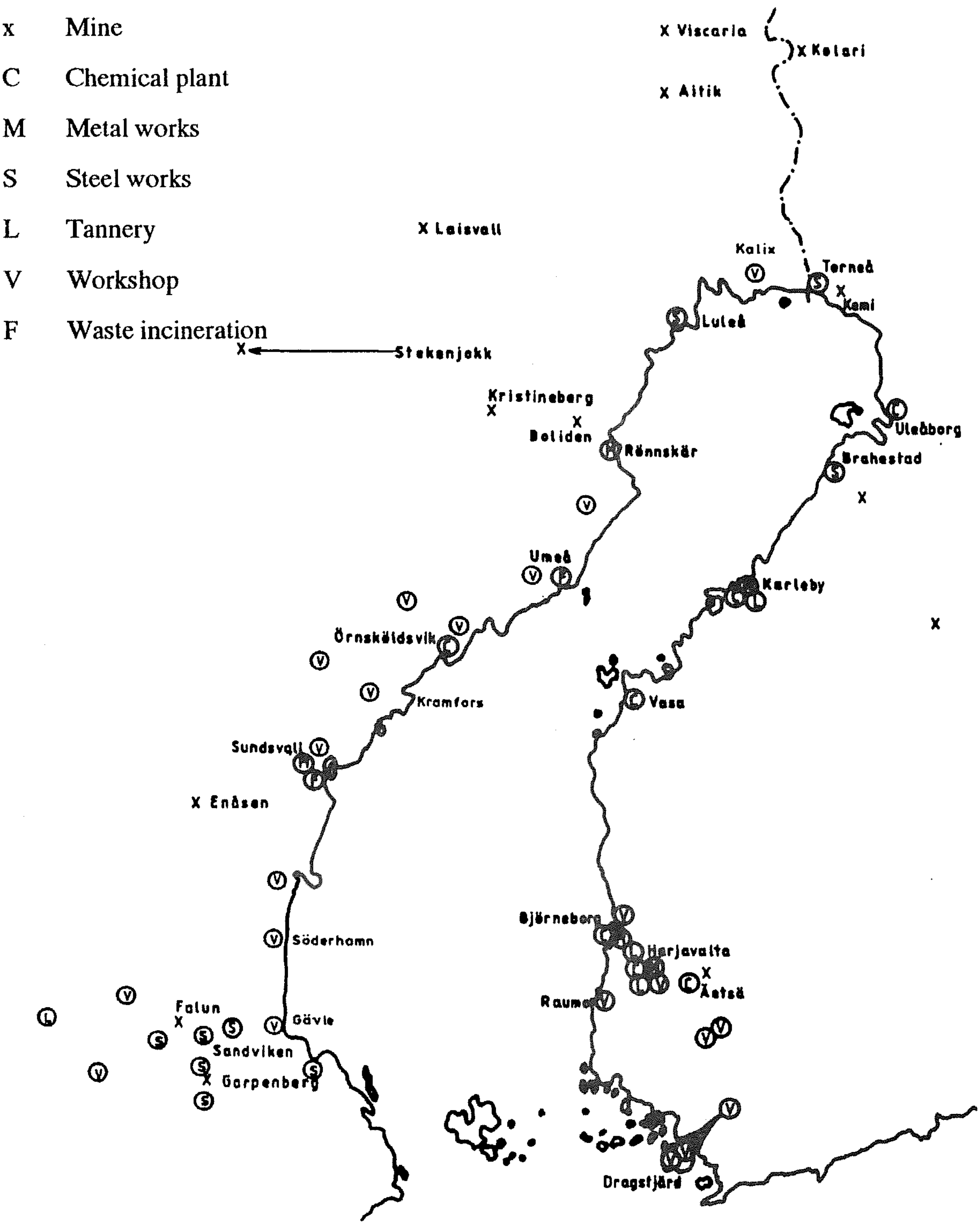


Fig. 4. Metal emissions from industrial plants to the gulf of Bothnia 1987.

The basic oxygen furnaces are a major source of emissions of Pb and Zn to the atmosphere. Through better separation of dust from the flue gases it would be possible to reduce emissions from the basic oxygen furnaces from the present 0.3 to less than 0.1 kg of dust per tonne of steel. Similarly, emissions from the blast furnaces could be reduced from about 0.2 to less than 0.1 kg per tonne with improved suction arrangements at pouring hole, ladle and tapping spout.

Metals are also emitted by the coking plant. The magnitude of these emissions is not completely charted.

Table 1. Wastewater from manufacturing plants discharged into the Bothnian Bay and its runoff area below the lakes.

Source		kg/year									
SWEDEN		Hg	Cd	Pb	Cu	Zn	Cr	Ni	As	Fe	Co
Mines2)	1980	-	50	7900	3500	20000	..	-	..	..	-
	1987	1	10	700	300	8300	150		200		-
	1995	-	<10	<700	<300	<8000	<150	-	<200	..	-
Mine waste deposits2)	1980-	-	30	-	1000	5000	-	-	-	..	-
	1995	-	<30	-	<1000	<5000	-	-	-	..	-
Engineering industry1)	1987	-	-	-	2	270	12	-	-	30	3
Primary smelter1)	1980	347	2500	5800	5200	13200	-	-	271000	..	-
	1987	60	110	1800	6900	4400	-	-	8500	..	-
	1995	60	110	1600	2000	4400	-	-	8500	..	-
Steel plant1)	1980	-	90	250	790	9400	540	510	80	14050	-
	1987	-	90	680	1360	27000	80	250	90	12090	-
	1995	-	55	100	1000	4000	50	150	50	10000	-
FINLAND											
Mines1)	1980	-	-	-	-	160	<100	-	-	15600	-
	1987	-	-	-	-	150	5100	-	-	4200	-
	1995	-	-	-	-	<500	<1000	-	-	<4000	-
Mines2)	1980	-	8	7	720	2250	1060	2910	-	15400	-
	1987	-	9	7	470	2150	1000	220	-	9400	-
	1995	-	<10	<10	<500	<2000	<1000	-	-	7000	-
Primary smelter1)	1980	14	100	-	17000	51000	-	60000	590	750000	51000
	1987	2	131	-	2400	18100	-	17600	95	190000	11800
	1995	<5	<100	-	<1000	<15000	-	<15000	<100	<200000	<10000
Steel plants1)	1980	-	-	-	-	28100	3000	370	-	167000	-
	1987	-	-	-	-	6900	2650	3120	-	42600	-
	1995	-	-	-	-	<6000	<3000	<2000	-	<40000	-
Chemical plants1)	1980	43	-	-	-	-	-	-	-	56000	-
	1987	28	-	-	-	-	-	-	-	58400	-
	1995	<30	-	-	-	-	-	-	-	<60000	-
Tannery2)	1980	-	-	-	-	-	2900	-	-	-	-
	1987	-	-	-	-	-	390	-	-	-	-
	1995	-	-	-	-	-	<500	-	-	-	-
total	1980	400	2800	14000	28200	129000	7700	64000	272000	$1x10^6$	51000
total	1987	90	380	3200	12500	73000	9400	21000	8900	320000	11800
forecast	1995	<90	<270	2400	<6000	<45000	<5500	<17000	8900	<320000	<10000

1) Emissions into the Bothnian Bay in the area below the final sampling station of controlled rivers.

2) Emissions into the runoff area of the Bothnian Bay between the final sampling station of controlled rivers and the system of lakes.

Table 2. Wastewater emissions from manufacturing plants into the Bothnian Sea and its runoff area below the lakes.

Source		kg/year											
SWEDEN		Hg	Cd	Pb	Cu	Zn	Cr	Ni	As	Fe	Co	Sb	V
Mines[2]	1980	-	400	2300	7000	375000	400	-	..	..	-	-	-
	1987	-	100	2300	1700	70000	800	-	100	..	-	-	-
	1995		<100	<2300	<1700	20000	<800	-	<100	..	-	-	-
Mine waste deposits[2]	1980-		400	-	6000	500000	-	-	-	..	-	-	-
	1995	-	50	-	600	50000	-	-	-	..	-	-	-
Steel plants[2]	1987	-	-	20	70	<30000	2300	1000	-	68000	-	-	-
	1995	-	-	<20	<70	<10000	<2000	<800	-	<60000	-	-	-
Alumina smelter[1]	1987	-	1	20	10	50	6	39	-	-	1	-	-
	1995	-	<1	<20	<10	<50	<6	<39	-	-	<1	-	-
Engineering industry[1]	1985	-	-	9	1890	244	56	42	-	320	4	-	-
Engineering industry[2]	1987	-	-	-	-	200	100	200	-	-	-	-	-
Chemical plants[1]	1985	4	-	-	-	-	100	10	-	-	-	-	-
Tannery[2]	1987	-	-	-	-	-	400	-	-	-	-	-	-
FINLAND													
Mines[2]	1980	-	-	-	17	-	-	20	-	1600	-	-	-
	1987	-	-	-	20	-	-	140	-	1400	-	-	-
	1995	-	-	-	-	-	-	-	-	-	-	-	-
Primary metal smelter[1]	1980	-	-	-	6000	2800	1240	2050	-	-	-	-	-
	1987	-	-	-	2200	1400	650	420	-	-	-	-	-
	1995	-	-	-	<2600	<1400	<700	<700	-	-	-	-	-
Primary metal smelter[2]	1980	4	130	200	3400	5600	-	9350	..	..	..	-	-
	1987	3	150	1200	10900	7100	-	10900	1900	..	-	-	-
	1995	<20	<200	<1000	<4000	<5000	-	<4000	<3000	<20000	-	-	-
Engineering industry[2]	1987	-	-	-	-	1400	35	380	-	500	-	-	-
	1995	-	-	-	-	..	..	..	-	..	-	-	-
Titanium dioxide plant[1]	1980	9	12	2700	8500	155000	74000	24000	-	24×10^6	8100	3400	289000
	1987	3	12	1400	2900	113000	57000	8800	-	18×10^6	4200	900	127000
	1995	<10	<20	<2000	<2000	<60000	<40000	<6000	-	$<10 \times 10^6$	<3000	<700	<70000
Other chemical plant[1]	1980	0.2	-	-	8	-	-	-	16	-	-	-	-
	1987	0.1	-	-	14	-	-	-	9	-	-	-	-
	1995	<1.3	-	-	<50	-	-	-	<50	-	-	-	-
Other chemical plant[2]	1980	51	320	945	5100	4100	-	350	3900	-	-	-	-
	1987	26	305	480	4200	2700	-	3800	1400	-	-	-	-
	1995	<15	-	-	-	-	-	-	-	-	-	-	-
Tannery[2]	1980	-	-	-	-	-	2500	-	-	-	-	-	-
	1987	-	-	-	-	-	620	-	-	-	-	-	-
	1995	-	-	-	-	-	<1000	-	-	-	-	-	
Total	1980	70	1300	6200	38000	1075000	82000	37000	..	24×10^6	8100	3400	289000
Total	1987	40	970	5400	30000	726000	62000	25000	3400	18×10^6	4200	900	127000
Forecast	1995	<50	<400	<5000	<13000	<150000	<45000	<12000	<3000	$<10 \times 10^6$	<3000	<700	<70000

[1] Emissions into the Bothnian Sea in the area below the final sampling station of controlled rivers.
[2] Emission into the runoff area of the Bothnian Sea between the final sampling station of controlled rivers and the system of lakes.

Table 3. Wastewater emissions from manufacturing plants into Archipelago Sea and its runoff area below the lakes.

Source		kg/year								
FINLAND		Hg	Cd	Pb	Cu	Zn	Cr	Ni	As	Fe
Steel plant[1]	1980	-	-	-	1	100	-	-	-	47000
	1987	-	-	427	3280	1030	-	-	-	228000
	1995	-	-	<300	<500	<400	-	-	-	<8000
Mines[1] (felspar)	1980	-	-	-	-	-	-	-	-	40600
	1987	-	-	-	-	-	-	-	-	20000
	1995	-	-	-	-	-	-	-	-	<40000
Engineering industry[2]	1987	-	-	-	30	5400	200	350	-	1000
	1995	-	-	-	..	<4000	<500	<500	-	..
Total	1987	-	-	430	3300	5300	200	100	-	250000
	1995	-	-	<300	<500	<5000	<500	<500	-	<50000

1) Emissions to Archipelago Sea in the area below the final sampling station of controlled rivers.

2) Emissions in Archipelago Sea's runoff area between the final sampling station of controlled rivers and the system of lakes.

Table 4. Metal emissions to the atmosphere from industrial plants in Sweden whose emissions affect the atmospheric deposition in the Gulf of Bothnia to a considerable extent.

Source		tonnes/year									
		Hg	Cd	Pb	Cu	Zn	Cr	Ni	As	Fe	V
Steel plant Luleå	1980	0.2	0.04	2	-	11	1	0.4	-	735	4
	1987	0.2	0.04	2	-	11	1	0.4	-	735	4
	1995	0.1	0.02	1	-	5	0.5	0.2	-	400	2
Primary smelter Rönnskär	1980	0.87	3.3	211	157	139	-	-	65	-	-
	1987	0.32	1.5	73	46	62	-	-	12	-	-
	1995	0.35	0.8	30	10	40	-	-	8	-	-
Steel plant Sandviken	1980	0.03	0.01	1	0.2	3	2	1	-	7	-
	1987	0.02	0.003	0.3	0.06	0.9	0.5	0.2	-	2.2	-
	1995	0.02	0.002	0.1	0.03	0.4	0.3	0.1	-	1	-
Chloralkali plant Örnsköldsvik	1980	0.16*	-	-	-	-	-	-	-	-	-
	1987	0.04	-	-	-	-	-	-	-	-	-
	1995	0.03	-	-	-	-	-	-	-	-	-
Waste incineration Umeå	1980										
	1987	0.02	0.01	0.6	-	1.4	0.5	0.3	-	-	-
	1995	0.01	0.005	0.3	-	0.7	0.2	0.1	-	-	-
Waste incineration Sundsvall	1980										
	1987	0.001		0.002	-	0.01	-	-	-	-	-
	1995	0.001		0.002	-	0.01	-	-	-	-	-
Total	1987	0.6	1.6	76	46	76	2	0.9	12	740	4
	1995	0.5	0.8	31	10	46	1	0.4	8	400	2

* of which 0.11 from factories which are now shut down.

Table 5. Metal emissions to the atmosphere in Sweden.

Source	Year	tonnes/year									
		Hg	Cd	Pb	Cu	Zn	Cr	Ni	As	Fe	V
Total	1970/73	5	25	2200	450	2500	800	250	160	30000	530
	1977/78	5	12	1500	280	1200	160	180	130	7000	460
	1985	5.5	5	950	70	560	75	50	40	5200	140
	1987	3.5	3	750	55	360	45	45	14	5200	140
	1995	2.5	2	550	30	300	30	40	10	4000	140
Distribution	1987										
Mines		0.05	0.1	4	<1	<1	2	2	<1	3000	7
Metal-works		0.3	1.5	73	46	110			12		
Ironworks and steelworks		0.7	0.7	43	2	105	7	5		2200	5
Ferro-allow works						10	35			30	
Factories and foundries						100					
Glassworks				3					1		
Chloralkali factories		0.3									
Refineries								4			12
Oil firing			0.1	4	1	2		33			110
Coal/coke firing		0.1		1							
Wood/peat firing		0.2	0.2	8	1	11		1			3
Refuse incineration		1.5	0.4	15	2	25					
Motor vehicle exhaust emissions			600								
Crematories		0.3									

The steelplant in Sandviken is scrap-based. The plant includes an electric arc furnace, AOD converter, continuous casting machine, rolling mill and pickling shop. About 100,000 tonnes of steel, chiefly stainless, are produced annually.

About 95 % of the water from the continuous casting machine and rolling mill is recirculated after cleaning in sand filters. Surface water is used as process water. Cleaning of the rinse water from the pickling process is carried out by neutralization, flocculation and sedimentation. As a result, the concentrations of Ni and Cr can be kept at around 2 mg/l in outgoing water. The discharge of metals could probably be reduced by reducing water consumption. Water is discharged into a lake in the course of the River Gävleån.

Extraction and cleaning of dust from the furnace and converter have been improved during the 1980s. Hoods have been installed in the ceiling. Cleaning is effected by means of fabric filters. Better extraction of the dust could be accomplished by building-in the furnace and converter, for example, so that dust emissions were reduced from the present 0.25 to about 0.1 kg per tonne of steel. This would result in a reduction of the emissions of Cr, Ni and other metals.

The primary smelter in Rönnskär is about 75 % ore-based. About 100,000 tonnes of copper and 100,000 tonnes of lead are produced annually. Several by-products, such as arsenic compounds, selenium compounds and sulphuric acid, are also produced. The plant has a roasting furnace, electric smelting furnace, converters, Kaldo process plant and electrolytic refining shop.

All process water with a metal content undergoes precipitation with sulphides and lime as well as sedimentation before it is discharged. A certain proportion of the water is recirculated.

Extraction and scrubbing of flue gases containing dust have been improved over the past ten years. Further improvements, particularly more efficient extraction of furnace gases, will be introduced in the next few years. After dust separation and scrubbing to remove mercury, the furnace gases are used for the production of sulphuric acid. Wet scrubbers and fabric filters are used for separating the dust. Surface filtration filters have been installed at some places. Dust emissions after these filters are lower than 1 mg/kg. Mercury is removed from the gases by carbon filters and selenium filters. After these cleaning stages, the mercury content is less than 0.09 mg/m^3 (ndg).

The alumina smelter in Sundsvall produces primary aluminium. Annual production is about 80,000 tonnes. The factory has two plants with slightly different production equipment.

Dust emitted to the atmosphere and suspended substances discharged into water are estimated at containing less than 5% aluminium but no appreciable concentration of other metals.

The mines responsible for the greatest leakage of metals are situated in Falun and Garpenberg on the River Dalälven. The largest volume of metals comes from old waste rock and tailings which have begun to disintegrate. Methods of covering waste deposits with layers limiting the transport of oxygen and water to the waste, can reduce the leakage of metals by about 90 %. Deposition of the waste in old water-filled mineshafts is also a way to prevent oxygen from reaching the waste and so reduce disintegration.

Metals are also discharged from ore dressing plants. The process water is recirculated to a large extent in Swedish plants. Wastewater undergoes precipitation and sedimentation before it is discharged.

Metal emissions to the atmosphere take place chiefly from ore dryers. At many Swedish mines the ore dryers have been replaced by air filters which give rise to no emissions at all.

Two chloralkali plants in Örnsköldsvik use the mercury method. Production is about 35,000 tonnes a year. A number of internal process measures have been taken to reduce the discharge of mercury. Outgoing mercury-polluted water is treated by precipitation with ferrous chloride and hydrazine in combination with ion exchange. The ventilation air is not cleaned at present. Mercury-free technology is available and used at some other Swedish plants.

Waste incinerator plants in Sundsvall and Umeå. The plant in Sundsvall incinerates about 8,000 tonnes of household refuse annually and the one in Umeå about 83,000 tonnes a year. Both plants have dust separating equipment in the form of electrostatic filters. Their permits will be reviewed within a year and stricter requirements are then expected to be introduced concerning emissions of dust, mercury and other substances. The blowing of lime into the flue gases and/or flue gas condensation has been introduced at several Swedish waste incinerator plants for the purpose of reducing mercury emissions, etc.

Finland

Presented below are the Finnish industrial plants which are situated in the runoff area of the Gulf of Bothnia below the lakes and under obligation to check their wastewater for metal content, and also those which emit metal to the atmosphere which may be of significance to the Gulf of Bothnia. The geographical location of the manufacturing plants and mines presented below will be evident from the map in Figure 4. Emission volumes are shown in tables 1-3 and 6 and also in Fig. 5.

Table 6. Metal emissions to the atmosphere in Finland.

Year	tonnes/year								
	Hg	Cd	Pb	Cu	Zn	Cr	Ni	As	V
1984	0.7	3.2	760	305	540	250	148	22	145
1986	0.7	3.3	400[1)]	305	520	210	180	20	145
1987	0.5	5.6	430	350	309	29	220	28	130

1) Approx. 300 tonnes from motor traffic.

The Clean Air Act came into force on October 1, 1982. It stipulates a notification procedure. Plants carrying on activities covered by the Act have to submit a written report to the county administration, which may approve the plant-owner's plan for air pollution control or issue special regulations for the plant's operations. Of the factories described here, only the steel plant in Raahe and the ferrochromium and steel plant in Tornio have received an air pollution control decision.

There are five <u>ore mines</u> in the runoff area of the Bothnian Bay. Operations at the oldest mine stretch from the early 1950s to the transition into the 1990s. Two of the mines, which began operations in the 1960s, will still be worked around 1995. Of the last two mines to start operations, which took place in the 1970s, one was closed after only 12 years of activity and the other will be closed around 1992. All the mines discharge process, drainage and surface water into sedimentation basins. The water is limed as necessary. Three of the four mines which are still active recycle a large proportion of the sedimentation basin water and the fourth has internal circulation systems. Of the effluent, it is primarily the discharge of chromium from the mine near Kemi that must be the subject of control measures. For this purpose an expansion of the soil basins was put into service in 1988. The present permit is from 1985. A new application was submitted in 1988. Only one small mine, which began operations in 1975 and closed down in 1987, exists in the runoff area in the Bothnian Sea. At the Archipelago Sea there is only a felspar mine where old mine stockpiles are at present still uncovered. Even though water quality control has given no cause for serious concern, the requirement of covering certain mine stockpiles should nevertheless be considered, if for no other reason than that of the landscape.

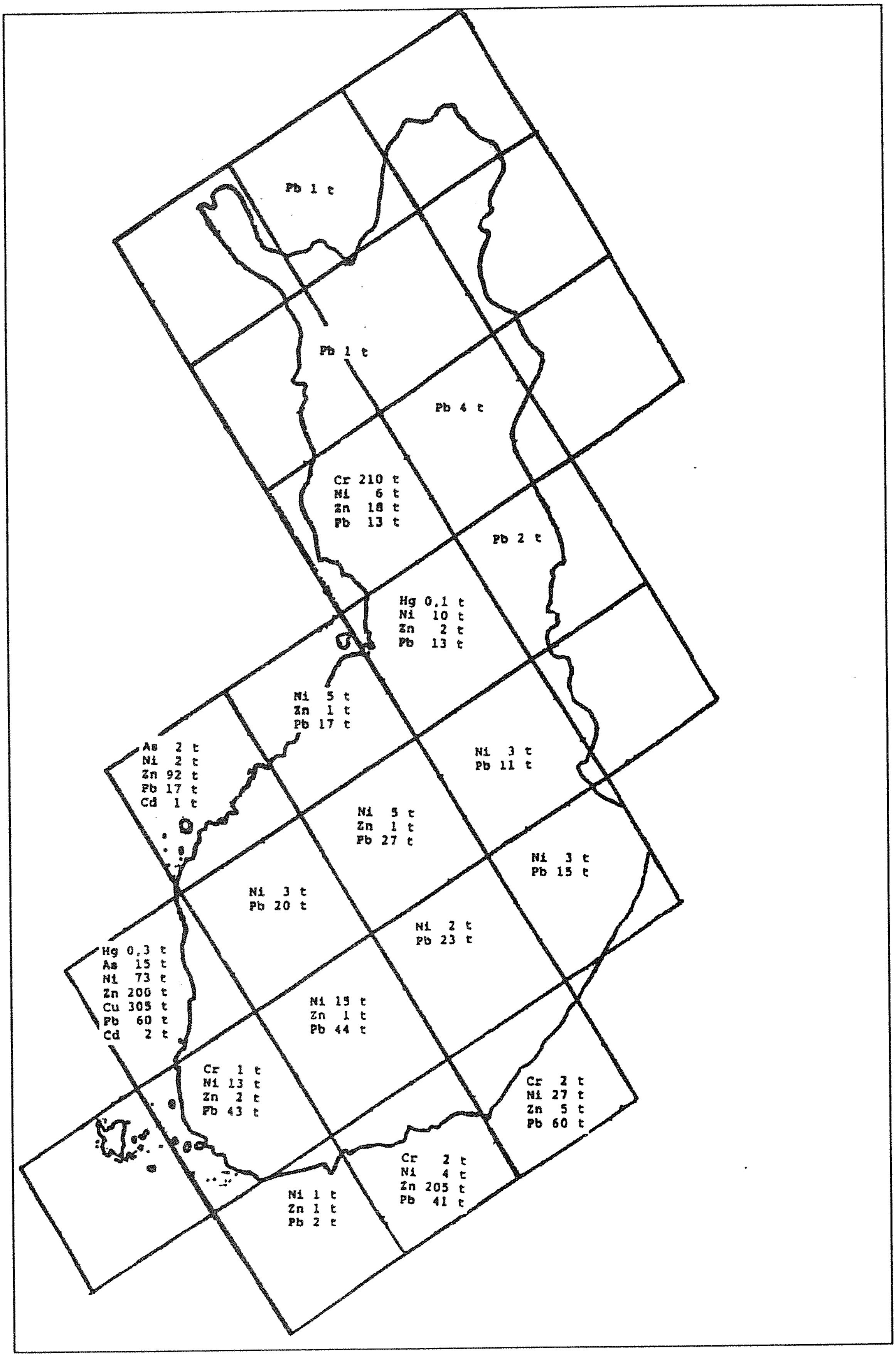


Fig. 5. Metal emissions to the atmosphere in Finland, 1986.

The ferrochromium and steel plant in Tornio began operations in 1968. The raw materials are obtained from a mine near the town of Kemi. Manufacture is carried out in electric arc furnaces and in hot and cold rolling mills. Production capacity is about 160,000 tonnes of ferrochromium and about 200,000 tonnes of fine steel annually.

Wastewater undergoes neutralization and sedimentation in soil basins, from which water is recirculated and used in the process again. In 1987 the amount of outgoing process and gas washing water was about 12 m^3 per tonne of fine steel produced. Pickling acids are regenerated for the most part. Efforts are made to keep regeneration at a level of 80 %. Through the expansion of the wastewater basins that were put into service in 1988, through an adjustment in the operation of the neutralization plant, and through an increase in process water circulation, discharges of metal will be reduced or maintained at the present level in spite of increasing production. The Border River Commission's permit was issued in 1988. The company has submitted a new application for its growing production.

The decision concerning the factory's air pollution control application was received in January, 1989. The factory's major discharges to the atmosphere used to come from the sinter plant. This now has an efficient wet separator and emissions of dust have been reduced from more than 900 tonnes to about 14 tonnes per year. At the same time, the entire factory's dust emissions have decreased from more than 1,300 tonnes (including 250 tonnes of chromium) to 280 tonnes (including 24 tonnes of chromium) a year. Emissions from the electric arcfurnace are collected and cleaned (max. dust emissions 0.3 kg/t steel) with new equipment which was installed in the spring of 1989.

The steelplant in Raahe began producing iron in 1964 and steel in 1967. Production equipment includes a blast furnace and hot rolling mill and, since 1987, also a coking plant. Production is about 2 million tonnes of steel annually.

Wastewater from the hot rolling mill and part of the continuous casting process goes via sedimentation basins to a closed bay which serves as a freshwater basin for the factories. This water is thus fully recirculated. Since the freshwater basin still has a certain landscape and recreational value, the permit issued by the water rights court nevertheless stipulates an upper limit for the volume of wastewater discharged into it. The degree of circulation for the blast furnace's and steel furnace's gas washing water is 95 % and 90 % respectively, but for that portion of the cooling water for continuous casting that does not go to the freshwater basin it is 80 % (these estimates are for 1986). An improvement could be called for here, even though it would be of no importance for other metal discharges besides iron. The volume of outgoing process and gas washing water discharged into the sea from the iron and steel plant in 1986 was somewhat more than 10 m^3 per tonne of steel produced. The permit is from 1986. A new application should be submitted not later than in 1992.

The sinter plant is the major source of emission. There are three sinter plants in the works. Multicyclones and electrostatic filters are used to clean the gases. In the blast furnaces nearly all the flue gases are collected and cleaned with electrostatic filters. Small amounts of dust are still emitted to the atmosphere at times, however. The smelting plant has three basic oxygen furnaces, all of which are equipped with venturi scrubbers. Dust from the works contains mainly different iron oxides and only small quantities of heavy metals.

The steelplant in Dragsfjärd in southeast Archipelago Sea goes back as far as 1686, when the country's first blast furnace was put into operation. In the 1970s the factory embraced a scrap-based steelplant, a foundry, a rolling mill and a wiredrawing mill. The steelplant and foundry were closed in 1983. More than 90 % of the wastewater from the rolling mill is circulated and all outgoing water is purified chemically.

Wastewater from the wiredrawing mill contains copper, lead, zinc and iron. In 1987 a wastewater treatment plant was put into operation. It has a purification efficiency of 75-85 % in respect of copper, zinc and lead and more than 97 % in respect of iron. Corresponding standard values for outgoing concentrations are 2.0 mg Cu/l, 1.5 mg Zn/l, 1.2 mg Pb/l and 15 mg Fe/l. The permit is from 1986. A new application ought to be submitted not later than in 1992.

The primary copper smelter in Harjavalta about 35 km from the coast in the Bothnian Bay was founded in 1944. Nickel has been produced there since 1960 and in 1987 a preprocessing plant and attendant chemical unit were installed for recovering enriched noble metals. Annual capacity is 100,000 tonnes of copper and 17,000 tonnes of nickel. The process embraces air furnaces, converters and electrolytic refining of nickel. The factory has also recently taken over the production of sulphuric acid.

The factory has three circulation systems for water: a sedimentation basin for copper slag, a closed cooling water system for the nickel plant, and a sedimentation basin for the nickel furnace's granular slag. Surface water from the factory area is collected in a special basin. The biggest load from the factory has come with the surface water. Treatment of the surface water and the sulphuric acid factory's condensation water through precipitation was improved in 1988. The permit issued by the water rights court is from 1978. The new application for a permit, which is at present the subject of inspection and expert appraisement, is expected to lead to a substantial sharpening of the water conservation requirements and more effective purification of all contaminated water.

There are three chimneys in the smelting works. Gases from furnaces where copper and nickel concentrates are dried, and the gases collected via hoods from the two air furnaces, go to one of the chimneys. Electrostatic filters are used to clean these gases. The process gases are conducted to separate cleaning units and then used in sulphuric acid production. The gases collected from converters via hoods go to the second chimney. The process gases are carried to separate cleaning units and then used in sulphuric acid production. Gases from electric furnaces go to the third chimney. Diffuse dust emissions also result from the removal of concentrate and these comprise nearly half of all dust emissions.

When sulphuric acid production was taken over by the smelter in the autumn of 1987 it also took over responsibility for the metal emissions that had previously been attributed to the fertilizer manufacturing plant in Harjavalta. It should also be noted that corresponding changes in the emission statistics are illusory and that in this report they are reflected only in the forecast for 1995.

Further processing of the anode copper from Harjavalta has been carried out since the 1940s at a metallurgical unit in Pori, where electrolytic refining of gold, silver and selenium also takes place. In the same factory there are also rolling mills, a foundry, facilities for surface finishing and the manufacture of chemicals. Different circulation systems and the precipitation and sedimentation of metals form part of the water conservation measures employed. In future decisions, consideration should be given to a sharpening of the limits for copper, zinc, nickel and chromium. The factory is the subject of inspection and expert appraisement at the same time as the factories in Harjavalta. The division of work between Harjavalta and Pori is the subject of redeployment, which may have an effect on the water conservation decisions.

Emissions into the atmosphere from the hydrometallurgical processes are fairly small. The largest emission volumes stem from nickel sulphate production.

The primary smelter in Kokkola began operations in 1962 with a sulphur factory and a power station. In 1969 a cobalt factory and a zinc factory were started. By 1978 both factories had expanded and begun production of the mercury, cadmium and selenium by-products (1974) while the sulphur factory was closed down (1977). Production of chemicals was started in 1983 and cobalt manufacture came to an end in 1987. Present-day production volume is about 160,000 tonnes of zinc, 650-700 tonnes of cadmium, 130 tonnes of mercury, less than 10 tonnes of selenium and 9,000-10,000 tonnes of chemicals annually.

Water conservation measures of the 1980s include improving the efficiency of sedimentation basins, redesigned washing systems to reduce the mercury content in flue gases, the collection and utilization of surface water in the processes from a 10 hectare large area, and circulation systems for cooling water. Since the cobalt roaster was closed, most of the emissions now come from washing water and surface water of different kinds, according to the company. Cobalt, copper, cadmium and iron emissions in particular declined heavily during and after 1987. In the future, the sources of the remaining emissions should be mapped out and special attention drawn to a further limitation of nickel and zinc emissions. The water rights court permit is from 1981. The new application for a permit, which is at present the subject of inspection and expert appraisal, is expected to lead to an appreciable sharpening of the emission limits.

Gases from the roasting of zinc concentrate are cleaned after heat recovery. After the hydrometallurgical process the zinc solution is cleaned and then passed on for electrolysis. The zinc cathodes are melted and cast. Cadmium, mercury and selenium are produced from the gas cleaning and solution cleaning residue in a by-product factory.

Gases with a sulphur dioxide content are passed on to the sulphuric acid factory. All processes in the by-product factory are of closed type. The largest emission volumes stem from the ventilation systems and heat output.

<u>The fertilizer factory in Kokkola</u> began operations in 1945. In addition to slightly more than 300,000 tonnes of fertilizer a year, this factory nowadays also manufactures sulphuric acid, potassium sulphate and calcium chloride. In 1984 an experimental plant for manufacturing pesticides was started and in 1987 a factory for full-scale production was put into operation. Raw material ore is fairly free from cadmium and no metals are used in the production of pesticides. The mercury emissions stemming from the sulphur dioxide gases used in the metal-work's production of sulphuric acid are nowadays small.

<u>The titanium dioxide factory in Pori</u> began operations in 1961. Production is based on the so-called sulphate process. Production capacity has been increased to 84,000 tonnes annually. Crystallized ferro sulphate has been systematically separated since 1974. The efficiency of the crystallization process was improved in 1980 by the addition of a vacuum plant. A concentration plant for acid filtrate was put into service in 1984, following which all filtrated acid (> 20 % concentration) and most of the acid from the subsequent washing stages could be recirculated in the process. The wastewater is discharged into the sea via the sedimentation basin through a 4.5 km long sewer. The sedimentation sludge is limed and stored in the factory area. The factory submitted a new application to the water rights court in 1987. According to the plans, recovery of sulphuric acid will be further improved. It is therefore expected that emissions of both sulphuric acid and iron will be reduced by 30 % before 1991. The company has plans to increase production capacity. In their pronouncement, the water authorities required emissions to be reduced by 50 % of the 1987 level in spite of the production increase and in conjunction with it or not later than 1995. It is expected that emissions of other metals besides iron will be reduced to the same extent.

The processes are mostly hydrometallurgical (only one calcining oven) and the emissions are raw material (ilmenite) or product (titanium dioxide). Emissions of heavy metals into the atmosphere can be expected to amount to several kg annually.

There is one chloralkali manufacturing plant in Oulu and another in Äetsä municipality on the River Kokemäenjoki about 70 km from the coast as the crow flies. The former plant began operations in 1957, the latter in 1939. The latter plant discontinued operations and closed down in 1984 and the factory still operating in Äetsä dates from 1955. The factories use the amalgam process and currently produce a total of slightly more than 100,000 tonnes of chorine per year.

Water protection measures include closed processes, renewed flooring and the collection of all contaminated water. Wastewater is purified chemically and, in Äetsä, also with ion exchangers. The water rights court permit in Oulu is from 1983. The factory in Äetsä has recently been the subject of inspection and expert appraisal and will be issued with a new permit within the near future. The limits for the factory's mercury emissions are expected to stay at the present level.

Emissions to the atmosphere are fairly low. Capital investment has been made in both plants with the aim of reducing mercury emissions.

Towards the end of the 1940s, the manufacture of pesticides in Vaasa was started. Seed disinfectant containing mercury was one of the first products. Nowadays, the factory only formats and packages pesticides for agriculture and forestry. Other chemicals and industrial safety accessories are also manufactured there. The processes are closed and the only outgoing water consists of cooling and sanitary water and process water from a chemical factory built in the 1980s. Metal discharges have been caused mainly by runoff from an old waste deposit. The total amount has been less than 100 kg a year (chiefly copper and arsenic). The waste deposit is at present being decontaminated. The factory's permit is from 1987. Application for a new permit must be made not later than 1994.

In the runoff area (below the lakes) on the Finnish coast of the Gulf of Bothnia there are somewhat more than ten mechanical engineering workshops with their own outflow to the recipient. Ordinary purification requirements are 2 mg Cr/l, 0.05 mg Cr^{+6}/l, 1 mg Cu/l, 3 mg Ni/l and 3-5 mg Zn/l.

There are a number of leather factories in Kokkola, three of which after long-drawn-out technical difficulties managed to get their chemical-biological purification plant to work in the 1980s. The others have been connected to the municipal sewer system or have discontinued operations. The town has a chemical purification plant. On the River Kokemäenjoki are two leather factories, one of which has a chemical-biological purification plant and the other is connected to the municipal sewer system. It should be possible to keep the leather industry's chromium discharge to water at the same level as in 1987.

3.2 MUNICIPALITIES

There are at present eleven population centres on the coast of the Gulf of Bothnia, each with more than 30,000 inhabitants (Fig.6). During the 1980s nearly 1.3 million inhabitants have been connected to municipal or similar water treatment works discharging straight into the Gulf of Bothnia. Biological purification with simultaneous precipitation is used mainly in Finland while Sweden uses biological purification and biological purification with postprecipitation (Table 7). Ferro sulphate is used mainly in Finland as the reagent while aluminium is used in Sweden.

Fig. 6. Larger municipalities discharging into the Gulf of Bothnia. Waste water treatment in 1987.

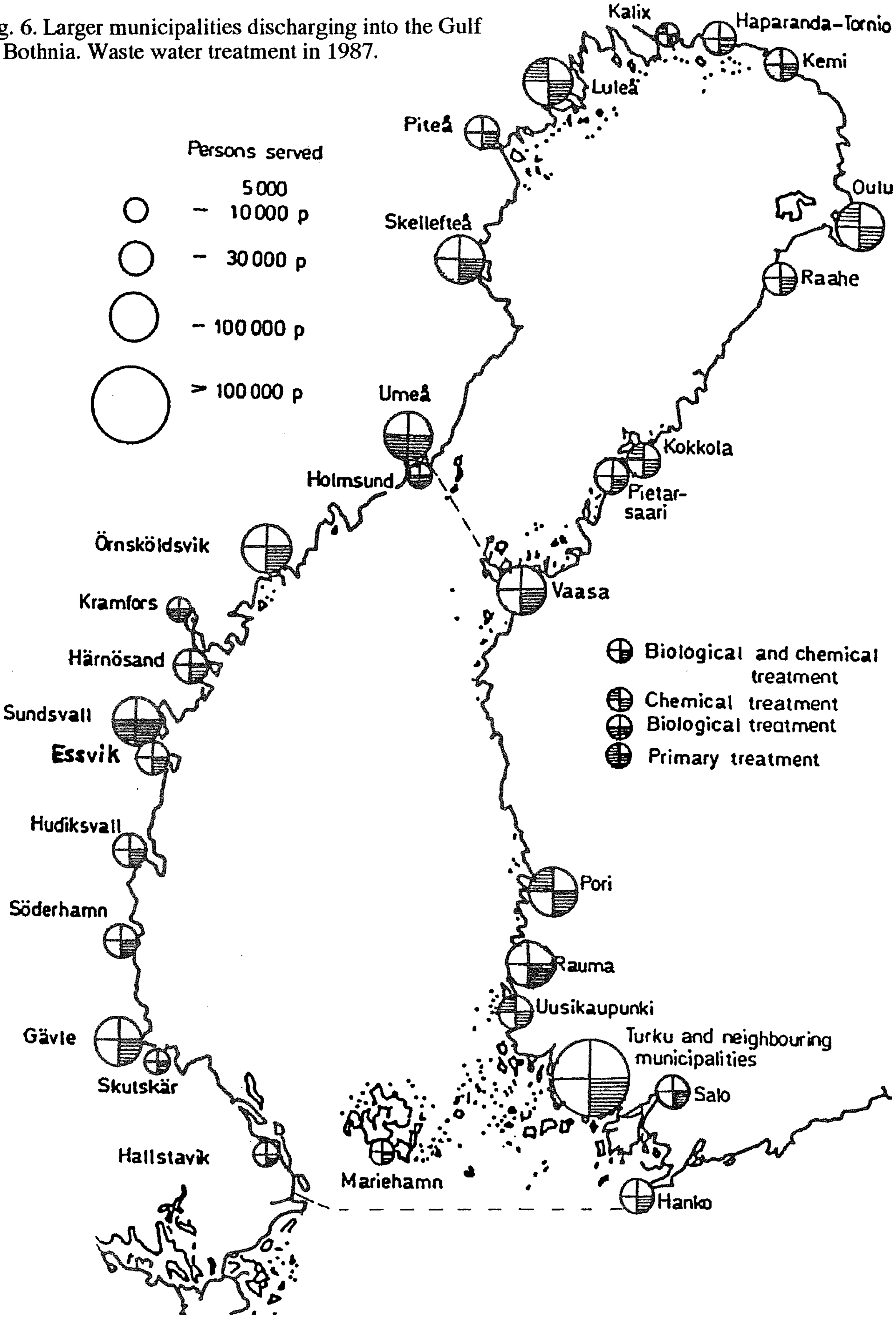


Table 7. Proportion of the municipal wastewater flow into the Gulf of Bothnia per purification method in 1982 and 1986.

Purification method	1982		1986	
	Finland %	Sweden %	Finland %	Sweden %
Biological-chemical	58	35	71	46
Biological	2	48	0	36
Chemical	36	15	29	18
No purification	4	2	0	0

In connection with wastewater treatment, a large proportion of the incoming metals are bonded to the sludge. According to a Finnish study, the metal concentrations are reduced in connection with chemical purification as follows:
Hg 40...60 %, Cd 50...90 %, Pb 50...60 %, Cu 40...60 % and Zn 50...60 %. With biological purification it may be assumed that the reduction is somewhat poorer and with biological-chemical purification somewhat better.

The purification requirements are similar in both countries (Table 8), as also are the purification results (Table 9). In each case it depends on the method of purification.

Table 8. Standard requirements in regard to municipal wastewater purification results.

Method	BOD_7		Phosphorus	
	mg/l	red-%	mg/l	red-%
Direct precipitation	60-70	60-70	1.0	85-90
Simultaneous precipitation	15-20	85-90	0.5-1.5	80-90
Postprecipitation	15	90	0.5	90

Table 9. Purification results in Finland and Sweden for plants serving more than 200 persons in 1987.

Parameters	Finnish coast of Gulf of Bothnia		Swedish coast of Gulf of Bothnia	
	mg/l	%	mg/l	%
BOD_{7ATU}	26	86	17	...
Phosphorus	0.7	91	1.3	...
Nitrogen	23	33	17	...
Flow, million m^3/year	101		123	

The present purification result vis-a-vis BOD and phosphorus is satisfactory but in Finland it is still considered possible to improve operations at existing plants and so reduce emissions by about 30 % more. It can then be assumed that metal emissions would also be reduced.

Environmental poisons, including metals, enter the sewer system with surface water and also from households, industrial processes, laboratories and the like. At the wastewater treatment plant, where they may give rise to disturbances, they are difficult to measure and difficult to control. In addition, their effect on the usefulness of the sludge is hard to judge.

Sources which particularly load the municipal sewage systems with metals are above all engineering industry and surface finishing plants, photographic laboratories and dental surgeries. In Kokkola and two other population centres further inland in the Finnish coastal area are several tanneries which burden the municipal sewer system with chromium.

In Sweden, the Swedish Water and Sewage Works' Association (VAV) published recommendations in 1983 for emissions of harmful substances into municipal sewer systems. For example, in regard to the process water from surface finishing in the mechanical engineering industry, they presuppose efficient chemical purification before connection to the municipal sewer system. In Finland, a cooperation project in 1979 involving the authorities, research scientists and industry resulted in recommendations for the concentrations of harmful substances entering municipal wastewater treatment plants. The recommendations take note of trouble-free operation of the wastewater treatment plant and also the utilization of sludge. The recommendations of both countries are shown in Table 10. However, in each country it is the municipality that decides on the demands which are made on the individual factory or plant.

Table 10. Recommended limits for metal concentrations in wastewater discharged into municipal sewer systems in Sweden and Finland.

	Sweden at connection point with municipal sewer mg/l	Finland incoming to municipal wastewater treatment plant mg/l
Hg	0.002	0.005
Ag	0.5	0.1
Cd	0.005	0.005
Cr	2.0	0.5
Cu	1.0	1.5
Pb	1.0	0.2
Ni	1.0	0.1
Zn	2.0	0.7
Co	1.0	
Se	1.0	
Sn	1.0	

The mercury, cadmium, lead, copper and zinc load from municipal wastewater systems on the Gulf of Bothnia in the 1980s has been calculated in Finland on the basis of the purification method used and the metal content of the sludge (Table 10).

The lead load with surface water has been calculated as less than 10 % of the waste-water load. Nickel and chromium probably also occur in municipal wastewater but no estimate of these emissions has been made. A summary of the metals discharged into the Gulf of Bothnia in the early 1980s is given in Table 11. A summary of all the estimated municipal emissions from Finland and Sweden is given in Table 12. The estimates are rough and have not been arrived at on the same grounds.

Table 11. Maximum municipal emissions of metals from Finland (SF) and Sweden (S) into the Gulf of Bothnia during the first half of the 1980s.

Area	kg/year				
	Hg	Cd	Pb	Cu	Zn
Bothnian Bay	S ..	35	..	1,000	3,000
	SF 20	40	1,000	1,000	7,000
Bothnian Sea	S ..	80	..	2,000	9,000
	SF 30	50	2,000	2,000	8,000
The Archipelago Sea	SF 30	30	1,000	2,000	12,000
Gulf of Bothnia	S ..	135	..	3,000	12,000
	SF 80	120	4,000	5,000	27,000

Table 12. Estimated municipal emissions in Sweden and Finland during the first half of the 1980s.

	kg/year						
	Hg	Cd	Pb	Cu	Zn	Cr	Ni
Finland	100	160	5,000	6,000	35,000	..	..
Sweden	..	150	900	7,000	24,000	1,200	1,300

The emissions of environmental poisons can be substantially reduced at the same time as the conditions for impeccable wastewater treatment plant operations are improved.

This means that

- leakage into the waste water sewer is prevented
- wrong connections in the sewer system are corrected
- informational activities with the aim of preventing toxic waste from being discharged into the sewage are carried out
- demands are made for the pretreatment of waste water from industrial processes
- the professional competence of wastewater treatment plant personnel is developed so that it corresponds to present-day requirements.

It should also be mentioned that the Helsinki Commission issued two recommendations in 1988 concerning the reduction of municipal emissions by means of efficient purification methods and concerning the reduction of emissions with surface water. Both recommendations call for measures in line with those described above and reporting to the Commission.

3.3 OTHER SOURCES

The Swedish Parliament has passed a resolution on a Plan of Action against pollution of the seas. According to the plan, emissions of metals must be reduced by about 50 % by 1995. Apart from steps taken in the iron and steel industry, metal-works and refuse incineration plants to achieve this reduction target, measures will also be taken in the following areas:

- Batteries. Collection of batteries containing Hg and Cd. The Government decided in 1989 that alkaline batteries shall not be allowed to contain more than 0.025 % of Hg. Combined with more efficient flue gas cleaning at waste incineration plants, these measures will result in a reduction of Hg emissions to the atmosphere from 3.3 tonnes in 1988 to 0.3 tonnes in 1995.
- Motor vehicle exhaust emissions. The introduction of catalytic converters and a reduction of the lead content in petrol will reduce the emissions of Pb to the atmosphere. Catalyzers are compulsory on all petrol-engined motor vehicles from 1989 model year vehicles. Lead emissions will decline from 750 tonnes in 1985 to about 280 tonnes in 1995.
- Pesticides. The use of pesticides containing mercury will not be allowed with effect from January 1, 1989.
- Mining waste. Leakage from mining waste in Falun and Garpenberg to be reduced by 90 %. This will reduce the metal flows in the River Dalälven.
- Tin organic compounds. Use on pleasure boats prohibited with effect from January 1, 1989.
- Fibre banks. Measures aimed at reducing Hg leakage.
- Refuse with a metal content. Greater demands will be made on deposition methods to reduce leaching from depositions of sludge, filter dust, etc.

Work is also being carried on in Finland to implement as rapidly as possible the guidelines agreed upon in Scandinavia and the Helsinki Commission and other national objectives.

- Batteries. The Ministry of the Environment and the central organization of the municipalities have issued directives for the collection of batteries. In addition, measures are being prepared to limit the Hg content in alkaline batteries. Marking of batteries is planned as a joint Scandinavian project.
- Motor vehicle exhaust emissions. Catalyzers will be compulsory on all petrol-engined motor vehicles with effect from model year 1992 vehicles.
- Pesticides. The Ministry of the Environment intends as soon as possible to take up with the Pesticide Commission the question of registering new seed disinfectants containing Hg.
- Tin organic compounds. When it comes into force, the new Chemicals Act will enable measures to be taken in accordance with the Helsinki Commission's recommendation 9/10 against the use of tin organic compounds on pleasure boats and fish-farming cages.

- Mine and industrial waste with a metal content. The requirement level is determined from case to case in connection with granting permits. An inventory of old deposition sites is to be made.

The deposition of metals in the Gulf of Bothnia is affected by emissions to the atmosphere throughout Sweden and Finland and other countries. Emissions of metals to the atmosphere throughout Sweden in 1978, 1987 and 1995 (forecast) are presented in Table 5 and in Finland in 1984, 1986 and 1987 in Table 6 and in 1986 in Fig. 5.

4. RIVERS

Sweden

The concentration of various metals in Swedish rivers is measured by random sampling every month. The flow rate is calculated on the basis of daily measurements. In most of the rivers the metals stem mainly from decomposed materials in the bedrock. Lakes and marshes in the course of the rivers affect the metal flow by acting as metal traps. The biggest annual variations in the metal flows which occur are due almost entirely to the way the rate of flow in the different rivers has varied from year to year. The combination of dry and wet periods can also affect the metal flows.

Important point sources of metal discharges into rivers are a number of mines, both discontinued and still in operation. The magnitude of metal emissions from waste rock and tailings at discontinued mines is in many cases unknown. The rivers in northern Sweden which are primarily affected by discharges from the mining industry, and by known discharges from discontinued mines, are the River Råneälv, the River Skellefteälv, the River Umeälv, the River Ångermanälven and especially the River Dalälven.

Swedish measurements of metal transportation in the rivers before 1984 are not fully reliable. For this reason, the results of measurements carried out in the period from 1984 to 1987 are presented in tables 13 and 14 as mean values or for the years in the period when measured values are available for the respective parameter.

No estimates have been made of metal transportation from areas situated between the runoff areas of the studied rivers.

Finland

Measurement of the metal transportation in Finnish rivers was begun in 1982. Before this, the methods of analysis were not sufficiently accurate for the low concentrations present in the rivers. From 1982 to 1986 the measurement programme embraced 22 rivers, of which 17 flow into the Gulf of Bothnia.

On account of the fairly wide and inexplicable variations in the measurement results, the effects of different sampling and analytical methods were closely studied in 1987 (Smolander et al, 1988). The measurement programme was resumed in 1988 with the methodological improvements which the study had suggested.

The Finnish methods of measurement and the results obtained in the years 1982-1986, as well as the reservations which on the basis of the 1987 study and the preliminary 1988 results can be made in respect of them, are described in the following.

Table 13. Metal transportation to the Bothnian Bay via the studied Swedish rivers, 1984-1987.

River	runoff area, km^2	Cd	Pb	Cu	Zn	Fe	Mn
		tonnes/year					
Torne älv	35 000	0.88	5.3	36	153	11 800	630
Kalix älv	17 930			15	18	9 200	570
Råne älv	4 160			2	2	1 590	71
Lule älv	25 545			33	41	4 100	460
Pite älv	11 155			37	204	2 300	108
Skellefte älv	11 600	0.12	1.8	11	45	1 220	128
Rickleån	1 670	0.01	0.1	1	3	360	18
Total	107 060	(1)	(7)	135	470	31 000	2 000

Table 14. Metal transportation to the Bothnian Sea via the studied Swedish rivers, 1984-1987.

River	runoff area, km^2	Cd	Pb	Cu	Zn	Fe	Mn
		tonnes/year					
Ume älv	26 540	0.28	7.6	26	70	4 300	279
Öre älv	3 025		0.5	6	15	1 370	67
Gide älv	3 425			4	8	880	53
Ångermanälven	30 365			23	31	4 250	357
Indalsälven	24 685	0.21	3.9	63	160	1 460	138
Ljungan	12 840			16	63	970	60
Delångersån	2 010			1	3	100	7
Ljusnan	19 815			20	50	2 930	192
Gävleån	2 455	0.02	0.8	5	15	520	51
Dalälven	27 920	0.73	9.0	129	721	4 700	568
Total	153 080	(1)	(21)	290	1 100	21 000	1 800

Materials and methods

Sampling was carried out once a month from 1982 to 1984 and more frequently in the case of increased flows (flow-dependent) from 1985. A typical measurement frequency for the different rivers was 8-12 samples a year. The flow was measured daily in all the rivers studied. The metals were analyzed with AAS after precipitation with $Mg((OH)_2$ (Koroleff 1984). Mercury was analyzed with flameless AAS (eg Verta et al. 1986). In 1987, all metals were analyzed with direct AAS and using Koroleff's method.

Annual material transportation was calculated for each individual river by multiplying the mean monthly flow by the mean monthly concentration. In cases where a monthly concentration was not available, it was replaced by the arithmetical average of the relevant year's mean monthly concentration. Figures for the coastal area and small rivers that were not measured were calculated by linear extrapolation of the average runoff per runoff area acreage that had been measured in nearby rivers.

Metal transportation in 1982-1983 and 1985-1986

The first attempt to estimate the magnitude of metal transportation in Finnish rivers was made on the basis of 1982-1983 data (Table 15, Pitkänen et al. 1988). These figures probably overestimate the actual amount of most metals transported, since not enough attention had been paid to contamination in connection with sampling, transport, storage and analysis.

The estimated mean amount transported in the years 1985-1986 (Tables 15 and 16) is generally smaller than for the earlier period. This is due chiefly to less contamination in connection with sampling and more critical examination of original data. The flow rate did not differ much in the various rivers during the two periods and can therefore not explain the differences. However, it is possible that the figures for 1985-1986 are also to some extent an overestimate of the actual transportation of most of the studied metals. This is indicated by the latest results from 1987-1988, when special attention was paid to avoiding contamination in all stages of the sampling and analytical processes.

Comparability between the results of the direct AAS method and the co-precipitation method were fairly good for copper. In the case of zinc, the figures for the direct method were clearly higher than the co-precipitation method. For lead, cadmium and chromium, the variations were fairly large but no clear systematic difference could be shown. This indicates that the transport values calculated for the metals are uncertain and only show the magnitude of the load.

Table 15. Estimate of total metal transportation to the Gulf of Bothnia via Finnish rivers 1982-83 (Pitkänen et al. 1988) and 1985-86 (Reinikainen & Pitkänen 1989).

Sea area	runoff area, km^2	period	transport, tonnes/year Cd	Pb	Cu	Zn	Cr	Fe $\times 10^3$
Bothnian Bay	169 000[1)]	82-83	1	30	90	300	-	75
		85-86	1.3	19	66	410	65	63
Bothnian Sea	39 000	82-83	2	20	30	100	-	23
		85-86	0.9	9	34	150	67	17
Archipelago Sea	9 000	82-83	0.4	4	10	30	-	9.5
		85-86	(0.1)	(4)	(5)	(30)	(10)	15
Gulf of Bothnia	217 000	82-83	3	50	130	400	-	110
		85-86	2.3	32	110	590	140	95

1) also includes the Swedish part of the Torne river's runoff area.

Metal transportation is clearly correlated with the river flow. According to the calculations, outgoing transportation from the Finnish side of the Gulf of Bothnia is concentrated mainly in two areas: the northeasterly area of the northern part of the Gulf of Bothnia, to which 60 % of the Finnish runoff area round the Gulf of Bothnia flows, and the area outside the mouth of the River Kokemäenjoki in the southern part of the Gulf of Bothnia.

Table 16. Metal transportation to the Gulf of Bothnia via the studied Finnish rivers, 1985-86 (Reinikainen & Pitkänen 1989).

River	runoff area, km^2	transport, tonnes/year Hg	Cd	Pb	Cu	Zn	Cr	As	Fe x 10^3
Tornionjoki	35 000	<	0.07	3.1	13	37	13	<	13
Kemijoki	51 400	<	0.2	5.6	15	51	12	<	14
Simojoki	3 175	0.006	0.01	0.4	0.9	4.2	0.9	<	1.5
Iijoki	14 385	0.1	0.07	2.3	4.0	32	4.7	<	4.6
Kiminkijoki	3 880	0.04	0.02	0.5	0.9	6.9	1.3	<	2.3
Oulujoki	22 925	<	0.09	2.1	6.7	32	5.5	<	4.2
Siikajoki	4 440	0.03	0.03	0.6	1.6	12	2.8	0.3	3.8
Pyhäjoki	3 680	0.007	0.04	0.3	1.7	13	2.8	0.4	1.7
Kalajoki	4 200	0.02	0.05	0.5	3.4	17	3.4	1.8	3.1
Lestijoki	1 335	..	0.01	0.2	0.9	3.8	0.6	(0.1)	0.8
Perhonjoki	2 690	0.007	0.03	0.4	1.0	12	2.6	0.6	1.9
Lapuanjoki	4 110	..	(0.2)	0.6	4.4	62	2.4	(1.5)	1.9
Kyrönjoki	4 900	0.2	0.2	0.6	4.9	52	4.7	2.3	2.8
Lappväärtinjoki	1 125	<	0.03	0.2	0.7	5.9	1.0	<	0.7
Kokemäenjoki	27 100	0.2	0.6	7.1	26	92	56	13	9.1

< concentration below limit of detection.
( ) unreliable due to insufficient samples (n/year 6).
.. too few samples for calculation of transportation (n/year 4).

The River Kokemäenjoki is the only Finnish river which is heavily loaded with metal emissions from point sources (Oravainen 1987). According to the emission statistics for 1986 and river transportation for 1985-1986, the emissions correspond to the following proportions of metal transportation in the river, expressed as percentages:

Metal	Hg	Cd	Pb	Cu	Zn	Cr	As
percentage	31	85	28	34	9	6	16

Over and above the point discharges, this river is affected by diffuse sources and polluted bottom sediment. The bottom sediment gives off appreciable amounts of mercury (Häkkilä 1987) and possibly other metals also which, particularly before the 1970s, were carried into the river with the industrial wastewater.

The Rivers Kyrönjoki and Lapuanjoki, which are affected by acid Litorina earths of alum, also carry appreciable amounts of As, Cd, Cu and Zn into the southerly part of the northern Gulf of Bothnia (Verta 1984).

Conclusions

On the basis of Finnish experience, the following conclusions can be drawn about the factors which affect the estimated transportation of metals in effluent discharged into the rivers:

- The calculated transportation values presented in this report should be regarded as guidelines. A serious indication of the uncertainty prevailing is the difference between the Finnish and Swedish estimates of metal transportation in the River Tornionjoki.

- Large rivers clearly dominate the total metal transportation picture, even though concentrations are usually larger in small rivers near the coast.

- Metal transportation is due to the flow in the river. However, owing to the methodology employed and the comparatively low sampling frequency, the available material is far too unreliable to permit calculations to be made of the relationship between concentration and flow.

- Partly on account of the same uncertainty, the effects of diffuse sources (agriculture and forestry, atmospheric deposition, etc.) cannot be distinguished. The effects of sea basins, bedrock, soil and the like are also difficult to show, even though they obviously affect the leaching of metals into the river. However, the effects of a major metal leakage from the soil can be shown in the rivers which flow into the southerly part of the northern Gulf of Bothnia.

- The effects of the load from point sources is reflected in the transportation values for the River Kokemäenjoki.

5. ATMOSPHERIC DEPOSITION

Measurement data are too limited for the deposition of metals from the atmosphere into the Gulf of Bothnia to be determined with accuracy. Table 17 shows estimates of the deposition of several different metals. The estimated values are based on data from different sources.

Table 17. Estimates of the deposition of heavy metals into the Gulf of Bothnia.

Tonnes/year	Bothnian Bay	Bothnian Sea	Total, approx.
Cd1	3.1	7.7	11
Pb1	53	129	182
Zn1	474	1,162	1,600
Cu1	146	358	500
Fe2	30	810	1,150
Mn2	90	220	310
Hg3	0.3	0.8	1
As4	4	6	10
Cr4	65	36	100
Ni4	24	54	80
V4	22	47	70

1. Deposition calculated on the basis of concentrations in rainfall at Hailuoto in 1987 for Pb and 1985-1987 for Cd, Cu and Zn.

2. Wet deposition calculated on the basis of concentrations in rainfall at Liehittaja (1985). The values for Fe are probably underestimated.

3. Wet deposition of Hg is calculated on the basis of concentrations in rainfall at Tikkakoski and Vindeln (1987).

4. Wet deposition estimated on the basis of studies of moss carried out in Sweden and Finland in 1985. The values for As are probably underestimated.

Comparisons between measurements of metal concentrations in moss in Sweden in 1975, 1980 and 1985 indicate that lead and cadmium fallout has diminished in all parts of the Gulf of Bothnia while chromium fallout has increased somewhat in the Bothnian Bay.

6. SUMMARIZING ASSESSMENT

Over a lengthy period of time the Gulf of Bothnia has been burdened with metals, chiefly from metal-works, the chemical industry and mines. Taking into account the development of industry, it may be assumed that this load was at its heaviest in the 1960s. It was also at this time that attention first began to be paid to the danger it represented to the environment. On the basis of sporadic measurements that were carried out then and somewhat more extensive measurements in the early 1970s, and on the basis of estimates presented by industry itself, the magnitude of the load from mines and industry on the water in the latter half of the 1960s can be roughly estimated, as has been done in the table below. By way of comparison, the level of the corresponding load 20 years later is given in the table, as also is a forecast for 1995.

Approximate magnitude of the metal load from mines and industry on water in the runoff area of the Gulf of Bothnia (below the lakes) in the latter half of the 1960s and 20 years later, and a forecast for 1995:

Tonnes/year

Period	Hg	Cd	Pb	Cu	Zn	Cr	Ni	As	Fe x 10^3
1965-70	10..20	10..15	200	200	3,000	30	60	2,400	50
1985-87	0.2	0.5	10	50	1,000	50	50	20	20
1995 (forecast)	< 0.2	0.2	< 10	< 30	< 750	< 30	< 30	< 10	< 10

At least two conclusions can be drawn from the table. Firstly, emissions of mercury, cadmium, lead and arsenic from mines and industry discharged into water during the 20-year period have obviously decreased by 95 % or more while emissions of copper, zinc and iron have decreased by 60...75 %. In regard to chromium and nickel, no clear trend is discernible. Secondly, it can be established that extremely large quantities of arsenic, zinc, lead, copper and iron and, in relation to their toxicity, also mercury and cadmium, have already been deposited and stored in the Gulf of Bothnia, which is also evident from the elevated concentrations in the sediment and biota. Accumulated quantities of chromium and nickel, on the other hand, have still not been shown to any appreciable extent.

The table above summarizes only a part of the load on the Gulf of Bothnia. This should be compared with the total load on the Gulf from manufacturing plants and municipalities discharging directly into the sea, from rivers and from the atmosphere (Table 18 and Fig. 7, page 39). From this comparison the following conclusions can be drawn:

- Deposition of mercury, cadmium and lead from the atmosphere in the 1980s has been of marked significance, even taking into consideration the fact that the transportation of cadmium and lead has been calculated for only a few of the Swedish rivers. The deposition of zinc and chromium is also comparatively extensive.

- River transportation of mercury and cadmium is considerable. However, it should be pointed out that the mercury concentration is below the detection limit in most of the rivers and the estimate is therefore unreliable.
- River transportation of copper, zinc, chromium and iron has long overshadowed other sources, which are still far from insignificant, however.
- Direct emissions of chromium and arsenic into the sea, and possibly also the emission of nickel, also comprise a substantial addition to the total load.

Table 18. The total load on the Gulf of Bothnia from sewage, rivers and atmospheric deposition round the mid-1980s.

A. Northern part of the Gulf of Bothnia

	tonnes/year								
	Hg	Cd	Pb	Cu	Zn	Cr	Ni	As	Fe
Industry									
Sweden (1987)	0.06	0.20	2.5	8.3	32	0.1	0.3	8.6	..
Finland (1987)	0.03	0.13	-	2.4	22	7.8	21	0.1	300
Municipalities									
Sweden (1980-83)	..	0.04	<0.5	1	3	<0.5	<0.5	-	..
Finland (1980-83)	<0.02	<0.04	<1	<1	<7	..	..	-	..
Rivers									
Sweden (1984-87)	<1	<1	2	99	313	..	..	..	19000
Finland (1985-86)	<1	1.2	16	53	370	52	..	..	50000
Tornionjoki[1]	<	0.07	3.1	13	37	13	..	..	13000
Deposition									
Aggregate (1984-87)[2]	0.3	3.1	53	140	470	65	24	4	330

B. Southern part of the Gulf of Bothnia and Archipelago Sea

	tonnes/year								
	Hg	Cd	Pb	Cu	Zn	Cr	Ni	As	Fe
Industry									
Sweden (1987)	<0.01	0.00	0.0	2	0.3	0.2	0.1	-	-
Finland (1987)	0.00	0.01	1.8	8.4	115	58	9.2	-	18000
Municipalities									
Sweden (1980-83)	..	0.08	<0.5	2	9	<0.5	<0.5	-	..
Finland (1980-83)	<0.06	<0.08	<3	<4	<20	..	..	-	..
Rivers									
Sweden (1984-87)	<1	1	21	290	1100	..	..	..	21000
Finland (1985-86)	<1	1	13	39	180	77	..	..	32000
Deposition									
Aggregate (1984-87)[2]	0.8	7.7	130	360	1100	36	54	6	810

C. Gulf of Bothnia

	tonnes/year								
	Hg	Cd	Pb	Cu	Zn	Cr	Ni	As	Fe
Industry									
Sweden (1987)	0.07	0.20	2.5	10	32	0.3	0.4	8.6	..
Finland ((1987)	0.03	0.14	1.8	11	137	66	30	0.1	18000
Municipalities									
Sweden (1980-83)	..	0.12	<1	3	12	<1	<1	-	..
Finland (1980-83)	<0.08	0.12	<4	<5	<27	..	..	-	..
Rivers									
Sweden (1984-87)	<2	2	23	390	1400	..	..	..	40000
Finland (1985-86)	<2	2.2	29	92	550	129	..	(<50)	82000
Tornionjoki[1]	<	0.07	3.1	13	38	13	..	<	13000
Deposition									
Aggregate (1984-87)[2]	1	11	180	500	1600	100	80	10	1150

[1] According to Finnish measurements 1985-86.

[2] See references in section 5.

Since estimates of the atmospheric deposition are based on different studies carried out on land and at the coast, there is some uncertainty about the results. Estimates of river transportation are also unreliable.

With the aim of creating a picture of the possibility of influencing atmospheric deposition and river transportation, emissions into the runoff area of the Gulf of Bothnia below the system of lakes have been collocated in Table 19, page 40. We now have data from which the following conclusions, at least, can be drawn:

- It should be possible to reduce industrial emissions of mercury and cadmium to the atmosphere, particularly in the Bothnian Bay, where they have been extensive in comparison with the deposition. It should also be possible to keep down emissions of cadmium to water.
- The proportion of lead emissions accounted for by motor vehicles is pronounced and their contribution to the deposition on the Gulf of Bothnia is probably high.
- The reasons for the high concentrations of copper in the water from Swedish rivers are unclear. Emissions of copper to the atmosphere in southwest Finland should be reduced.
- The supply of zinc, especially to the Swedish coast in the southern part of the Gulf of Bothnia (via the River Dal), ought to be reduced. The proportion of deposition accounted for by emissions to the atmosphere appears to be quite small, however.
- Emissions of chromium to the southern part of the Gulf of Bothnia and emissions at the northern part from Finnish industry have been extensive in relation to river transportation and atmospheric deposition. It should be possible to reduce these emissions to a lower level.
- The addition of nickel from Finnish industry may constitute a risk factor but its relative importance is not clear.

Fig. 7. The metal load on the Gulf of Bothnia and its distribution by source around the middle of the 1980s.

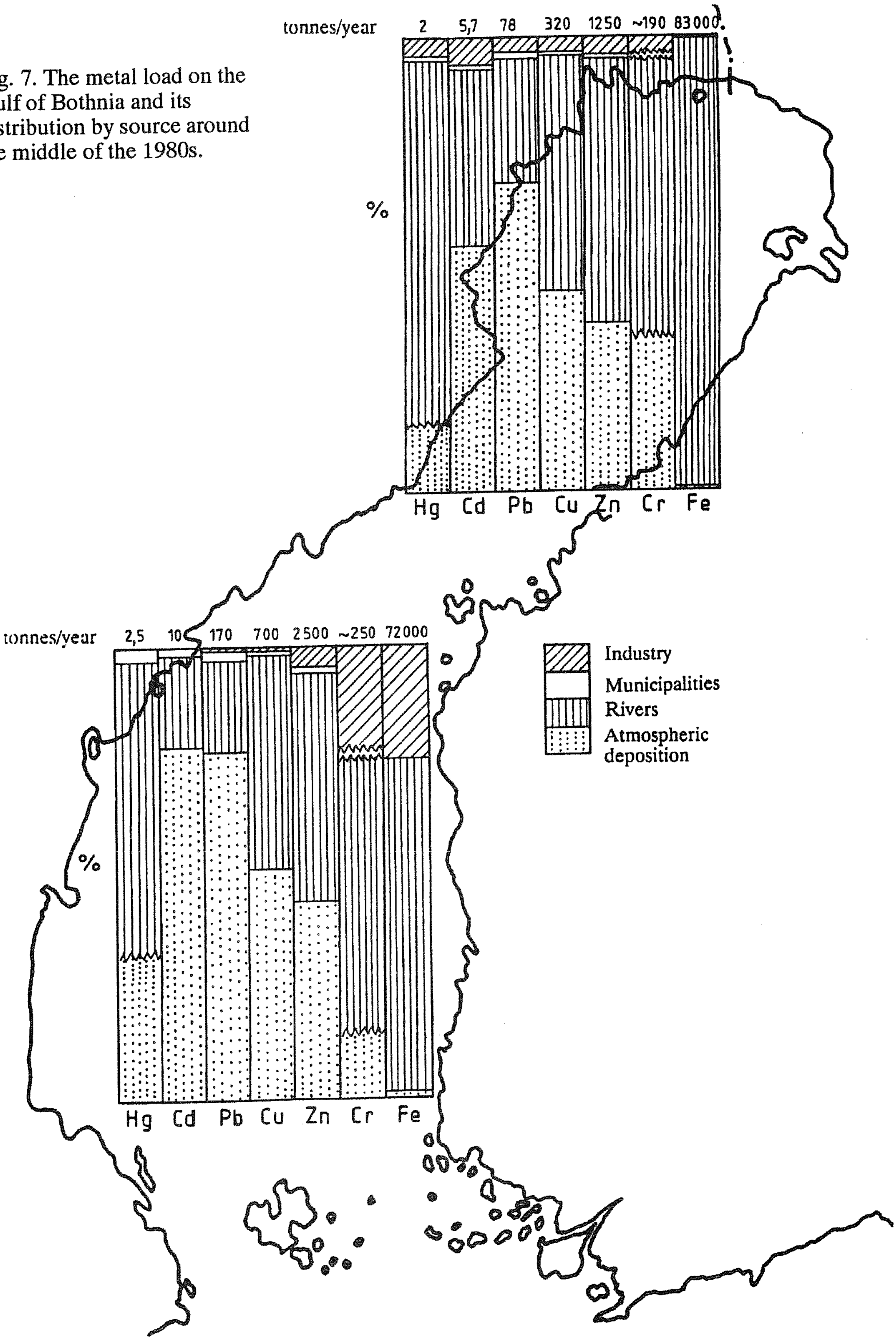


Table 19. Emissions from industry, including mines (1987), municipalities (1980-83) and motor traffic (1986), into the Gulf of Bothnia's runoff area below the system of lakes.

A. Northern part of the Gulf of Bothnia

	tonnes/year								
	Hg	Cd	Pb	Cu	Zn	Cr	Ni	As	Fe
<u>Industry</u>									
to water									
Sweden	0.06	0.24	3.2	9.6	45	0.2	0.3	8.8	..
Finland	0.03	0.14	0.01	2.9	27	9.1	21	0.1	305
to air									
Sweden	0.5	1.5	75	46	73	1	0.4	12	735
Finland (1986)1)	0.08	0.85	0.5	-	120	22	2.4	1.7	60
<u>Municipalities</u>									
to water									
Sweden	..	0.04	<0.5	1	3	<0.5	<0.5	-	..
Finland	<0.02	<0.04	<1	<1	<7	..	..	-	..
<u>Motor traffic</u>									
to air									
Sweden	-	-	..	-	-	-	-	-	-
Finland	-	-	40	-	-	-	-	-	-

B. Southern part of the Gulf of Bothnia and Archipelago Sea

	tonnes/year								
	Hg	Cd	Pb	Cu	Zn	Cr	Ni	As	Fe
<u>Industry</u>									
to water									
Sweden	0.01	0.5	2.3	9.7	600	4	1.3	0.1	68
Finland	0.03	0.5	3.1	20	126	58	24	3.3	18000
to air									
Sweden	0.08	0.02	1	0.1	2.3	1	0.5	-	2
Finland (1986)[1)]	0.4	2	60	305	200	1	86	15	..
<u>Municipalities</u>									
to water									
Sweden	..	0.08	<0.5	2	9	<0.5	<0.5	-	..
Finland	<0.06	<0.08	<3	<4	<20	..	..	-	..
<u>Motor traffic</u>									
to air									
Sweden	-	-	..	-	-	-	-	-	-
Finland	-	-	40	-	-	-	-	-	-

C. Gulf of Bothnia

	tonnes/year								
	Hg	Cd	Pb	Cu	Zn	Cr	Ni	As	Fe
<u>Industry</u>									
to water									
Sweden	0.07	0.79	5.5	19	645	4	1.6	8.9	..
Finland	0.06	0.65	3.1	23	150	67	45	3.4	18300
to air									
Sweden	0.6	1.5	76	46	75	2	1	12	740
Finland (1986)[1]	0.5	2.9	60	305	320	23	88	17	60
<u>Municipalities</u>									
to water									
Sweden	..	0.12	<1	3	12	<1	<1	..	..
Finland	<0.08	<0.12	<4	<5	<27	..	..	..	..
<u>Motor traffic</u>									
to air									
Sweden	-	-	..	-	-	-	-	-	-
Finland	-	-	80	-	-	-	-	-	-

[1] Estimated from EMEP map (Fig. 5) and Table 6.

- Emissions of <u>arsenic</u> to the water and the atmosphere are still large in relation to river transportation and atmospheric deposition.
- Emissions of <u>iron</u> from Finnish industry to the southern part of the Gulf of Bothnia are still extensive.

As has been described in earlier sections, a whole series of measures - the effects of which are not reflected in tables 16 and 17 - has also been taken during the past two years. These measures, and those which it is already known will be taken before 1995, are reflected to some extent in the above forecast of emissions to water in 1995. Taking into consideration the measures that have already been implemented, and measures that have been more or less decided on, it is possible in conclusion to indicate some of the problem areas which still do not seem to have been satisfactorily solved. Such remaining problem areas concerning the metal load on the Gulf of Bothnia are at least the following:

- emissions of mercury, cadmium and lead to the atmosphere ought to be reduced
- the diffuse supply of mercury and cadmium to rivers and the possible significance of commercial fertilizer and pesticides ought to be studied
- the reasons for the differences in the results of Swedish and Finnish analyses of copper and other metals in rivers ought to be studied
- leakage from mining waste deposits and refuse dumps should be remedied in order to reduce the supply of zinc, etc.
- emissions of iron, zinc and chromium which are discharged directly into the Bothnian Sea from the Finnish titanium dioxide manufacturing plant should be reduced

- emissions of several metals which are discharged directly into the Bothnian Bay from both Swedish and Finnish industry ought to be reduced
- emissions of metals from the forest industry should be surveyed
- sufficiently effective control of discharges and emissions and uniform reporting of emission data are necessary
- reliable data for estimating leakage from old mining waste deposits and refuse dumps, as well as for estimating municipal emissions, should be obtained
- measurement of river transportation should be harmonized
- knowledge about the large quantities of metals deposited in the Gulf of Bothnia's sediment should be improved
- preparedness in the event of increased mobilization of toxic effects in the Gulf of Bothnia or its subsidiary areas is necessary.

Finally, it can be established that the metal load on the Gulf of Bothnia has been so great that harmful effects on biological material have been shown. It is often difficult to say which metal or metals give rise to a certain effect. It is also possible that other effects occur with such a long delay that they have still not been discovered and that climatic changes and synergistic effects, for example, or other disequilibriums in the sea environment, will give rise to new serious situations and toxicological consequences. There is therefore every reason to reduce the load of all metals as much as possible. Reducing emissions to water and the atmosphere should be effected by using the best available technology on the industrial and municipal emission sources which affect the Gulf of Bothnia.

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