



Chapter 4

Persistent toxic substances (PTS) sources and pathways



4.1. Introduction

In general, the human environment is a combination of the physical, chemical, biological, social and cultural factors that affect human health. It should be recognized that exposure of humans to PTS can, to certain extent, be dependant on each of these factors. The precise role differs depending on the contaminant concerned, however, with respect to human intake, the chain consisting of 'source – pathway – biological availability' applies to all contaminants. Leaving aside the biological aspect of the problem, this chapter focuses on PTS sources, and their physical transport pathways.

Contaminant sources can be provisionally separated into three categories:

- **Distant sources:** Located far from receptor sites in the Arctic. Contaminants can reach receptor areas via air currents, riverine flow, and ocean currents. During their transport, contaminants are affected by the combined effects of physical and chemical factors. Persistence in the environment is, therefore, one of the most important characteristic in determining the ability of contaminants to reach the Arctic. In this respect, PTS, due to their low degradation rates, are often considered to be 'global contaminants' subject to long-range transportation.
- **Local sources:** These are located in receptor region, often in the vicinity of indigenous communities. Although transport of contaminants from local sources to recipients is determined by the same physical and chemical processes as contaminants from distant sources, there are a wider range of pathways and mechanisms that may be involved in the case of local sources. For example, mechanisms of soil contamination from local sources can differ significantly, such that effects of local contamination can be much greater than those resulting from contamination from distant sources. In contrast to distant sources, local sources can also affect recipients through contamination by more readily degradable substances as well as the persistent contaminants. Although non-persistent contaminants are beyond the scope of this project, it is important to note that the effects of PTS, when combined with those of other types of contaminants originating from local sources, may be substantially increased. Similarly, humans exposed to and affected by PTS may be more sensitive to the acute toxic effects of other less persistent contaminants from local sources.
- **Contact sources:** These comprise the intentional or unintentional use of chemicals by recipients in everyday household and occupational uses. For example, the health of individuals using PTS-containing insecticides for pest control or for the treatment of reindeer may be directly affected by the products. A typical example of an unintentional contact contaminant source would be the use of paints and insulating materials containing PTS in the indoor environment.

4.2. Assessment of distant sources: Long-range atmospheric transport

Due to the nature of atmospheric circulation, emission sources located within the Northern Hemisphere, particularly those in Europe and Asia, play a dominant role in the contamination of the Arctic. Given the spatial distribution of PTS emission sources, and their potential for 'global' transport, evaluation of long-range atmospheric transport of PTS to the Arctic region necessarily involves modeling on the hemispheric/global scale using a multi-compartment approach. To meet these requirements, appropriate modeling tools have been developed.

Extensive efforts were made in the collection and preparation of input data for modeling. This included the required meteorological and geophysical information, and data on the physical and chemical properties of both the selected substances and of their emissions. It should be noted that reliable and relatively comprehensive information on emission sources is currently not available for most PTS. Therefore, an assessment of long-range atmospheric transport was undertaken for substances for which emission source information is sufficient to meet modeling requirements, namely, mercury (Hg), polychlorinated biphenyls (PCBs) and γ -hexachlorocyclohexane (γ -HCH). It was considered that modeling results obtained for these contaminants could be extrapolated to give a general overview on the situation with respect to long-range atmospheric transport of other PTS in the study.

An assessment of mercury, PCB and γ -HCH pollution arising from emission sources in the Northern Hemisphere and affecting regions of the Russian North inhabited by indigenous peoples, was carried out for the reference year 1996. This assessment included an evaluation of air concentrations and deposition levels, as well as source-receptor relationships for selected regions and for the Arctic as a whole. Particular attention was given to the fate of contaminants in different environmental compartments (air, soil, water, etc.). The effect of PCBs and γ -HCH transport via ocean currents, ice cover dynamics, and 'Mercury Depletion Event' (MDE) (Schroeder *et al.*, 1998) chemistry on Arctic pollution were also examined.

4.2.1. Climate conditions and atmospheric circulation patterns

The climate of the Russian Arctic is characterized by a lack of solar radiation during the winter, which leads to very low temperatures. In contrast, solar radiation flux in the summer is significant, but temperatures are still not high, as most incoming solar energy is utilized in the melting of ice and snow. Atmospheric circulation is characterized by cyclonic activity in all seasons, which promotes the exchange of air masses between the middle and high latitudes. As a result of the prevailing westerly airflows, the Russian Arctic experiences the mod-

erating influence of the Atlantic (North Atlantic Current). This influence is stronger in western parts than in central and eastern parts. The western Russian Arctic is therefore warmer, with a much lower temperature variation between winter and summer than that found in the eastern part of the Russian North, which is characterized by the more severe climatic conditions.

Atmospheric circulation in the Arctic region differs between winter and summer (Figure 4.1) with the prevailing atmospheric currents in the lower Arctic troposphere depending upon the location of quasi-stationary pressure systems in the Northern Hemisphere, the Icelandic and Aleutian Lows, and Siberian and North American Highs.

In winter, due to the geographical position of these systems, air masses move into the Arctic from Europe in a northeasterly direction, or from central Asia and Siberia. Western regions of the Russian North – Murmansk Oblast and the Nenets Autonomous Okrug (AO) – are affected mainly by southwesterly or westerly airflows, bringing air masses from Eastern and Central Europe, as well as from central Russia. In the central regions – Yamalo-Nenets AO, Taymir AO, and the Republic of Sakha (Yakutia) – southerly airflows prevail, transporting air masses from central Russia, the Urals, the south of Siberia and central and eastern Asia. Over the easternmost region – the Chukchi AO – northerly airflows predominate in winter.

In summer, the continental high-pressure systems disappear and oceanic low-pressure systems weaken. Over the Arctic Ocean, high-pressure systems occur more frequently than in winter, causing an outflow of Arctic air in the meridional direction. The European region comes under the impact of the Azores anticyclone. Over central Eurasia and the central part of North America, low-pressure systems dominate. The influx of air masses to the Arctic mainly occurs over the Aleutian Islands/Bering Sea region in the east, and from the North Atlantic, along the north-western periphery of Azores anticyclone, in the west. Compared with winter, the northerly component is more frequent in atmospheric transport in summer across all regions of the Russian Arctic except for Chukotka. Chukotka, during the summer, is predominantly affected by transport either from the Pacific Ocean, or from Eastern Asia and the Russian Far East, some transport from the north still occurs however.

Atmospheric circulation is also responsible for the precipitation pattern in the Russian Arctic. The most abundant annual precipitation takes place in the western part and can reach 500-600 mm/y. Annual precipitation decreases from the west towards the east, and over the north of the Republic of Sakha (Yakutia) is mainly within the range of 100-150 mm/y. In the easternmost part of the Russian Arctic, precipitation is relatively high (300-600 mm/y), and caused by the southerly transport of air masses from the Pacific Ocean, especially during summer.

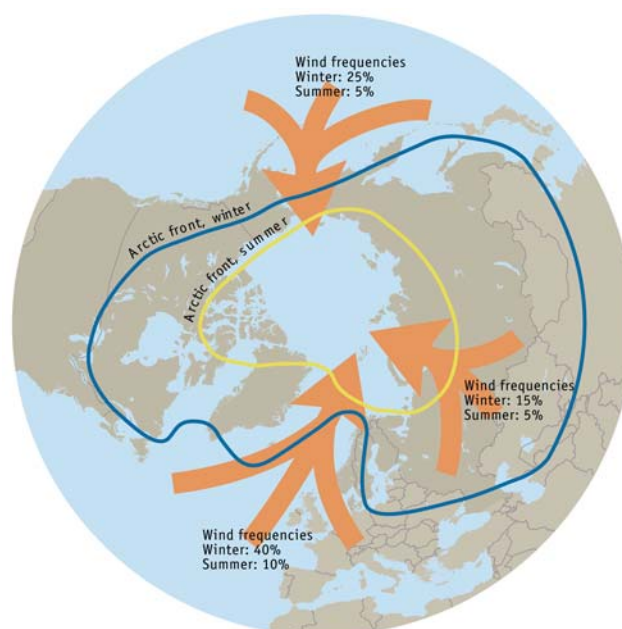


Figure 4.1. Mean position of the Arctic air mass in January and July, and the winter and summer frequencies of winds (AMAP, 1997).

4.2.2. Emission sources

Emission sources of Hg, PCBs and γ -HCH were divided into several groups according to their geographical location (Figure 4.2). The key criterion used for the selection of a specific region as an aggregate emission source was the possible influence of emissions from this region on the Russian North.



Figure 4.2. Source regions of the Northern Hemisphere considered in the source-receptor analysis.

The number of the selected regions varies for different pollutants. For simplicity, generalized names were used for some regions, e.g., the region identified as 'Central Asia' actually includes central, western, and southern Asia. Selected emission sources regions for the pollutants under consideration are presented in Table 4.1. Source region boundaries also vary depending upon the contaminant in question. For example, China and Japan are con-

sidered as separate sources for mercury, but included in larger Asian source regions for the other contaminants. For γ -HCH, China and India are important enough sources to consider their emissions separately, whereas Northern Europe was omitted as γ -HCH emissions in this region in 1996 were insignificant. The Americas (North and Central) are included as a single source region, due to their greater distance from the Russian North.

Hg	PCBs	γ -HCH
1. Russia	1. Russia	1. Russia
2. Northern Europe	2. Northwestern Europe	2. Western Europe
3. Western Europe	3. Southeastern Europe	3. Eastern Europe
4. Eastern Europe	4. Americas	4. Southern Europe
5. Southern Europe	5. Southeastern Asia (including China and Japan)	5. Americas
6. Americas	6. Central Asia (including India) and Africa	6. China
7. Central Asia (including India)		7. India
8. China		8. Asia (Central and South-eastern Asia)
9. Japan		9. Africa
10. Southeastern Asia		
11. Africa		

Table 4.1. Regions of the Northern Hemisphere selected as source areas for long-range transported pollutants.

Due to their proximity to the Russian North and the significant polluting influence of some regions of the Russian Federation, the territory of Russia was subdivided into twelve source regions according to current administrative boundaries and to their potential impact on Arctic ecosystems. The Location of these regions and abbreviated identification codes is shown in Figure 4.3. The first five regions (MUR, NEN, YNT, YAK, and CHU) are also considered as the receptor regions.

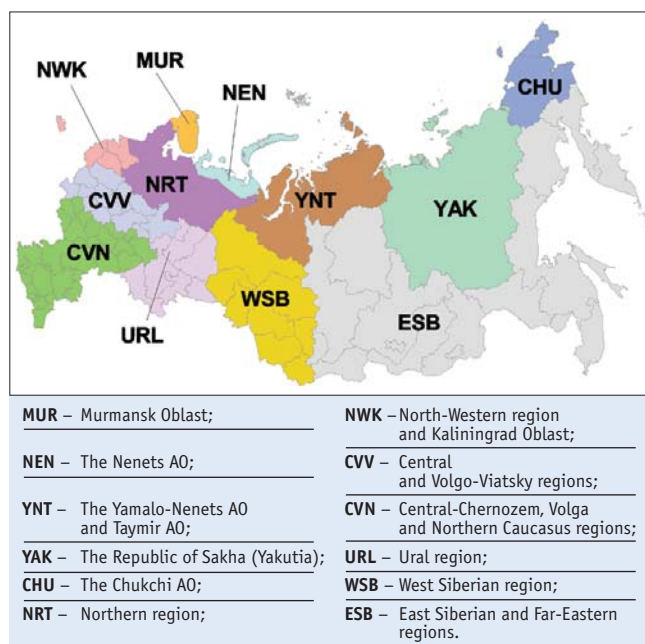


Figure 4.3. Aggregated regions of the Russian Federation chosen for source-receptor analysis. The first five regions listed (MUR, NEN, YNT, YAK, and CHU) are considered as both source and receptor regions, the rest are considered as source regions.

Mercury

The industrial and urbanized regions of the world account for the majority of anthropogenic mercury emissions to the atmosphere. To evaluate the anthropogenic input of mercury to the Northern Hemisphere, the most recently available global emission inventory, that for 1995, (Pacyna and Pacyna, 2002) was used. The original global emissions dataset has a resolution of $1^\circ \times 1^\circ$ lat./long., with mercury emissions speciated into three chemical forms: gaseous elemental mercury (Hg^0), gaseous oxidized mercury (Hg^{2+}), and particulate mercury (Hg_{part}). These emission data were redistributed to a lower resolution ($2.5^\circ \times 2.5^\circ$), suitable for input to the air transport model employed, assuming uniform distribution over each grid cell.

The most significant emission sources are in Eastern Asia, Europe and the eastern part of North America. Considerable emissions also occur in the Indian subcontinent and the Arabian Peninsula. The total amount of anthropogenic mercury emissions in 1995 from the Northern Hemisphere was estimated as 1887 tonnes.

In order to assess the impact of different mercury emission sources on the contamination of the Russian North, the entire hemispheric emission field was divided into 11 regions: Russia, China, Central Asia, the Americas, Japan, Southeast Asia, Africa, Eastern Europe, Western Europe, Southern Europe, and Northern Europe. The relative contribution of each region to total mercury emissions in the Northern Hemisphere is presented in Figure 4.4(a).

This diagram shows that more than one third (34%) of the total mercury emissions originate in China. Considerable emissions also originate in Central Asia (14%), the Americas (11%), Japan (9%), and Russia (8%). The contribution of other regions specified does not exceed 7%.

Figure 4.4(b) shows total mercury emissions from different regions of the Russian Federation. The most significant emission sources are located in the Central-Chernozem, Volga, and North-Caucasian regions (CVN), the Ural region (URL), and the Central and Volgo-Viatsky regions (CVV).

Mercury emissions from natural sources contribute a significant proportion of the total mercury input to the atmosphere. Estimates for the value of natural emissions and re-emissions were based on a literature survey. Mercury emissions from natural sources were apportioned over the Northern Hemisphere on the basis of the nature of the underlying land/sea surface. Five surface categories were distinguished: ice covered land (glaciers, etc), seawater, soil developed from geochemical mercury belts, soils in areas of mercury deposits, and other (background) soils. It was assumed that there is zero mercury emission from ice caps/gla-

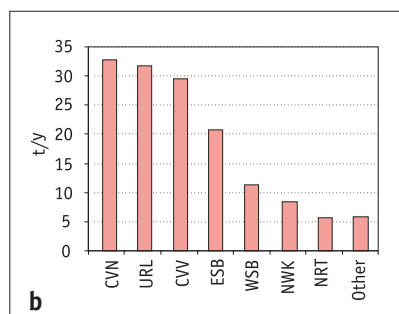
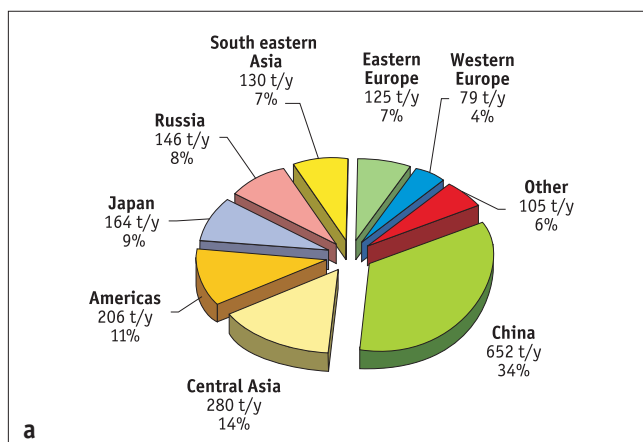


Figure 4.4.
(a) Contribution of different regions of the Northern Hemisphere to total anthropogenic mercury emissions, (b) total anthropogenic mercury emissions from different regions of the Russian Federation.

ciers. Natural emissions from seawater were distributed proportionally to the ocean's primary production of carbon. Emissions from soil are most significant from soils occurring over mercury deposits and lowest for background soils. In addition, the temperature dependence of emission fluxes was also calculated, based on data obtained through measurements.

PCBs

Modeling long-range transport of individual PCB congeners to the Russian North was made using a global emission inventory concerning 22 individual PCB congeners covering the period 1930-2000 (Breivik *et al.*, 2002b). This inventory is based on estimates of the global production and consumption of these PCBs in 114 countries (Breivik *et al.*, 2002a). The emissions were distributed to the (2.5° x 2.5° lat./long.) model grid using (as a proxy for emission distribution) a 1990 population distribution data set obtained from the CGEIC website (<http://www.ortech.ca/cgeic>).

The total global production of PCBs from 1930-1993 amounted to approximately 1.3 million tonnes. Almost 97% of intentionally produced PCBs were used in the Northern Hemisphere. Emission data for individual congeners for 1996 were used in all model calculations and, according to the high emission scenario discussed by Breivik *et al.* (2002b), total emissions of the 22 PCB congeners in the Northern Hemisphere in 1996 amounted to about 662 tonnes. Total emissions of PCB-28, -118, -153, and -180 from the Northern Hemisphere

in 1996 were about 80, 23, 16, and 4.5 tonnes, respectively. Congener composition of PCB emissions varies between source regions.

In order to study the contributions of different source regions in the Northern Hemisphere to the contamination of the receptor-regions in the Russian Arctic, six main regional sources were identified, based on the emission distribution: Russia, Northwest Europe, Southeast Europe, the Americas, Southeast Asia, and Central Asia and Africa.

The major emission sources of PCBs in the Northern Hemisphere in 1996 were the Americas (24%), Russia (23%), Southeast Europe (19%), and Northwest Europe (16%) (Figure 4.5(a)). The main Russian emission sources are located in Central-Chernozem, Volga and North-Caucasus regions (CVN) as well as in Central and Volgo-Viatsky regions (CVV) (Figure 4.5(b)).

γ HCH

The scenario for γ HCH emissions in the Northern Hemisphere was based on official data submitted to the UN ECE Secretariat in 2002 (Vestreng and Klein, 2000) and available expert estimates (Pacyna *et al.*, 1999). In addition, γ HCH emissions for 1990-1996 from the Russian Federation, and some other countries in the Northern Hemisphere were estimated from information in a range of literature sources (Revich *et al.*, 1999, Year-books, 1992, 1993 1999,

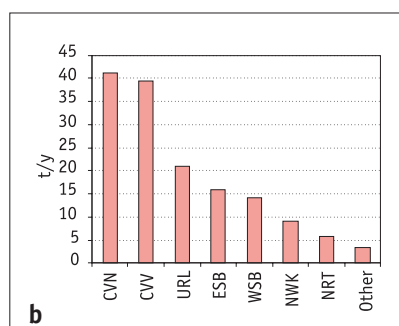
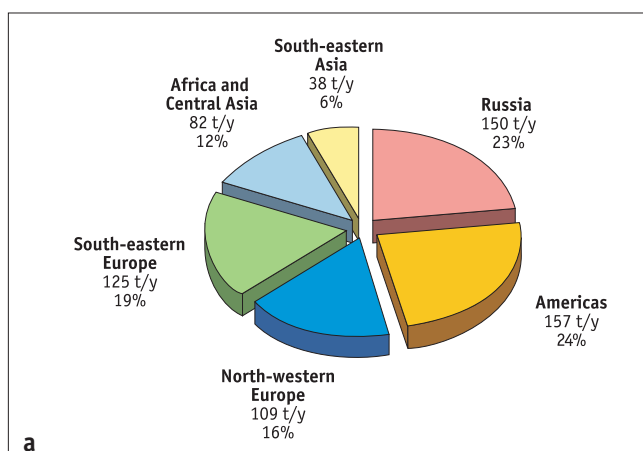


Figure 4.5.
(a) Contribution of different regions to PCB emissions (22 congeners) in the Northern Hemisphere for 1996, (b) PCB emissions (22 congeners) from different regions of the Russian Federation in 1996.

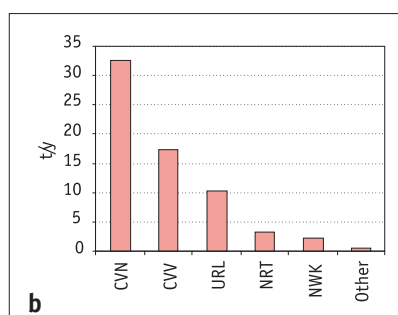
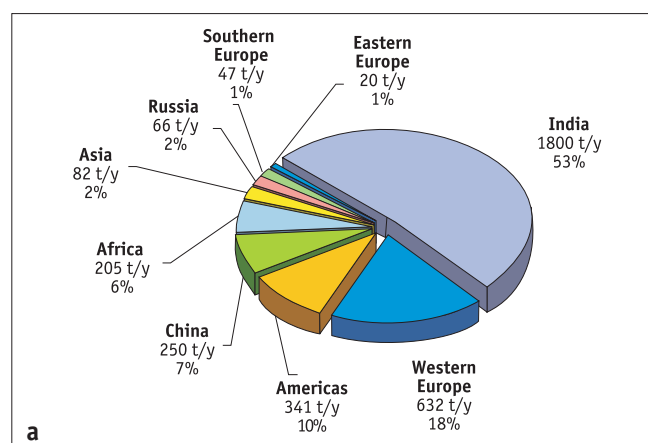


Figure 4.6.

(a) Contribution of different regions to γ -HCH emission in the Northern Hemisphere for 1996, (b) γ -HCH emissions from different regions of the Russian Federation in 1996.

Ananieva *et al.*, 1990, Li *et al.*, 1996, 1998,1999, and Macdonald *et al.*, 2000) regarding the use of this insecticide. To estimate emissions from data on insecticide use, the emission factor for lindane in agricultural use (0.5) (Guidebook, 1999) was applied. The resulting estimate for total γ -HCH emissions from the Northern Hemisphere in 1996 was about 3445 tonnes. The spatial distribution of these γ -HCH emissions in the Northern Hemisphere, for modeling purposes, was made using crop area as a surrogate parameter (Pacyna *et al.*, 1999).

To model long-range atmospheric transport of γ -HCH to the Russian North, nine source regions were identified in the Northern Hemisphere: Russia, Western Europe, Eastern Europe, Southern Europe, the Americas, China, India, the rest of Asia, and Africa. China and India were considered as individual source regions due to their high use of this insecticide compared to the rest of Asia. Estimates of the contribution of main source regions to total γ -HCH emissions in the Northern Hemisphere in 1996, based on the selected emission scenario, is shown in Figure 4.6(a). γ -HCH emissions from Russian regions in 1996 are shown in Figure 4.6(b).

The main contribution to γ -HCH emissions in the Northern Hemisphere, was made by India (53%) and Western Europe (18%). The contribution from Russia is only 2%. Major Russian γ -HCH emissions in 1996 originated from the European part of the Russian Federation. The highest Russian γ -HCH contributions were made by sources located in the Central-Chernozem, Volga and North-Caucasian regions (CVN).

4.2.3. Contamination levels in the Arctic resulting from long-range atmospheric transport

To evaluate levels of contamination of the Arctic region by global pollutants (mercury, PCBs, and γ -HCH) resulting from long-range atmospheric transport, a hemispheric modeling approach was employed. For this purpose, the EMEP Meteorological Synthesizing Centre-East (MSC-E) have developed hemispheric multi-compartment transport models 'MSCE-Hg-Hem' and 'MSCE-POP'.

Mercury, PCB and γ -HCH concentrations in air and their deposition loads as evaluated for the Northern Hemisphere and the Arctic for 1996, are discussed below in the relevant subsections. Particular attention has been given to atmospheric long-range transport to, and deposition of these pollutants in the Russian Arctic. For mercury, the effect of Mercury Depletion Event (MDE) chemistry on Arctic deposition was considered. In addition, for the assessment of environmental pollution by PCBs and γ -HCH, the role of transport via sea currents and ice cover dynamics were taken into account. The marine environment is particularly important in relation to the transport and fate of γ -HCH. Characteristic values of mean annual air concentrations and deposition fluxes of mercury, PCBs and γ -HCH over the Arctic area are summarized in Table 4.2. The consistency of the modeling results was verified by comparison with available measurements.

Pollutant	Air concentrations, ng/m ³			Deposition flux, g/km ² /y			Total deposition, t/y
	Min	Max	Average	Min	Max	Average	
Hg	1.11	1.76	1.47	1.6	29.9	7.2	240
PCB-28	0.0003	0.0186	0.0014	0.002	0.320	0.021	2.7
PCB-118	0.0002	0.0057	0.0006	0.003	0.377	0.026	1.1
PCB-153	0.0002	0.0041	0.0008	0.007	0.367	0.043	1.15
PCB-180	0.0001	0.0012	0.0003	0.004	0.204	0.025	0.5
γ -HCH	0.009	0.113	0.023	0.159	3.140	0.671	78

Table 4.2. Characteristic values of mean annual air concentrations and annual deposition fluxes for mercury, selected PCBs, and μ -HCH over the Arctic in 1996.

Mercury

Figure 4.7 shows the annual deposition flux of mercury in the Northern Hemisphere. Highest deposition levels are in those regions with considerable emissions: i.e. Southeast Asia, Europe, and the eastern part of North America. For other areas, the deposition pattern, to some extent, corresponds to annual precipitation values, since wet deposition plays a dominant role in removing mercury from the atmosphere. From the model results, total deposition over the Arctic region in 1996 amounted to 240 tonnes. The influence of MDEs on deposition fluxes within the Arctic region has been the subject of considerable research in recent years. The postulated MDE mechanism (Lindberg *et al.*, 2002) includes complicated

chemistry, involving the formation of halogen related radicals. The development of a detailed model component for MDE chemistry is the subject of a separate study. For the purposes of this study, an attempt was made to qualitatively estimate the effect of MDE on Arctic Hg contamination by using a simplified set of parameters.

As illustrated in the enlarged panel in Figure 4.7, even short-term phenomena such as MDEs, which occur during only a few weeks of the year, can considerably increase the annual deposition of mercury in some regions of the Arctic, in particular coastal areas. The influence of MDEs on total annual mercury deposition is illustrated in Figure 4.8(a). Additional contributions of mercury as a result of MDEs can amount to more than 50 percent of total deposition values in areas adjacent to Arctic coasts (i.e. within about 300 km of the coast inland and offshore). These areas include the Queen Elizabeth Islands, Hudson Bay, the White Sea, the Gulf of the Ob river, and the Laptev Sea coast, among others. Negative values (for percentage increase in deposition due to MDEs) show that increased deposition fluxes due to MDEs in some regions, lead to decreased fluxes in other areas. A part of the mercury transported by the air therefore does not enter the High Arctic during springtime, due to it being scavenged during MDEs over coastal and contiguous regions.

Figure 4.8(b) shows the seasonal variation in total mercury deposition in the Arctic. The model predicts that the most pronounced MDE effect is in May and June (taking into account a temporal shift due

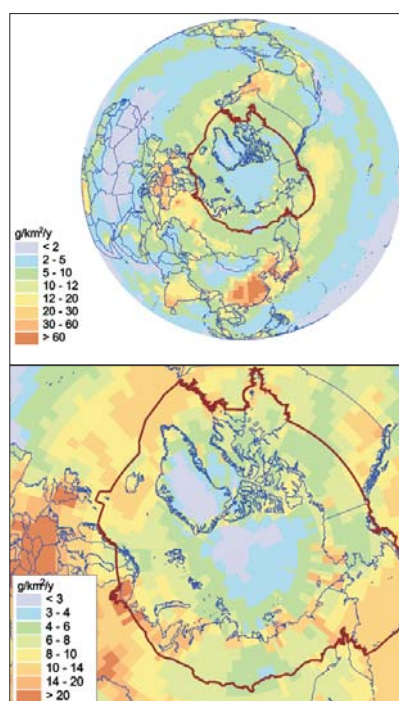


Figure 4.7. Annual deposition of total mercury in the Northern Hemisphere. The enlarged panel shows elevated mercury deposition over the Arctic coast due to MDEs.

to the model parameters used), when monthly deposition in the Arctic increased two-fold or greater. The calculations predict that MDE are responsible for deposition of about 50 tonnes of mercury per year in the Arctic – about 20% of the total annual deposition.

Due to the high transport potential of mercury in the atmosphere, many anthropogenic and natural sources from different regions of the Northern Hemisphere contribute to Arctic pollution. The contribution from

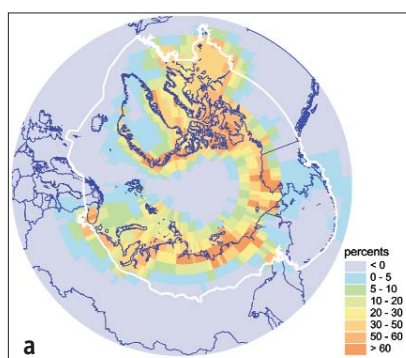


Figure 4.8. (a) Influence of MDEs on total annual mercury deposition in the Arctic (area defined by the white (AMAP area) boundary), and (b) seasonal variation in total mercury deposition to the Arctic with and without MDEs. The figures present the difference between two model computational runs – one with and one without MDEs included.

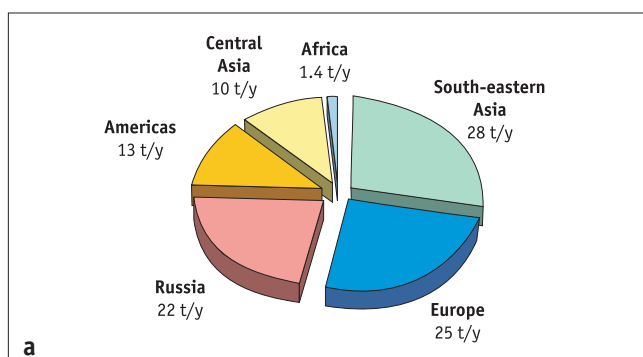
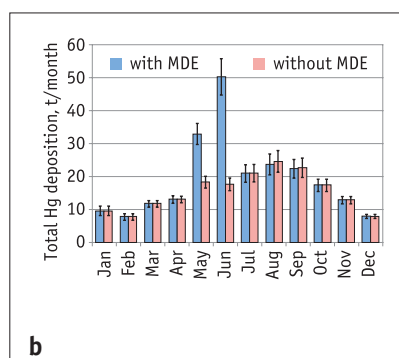
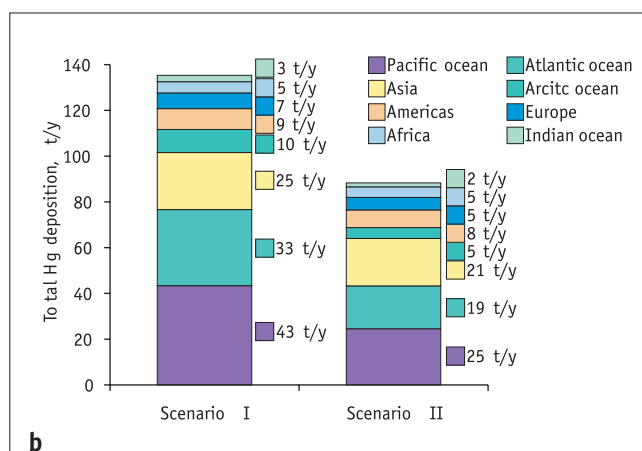
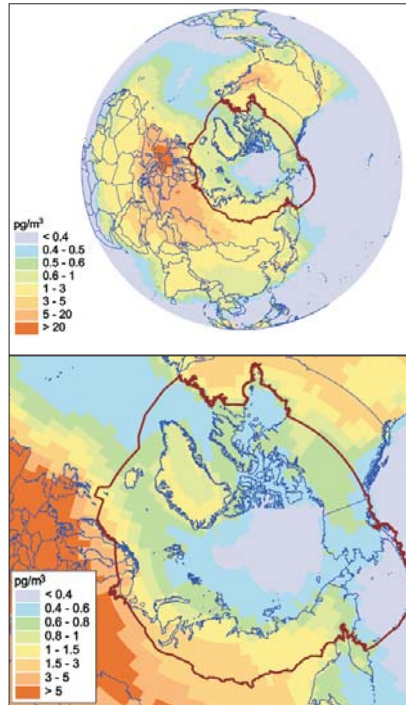


Figure 4.9. Contribution of different source regions to the annual deposition of mercury in the Arctic arising from (a) anthropogenic sources and (b) natural sources and re-emissions.



the various regions of the Northern Hemisphere to total annual mercury deposition in the Arctic from anthropogenic and from natural sources is shown in Figures 4.9(a) and 4.9(b), respectively for the upper (Scenario I) and lower (Scenario II) limits of emission estimates.

Figure 4.10.
Mean annual air concentrations of PCB-153 over the Northern Hemisphere. The enlarged panel shows the air concentration pattern over the Arctic region.



The most significant contribution to anthropogenic mercury deposition in the Arctic come from sources located in Southeast Asia, Europe and Russia. The most significant contributions to the natural component of annual deposition in the Arctic are from the Pacific and Atlantic Oceans, and from Asia. Bearing in mind that there is still

Figure 4.12.
Air concentrations of PCB-153 emitted in January and May from sources in the Americas and Northwest Europe, respectively, from modelling results for 1996.

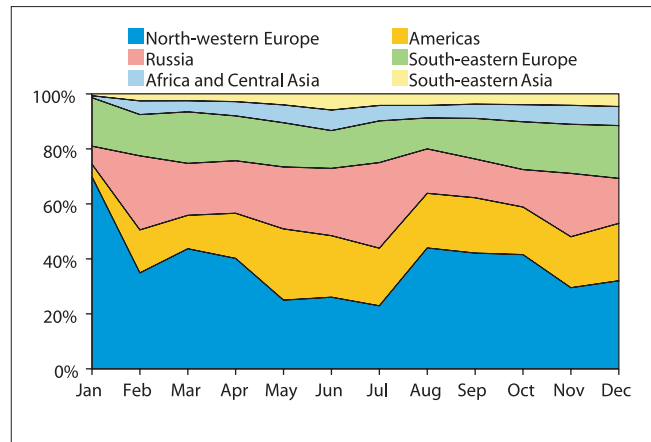
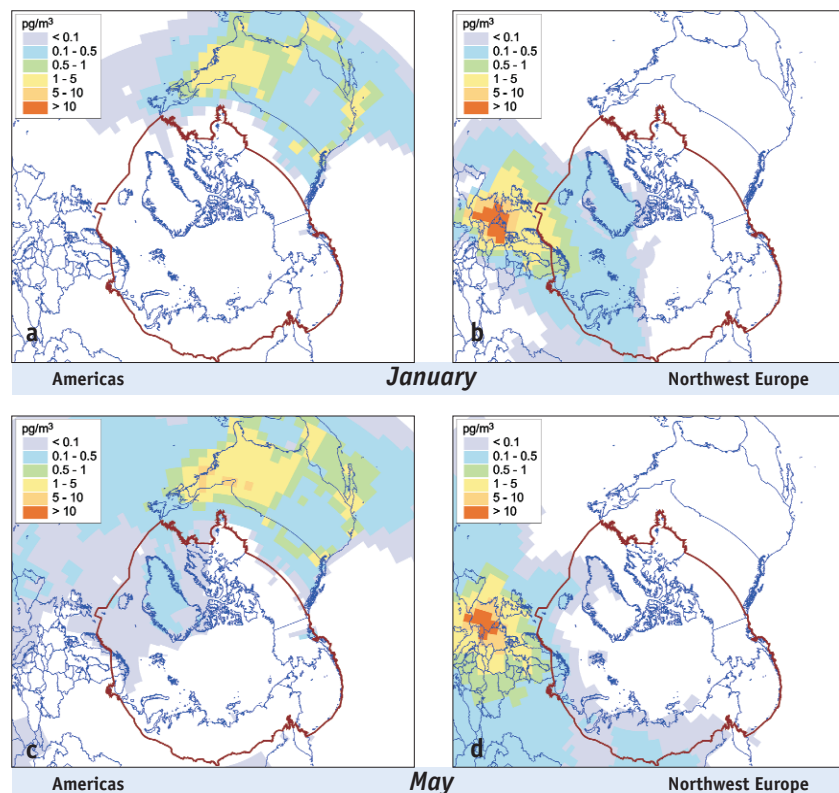


Figure 4.11.
Seasonal variation in the relative contributions of different source regions to PCB-153 deposition in the Arctic.

considerable uncertainty regarding the input parameters used for the modeling of natural emission and re-emission processes, and that natural emissions cannot be controlled by political decisions, attention should be focused on deposition from anthropogenic sources.

PCBs

Levels of PCB contamination are exemplified by PCB-153. Figure 4.10 shows that areas with the highest air concentrations of PCB-153 are located close to European and North American source regions. Air concentrations range from 5 to 20 pg/m^3 in contaminated areas of North America, and can exceed 20 pg/m^3 in Europe. European sources make the largest contribution to the contamination of the Arctic region. The mean annual air concentration of PCB-153 over the Arctic ranges from 0.2 to 4 pg/m^3 .

The relative contributions made by different source regions to PCB-153 deposition in the Arctic are subject to seasonal variations, as shown in Figure 4.11. The contribution from sources in Northwest Europe is the most variable, varying from about 70% in January, to about 25% in May. The amount contributed by the Americas is only about 5% in January, but in May it amounts to 26%, and is comparable with the contribution from sources in Northwest Europe.

These noticeable variations are explained by the peculiarities of atmospheric circulation in the Arctic during various seasons, and also by seasonal variations in temperature, precipitation, and degradation rates. Seasonal variation of emissions are not taken into account in this assessment. To illustrate pathways of atmospheric transport, simulation results of PCB-153 transport from two source regions (the Americas and Northwest Europe) for 1996 were examined. Figures. 4.12 show air concentrations of PCB-153 emitted in the Americas and Northwestern Europe in January. The air concentrations of PCB-153 originating from the same sources in May are given in Figures. 4.12.

Figure 4.13 shows the contribution of different source regions to PCB-153 deposition in the Arctic. The major contribution is from sources in Northwest Europe (about 40%). Other significant contributors are Russia (19%), the Americas (17%) and Southeast Europe (16%). For PCB-28 and PCB-118, Northwest Europe and Russia are the main contributors. However, for PCB-180, main contributors are Northwest Europe and the Americas.

The total amount of PCB-153 deposited in the Arctic region from emissions in 1996 was estimated at 527 kg. The contribution from re-emission of PCB-153 accumulated in the environment in the period

preceding 1996 equals 629 kg. Therefore, the estimated total PCB-153 deposition to the Arctic in 1996 was 1.15 tonnes.

On the basis of the transport simulations for the four congeners (PCB-28, -118, -153, and -180), and taking into account the fractions of these congeners in the typical PCB mixture in air, a rough estimate of total PCB deposition in the Arctic in 1996 of approximately 40 tonnes was made.

γ HCH

Figure 4.14 represents the spatial distribution of γ -HCH concentrations in the air over the Northern Hemisphere and the Arctic. High concentrations (up to 5 ng/m³ or more) are mainly characteristic of regions with high emissions. However, in spite of the fact that there are no significant sources in the Arctic region, relatively high concentrations (from 0.01 to 0.11 ng/m³) are also observed there. These concentrations result from long-range transport of γ -HCH from remote sources, mainly in Western Europe, India, and the Americas.

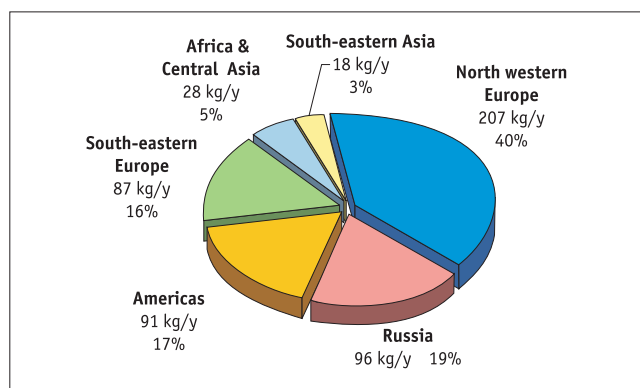


Figure 4.13. Contributions of different source regions to PCB-153 deposition in the Arctic region in 1996.

Figure 4.14. γ -HCH concentrations in air of the lower atmosphere over the Northern Hemisphere and the Arctic.

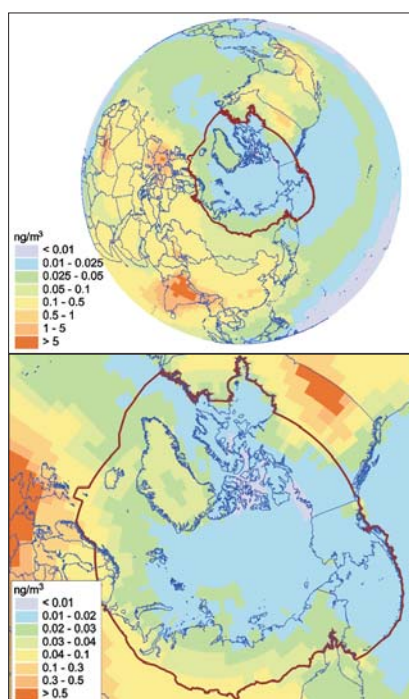
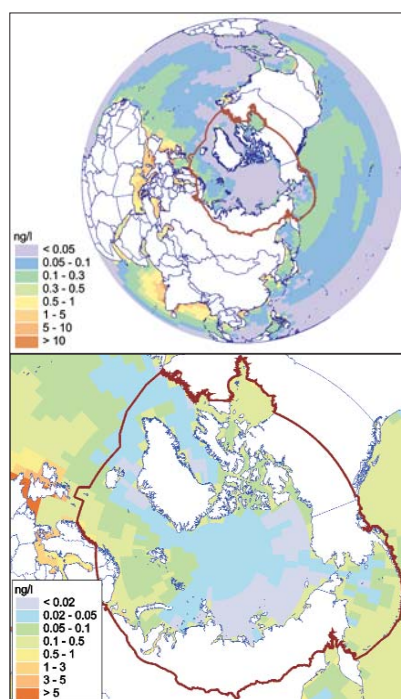


Figure 4.15. Mean annual concentrations of γ -HCH in seawater in the Northern Hemisphere. The enlarged panel shows the seawater concentrations pattern over the Arctic Ocean.



Since γ -HCH tends to accumulate in seawater (which accounts for about 80% of the overall environmental pool of this substance), the spatial distribution of γ -HCH in seawater is of interest. The distribution of γ -HCH in seawater (Figure 4.15) reveals that maximum concentrations are found in the Indian Ocean, the Mediterranean Sea, and the East Atlantic. Considerable amounts of γ -HCH flow into the Arctic Ocean from the North Atlantic, as reflected in the higher seawater concentrations in the Barents Sea in the region between northern Norway and Svalbard. Seawater concentrations in the seas along the coast of northern Russian are in the range 0.01–2 ng/L.

The total amount of γ -HCH deposited in the Arctic region in 1996 from the atmosphere was estimated to be 78 tonnes. Due to high deposition rates over the sea (the models assume this rate to be twice as high over sea as on land), and taking into account the large proportion of the Arctic area that is covered by ocean (about 60%, according to figures provided by AMAP, 1998), this equates to an estimate for γ -HCH deposited to the Arctic Ocean in 1996 of 58 tonnes.

Modeling results have been used to indicate contributions of different emission sources to the contamination of the Arctic region by γ -HCH (Figure 4.16). Western Europe is the largest contributor to this region (about 40%), followed by India (19%), the Americas (17%), China (10%), and Russia (6%), with other source regions responsible for the remaining 8%.

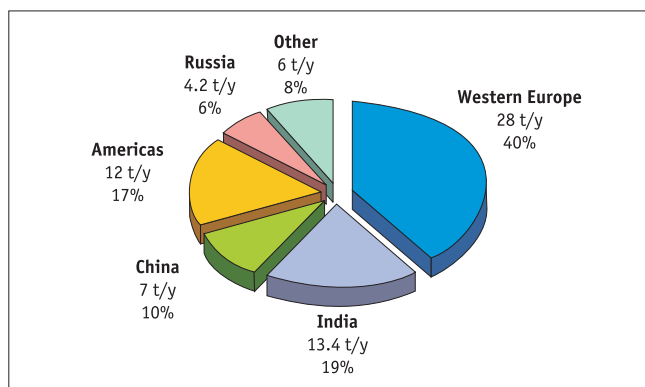


Figure 4.16. Contributions of different source regions to γ -HCH deposition in the Arctic in 1996.

4.2.4. Contamination levels and deposition loads resulting from long-range atmospheric transport to the Russian North

Mercury

Figure 4.17 shows the modeled spatial distribution of mean annual concentrations of total gaseous mercury (TGM) in the air in northern Russia, which are fairly constant across the territory (from 1.4 to 1.8 ng/m³) (see also Table 4.3). Concentration levels over Murmansk Oblast and in the central Republic of Sakha (Yakutia) are slightly elevated, mainly due to local emission sources. There is also a weak decreasing gradient in mercury concentrations to the north over

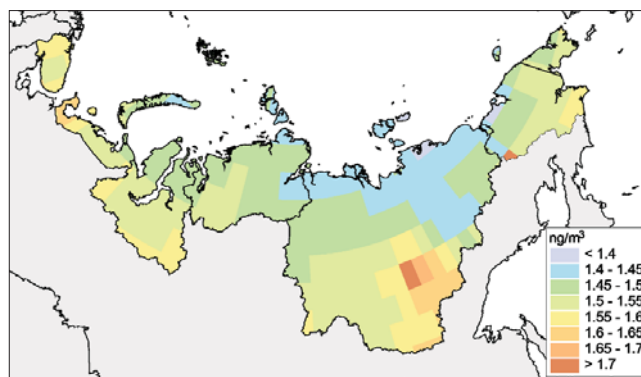


Figure 4.17. Spatial distribution of mean annual air concentrations of total gaseous mercury in the Russian North.

regions including the Yamalo-Nenets AO, the Republic of Sakha (Yakutia), and the Chukchi AO. A possible reason for this, in addition to distance from main emissions areas, is the decrease in elemental mercury concentration over the Arctic coast during springtime, as a result of MDEs.

Region	min	max	average
MUR	1.52	1.62	1.56
NEN	1.44	1.66	1.52
YNT	1.43	1.58	1.5
YAK	1.38	1.75	1.5
CHU	1.38	1.71	1.5

Table 4.3. Characteristic values of mercury air concentrations in the Russian North, ng/m³.

The spatial distribution of annual deposition loads of total mercury in the Russian North is shown in Figure 4.18. The highest depositions, exceeding 20 g/km²/y, are observed over the coast of the Arctic Ocean, due to MDEs (Table 4.4). The lowest depositions (less than 5 g/km²/y), are in Central Yakutia, an area of low annual precipitation. Values of total mercury deposition for regions of the Russian North and the Arctic as a whole are given in Table 4.5.

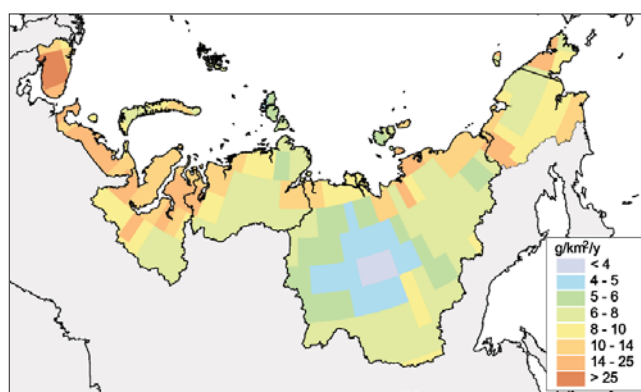


Figure 4.18. Annual deposition of total mercury in the Russian North.

Table 4.4. Characteristic values of total annual mercury deposition loads in the Russian North, g/km²/y.

Region	min	max	average
MUR	8	30	21
NEN	6	26	14
YNT	5	15	10
YAK	3	17	7
CHU	6	18	10

Region	MUR	NEN	YNT	YAK	CHU	Arctic
Mercury deposition	3	4	15	21	7	240

Table 4.5. Total deposition of mercury in 1996 in different regions of the Russian North, and the Arctic as a whole, t/y.

PCBs

Figures 4.19 and 4.20 show the spatial distributions of mean annual air concentrations and annual deposition loads of PCB-153 over selected regions of the Russian North for 1996. There is a clear decrease in PCB-153 air concentrations from western to eastern areas of the Russian North, with increasing distance from source areas in Europe. Relatively high air concentrations (up to 4 pg/m³) occur in Murmansk Oblast, the Nenets AO, and the southern part of the Yamalo-Nenets and Taymir AOs (Table 4.6). Moderate values (1–2 pg/m³) are characteristic of the northern part of the Yamalo-Nenets AO, the Taymir AO, and the Republic of Sakha (Yakutia). The Chukchi AO is characterized by low values (<1 pg/m³).

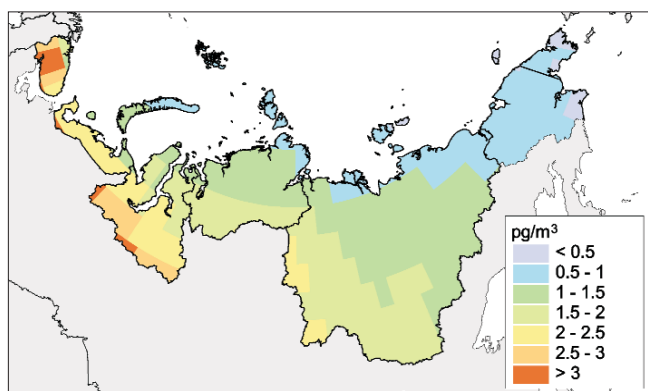


Figure 4.19. Spatial distribution of mean annual air concentrations of PCB-153 in the Russian North, calculated for 1996.

Table 4.6. Characteristic values of PCB-153 air concentrations in the Russian North, pg/m³.

Region	min	max	average
MUR	1.3	4.1	2.6
NEN	0.5	3.8	1.7
YNT	0.5	3.3	1.8
YAK	0.4	2.3	1.4
CHU	0.4	1	0.7

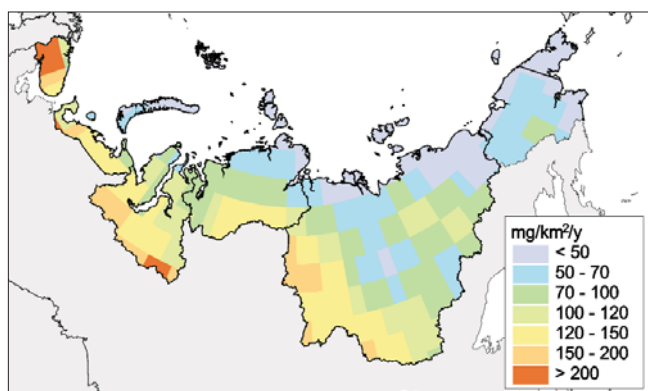


Figure 4.20. Annual deposition of PCB-153 in the Russian North, calculated for 1996.

A similar pattern is seen for deposition loads. Substantial values (>150 mg/km²/y) are estimated for Murmansk Oblast, the Nenets AO and the southern part of the Yamalo-Nenets and Taymir AOs as well as for the western part of the Sakha Republic. Moderate values (70–150 mg/km²/y) are obtained for the northern part of the Yamalo-Nenets and Taymir AOs, the Republic of Sakha (Yakutia), and the western part of Chukchi AO. The northern parts of the Russian North are characterized by lower values for deposition loads (<70 mg/km²/y) (Table 4.7).

Region	min	max	average
MUR	70	333	208
NEN	27	373	97
YNT	27	216	106
YAK	16	224	89
CHU	16	74	51

Table 4.7. Characteristic values of PCB-153 annual deposition loads in the Russian North, mg/km²/y.

Depositions of PCB-153 and of total PCBs to the Russian North and the Arctic are given in Table 4.8. To calculate these depositions, emissions of the 22 PCB congeners considered, from all source regions, were divided into four groups: di- plus tri-chlorinated PCBs, tetra- plus penta-chlorinated PCBs, hexachlorinated PCBs, and hepta- plus octa-chlorinated PCBs. It was assumed that these groups are transported in a similar way to PCB-28, -118, -153 and -180, respectively. Together, these 22 congeners represent about one half of total PCB emissions, a fact that was taken into account in the calculation.

Region	MUR	NEN	YNT	YAK	CHU	Arctic
PCB-153	0.020	0.031	0.095	0.038	0.012	1.15
Σ PCB	1.6	1.7	4.8	4	0.46	40

Table 4.8. Total deposition of PCB-153 and total PCB in 1996 in different regions of the Russian North, and the Arctic, t/y.

By undertaking simulations of long-range transport and the accumulation of four PCB congeners (PCB-28, -118, -153 and -180), it was possible to compare the congener compositions in the air of different regions of the Russian North (Figure 4.21).

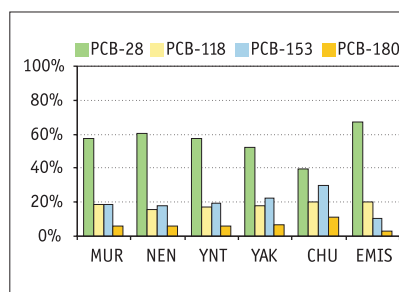


Figure 4.21. PCB congener composition in air of different regions of the Russian North.

For all receptor regions, the fraction of PCB-28 is the highest and PCB-180 the lowest, with other congeners falling between, however, the congener patterns vary noticeably between the regions.

γ HCH

Mean annual air concentrations of γ -HCH in the receptor regions of the Russian North, for 1996, are illustrated in Figure 4.22. Higher air concentration levels (from 0.02 to 0.07 ng/m³) are characteristic for Murmansk Oblast, the Nenets AO, the south of the Yamalo-Nenets AO, and the Republic of Sakha (Yakutia). Lower levels (from 0.01 to 0.3 ng/m³) are characteristic for the Taymir AO, the Chukchi AO, and the north of the Republic of Sakha (Yakutia) (Table 4.9).

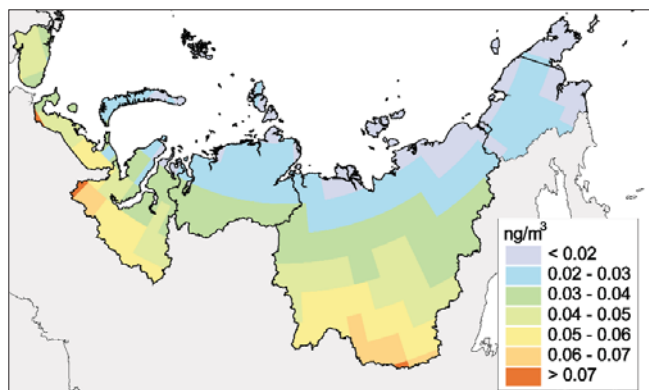


Figure 4.22. Spatial distribution of mean annual air concentrations of γ -HCH in the Russian North, calculated for 1996.

Table 4.9.
Characteristic values
of γ -HCH air concentrations
in the Russian North, ng/m³.

Region	min	max	average
MUR	0.029	0.066	0.043
NEN	0.016	0.082	0.038
YNT	0.018	0.071	0.036
YAK	0.014	0.072	0.038
CHU	0.013	0.027	0.02

The spatial distribution of γ -HCH annual deposition loads is shown in Figure 4.23. Deposition loads are larger for Murmansk Oblast, the Nenets AO, and the Yamalo-Nenets AO (from 2 to 7 g/km²/y or more) and

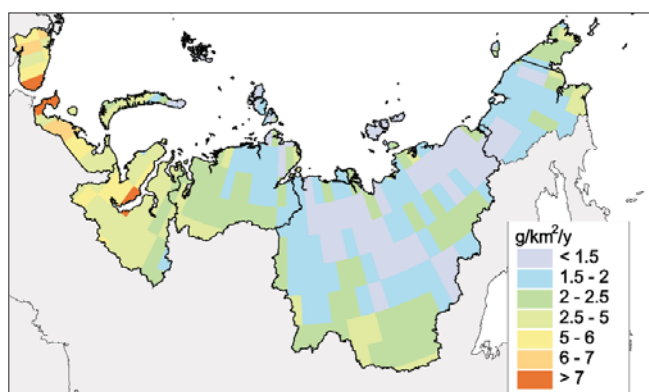


Figure 4.23. Annual deposition of γ -HCH in the Russian North, calculated for 1996.

Table 4.10.
Characteristic values of γ -HCH
annual deposition loads in the
Russian North, g/km²/y.

Region	min	max	average
MUR	3.5	14	6
NEN	0.9	9.7	4.3
YNT	0.8	8	2.7
YAK	0.5	4.3	1.8
CHU	0.7	4.6	1.9

lower for the Taymir AO, the Republic of Sakha (Yakutia), and the Chukchi AO (0.1–3 g/km²/y). Annual deposition loads vary from region to region (Table 4.10). This is mainly due to different precipitation levels in these regions.

Estimated values for total deposition of γ -HCH in the regions of the Russian North and the Arctic as a whole are given in Table 4.11.

Regions	MUR	NEN	YNT	YAK	CHU	Arctic
Total depositions	0.8	1.1	4	5.4	1.3	78

Table 4.11. Total deposition of γ -HCH in 1996 in different regions of the Russian North, and the Arctic as a whole, t/y.

4.2.5. Source-receptor relationships for the selected pilot study regions.

4.2.5.1. Murmansk Oblast

Mercury

Murmansk Oblast is the most westerly region of Russia and is located on the Kola Peninsula. This explains the greater influence of European sources of mercury on this region (including sources both inside and outside the territories of Russia). Figures 4.24(a) and 4.24(b) illustrate the contributions of major Northern Hemispheric and Russian anthropogenic mercury source regions to annual mercury deposition in Murmansk Oblast. The largest contribution is made by Russian sources (35%). Among these, about 13% is from Murmansk Oblast itself (MUR) and 18% from other Russian European regions (NRT, NWK, CVV, CVN and URL). The most important sources outside of Russia are those in Eastern Europe (12%), China (11%), the Americas (10%), and Western Europe (10%). The 'other' category (defined in this and other sections addressing mercury source-receptor relationships) includes Northern and Southern Europe, Southeast Asia (excluding China and Japan), and Africa, due to their relatively small contributions to depositions in the receptor area.

PCB

The largest contributions to PCB-153 deposition in Murmansk Oblast are from emission sources in Russia (44%), Northwest Europe (35%) and Southeast Europe (14%) (Figure 4.25(a)). Contributions from sources located in the Americas, Africa, and Central Asia are less significant due to their considerable distance from the Oblast. Amongst Russian sources (Figure 4.25(b)), the major contribution is made by emissions from Murmansk Oblast itself (22%).

γ HCH

γ -HCH sources in Western Europe make the largest contribution to deposition in Murmansk Oblast (more than 50%). Other significant contributors are Russia (17 %) and India (9%) (Figure 4.26(a)).

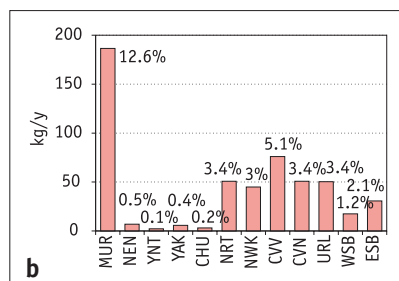
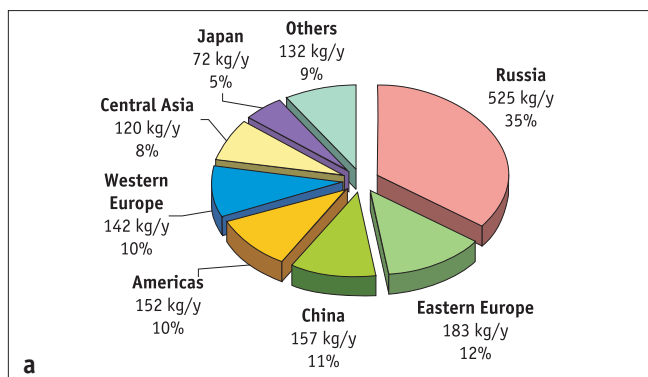


Figure 4.24. Contributions from anthropogenic sources in (a) regions of the Northern Hemisphere, (b) regions of Russia to annual mercury deposition in Murmansk Oblast.

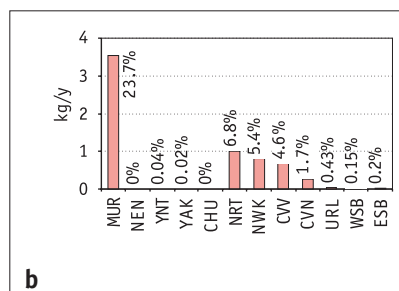
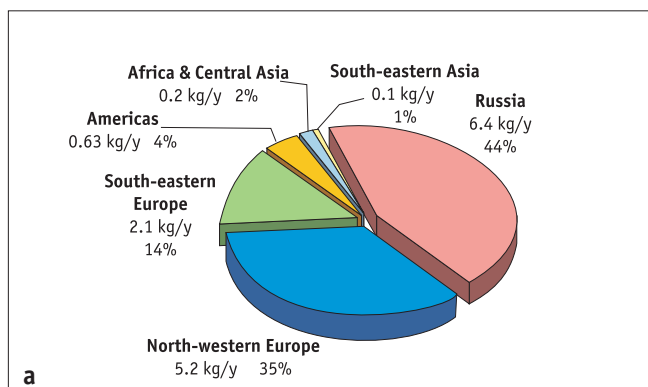


Figure 4.25. Contributions from anthropogenic sources in (a) regions of the Northern Hemisphere, (b) regions of Russia to annual PCB-153 deposition in Murmansk Oblast.

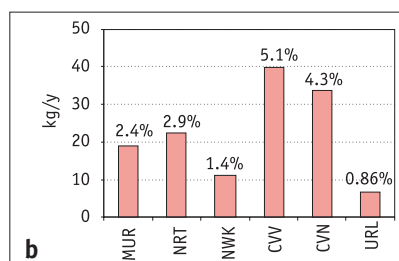
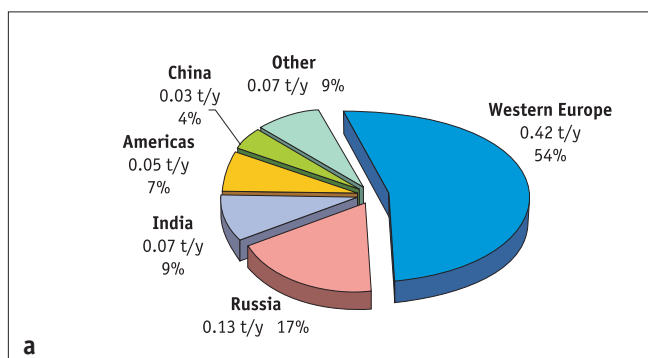


Figure 4.26. Contributions from anthropogenic sources in (a) regions of the Northern Hemisphere, and (b) regions of Russia to annual γ -HCH deposition in Murmansk Oblast.

Russian contributions to γ -HCH depositions in Murmansk Oblast are mostly made by the Central and Volgo-Viatsky regions (CVV) and the Central-Chernozem, Volga, and North-Caucasian regions (CVN), 5% and 4%, respectively. The inputs from other regions are comparatively small (Figure 4.26(b)). For the purposes of this report, contributions from Russian emission sources to γ -HCH depositions in receptor areas are shown only for those regions with significant emissions of γ -HCH.

4.2.5.2. The Nenets Autonomous Okrug

Mercury

The Nenets AO is located in the northern part of European Russia. Therefore the main source areas of long-range atmospherically transported pollution affecting the region are similar to those affecting Murmansk Oblast. Differences in deposition are associated mainly with the greater significance of Russian emission source regions. Figures 4.27(a) and 4.27(b)

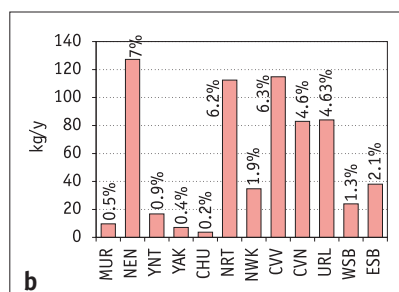
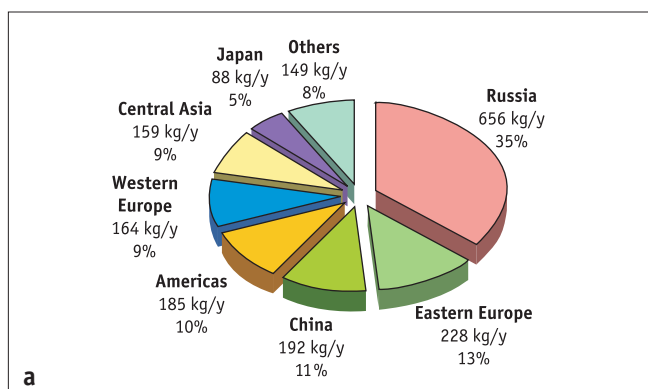
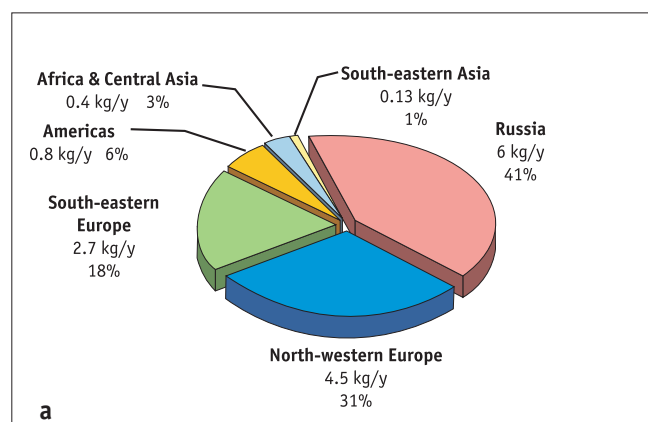


Figure 4.27. Contributions from anthropogenic sources in (a) regions of the Northern Hemisphere, (b) regions of Russia to annual mercury deposition in the Nenets AO.

show the relative contribution of the different regions to the total annual deposition of mercury in the Nenets AO from anthropogenic sources. The largest contribution is from Russian sources (35%). However, sources within the Nenets AO itself only contribute 7%, whereas the combined contribution of regions in European Russia make up 24% of the deposition. The most important of these are the Northern region (NRT) and the Central and Volgo-Viatsky regions (CVV). The most significant external contributors are Eastern Europe (13%), China (11%), the Americas (10%), Western Europe (9%), and Central Asia (9%).

PCB

The largest contributions to PCB-153 depositions are made by Russia (41%), Northwest Europe (31%) and Southeast Europe (18%) (Figure 4.28(a)). The main contributions among Russian sources (Figure 4.28(b)) are made by the Central and Volgo-Viatsky regions (CVV) and the Northern region (NRT), with values of 15% and 10%, respectively.



γ HCH

The major contributions to the contamination of the Nenets AO by γ -HCH are from emission sources in Western Europe (49%), Russia (23%), and India (9%) (Figure 4.29(a)). The main sources within the Russian Federation are the Central and Volgo-Viatsky regions (CVV) and the Central-Chernozem, Volga, and North-Caucasian regions (CNV), contributing 8% each (Figure 4.29(b)).

4.2.5.3. The Yamalo-Nenets and Taymir Autonomous Okrugs

Mercury

The location of the Yamalo-Nenets AO and the Taymir AO in the northern part of western Siberia, accounts for the fact that Asian sources play a noticeable role in their contamination. European sources, however, still continue to exert a considerable influence. Up to 30% of all mercury annually deposited in these two regions is from Russian sources (Figure 4.30(a)). The contribution from sources within the Yamalo-Nenets and

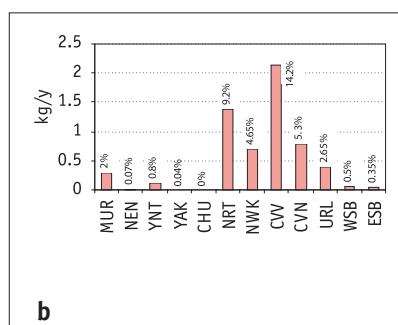


Figure 4.28. Contributions from anthropogenic sources in (a) regions of the Northern Hemisphere, (b) regions of Russia to annual PCB-153 deposition in the Nenets AO.

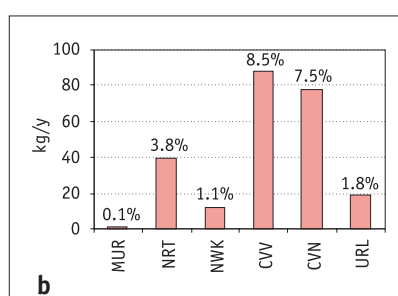
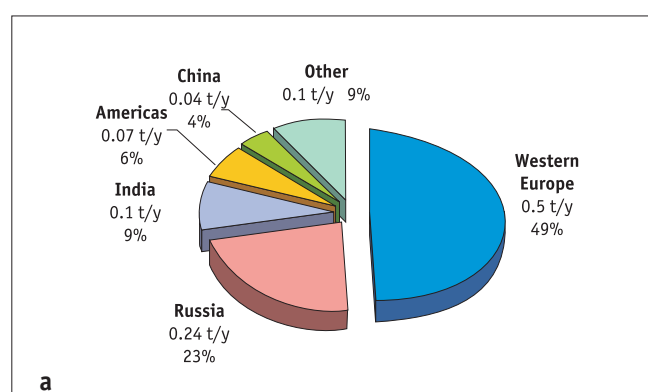


Figure 4.29. Contributions from anthropogenic sources in (a) regions of the Northern Hemisphere, (b) regions of Russia to annual γ -HCH deposition in the Nenets AO.

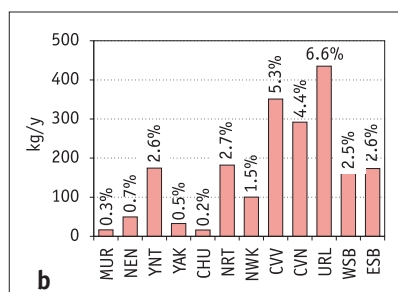
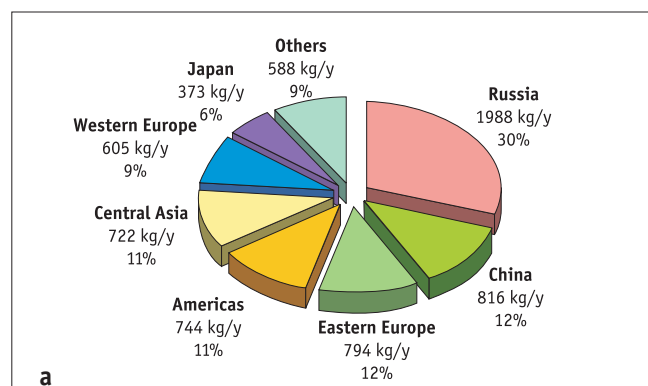


Figure 4.30. Contributions from anthropogenic sources in (a) regions of the Northern Hemisphere, (b) regions of Russia to annual mercury deposition in the Yamalo-Nenets AO and the Taymir AO.

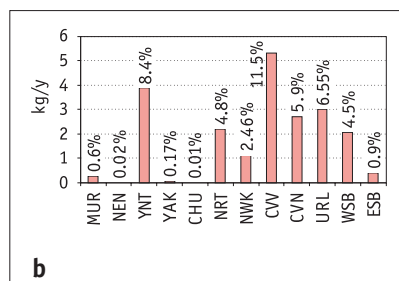
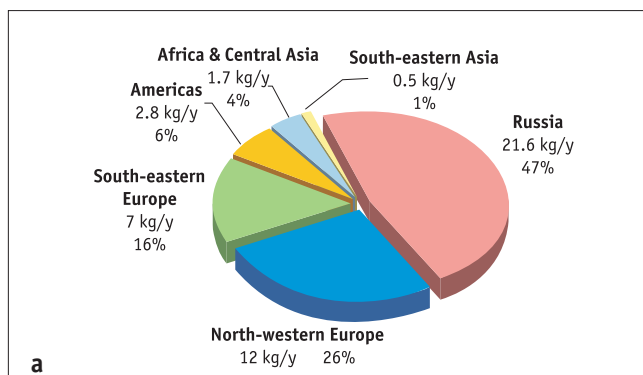


Figure 4.31. Contributions from anthropogenic sources in (a) regions of the Northern Hemisphere, (b) regions of Russia to annual PCB-153 deposition in the Yamalo-Nenets AO and the Taymir AO.

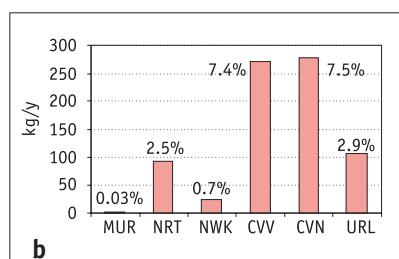
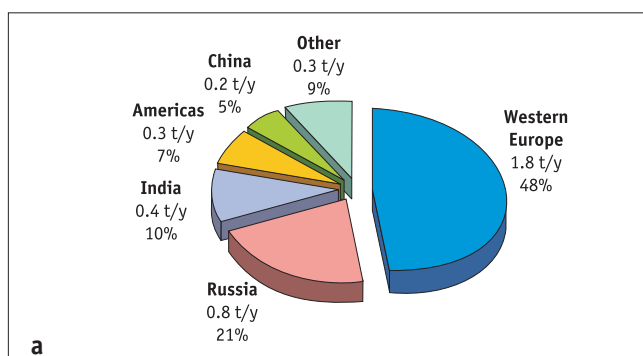


Figure 4.32. Contributions from anthropogenic sources in (a) regions of the Northern Hemisphere, (b) regions of Russia to annual γ -HCH deposition in the Yamalo-Nenets AO and the Taymir AO.

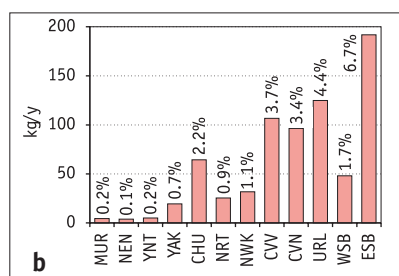
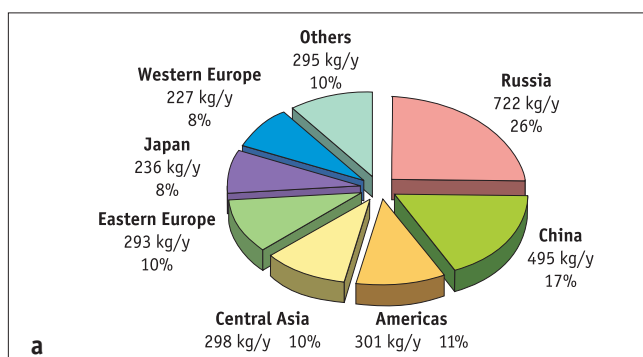


Figure 4.33. Contributions from anthropogenic sources in (a) regions of the Northern Hemisphere, (b) regions of Russia to annual mercury deposition in the Chukchi AO.

Taymir AOs themselves is comparatively low (only about 3%), whereas three major Russian contributors (CVV, CVN, and URL) make up 16% of total deposition (Figure 4.30(b)). The two major external contributors are China (12%) and Eastern Europe (12%). Some impact is also made by the Americas (11%), Central Asia (11%) and Western Europe (9%).

PCB

Major contributions to PCB deposition in the Yamalo-Nenets and Taymir AOs are made by sources in Russia (47%), Northwest Europe (26%) and Southeast Europe (16%) (Figure 4.31(a)). Among Russian sources (Figure 4.31(b)), the largest contribution (12%) to depositions are made by the Central and Volgo-Viatsky regions (CVV). The contribution of emission sources located within the Yamalo-Nenets and Taymir AOs is 9%.

γ HCH

Main contributors to depositions of γ -HCH in the Yamalo-Nenets and Taymir AOs are similar to those for the Nenets AO. Sources in Western Europe make the largest contribution to ongoing deposition in these territories (48%). Russia is responsible for 21% and India, for

10% (Figure 4.32(a)). Russian contributions to depositions in the Yamalo-Nenets and Taymir AOs are mainly from the Central and Volgo-Viatsky regions (CVV) and the Central-Chernozem, Volga, and North-Caucasian regions (CVN), 7% and 8% respectively (Figure 4.32(b)).

4.2.5.4. Chukchi Autonomous Okrug

Mercury

The Chukchi AO is the most eastern and remote region of the Russian North. Its location, far from major industrial regions, accounts for the fact that the global background pool of atmospheric mercury is the main source of mercury contamination in this region. Figure 4.33(a) demonstrates the relative contributions of different source regions to annual mercury deposition in the Chukchi AO. The main contributor is Russia (26%), however, contributions from China are also considerable (17%). Among other sources, the Americas (11%), Central Asia (10%), and Eastern Europe (10%) are of note. The contribution from the Chukotka AO itself is insignificant compared to emission sources located in Eastern Siberia and the Far East (Figure 4.33(b)). However, the influence of major emission regions in European Russia (CVV, CVN, URL) are also apparent.

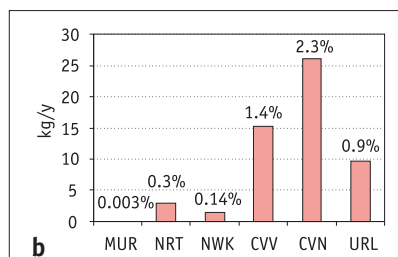
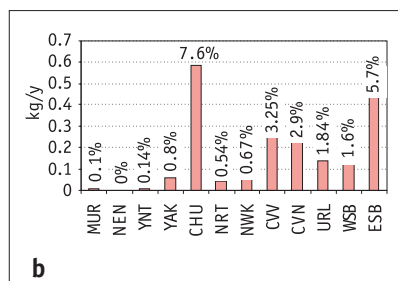
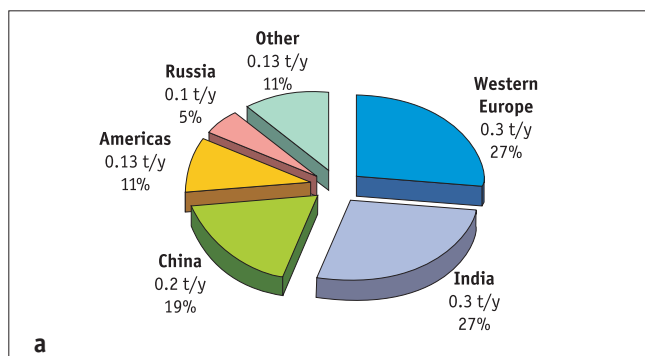
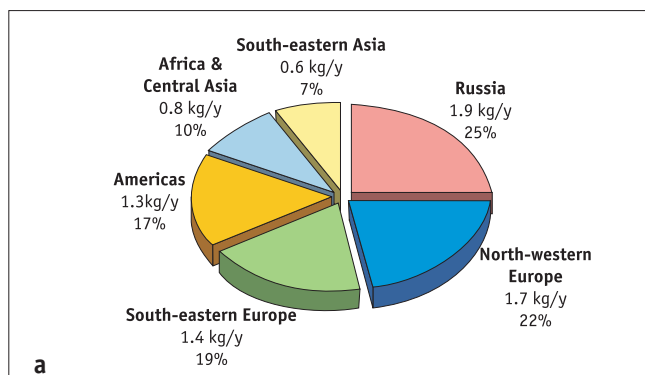


Figure 4.34. Contributions from anthropogenic sources in (a) regions of the Northern Hemisphere, (b) regions of Russia to annual PCB-153 deposition in the Chukchi AO.

Figure 4.35. Contributions from anthropogenic sources in (a) regions of the Northern Hemisphere, (b) regions of Russia to annual γ -HCH deposition in the Chukchi AO.

PCB

The most important contributions to PCB-153 deposition in the Chukchi AO are made by sources located in Russia (25%), Northwest Europe (22%), and Southeast Europe (19%), followed by American sources (17%). (Figure 4.34(a)). The main contribution from the Russian source regions (Figure 4.34(b)) is made by emissions from the Chukchi AO itself (8%).

γ HCH

For the Chukchi AO, the main contributions to γ HCH contamination are made by India (27%), Western Europe (27%), China (19%), and the Americas (11%) (Figure 4.35(a)). The contribution from all Russian sources accounts for only 5% (Figure 4.35(b)).

4.2.6. Conclusions

Murmansk Oblast

The largest contribution to anthropogenic mercury deposition in the Oblast is made by Russian sources (35%) of which 13% is from sources within Murmansk Oblast itself. The most important external sources are Eastern Europe (12%), China (11%), the Americas (10%), and Western Europe (10%). Total annual deposition of mercury is around 3 t, including 1.5 t from anthropogenic sources.

A major contribution to PCB deposition is made by Russian sources (44%) including 22% from sources within Murmansk Oblast itself. Among other emission sources, significant contributions originate in Northwest Europe (35%), and Southeast Europe (14%). Total annual deposition of PCB-153 in Murmansk Oblast amounts to 20 kg, and of total PCBs, 0.7 t.

Main contributions to γ HCH deposition are made by sources within Western Europe (54%), Russia (17%), and India (9%). Russian contributions to deposition are mainly from sources located in the Central and Volgo-Viatsky regions (5%), and Central-Chernozem, Volga, and North-Caucasian regions (4%). Total annual deposition of γ -HCH amounts to 0.8 t.

The Nenets Autonomous Okrug

The most important contribution to anthropogenic mercury depositions in the Nenets AO is made by Russian emission sources (35%). As well as deposition from sources within the Nenets AO itself (7%), emissions from regions in the European part of Russia contribute considerably to the pollution of this region (24%). The most important external contributors are Eastern Europe (13%), China (11%), and the Americas (10%). Total annual deposition of mercury in the Nenets AO amounts to 4 t, of which 1.8 t is from anthropogenic sources.

Main contributions to PCB deposition in the Nenets AO are from sources in Russia (41%), Northwest Europe (31%), and Southeast Europe (18%). Major contributions from sources within the Russian Federation are made by the Central and Volgo-Viatsky regions (15%), and the Northern region (10%). The contribution of local sources to deposition in the Nenets AO is negligible. Total annual deposition of PCB-153 in this Okrug amounts to 31 kg, and of total PCBs, 1 t.

γ HCH pollution of the Nenets AO is due to emission sources in Western Europe (49%), Russia (23%), and India (9%). The main sources within the Russian Federation are the Central and Volgo-Viatsky regions

(8%), and the Central-Chernozem, Volga, and North-Caucasian regions (8%). Total annual deposition of γ -HCH to this Okrug is 1.1 t.

The Yamalo-Nenets and Taymir Autonomous Okrugs

The major contribution to anthropogenic mercury deposition in these regions is from emissions sources in Russia (30%). Among Russian sources, the main contributors are sources in the Ural, Central and Volgo-Viatsky regions, and the Central-Chernozem, Volga, and North-Caucasian regions (16% in total). Main external contributors are China (12%), Eastern Europe (12%), the Americas (11%), and Central Asia (11%). Total annual deposition of mercury is estimated at 15 t, of which 6.6 t is from anthropogenic sources.

Major contributions to PCB depositions are made by sources located in Russia (47%), Northwest Europe (26%) and Southeast Europe (16%). Among Russian sources, the largest contribution to deposition is made by the Central and Volgo-Viatsky regions (12%). Total annual deposition of PCB-153 is 95 kg, and 3.2 t for total PCBs.

Main contributions to γ -HCH depositions are made by Western Europe (48%), Russia (21%), and India (10%). Main sources within the Russian Federation are the Central and Volgo-Viatsky regions (7%) and the Central-Chernozem, Volga, and North-Caucasian regions (8%). Total annual deposition of γ -HCH amounts to 4 t.

The Chukchi Autonomous Okrug

The main contributions to anthropogenic mercury deposition in this Okrug originate from Russian sources (26%). Emission sources from Eastern Siberia and the Far East are the dominant influences on mercury contamination of the Chukchi AO. The main external contributor to the region's pollution is China (17%), with a contribution comparable to that of Russian sources, although this varies slightly during the year. Among others, the Americas contribute 11% and Central Asia 10% to the deposition. Total annual deposition of mercury is estimated at 7 t, of which 2.9 t is from anthropogenic sources.

The main contributors to PCB deposition are the following: Russia (25%), Northwest Europe (22%), and Southeast Europe (19%), followed by American sources (17%). The Chukchi AO itself contributes 8%. The total annual deposition of PCB-153 amounts to 11.8 kg, and of total PCBs, 0.4 t.

Main contributions to γ -HCH deposition are made by India (27%), Western Europe (27%), China (19%), and the Americas (11%). The contribution from Russian sources accounts for 5%. Total annual deposition of γ -HCH in the Chukchi AO is estimated at 1.4 t.

In addition, the following general conclusions can be made, based on the studies undertaken:

- Europe, North America, and Southeast Asia are the most significant emission source regions for mercury, PCBs and γ -HCH. The main Russian emission sources are located in the European part of the Russian Federation. Due to their geographical location, and to meteorological conditions, European sources make the greatest contribution to the contamination of the western regions of the Russian North. Asian and North American sources play a more significant role in the pollution of the eastern territories of the Russian Arctic, although the contribution of European sources is still considerable.
- The results obtained make it possible to make some predictions for the near future regarding contamination levels in the Russian Arctic. An analysis of emission data shows that mercury emissions are decreasing in Europe and North America, whereas emissions from Southeast Asia are increasing. Asian sources may eventually become the more significant, thus contamination levels of this pollutant in some regions of the Russian North, in particular the Chukchi AO, may increase in the future. Regarding γ -HCH, use of technical-HCH (a mixture of HCH isomers, including γ -HCH) is now banned in most western countries, and in Russia since the late-1980s; China, a major user, also switched to lindane (pure γ -HCH) in 1984. Although restricted in most countries, lindane is still widely used in North America, Europe and Asia, for seed treatment and other applications (AMAP, 2002). Thus the relative influence of Asian countries on pollution of the Russian Arctic by γ -HCH is likely to increase. PCB contamination levels are expected to decrease with emission reductions resulting from bans and controls on use of PCBs. However PCB contamination is likely to continue for many years as a result of re-emissions from PCBs accumulated in the general environment over the last 50-years.

4.3. Preliminary assessment of riverine fluxes as PTS sources

4.3.1. Introduction

Flows of large Arctic rivers are considered one of the most significant pathways by which contaminants reach the Arctic. Riverine transport is particularly relevant for PTS, as potentially PTS contamination within the entire catchment areas of these rivers can be transported to the Arctic through watershed runoff, and these catchments include heavily industrialized areas and agricultural regions (Figure 4.36).

Riverine PTS transport is particularly important for two of the study areas selected for project implementation: the lower Pechora basin, and the eastern part of the Taymir Peninsula, in the area of the Yenisey river.

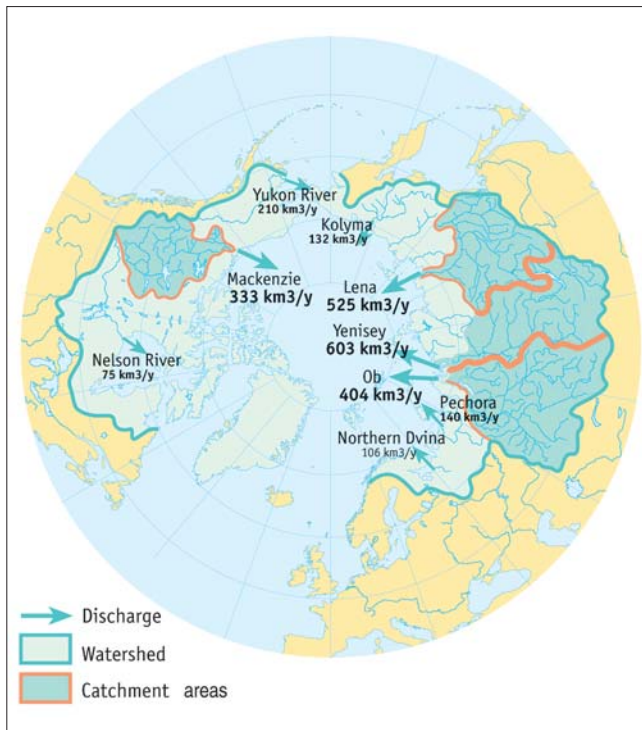


Figure 4.36. Arctic Ocean watershed, and catchment areas of the largest Arctic rivers (AMAP, 1998).

The Yenisey is one of the world's ten largest rivers, with a catchment area of 2.59 million km² (world ranking: 7) and mean long-term annual runoff of 603 km³ (world ranking – 5) (GRDC, 1994). Its basin incorporates the East-Siberian economic region, parts of which, particularly those located in the upper and central parts of the

Yenisey basin, are heavily industrialized. Industrial enterprises within these areas include non-ferrous metallurgy, pulp and paper manufacture, chemical industries, and mining, etc., which are recognized as significant sources of PTS emissions and discharges.

The catchment area of the Pechora river comprises 0.325 million km² (world ranking – 46), with a mean long-term annual runoff of 141 km³ (world ranking: 30). The Pechora river basin, including the catchments of its primary and secondary tributaries the Vorkuta, Bol'shaya Inta, Kolva, Izhma and Ukhta rivers, contain areas rich in mineral resources, with associated oil, gas and coal extraction activities.

4.3.2. Objectives and methodology of the study

The objective of this study was to estimate PTS fluxes in the flows of the Pechora and Yenisey rivers to areas inhabited by indigenous peoples. Calculations of PTS loads in the lower reaches of the Pechora and Yenisey rivers used a range of data, included hydrometric measurements at the closing cross-sections of the Roshydromet basic hydrological network (in the area of Oksino settlement on the Pechora River and Igarka settlement on the Yenisey River), and at the lowermost cross-sections in the delta apexes, upstream of the rivers' main branching points (in the vicinity of Andeg settlement, on both the Large and Small Pechora rivers, and of Ust'-Port settlement, on the Yenisey River) (Figures 4.37 and 4.38). In addition, data were obtained from analysis of pooled water and suspended matter samples collected during periods of hydrological observations.

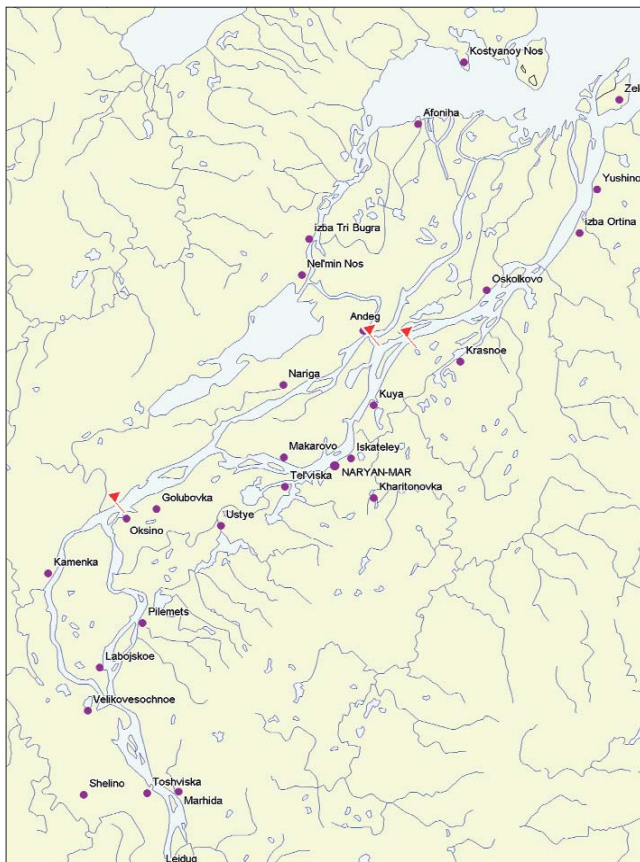


Figure 4.37. Location of hydrometric cross-sections on the Pechora river.

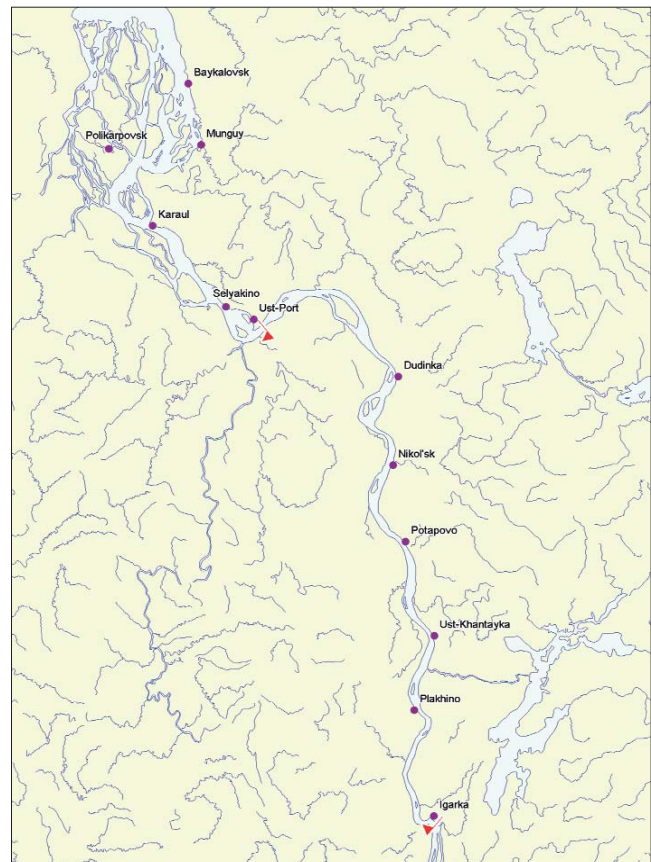


Figure 4.38. Location of hydrometric cross-sections on the Yenisey river.

Hydrometric measurements and water sampling at each of the cross-sections were carried out according to internationally accepted methodologies (GEMS, 1991; Chapman, 1996) during four typical hydrological water regime phases: during the spring flood fall period (late-June to early-July), during the summer low water period (late-July to early-August), before ice formation during the period of rain-fed floods (late-September to October), and during the winter low water period (March to April).

During each field survey period, measurements of flow velocity at various sampling points in the channel profile were made every 6 hours, for 3 days. Water level observations were conducted every 2 hours. Water sampling was carried out twice during the first observation day and once a day during the next two days (a total of 4 single samples for each sampling point). The volume of each pooled sample was not less than 20 litres.

Initial data for each water regime phase included:

- For the Pechora river at the closing cross-section near Oksino settlement (see Figure 4.39):
 - 15 flow velocity measurements (3 horizontal levels on each of 5 vertical profiles);
 - measurement of the channel profile;
 - 36 measurements of the river water level;
 - analytical data on PTS concentrations in 11 pooled water and 11 pooled suspended matter samples collected over a 3-day period in 11 cross-section segments;
 - suspended matter concentrations for samples taken at the flow velocity measurement points, in 11 pooled water samples, collected over a 3-day period in 11 cross-section segments.
- For the Large and Small Pechora rivers at the downstream cross-sections near Andeg settlement (see Figures 4.40 and 4.41):
 - 12 flow velocity measurements (3 horizontal levels on each of 4 vertical profiles, in both rivers);
 - measurement of the channel profile;
 - 36 measurements of the river water level;
 - analytical data on PTS concentrations in 3 pooled water samples and 3 pooled suspended matter samples from the surface, middle and near-bottom horizons collected over a 3-day period;
 - suspended matter concentrations in 3 pooled water samples collected over a 3-day period from the surface, middle and near-bottom horizons.
- For the Yenisey river at the closing cross-section near Igarka settlement (see Figure 4.42):
 - 15 flow velocity measurements (3 horizontal levels on each of 5 vertical profiles);
 - measurement of the channel profile;
 - 36 measurements of the river water level;
 - analytical data on PTS concentrations in 11 pooled water samples and 11 pooled suspended

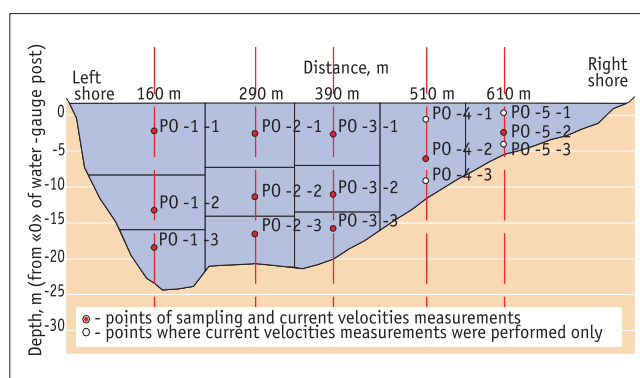


Figure 4.39. Channel profile and sampling/measurement points on the Large Pechora river at the closing cross-section near Oksino settlement.

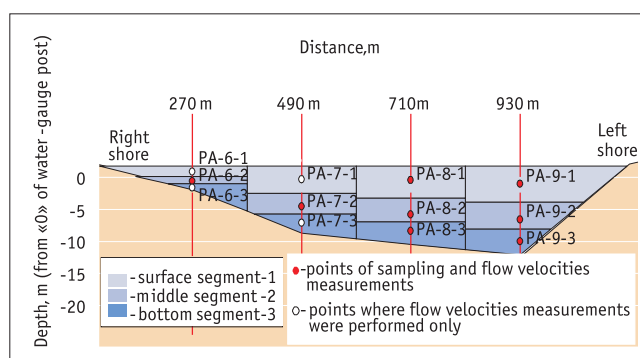


Figure 4.40. Channel profile and sampling/measurement points on the Large Pechora river at the downstream cross-section near Andeg settlement.

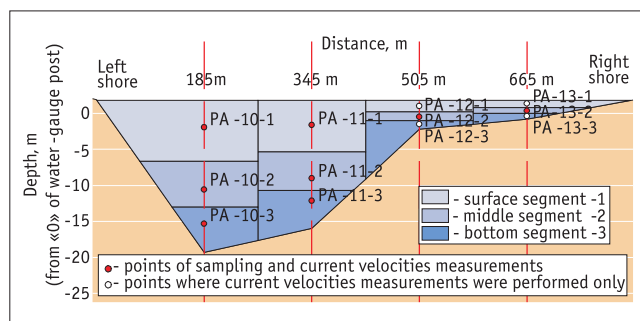


Figure 4.41. Channel profile and sampling/measurement points on the Small Pechora river at the downstream cross-section near Andeg settlement.

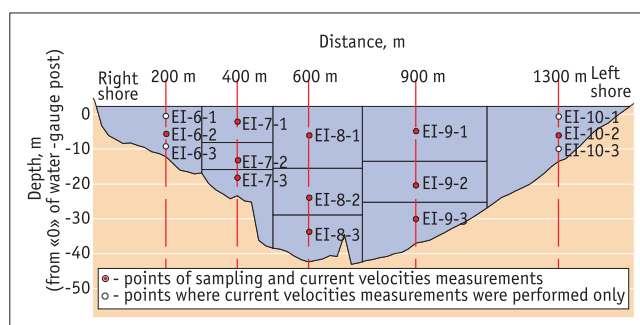


Figure 4.42. Channel profile and sampling/measurement points on the Yenisey river at the closing cross-section near Igarka settlement.

matter samples collected over a 3-day period in 11 cross-section segments;

- suspended matter concentrations for the flow velocity measurement points in 11 pooled water samples, collected over a 3-day period from 11 cross-section segments.

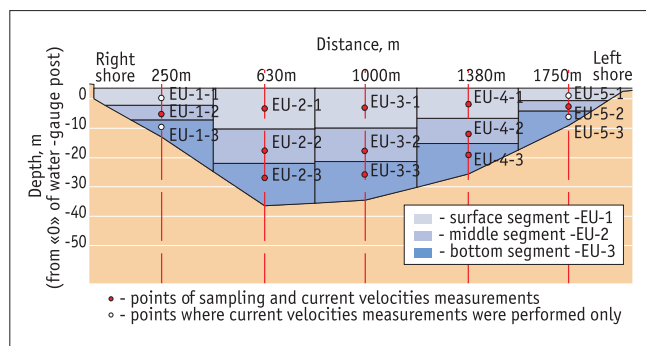


Figure 4.43. Channel profile and sampling/measurement points on the Yenisey river at the downstream cross-section near Ust'-Port.

- For the Yenisey river at the downstream cross-section near Ust'-Port settlement (see Figure 4.43):
 - 15 flow velocity measurements (3 horizontal levels on each of 5 vertical profiles);
 - measurement of the channel profile;
 - 36 measurements of the river water level;
 - analytical data on PTS concentrations for 3 pooled water samples and 3 pooled suspended matter samples from the surface, middle and near-bottom horizons collected over a 3-day period;
 - suspended matter concentrations in 3 pooled water samples collected over a 3-day period from the surface, middle and near-bottom horizons.

During the winter low water period, ice thickness was also measured at each of the cross-sections.

For calculations of mean monthly and annual PTS fluxes through the closing and downstream cross-sections for the year in which the observations were made, operational data consisting of water discharge measurements at river cross-sections in the area of Oksino and Igarka settlements were used. These data were provided by the Northern (Pechora river) and Central Siberian (Yenisey river) Territorial Branches of Roshydromet.

In order to calculate mean monthly and annual PTS fluxes through the closing cross-sections of the rivers for a year with 'average' runoff, and to assist in the preparation of a brief review of the inter-annual variability in water runoff via the Pechora and Yenisey rivers, published hydrographical data from 1932-1998, obtained from the Roshydromet hydrological network, were used.

Calculation of mean daily PTS fluxes over the 3-day observation periods was undertaken in several stages:

1. evaluation of the river channel profiles at the cross-sections where hydrometric measurements were taken;
2. division of the cross-sectional area into segments, for calculation of partial discharges and PTS fluxes;
3. calculation of the partial mean daily water and suspended matter discharges (for each segment identified) and total water and suspended matter discharges (for the whole cross-section) during each of the typical water regime phases;

4. calculation of partial and total mean daily fluxes of PTS in dissolved form during the typical water regime phases;
5. calculation of partial and total mean daily fluxes of PTS in suspended matter during the typical water regime phases.

The river channel profiles used in the hydrometric measurement cross-sections were evaluated on the basis of depth measurements and water level observations. Depth measurements (at various points across the channel) were taken once, prior to the start of the 3-day observation period. Water level observations were then made every two hours for three days. To model the channel profile, an averaged single value for water level above the original gauging station datum was applied across the river cross section. Thus, 16 profiles were evaluated (one for each of the four cross-sections in each of the four water regime phases) on the basis of average 'effective' cross-sectional areas during the 3-day observational periods. Ice thickness was taken into account in the construction of the channel profile during the winter low water period.

The cross-section areas were subdivided into segments corresponding to the points of flow velocity measurements and sampling. The profile schemes for each cross-section showing segments are presented in Figures 4.39 to 4.43. The numbers of segments coincides with the number of observations points.

In order to calculate partial and total mean daily PTS fluxes in dissolved and suspended form during the typical water regime phases, the following assumptions were made:

- At the closing cross-section, within a given segment, the PTS concentrations in water and suspended matter do not vary over the time period being represented, and are equal to the measured concentration at the corresponding observation point.
- At the downstream cross-section, within the combined segments identified, the PTS concentrations in water and suspended matter do not vary over the time period being represented, and are equal to the measured concentrations in the corresponding pooled samples.
- Any PTS that were either not found in any of the samples during the entire observation period, or were found in less than 10% of the total number of samples collected at both the closing and the more downstream cross-sections of a river, were excluded from PTS flux calculations for the given hydrological phase.
- Edge effects are not taken into account.

An assessment of mean monthly PTS flux (μ_y) in dissolved and suspended form was made according to the calculation method proposed by E.M.L. Beal (Frazer and Wilson, 1981).

$$\mu_y = \mu_x \frac{m_y}{m_x} \left(\frac{1 + \frac{1}{n} \frac{S_y}{m_y m_x}}{1 + \frac{1}{n} \frac{S_x^2}{m_x^2}} \right) \quad (4.1)$$

where:

μ_x – mean daily water discharge for the given month (L/day);

m_y – mean daily flux of the substance under consideration in the dissolved or suspended forms (kg/day), obtained for a 3-day observation period;

m_x – mean daily water discharge (L/day), obtained for a 3-day observation period;

n – number of observation days in a month (using our assumptions – three).

$$S_y = \frac{\sum_{i=1}^n X_i Y_i - n \cdot m_y \cdot m_x}{n - 1} \quad S_x^2 = \frac{\sum_{i=1}^n X_i^2 - n \cdot m_x^2}{n - 1}$$

and:

X_i , Y_i – values of the water discharge and flux of the substance under consideration for each specific day when measurements were conducted.

In our case $Y_i = m_y$ and $X_i = m_x$, as the concentration of suspended matter and PTS concentrations were determined from a single integral sample collected during the 3-day observation period and the water discharges were calculated on the basis of the average flow velocity for a 3-day period.

In this case, equation (1) above for the calculation of mean monthly PTS flux can be simplified to:

$$\mu_y = \mu_x \frac{m_y}{m_x} \quad (4.2)$$

In applying this, the following assumptions were adopted:

- Values of m_y and m_x were assumed to be constant for the months which fall within each hydrological season: i.e., May-July (spring flood); August-September (summer low water period); October (period before the onset of ice formation); November-April (winter low water period).
- The ratio of the PTS fluxes in dissolved and particulate associated phases is constant inside the cross-section and during the hydrological season represented.
- The ratio of the PTS fluxes in dissolved and particulate associated phases during the spring freshet is assumed to be equal to the ratio during periods of low discharge.

As mentioned above, mean monthly water discharges at the closing cross-sections of the Pechora and Yenisey rivers (near Oksino settlement and Igarka, respectively) for both the observation year and an 'average' water discharge year, for use in the calculations, were provided by Roshydromet. For the two downstream cross-sections, similar data were not available. Consequently, the following assumptions were adopted for calculation purposes:

Congener	Form	R. Pechora (at Oksino)		R. Yenisey (at Igarka)	
		2001- 2002	Long- term	2001- 2002	Long- term
CB28	Dissolved	115	122	125	107
	Suspended	639	678	609	520
	Total	754	800	734	627
CB31	Dissolved	93	99	102	87
	Suspended	692	734	727	621
	Total	785	833	829	708
CB52	Dissolved	187	198	146	125
	Suspended	274	291	465	398
	Total	461	489	611	523
CB99	Dissolved	10	11	324	277
	Suspended	85	90	232	198
	Total	95	101	556	475
CB101	Dissolved	5	5	214	183
	Suspended	49	52	36	31
	Total	54	57	250	214
CB105	Dissolved	13	14	243	208
	Suspended	48	51	48	41
	Total	61	65	291	249
CB118	Dissolved	12	13	75	64
	Suspended	8	8	349	298
	Total	20	21	424	362
CB128	Dissolved	0	0	118	101
	Suspended	1	1	51	44
	Total	1	1	169	145
CB138	Dissolved	10	11	102	87
	Suspended	27	29	265	227
	Total	37	40	367	314
CB153	Dissolved	3	3	1	1
	Suspended	0	0	58	50
	Total	3	3	59	51
CB156	Dissolved	2	2	0	0
	Suspended	0	0	34	29
	Total	2	2	34	29
CB170	Dissolved	0	0	2	2
	Suspended	0	0	2	2
	Total	0	0	4	4
CB183	Dissolved	6	6	9	8
	Suspended	0	0	55	47
	Total	6	6	64	55
CB187	Dissolved	3	3	0	0
	Suspended	4	4	0	0
	Total	7	7	0	0
Σ PCB	Dissolved	456	484	1460	1250
	Suspended	1830	1940	2930	2510
	Total	2280	2420	4390	3760

Table 4.12. PCB flux (kg/y) at the closing cross-sections of the Roshydromet network, calculated for the period of observations (2001-2002), and for the long-term mean annual water discharge.

- For the Pechora, mean monthly water discharges at the Andeg cross-section were assumed to be equal to the discharges at the Oksino cross-section.
- For the Yenisey, mean monthly water discharges at the Ust'-Port cross-section were assumed to be 3% higher than the discharges at the Igarka cross-section.

Analytical studies covered the whole range of PTS included within the project scope, with the exception of dioxins and brominated compounds, which were excluded due to their extremely low levels in abiotic freshwater environments. However, analysis of samples collected during field work also showed that levels of toxaphene compounds in all samples from the Pechora and Yenisey were lower

than effective detection limits (0.05 ng/L for water, and 0.01 ng/mg for suspended matter), therefore toxa-phene was also excluded from the assessment of fluxes.

4.3.3. Overview of the assessment results

PCB

Estimated PCB fluxes via the Pechora and Yenisey rivers are presented in Table 4.12. It is worth noting that the estimated fluxes of specific PCB congeners through both the closing cross-sections of the regular hydrometric network and the downstream cross-sections are very similar (Figure 4.44). Based on this information, the overview of assessment results for other contaminant groups, below, focuses mainly on fluxes in the closing cross-sections of the rivers.

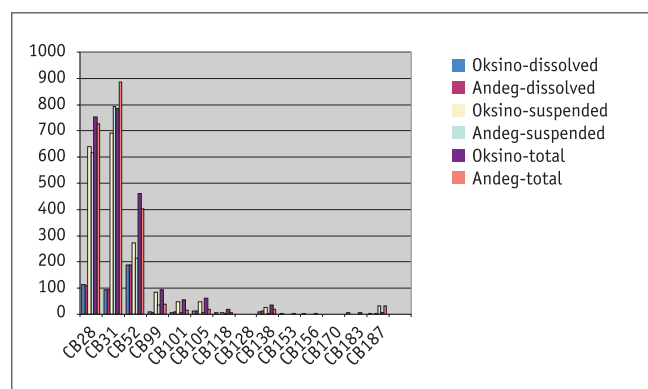
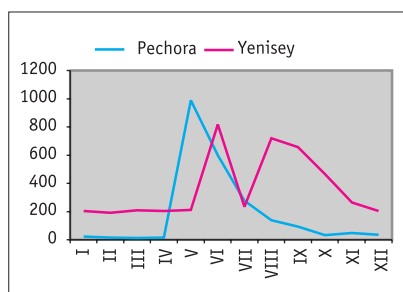


Figure 4.44. Estimated fluxes (kg/y) of PCB congeners at the closing (Oksino) and downstream (Andeg) cross-sections of the Pechora river.

The total PCB flux in the Pechora river consists almost entirely of tri- and tetra-chlorobiphenyls. Fluxes of the heavier PCB congeners are negligible. This is consistent with information presented to the OSPAR Commission by Sweden (Axelman, 1998).

The structure of PCB fluxes in the Yenisey river are more complex. As expected, peak PCB fluxes in both rivers coincide with springtime peaks in water discharge, which occur later in the lower Yenisey than in the lower Pechora. However, flux values for the Yenisey river also exhibit a distinct second peak in the late summer-autumn period (Figure 4.45).

Figure 4.45. Monthly fluxes (kg) of PCB in the Pechora and Yenisey rivers.



Two possible explanations for the second peak are:

- instrumental/procedural errors during analysis of the samples;
- accidental PCB release from some unknown pollution source.

Although it is difficult to make a definite conclusion regarding the cause of this peak appearance, the following information should be noted:

- the peak was observed not only during the summer low water period, when it was detected for the first time, but also during the period before ice formation in October (Figure 4.62);
- the peak is due to increased fluxes in PCB congeners associated with suspended matter, with dissolved forms showing practically unchanged fluxes;
- compared to the spring flood peak, which, as in the case of the Pechora, is a result of fluxes of tri- and tetra-chlorobiphenyls, the second flux peak has a higher contribution of penta- and hexa-chlorobiphenyls, particularly CB118 and CB138 (Figure 4.46).

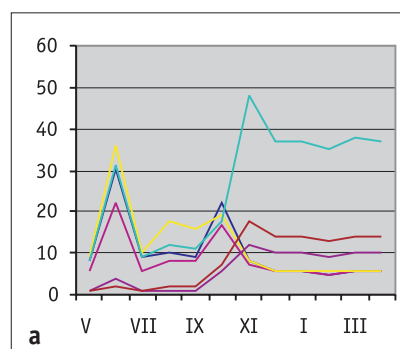
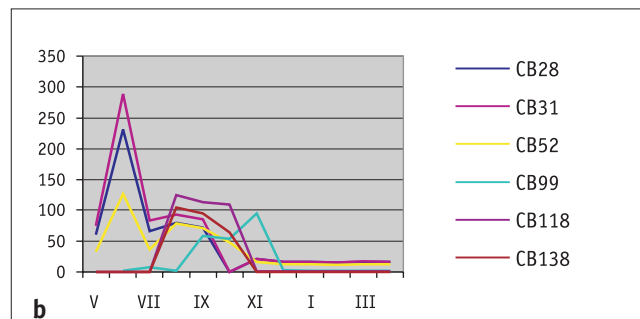


Figure 4.46. Monthly fluxes (kg) of selected PCB congeners in (a) dissolved (b) suspended form in the Yenisey river.



Compound	Form	Pechora		Yenisey	
		2001-2002	Long-term	2001-2002	Long-term
1234-TeCBz	Dissolved	6.6	7	0	0
	Suspended	2.4	2.5	16	12
	Total	9	9.5	16	12.7
1235-TeCBz	Dissolved	0	0	0	0
	Suspended	0	0	0	0
	Total	0	0	0	0
1245-TeCBz	Dissolved	8.8	9.7	138	112
	Suspended	5.9	6.3	170	131
	Total	14.7	16	308	242
QCB (PeCBz)	Dissolved	8.7	9.4	29.7	24.7
	Suspended	59.7	65.1	189	171
	Total	68.4	74.5	218	196
HCB (HxCBz)	Dissolved	73.8	79.1	200	175
	Suspended	143	155	161	139
	Total	217	235	362	314
ΣPCBz	Dissolved	97.9	105	368	311
	Suspended	211	229	536	454
	Total	309	335	904	765

Table 4.13. Fluxes of polychlorinated benzenes (kg/y) in flows of the Pechora and Yenisey rivers, calculated for the period of observations (2001-2002), and for the long-term mean annual water discharge.

This evidence, whilst indirect, argues for the likely explanation being an accidental PCB release from a non-identified local source. However, in case of a short-term release, estimation of the annual flux based of this data can be overestimated.

Polychlorinated benzenes

Estimates of annual fluxes of polychlorinated benzenes (PCBz) in the flows of the Pechora and Yenisey rivers are presented in Table 4.13. As expected, hexachlorobenzene (HCB) is the main compound in this contaminant group, with relatively high fluxes in both rivers. Although tetra-chlorinated benzenes (TeCBz) have occasionally been found in both water and suspended matter of both rivers, their concentrations were close to detection levels, and as such they cannot be considered contaminants that pose a significant threat to either the aquatic environment or humans. Seasonal distribution of fluxes exhibit the a typical pattern of a peak during the spring flood period (Figure 4.47).

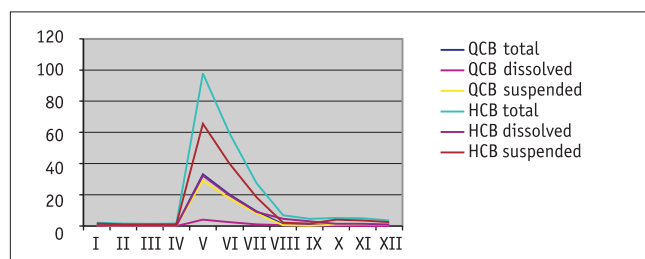


Figure 4.47. Monthly fluxes (kg) of QCB and HCB in the Pechora river.

Contaminant	Form	Pechora		Yenisey	
		Oksino	Andeg	Igarka	Ust-Port
α -HCH	Dissolved	98.4	157	71.6	60.2
	Suspended	85.4	351	699	271
	Total	184	509	771	210
β -HCH	Dissolved	14.8	34.5	16.4	16.9
	Suspended	71.6	158	161	0
	Total	86.4	192	177.6	16.9
γ -HCH	Dissolved	109	190	109	47.2
	Suspended	159	721	751	218
	Total	267	912	859	265
Σ HCH	Dissolved	222	382	197	123
	Suspended	316	1230	1610	488
	Total	537	1610	1810	612

Table 4.14. Fluxes of HCH compounds (kg/y) in flows of the Pechora and Yenisey rivers for 2001-2002.

Organochlorine pesticides and their metabolites

(a) Hexachlorocyclohexane (HCH)

Data on HCH fluxes in the Pechora and Yenisey rivers are presented in Table 4.14. For both rivers, total HCH fluxes are dominated by α - and γ -HCH isomers, with γ -HCH the most prevalent. However, the two rivers do not show consistent trends between the closing cross-sections of the regular observation network and the more downstream cross-sections, established close to areas inhabited by indigenous population. Fluxes of all

Contaminant	Form	Pechora		Yenisey	
		Oksino	Andeg	Igarka	Ust-Port
<i>o,p'</i> -DDT	Dissolved	18.0	20.7	93.2	115
	Suspended	55.9	476	417	93.1
	Total	73.9	497	511	209
<i>p,p'</i> -DDT	Dissolved	33.8	90.8	247	200
	Suspended	119	855	835	238
	Total	153	945	1080	438
Σ DDT	Dissolved	51.8	112	340	315
	Suspended	175	1440	1250	331
	Total	227	1554	1590	646
<i>o,p'</i> -DDE	Dissolved	5.5	3.7	10.9	8.7
	Suspended	30.2	59.2	155	73.2
	Total	35.7	62.9	166	81.9
<i>p,p'</i> -DDE	Dissolved	14.7	21.2	46.4	30.8
	Suspended	75.6	93.7	354	137
	Total	90.3	115	400	168
Σ DDE	Dissolved	20.2	24.9	57.3	39.5
	Suspended	106	153	509	210
	Total	126	178	566	250
<i>o,p'</i> -DDD	Dissolved	20.2	13.3	127.3	68.0
	Suspended	30.1	45.3	24.5	6.5
	Total	50.3	58.6	151.8	74.5
<i>p,p'</i> -DDD	Dissolved	5.6	~0	333.0	229.7
	Suspended	0.5	94.9	84.8	~0
	Total	6.1	94.9	418	230
Σ DDD	Dissolved	25.8	13.3	460	297
	Suspended	30.6	140	109	6.5
	Total	56.4	154	570	303
Σ DDTs	Dissolved	97.8	146	857	652
	Suspended	311	1740	1870	548
	Total	409	1880	2730	1200
DDE:DDT ratio	Dissolved	0.39	0.22	0.17	0.13
	Suspended	0.6	0.11	0.41	0.63
	Total	0.55	0.12	0.36	0.39

Table 4.15. Fluxes of DDT compounds (kg/y) in flows of the Pechora and Yenisey rivers for 2001-2002.

HCH compounds increase downstream in the Pechora river, while the Yenisey shows the opposite trend. A possible explanation is that the downstream section of the Pechora rivers shows the impact of local HCH usage, while HCH fluxes in the lower Yenisey river are the result of long-range transport alone, and thus the downstream section of the river has lower loads due to self-purification processes in the aquatic environment. It should be noted however that in case of short-term environmental releases annual fluxes can be overestimated.

(b) DDTs

Fluxes of DDTs in flows of the Pechora and Yenisey rivers show similar trends as for HCHs (Table 4.15), with a strong increase in concentrations between the Oksino and Andeg cross-sections of the Pechora, and a decrease between the Igarka and Ust'-Port cross-sections of the Yenisey. This can be explained by a large local input of DDT into the lower part of Pechora, particularly during the spring flood period (Figure 4.48), whereas in the Yenisey, the contamination is the result of long-range transport of contaminants in the Yenisey, with fluxes decreasing downstream due to self-purification. This conclusion is supported by the significant change seen in the composition of the total DDTs flux at the downstream Andeg cross-section when compared to Oksino. At Andeg, the proportion of the DDT

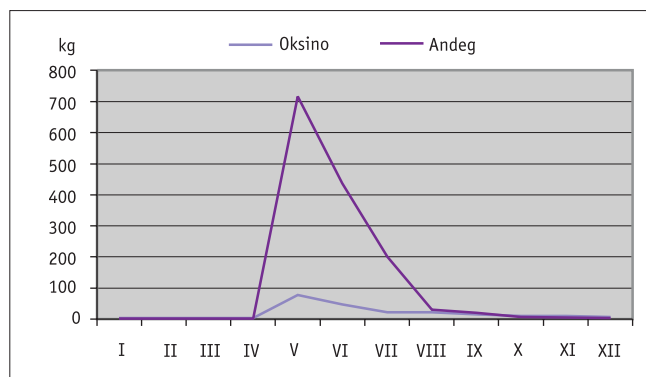


Figure 4.48. Monthly fluxes (kg) of DDT in the Pechora river.

component is far greater (Figure 4.49). Considering that the absolute value of Σ DDD, which is a dechlorinated DDT analog in the technical DDT mixture (AMAP, 1998), also shows an almost three-fold increase, it is reasonable to assume that the DDT flux increase is due to fresh local input of DDT. For the Yenisey river, the Σ DDT flux composition did not alter between the two cross-sections. In this case, like in case of HCH, annual fluxes can be overestimated.

It should be noted that the increase in DDT flux at the

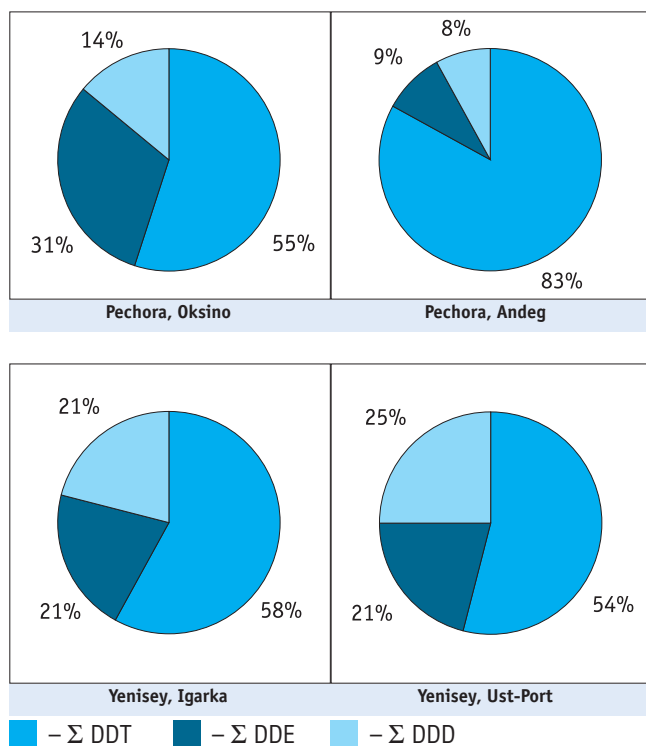


Figure 4.49. Composition of total DDT fluxes in the Pechora and Yenisey rivers.

Andeg cross-section is mostly determined by an increase in its suspended form. Data quality can be verified from the comparability of data obtained for the suspended matter flux in different layers of the Andeg cross-section (Figure 4.50). The ratio of *o,p'*-DDT to *p,p'*-DDT in the surface, middle and bottom layers of the river flow remains constant, however, the surface layer shows lower levels of DDT when compared to the middle and bottom layers.

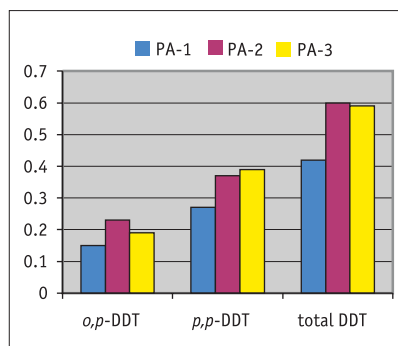


Figure 4.50. DDT concentrations (ng/mg) in suspended matter of the Pechora river at the Andeg cross-section (PA-1: surface layer, PA-2: middle layer, PA-3: bottom layer) (see Figures 4.40 and 4.49).

(c) Other chlorinated pesticides

Other chlorinated pesticides included in the priority list of PTS considered in the project were either found only at levels below detection limits, or had fluxes that would not be expected to have any noticeable impact on the health of indigenous human populations (Table 4.16).

Contaminant	Form	Pechora		Yenisey	
		Oksino	Andeg	Igarka	Ust-Port
Heptachlor	Dissolved	11.9	21.2	7.0	1.1
	Suspended	0.5	0	2.7	0
	Total	12.4	21.2	9.7	1.1
Heptachlorepoide	Dissolved	0	0	0	0
	Suspended	0.9	0	1.5	0
	Total	0.9	0	1.5	0
Cis-chlordane	Dissolved	0	0	0	0
	Suspended	0	0	0	0
	Total	0	0	0	0
Trans-chlordane	Dissolved	6.6	17.4	117	99
	Suspended	0.5	0	0.3	0
	Total	7.1	17.4	118	99
Cis-nonachlor	Dissolved	0	0	0	0
	Suspended	0	0	0	0
	Total	0	0	0	0
Trans-nonachlor	Dissolved	10.3	19.5	7.2	0
	Suspended	1.3	0	7.9	0
	Total	11.6	19.4	15.1	0
Photomirex	Dissolved	0	0	0	0
	Suspended	0	0	0	0
	Total	0	0	0	0
Mirex	Dissolved	0	0	0	0
	Suspended	2.6	3.1	0	0
	Total	2.6	3.1	0	0

Table 4.16. Fluxes of other chlorinated pesticides (kg/y) in flows of the Pechora and Yenisey rivers for 2001-2002.

Polycyclic aromatic hydrocarbons (PAHs)

The list of PAHs included in the scope of the preliminary assessment of riverine fluxes included 20 compounds. Annual fluxes of 10 PAHs in the Pechora and Yenisey are presented in Figures 4.51 and 4.52, respectively. However, fluxes of several PAHs could not be assessed, as their concentrations in water and suspended matter in both rivers were below detection limits.

These were:

acenaphthene, benzo[*a*]anthracene, benzo[*b*]fluoranthene, benzo[*e*]pyrene, perylene, benzo[*k*]fluoranthene, benzo[*a*]pyrene, dibenzo[*a,h*]anthracene, indeno[1,2,3-*c,d*]pyrene, and benzo[*ghi*]perylene.

In both rivers, PAH fluxes are dominated by the more soluble 2-cyclic PAHs (naphthalene, 2-methylnaphthalene, biphenyl) and, to certain extent, 3-cyclic PAHs (fluorene, phenanthrene). At the downstream Ust'-Port cross-section of the Yenisey river, PAH fluxes are significantly lower. This confirms an absence of additional PAH sources between the two cross-sections along this part of the river. However, fluxes of some PAHs at the downstream Andeg cross-section of the Pechora river are significantly higher than at the upstream Oksino cross-section. This is true not only for 2- and 3-cyclic PAHs, such as 2-methylnaphthalene, fluorene and phenanthrene, but also for the heavier

PAHs (fluoranthene and pyrene). Increase in fluxes of these less readily transported 4-cyclic PAHs provides additional evidence of local pollution sources between the Oksino and Andeg cross-sections of the Pechora river.

Heavy metals.

Data on annual fluxes of heavy metals that were included in the study (lead, cadmium, and mercury) are presented in Table 4.17.

(a) Lead

The intra-annual distribution of lead fluxes in flows of the Pechora and Yenisey rivers are presented in Figures 4.53 and 4.54. For both rivers, peaks of lead fluxes coincide with the peak of the spring flood. It is noticeable that the composition and annual distribution of lead flux in the Yenisey river has a more complicated pattern than that of the Pechora river. During low-water periods, and particularly during the ice cover season, lead flux at both the Igarka and Ust'-Port cross-sections is dominated by the dissolved form of the metal, with levels almost twice as high at the upstream cross-section. However, during the flood period, the flux at the Ust'-Port cross-section is significantly higher than at Igarka, and is mostly due to suspended forms of lead.

Contaminant	Form	Pechora		Yenisey	
		Oksino	Andeg	Igarka	Ust-Port
Lead	Dissolved	89.2	77.1	624	375
	Suspended	77.2	24.4	114	535
	Total	166	101	738	911
Cadmium	Dissolved	6.77	3.31	124	122
	Suspended	22.05	9.90	4.34	26.98
	Total	28.8	13.2	129	149
Mercury	Dissolved	1.02	0.472	0	0
	Suspended	1.82	1.75	2.79	9.10
	Total	2.84	2.22	2.79	9.10

Table 4.17. Fluxes of heavy metals (t/y) in flows of the Pechora and Yenisey rivers for 2001-2002.

Figure 4.51.
Estimated fluxes (t/y)
of PAHs in the flow
of the Pechora river.

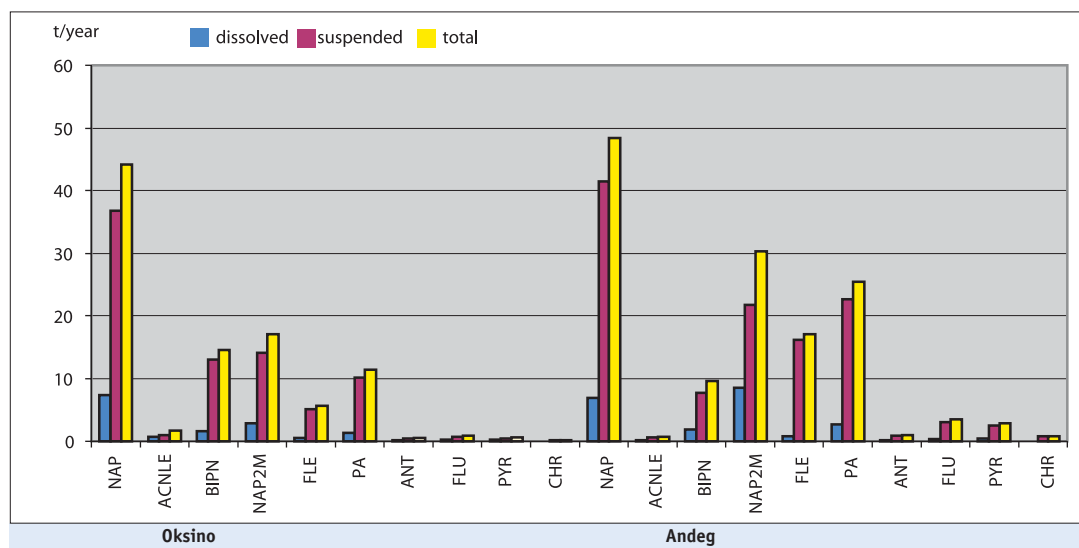
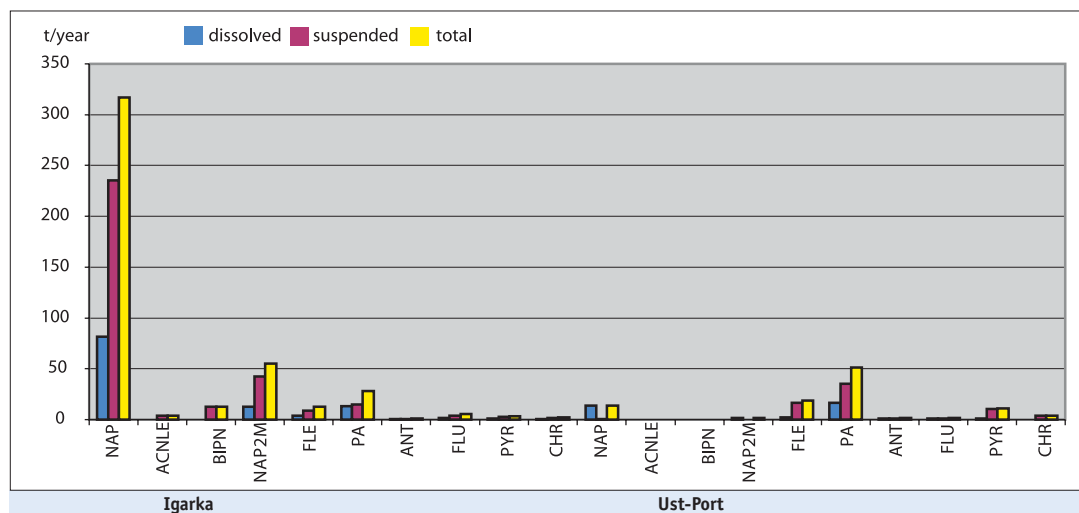


Figure 4.52.
Estimated fluxes (t/y)
of PAHs in the flow
of the Yenisey river.



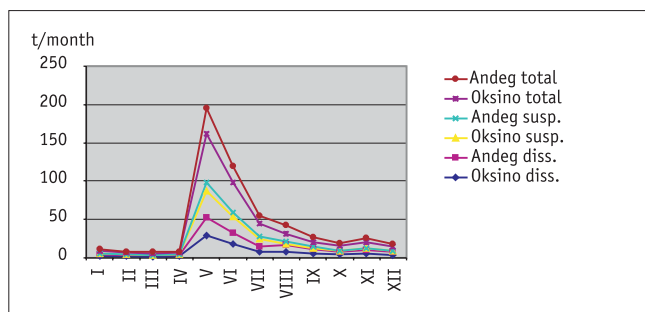


Figure 4.53. Monthly fluxes (t) of lead in the Pechora river.

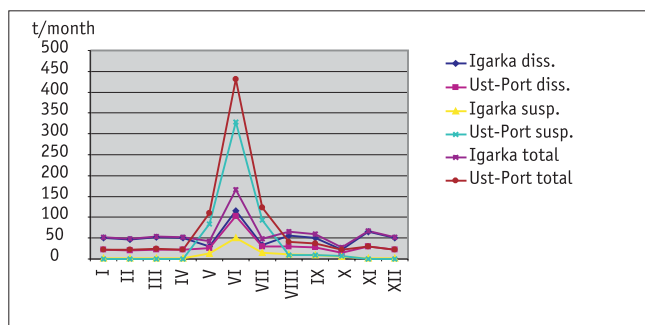


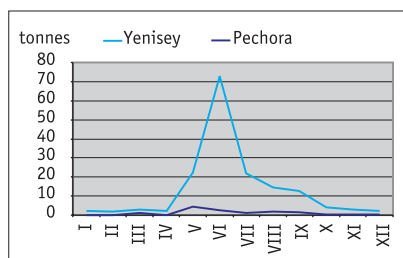
Figure 4.54. Monthly fluxes (t) of lead in the Yenisey river.

This suggests that during the ice cover season, lead flux is almost totally determined by long-range transport of the more mobile dissolved form of lead, from industrialized regions in the central part of the Yenisey basin; whereas, during the flood period, lead flux is dominated by local runoff from the area between Igarka and Ust'-Port, which can be significantly affected by the Norilsk industrial region.

(b) Cadmium

Compared to the other PTS, the difference in cadmium fluxes seen in the flows of the Pechora and Yenisey rivers is much more pronounced (Figure 4.55). It is also notable that the composition of cadmium fluxes in the two rivers are different (Figures 4.56 and 4.57). The Pechora river flux has a much greater proportion of the suspended form of cadmium, particularly during the spring flood period. During the ice cover season, this difference is not so noticeable. This could be explained by the higher sediment load of the Pechora, compared to the Yenisey.

Figure 4.55. Monthly fluxes (t) of (dissolved+suspended) cadmium in the Pechora and Yenisey rivers.



(c) Mercury

In general, the intra-annual distribution of mercury fluxes in the Pechora and Yenisey correspond to the respective river hydrographs, with the highest fluxes

during the spring flood period (Figures 4.58 and 4.59). The Yenisey river mercury flux almost totally consists of suspended forms of the metal. The composition of the mercury flux of the Pechora river is more complicated, and differs between the Oksino and Andeg cross-sections (Figure 4.60). Total flux at the upstream Oksino cross-section is higher relative to that at Andeg (Figure 4.61). During the spring flood period, suspended forms of mercury are dominant in the flux, particularly at

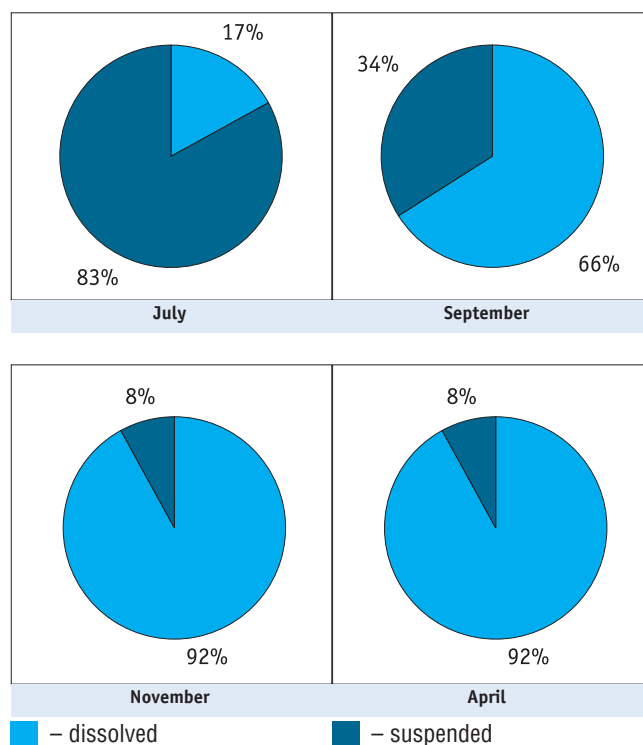


Figure 4.56. Seasonal changes in the ratio of dissolved and suspended fluxes of cadmium in the Pechora river flow.

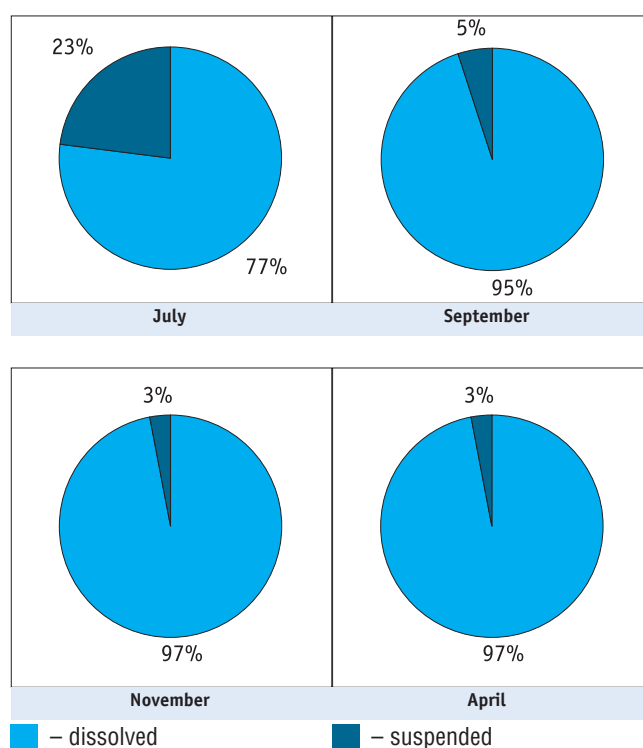


Figure 4.57. Seasonal changes in the ratio of dissolved and suspended fluxes of cadmium in the Yenisey river flow.

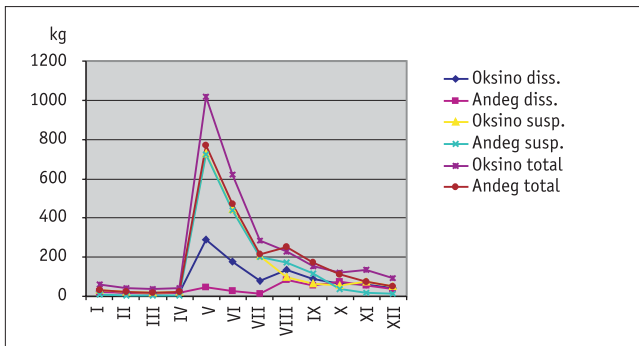
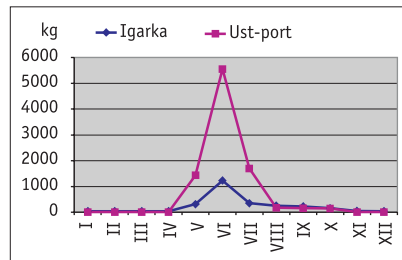


Figure 4.58. Monthly fluxes (kg) of mercury in the Pechora river.

Figure 4.59. Monthly fluxes (kg) of mercury in the Yenisey river.



Andeg. During low water periods, the dissolved proportion of the total mercury flux is larger, amounting to 74% of the total at Andeg during the ice cover season. It should be also noted that during this period, the dissolved flux at these two cross-sections is fairly constant (17-20 kg), while suspended flux is noticeably lower at Andeg than at Oksino (Figure 4.61); this can be explained by sedimentation processes.

The significant difference in the composition of mercury fluxes in the Pechora and Yenisey rivers may be explained by differences in their water composition. Concentrations of total organic matter in the Pechora are almost twice as high as those in the Yenisey, reaching 13-15 mg/L Total Organic Carbon (TOC), 98% of which is in dissolved form (Kimstach *et al.*, 1998). As TOC in natural waters is mostly represented by humic and fulvic acids, which form strong complexes with mercury, the trends in the Pechora mercury fluxes are understandable.

4.3.4. Conclusions

1. In general, PTS fluxes in the Pechora and Yenisey river flows correspond to seasonal river discharges. Highest fluxes usually coincide with spring peak discharges.
2. Among the chlorinated persistent organic pollutants, the highest fluxes are observed for PCBs, HCH and DDTs. The amounts of these contaminants transported by river flows to areas inhabited by indigenous peoples are such that they could contribute to risks to human health.
3. Levels of other chlorinated organic pollutants are either below detection limits, or their fluxes are not sufficiently high to represent a significant risk to the indigenous population.

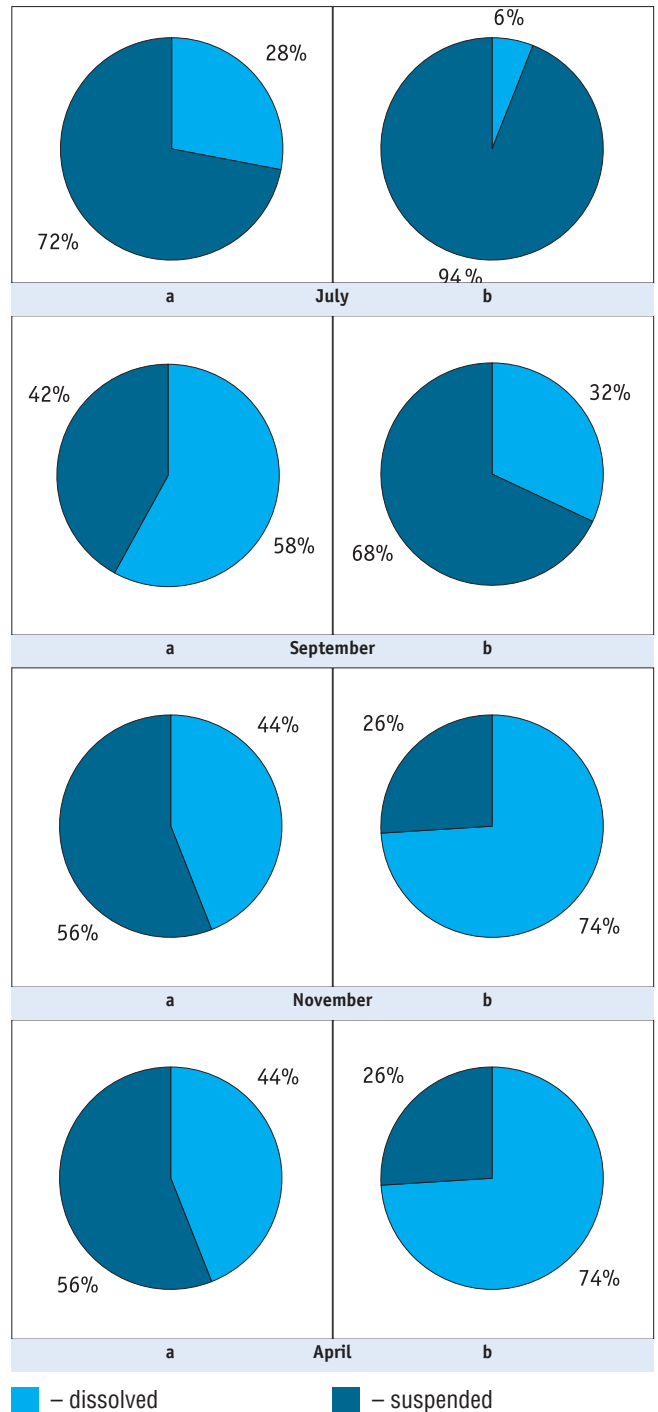


Figure 4.60. Ratio of dissolved and suspended fluxes of mercury at (a) the Oksino and (b) the Andeg cross-sections of the Pechora river

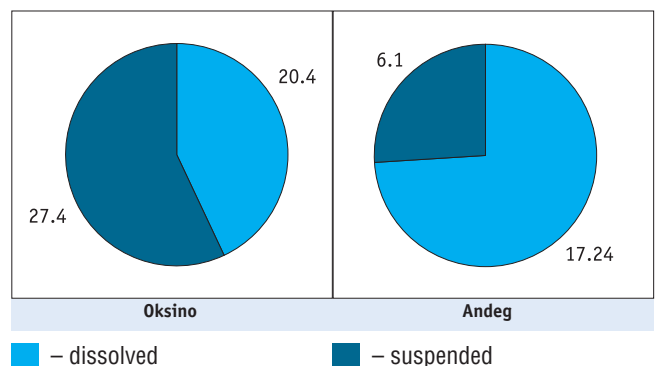


Figure 4.61. Mercury fluxes (kg) at two cross-sections in the Pechora river in April 2002

4. PCB fluxes are mostly in the form of tri- and tetra-chlorobiphenyls. Fluxes of the heavier PCB congeners are practically negligible.
5. HCH and DDT fluxes in the Yenisey river flow are the result of long-range transport. In the Pechora river, local sources may contribute to the fluxes of HCH and DDT in the lower reaches of the river. DDE to DDT ratios indicates that the increased DDT flux in the lower part of the river may be caused by fresh use of this pesticide. However, taking into account possible short-term environmental release of these substances, their annual fluxes can be overestimated.
6. Fluxes of polycyclic aromatic hydrocarbons (PAHs) in both rivers consist mostly of 2- and 3-cyclic compounds. In addition to contamination through long-range transport, the lower reaches of the Pechora river may also be affected by local sources of PAHs, which contribute some heavier compounds.
7. Fluxes of heavy metals (lead, cadmium and mercury) in the flow of the Yenisey river, are the result of local contamination, in addition to contamination from long-range transport, particularly during the spring flood period. This can be explained by the influence of pollution from the Norilsk industrial complex.

4.4. Local pollution sources in the vicinities of indigenous communities

4.4.1. Introduction

The main objectives of undertaking an assessment of local pollution sources were to determine their role in general environmental pollution, in the contamination of traditional food products and, accordingly, to determine their influence on human health. For inventory purposes, 'local sources' were taken to mean sources within an approximate maximum distance of 100 km of sites of residence of indigenous peoples. Specific boundaries for inventory zones, however, were defined more exactly in each case by taking account of local conditions (dominating winds, river flows and the scale of regional sources, etc.). As some of the pilot study areas within the project are affected by pollution which originates from large industrial complexes located in their vicinity, the pollution source inventory included such towns as Apatity, Monchegorsk, Olenegorsk, Revda, and Kirovsk (in Murmansk Oblast); Nar'yan-Mar (in the Nenets AO); Norilsk (located in the Taymir AO, but under the administrative authority of Krasnoyarsk Krai); and Anadyr (in the Chukotka AO).

The assessment was based on official data relating to PTS emissions, obtained from the various administrative territories and regions, representatives of the Russian Association of Indigenous People of the

North (RAIPON), and also from expert estimates of PTS release resulting from use of organic fuel (as this information is not included in official statistical data on PTS emissions). This latter source of atmospheric PTS is important for pollutants such as heavy metals, PAHs, and dioxins. It should be mentioned that in Russia, dioxin emissions have not been recorded and, among PAHs, only benzo[*a*]pyrene emissions are recorded.

Under the study, expert estimates were made for emissions of the following PTS: lead, cadmium, mercury, benzo[*a*]pyrene, benzo[*k*]fluoranthene, indeno[1,2,3-*c,d*]pyrene, and dioxins. These estimates were made using statistical data relating to consumption of the various kinds of fuels and associated emission factors (for the amount of contaminants released to the atmosphere per tonne of a specific fuel). Emission factors were determined either in accordance with existing Russian methodology, or by adapting Western European emissions factors to take account of Russian technologies.

Statistical data were provided by the State statistic offices of the relevant administrative territories of the Russian Federation, environmental protection authorities, and reports by the Russian Federation's State Committee for Statistics (Goskomstat).

Regional Branches (Committees) of the Russian Federation's Ministry of Natural Resources were responsible for the initial collection and processing of data and information. The inventory of pollution sources was based upon the following sources of information:

- State Statistic Reports on emissions of gaseous pollutants discharges of waste waters, and solid waste from industrial, municipal and agricultural enterprises and transport;
- Ecological passports of industrial enterprises;
- Reports on environmental protection activities of the local environmental protection authorities, sanitary-epidemiological control services, agricultural administrative authorities, and other information sources (Murmansk, 1991-2000; Murmansk, 1996-2000; Murmansk, 2001; Murmansk, 1994-2000; Nenets, 1998; Nenets, 1999; Nenets, 2001);
- Annual reports and reviews of Federal Ministries and Departments (MNR, 2001; Roshydromet, 1995-2000);
- Other relevant official sources and literature.

It is necessary to mention, however, that there was variation in the completeness and volume of information provided by the various regions for the inventory, due to different technical, organizational, and other aspects of the relevant local services. Due to this, a certain amount of data are derived from expert estimates.

City/District (Rayon)	Total	SO ₂	NO _x	CO	Dust
Murmansk	26.8	19.6	2.8	2.2	1.7
Apatity	21.9	12.0	3.9	0.2	5.8
Kirovsk	11.5	6.7	2.1	1.1	1.4
Kandalaksha	22.8	5.4	0.6	7.2	8.2
Monchegorsk	58.1	43.9	1.2	3.8	7.8
Olenegorsk	12.4	4.4	1.0	2.6	3.9
Severomorsk	10.2	6.4	0.6	2.3	0.7
Kovdorsky District	7.7	3.8	0.5	1.9	1.4
Kolsky District	5.0	2.3	0.3	1.7	0.7
Lovozerky District	2.0	1.3	0.2	0.3	0.1
Pechengsky District	137.9	124.4	0.6	2.2	10.6
Total emissions in Murmansk Oblast	332.5	240.1	14.7	29.8	43.7
Total emissions in inventory area	105.9	61.6	8.4	8.0	19.0
Percentage of the Oblast's emissions occurring in the inventory area	31.8	25.7	57.1	26.8	43.5

Table 4.18. Industrial air emissions of major contaminants in the cities and districts of the Murmansk Oblast in 2002, thousand tonnes (NEFCO, 2003).

4.4.2. Murmansk Oblast

4.4.2.1. General description

The inventory of PTS sources covered the territory within a radius of at least 100 km of the settlement of Lovozero. It includes the cities of Monchegorsk, Olenegorsk, Apatity, Kirovsk, and Revda.

Murmansk Oblast is one of the largest and most economically developed regions of Russia's European North. Almost the entire territory lies to the North of the Arctic Circle. The population amounts to 958,400 residents, of whom 91.7% are urban and 8.3% percent are rural. The northern indigenous peoples, mostly Saami, amount to 0.2% of the total population.

The economy of Murmansk Oblast is mainly oriented towards the extraction and reprocessing of natural resources. The region produces 100% of Russia's apatite concentrate, 12% of iron-ore concentrate, 14% of refined copper, 43% of nickel, and 14% of fish food-stuffs. Concerning production industries, 90% of the gross regional product is created by primary industrial enterprises.

Estimates of emissions of general air pollutants (SO₂, NO_x, CO, and dust) from industries in the region are presented in Table 4.18. Although these pollutants are not representative of any specific PTS, they do characterize levels of general environmental pollution, and thus are related to pollution impacts on human health. As shown, industrial enterprises located in the vicinity of the study area, which is densely populated by the Saami people, emit a significant part of the total industrial air emissions in Murmansk Oblast, particularly NO_x and dust.

Mining and processing plants provide the basis for the economies of the majority of the regions large towns and cities where a third of the Oblast's population live.

City/District	Enterprise	Total emissions	% in city/district
Apatity	Apatity heat and power plant	18.5	84
	'Apatit' JSC	3.5	16
Kirovsk	'Apatit' JSC	11.5	99.7
Monchegorsk	'Severonickel' NCS	51.8	89.2
Olenegorsk	'Olcon' JSC	10.9	87.9
Lovozerky District	Revda heat and power plant	0.8	40
	'Lovozero GOC' JSC	0.3	15

Table 4.19. Total air emissions of pollutants (thousand tonnes) from major industrial pollution sources in the inventory area in Murmansk Oblast, 2002, and their percentage contribution to emissions from the corresponding cities/districts.

Enterprise	Total discharge	Biodegradable organic substances	Suspended matter	SO ₄ ²⁻	Cl ⁻	Ni	Cu
'Severonickel' NCS	14.7	48.7	364	38780	6800	10.9	2.1
Lovozero GOC	13.6	21.0	200	82	76	-	-
'Apatit' JSC	145.5	288	514	8694	909	-	-

Table 4.20. Wastewater discharges (million m³) from selected large industrial enterprises in 2002, and associated discharges (tonnes) (NEFCO, 2002).

These include the Nickel and Copper Combined Smelter JSC GMK Pechenganikel, in the city of Zapolyarny and the town of Nickel; the Iron Ore Concentration Plant JSC Olkon, in the city of Olenegorsk; the Nickel and Copper Combined Smelter JSC Severonikel, in the city of Monchegorsk; the Mining Plant Apatit JSC, in the cities of Kirovsk and Apatity; the Iron Ore Kovdor Mining and Concentration Plant JSC, and the Concentration Plant Kovdorslyuda JSC, in the city of Kovdor; and the rare metals extraction and concentration plant Sevredmet JSC, in the settlement of Revda. The contributions made by the large enterprises located in the inventory area to total air emissions in the corresponding city/district are presented in Table 4.19.

Surface water bodies located close to settlements and industrial complexes have a high degree of pollution, as determined by their acidification (pH) and levels of fluorine (F), aluminium (Al), iron (Fe), and manganese (Mn), which all exceed maximum permissible concentrations. Data on wastewater discharges from the selected large industrial enterprises in the survey area are presented in Table 4.20.

Monchegorsk area

A zone of 'extremely unfavorable environmental pollution' lies within the area influenced by the cities of Monchegorsk and Olenegorsk. This zone occupies an area of about 1400 km², and has the form of an ellipse with the city of Monchegorsk at its epicenter and its long axis extending 48-50 km to the south (due to the prevailing wind direction). In the north, the zone extends as far as the city of Olenegorsk,

incorporating the urban agglomeration, and in the south, it extends to Viteguba. The Monchegorsk area is characterized by extreme levels of annual deposition of nickel (Ni) and copper (Cu) (115.9 and 136.5 kg/km², respectively). Cadmium levels in the surface geological horizon in this area are five times higher than the background level for the region. These figures confirm the high environmental impact of the Monchegorsk 'Severonickel' combined smelter.

Kirovsk – Apatity

This area is located within the limits of the Khibiny Massif, which is a natural geochemical anomaly with respect to the vast number elements and the unique deposits of apatite and nepheline ores. 'Apatit' JSC, which processes and enriches deposits of apatite and nepheline ores, is considered as the main pollution source for this area. The plant is one of the world's biggest manufacturers of raw phosphate used in the production of mineral fertilizers. 'Apatit' JSC is a huge mining and chemical complex which currently includes four mines, a concentration plant, railway facilities, an automobile workshop, and about thirty other service workshops.

Since opening, the 'Apatit' plant has extracted and transported more than 1.4×10^9 tonnes of ore to the concentration plant, and produced about 520 million tonnes of apatite and more than 52 million tonnes of nepheline concentrates. The concentrates also contain fluorine, strontium oxide, and rare-earth elements, which may be separated as individual products during processing. Nepheline concentrate is used as a raw material for producing alumina, and in the glass and ceramic industries. It is also used as a raw material for producing soda, potash, cement, and other products.

Lovozero – Revda

This area is located in a zone of heavy metal contamination created by the 'Severonickel' combined smelter. The largest local pollution source is the rare metals combined enterprise JSC 'Lovozero GOC' (formerly known as – 'Sevredmet'), located in the settlement of Revda. The enterprise consists of two mines (Karnasurt and Umbozero) and two concentration plants. Tailings and rocks left after drifting and stripping are stockpiled in surface dumps and storage sites. Mining and drainage waters are discharged into surface water bodies.

The river with the highest anthropogenic load is the Sergevan, which receives untreated and poorly-treated mining, filtration, and domestic wastewaters from the Karnasurt mine and concentration plant. Fluorine, sulphates, and nitrates are typical constituents of the mining waters. Environmental and geochemical mapping of the northern part of the Lovozero Massif which was carried out between 1993 and 1996, (Lipov, 1997), depicted areas classed as extremely hazardous (125

km²), hazardous (200 km²), moderately hazardous (240 km²) and acceptable (435 km²) with respect to pollution of soils. The total area of polluted land amounted to 565 km². With increasing distance from the industrial pollution sources and the Lovozero Massif (an ore-rich feature, which itself creates a natural geochemical anomaly), a drastic reduction in the content of all polluting substances in soils, with the exception of sulphur, can be observed. Sulphur content in soils has a patchy occurrence, with localised 'hotspots', usually seen in remote places, far from the sources of gas and dust emissions.

As in the case of soils, the highest pollution levels in mineral bottom sediments of water bodies are observed in the area of the Lovozero Massif and its spurs, where the main mining and concentration plants are located. Similar to soils, the maximum levels of toxic elements (for the same group of main pollutants) found in bottom sediments generally correspond to the level of emissions. Contrary to its distribution in soils, however, maximum concentrations of sulphur are found in the bottom sediments of water courses in urban areas.

4.4.2.2. Inventory of PTS pollution sources

Pesticides

According to data provided by the Murmansk Territorial Station for Plant Protection, chlorinated pesticides that are the main subject of the PTS inventory have not been used, and are not currently used, in Murmansk Oblast. Other types of pesticides used over the last twenty years, according to the information available from this office, are shown in Table 4.21. The quantity of pesticides used on open ground varies from tens to a few hundred kilograms in weight, because the area of agricultural land is limited.

Enterprise	Pesticide	Amount used, kg	Treated area, hectares
Sovkhoz 'Industria', Apatity	Prometrin	3340	668
	Zenkor	70	100
	Fosulene	42	7
	Syrtin	500	100
	Licoprop	500	125
	Likmin	531	161
	Lontrel	90	90
	Bazargan	248	161
	Ramrod	50	5
Sovkhoz 'Monchegorsky', Monchegorsk	Licoprop	724	181
	Likmin	540	180
	Bazargan	370	185
	Ramrod	180	18
	Prometrin	24	9
Sovkhoz 'Tundra', Lovozero	Licoprop	80	20
	Likmin	60	20
Sovkhoz 'Revda', Revda	Licoprop	520	130
	Likmin	270	90
	Bazargan	184	92
POSVIR, Apatity	Prometrin	390	78

Table 4.21. Use of pesticides in 1990-2000 in the Murmansk Oblast inventory area, data from the Murmansk Territorial Station for Plant Protection.

Such agricultural enterprises as ‘Industria’, ‘Revda’, and ‘Monchegorsky’ and “POSVIR”, store pesticides in standard or customized warehouses, which are registered by the sanitary and epidemiological surveillance bodies. The agricultural enterprise ‘Tundra’ has received one-off permissions for delivery and use of plant protection chemicals.

It should be noted that the table contains data on herbicides only, and that no other types of pesticides, particularly insecticides, are included. It is, therefore, likely that the data and information provided by the regional authorities responsible for pesticide use and handling is incomplete.

According to the Regional Veterinary Medicine Administration (pers. comm.: letter no. 38/482 of 08.04.2003), the pesticide ‘Etacyde’ was used in the 1960-1970s on reindeer farms in the Murmansk region to treat the animals against subcutaneous reindeer gadflies. From the early-1980s until the present, the pesticide ‘Ivomex’ has been used. According to the information received, there has been no treatment used against blood-sucking insects.

A tentative (but not comprehensive) inventory of stocks of obsolete pesticides in Murmansk Oblast, has identified a number of stocks in the study area (Table 4.22). It should be noted that this information also lacks data on stocks of chlorinated pesticides, except one enterprise in the city of Murmansk.

Location	Total	Chlorinated	Phosphorus-based	Mercury-based	Other	Poor state
Apatity	714	-	278	-	436	138
Tuloma, Kolsky District	995	-	-	-	995	-
Polyarnye Zori	7584	-	-	-	7584	-
Murmansk	195	13	75	-	107	-
Kirovsk	77	-	74	-	3	-
Murmashi, Apatitsky District	53	-	-	-	53	-
Total in Murmansk Oblast	9623	13	427	-	9183	138
Total in the inventory area	8428	-	352	-	8076	138

Table 4.22. Stocks of obsolete pesticides in the Murmansk Oblast, kg. (in bold letters - the inventory area)

Polychlorinated biphenyls (PCBs)

There is no statistical registration or control of PCB release to the environment. Therefore, for the inventory of possible PCB pollution sources, all enterprises in the cities and villages mentioned above, plus the enterprises of the regional energy company ‘Kolenergo’ JSC were canvassed. According to data provided by these enterprises, the total number of power transformers in the survey area is 1590, including 1458 in operation and 132 in reserve. However, most of them are filled with the following mineral oils: T-1500, Tkp, Tk, T-750, GOST 982-56, GOST 10121-76, TP-22, and OMTI,

which, according to available information, contain no synthetic PCB additives. The PCB-containing transformer fluid ‘Sovtol’ (total amount: 35.92 t) is used only in 13 transformers of the TNZ type at ‘Apatit’ JSC. The inventory did not find any other enterprises within Murmansk Oblast that use PCB-containing fluids in any type of electric equipment.

At the same time, it is notable that of the 180000 t of PCB that was produced in the former USSR/Russia, 53000 t were in the form of the product ‘Sovol’ that was used in the production of varnish and paint (37000 t) and lubricants (10000 t). In addition, ca. 5500 t were used by defence-related industrial enterprises for unknown purposes (AMAP, 2000) and tracing the fate of these PCB-containing products has proved problematic. In view of the fact that Murmansk Oblast is known to have a high concentration of defence-related activities, particularly in previous decades, it might reasonably be assumed that a considerable proportion of these products were used here, and probably contributed to PCB contamination of the area.

Dioxins and Furans

Data on emissions of dioxins and furans from industrial enterprises are not included in the state statistical reporting system, and therefore there is no information on their contribution to pollution of the survey area. Some enterprises, such as the combined nickel smelter ‘Severonikel’ are likely to be sources of dioxins, but there is no information available to confirm this assumption. Overall, there are a number of dioxin sources that are likely to affect the survey area (Table 4.23).

Dioxin sources	Emission factors (TEQ)
Incineration of domestic waste	38.2 ng/kg
Incineration of medical waste	589 ng/kg
Automobile transport:	
- leaded gasoline	45 pg/km
- diesel fuel	172 pg/km
- unleaded gasoline	1.5 pg/kg
Incineration of waste water residues	6.94 ng/kg d.w.
Cremation	17 µg/body
Burning of spent tires	0.282 ng/kg
Domestic burning of wood fuel	2 ng/kg
Cement kilns	
- with incineration of hazardous wastes	1.04 - 28.58 ng/kg cement
- without incineration of hazardous wastes	0.27 ng/kg cement
Coal re-activation	1.2 ng/kg
Smoking	0.43 - 2.9 pg/cigarette
Natural fires	2 ng/kg of biomass
Ferrous metallurgy	0.55 - 4.14 ng/kg agglomerate
Copper recycling	3.6 - 16600 ng/kg scrap
Aluminum recycling	21.1 ng/kg scrap
Open air burning of domestic waste	140 ng/kg
Industrial coal combustion	0.6 ng/kg
Domestic coal heating	6 ng/kg
Accidental fires	~66.5 µg/fire
Steel production	1.26 ng/kg raw materials
Asphalt production	14 ng/t

Table 4.23. Main sources of dioxin formation and emissions (Kluyev *et al.*, 2001).

Polyaromatic hydrocarbons (PAHs)

Of the large group of PAH compounds, only emissions of benzo[*a*]pyrene are documented. No instrumental control measurements of benzo[*a*]pyrene emissions are carried out, however. Emissions have therefore been estimated for heat and power plants using fossil fuels; metallurgical plants ('Severonikel' JSC, 'Olcon' JSC); and mining enterprises ('Apatit' JSC, 'Sevredmet' JSC).

In general, the two major PAH pollution sources are fossil fuel, including raw oil, combustion, and the incomplete incineration of organic materials such as wood, coal and oil. Usually, the heavier the fuel source, the higher the PAH content.

The main anthropogenic sources of PAH are:

- production of acetylene from raw gas;
- pyrolysis of wood, producing charcoal, tar and soot;
- pyrolysis of kerosene, producing benzene, toluene and other organic solvents;
- electrolytic aluminum production with graphite electrodes;
- coke production;
- coal gasification;
- production of synthetic alcohol;
- oil-cracking.

Large amounts of PAH can also be formed as a result of:

- incineration of industrial and domestic wastes;
- forest fires;
- energy production based on the incineration of fossil fuel;
- motor vehicles.

Benzo[*a*]pyrene emission data for the inventory area (Table 4.24), clearly show that information on emissions from industrial enterprises, even based on estimates, is extremely scarce.

Mercury

Intentional use of mercury in industrial production within Murmansk Oblast has not been documented. However, mercury-containing devices, luminescent lamps in particular, are widely used and contribute to environmental contamination, due to the lack of environmentally sound waste handling. Mercury-containing wastes (mostly discarded luminescent lamps), are the main contributors to wastes of the highest hazard class (31.7 t in 2001. There are two enterprises involved in the treatment of spent luminescent lamps:

- 'Rick-market' Ltd (Kolsky Distrikt), a new installation with environmentally sound recovery of mercury wastes;
- 'Ecord' Ltd (Kirovsk), an outdated installation that entered into operation in 1994. According to environmental protection authorities, this plant, although utilizing a proportion of lamps from Murmansk Oblast, actually contributes itself to mercury contamination of the environment. It should be stressed that this enterprise is located within the survey area.

Re-cycling of other equipment and instruments containing mercury, as well as of metallic mercury itself, is not systematically organized. Also, the two plants mentioned above only treat used lamps from industrial enterprises and not from the wider community.

Another significant source of mercury contamination is the mobilisation of mercury impurities within different industrial activities. According to expert estimates, the annual mobilization of mercury impurities within the Russian Federation comprises 83% of the annual intentional use of this metal. However, the amount of mercury released to the air through mobilisation is six times greater than that from intentional use (COWI, 2004).

Nickel and copper production are among the most important sources of mercury mobilisation. As one of the largest producers of primary nickel in the Russian Federation, the 'Severonikel' combined smelter (with annual production of 103000 t of nickel and 132700 t of copper in 2001) is located in Monchegorsk, it must be considered as a significant source of mercury contamination in the area. The average content of mercury in the sulphide copper-and-nickel ore that is used in this smelter is 1 mg/kg (Fedorchuk, 1983). However, this level can vary depending on the origin of the ore, from 0.05-0.11 mg/kg in ore from the Monchegorsk deposit to 2.78 mg/kg in ore from the Nittis-Kumuzhie (Kola peninsula) deposit. It should be noted that, in recent decades, the 'Severonikel' combined smelter has also used ore from different deposits, including those on the Taymir peninsula. Given this, the average content of 1 mg/kg provided above may be considered as a fair estimate. Expert estimates carried out within the ACAP project 'Assessment of Mercury Releases from the Russian Federation' concluded that mercury emissions from the 'Severonikel' combined smelter were 0.18-0.22 t in 2001. In addition, a further 0.075-0.111 t was accumulated in captured dust (COWI, 2004).

Table 4.24.
Trends in emissions
of benzo[*a*]pyrene to the
atmosphere in the Murmansk
Oblast inventory area.

City/district	Emission, kg									
	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Kirovsk	29	27	na	na	na	na	9	na	na	na
Monchegorsk	na	na	na	na	na	na	14	22	19	27
Olenegorsk	6	9	na	na	na	na	na	7	6	4
Revda	na	na	na	na	na	na	na	3	na	10
Apatity	300	na	na	1	na	na	na	na	na	na
Lovozero District	na	na	na	na	na	na	na	5	1	3

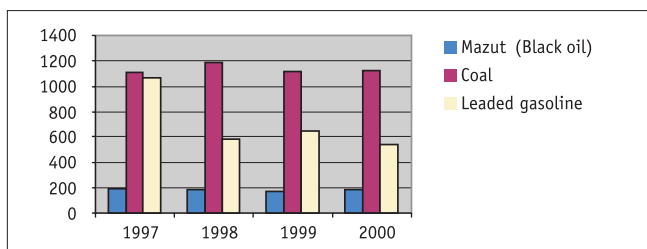


Figure 4.62. Trends in lead emissions from the combustion of fossil fuels in the Lovozero area, kg.

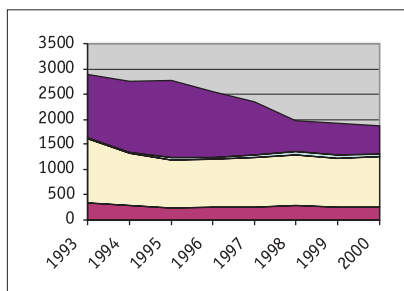


Figure 4.63. Contribution of different branches of economic activity to total lead emissions through the use of fossil fuels in the Lovozero area, kg.

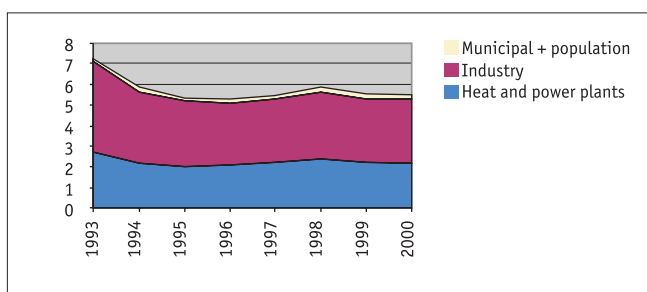


Figure 4.64. Contribution of different branches of the economy to total mercury emissions through fossil fuel combustion in the Lovozero area, kg.

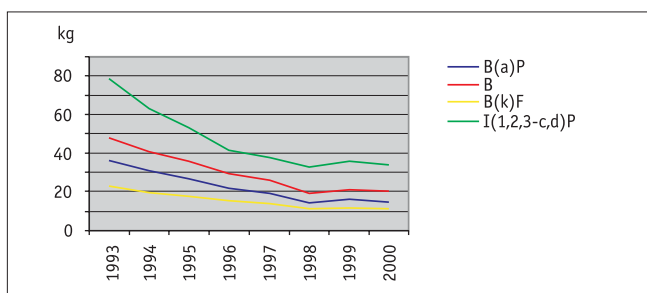


Figure 4.65. Mobilization of PAH compounds (benzo[a]pyrene, benzo[b]fluoranthene, benzo[k]fluoranthene, and indeno[1,2,3-c,d]pyrene) through the combustion of organic fuel in the Lovozero area.

4.4.2.3. PTS mobilization from combustion of fossil fuels

Official statistical data exists on the consumption of fossil fuels in Murmansk Oblast as a whole, but there are no data on organic fuel consumption in the survey area itself. According to statistics, about 23% of the total population of the Murmansk Oblast live in the survey area, and in order to estimate emissions from fossil fuel consumption it was therefore decided to assume that use of fuel is proportional to the share of the population. For calculation of dioxin and lead emissions from gasoline combustion, it was assumed that consumption of leaded gasoline in the survey area comprised about 20% of total gasoline consumption within the Oblast.

Lead

Coal combustion is considered a major contributor to lead emissions, along with the combustion of other fossil fuels. (Figure 4.62). In the middle of the 1990s, contributions from coal and gasoline combustion were comparable. However, in the late-1990s, due to the reduction in the use of leaded gasoline, coal became the dominant source of lead emissions. Total emissions from the combustion of fossil fuels in the area have decreased in recent years, mainly due to the reduction in emissions from motor vehicles (Figure 4.63).

Mercury

Mercury mobilization due to the use of fossil fuels is mostly determined by fuel combustion in industrial sectors and energy plants (heat and power plants, HPP). Fuel consumption by municipal services and the general population comprises only a minor part of total emissions (Figure 4.64). It should be noted that mercury emissions from this source have not changed significantly during recent years.

The role played by fossil fuel combustion in total mercury contamination arising from local sources, is significantly less than that due to mercury mobilization through nickel and copper production at the 'Severonickel' combined smelter (not more than 3%). However, given that domestic use of organic fuel, particularly coal, often contributes to the contamination of the indoor environment, its significance in terms of human intake may be much greater.

Polyaromatic hydrocarbons (PAHs)

Estimates of PAH mobilization through the use of organic fuel in the Lovozero area were made using methods similar to those for heavy metals (Figure 4.65).

PAH releases have gradually decreased since the early-1990s, possibly due to changes in the fuel types used. However, after 1998, the amount of PAH released stabilized, possibly due to the recovery of economy after the 1997 crisis.

Dioxins

The trend in dioxin emissions with organic fuel combustion in the Lovozero area is presented in Figure 4.66, which shows a decline during the early-1990s, but little change in emission levels since the mid-1990s.

Industrial enterprises are the main source of dioxin pollution from organic fuel in the Lovozero area according to Figure 4.67. However, it should be noted

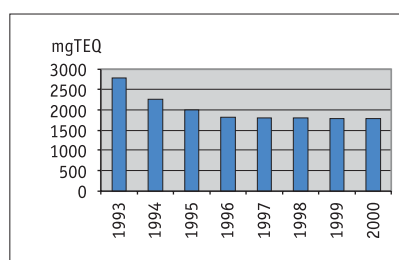


Figure 4.66. Dioxin emission trend in the Lovozero area from organic fuel combustion.

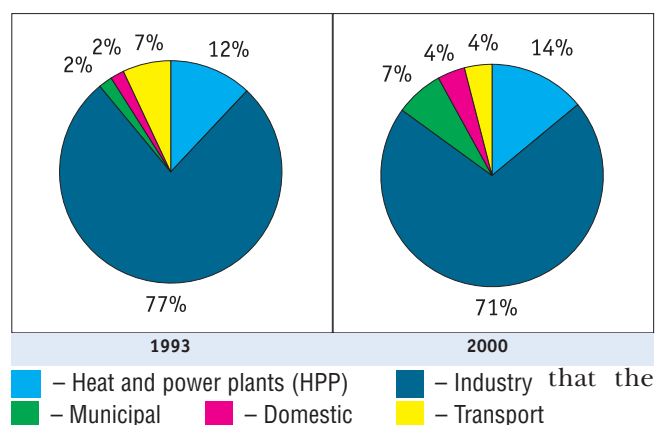


Figure 4.67. Contribution of different types of activities in the Lovozero area to dioxin emissions through the combustion of organic fuel.

contribution from the municipal sector, particularly from local boilers used for non-centralized heating, has significantly increased in recent years. Although still much less than emissions from industrial enterprises, the three-fold growth in dioxin emissions from municipal sources within seven years (from 42.23 mg TEQ in 1993 to 122 mg TEQ in 2000) is a matter of concern.

4.4.3. Nenets Autonomous Okrug (NAO)

4.4.3.1. General description

The main focus of the PTS source inventory within the NAO is data acquired from the city of Nar'yan-Mar, which is the most significant pollution source in the vicinity of the indigenous settlement of Nelmin-Nos.

Construction of various industrial facilities, and roads, as well as extraction and transportation of minerals (primarily oil and gas), have had a considerable impact on the environment in the NAO. A total of eighty-one deposits of petroleum hydrocarbons have been found in the territory of the NAO, of which seventy-eight are on land and three on the Barents Sea shelf. Among the terrestrial deposits, sixty-six are of oil; six of oil and gas

condensate; four of gas condensate; one of gas; and one of gas and oil. The city of Nar'yan-Mar and the settlement of Harjaga could both be considered as regional pollution sources.

Growth of activities associated with the development of oil and gas deposits has been followed by an increase in anthropogenic pollution impacts on the environment, including:

- air pollution due to emissions of hazardous substances (including that from associated gas flaring);
- pollution of surface and ground waters through discharges of polluting substances;
- extraction, together with oil, of associated highly mineralized production water;
- changes in the landscape (excavations, extraction of materials for construction of the oil and gas production infrastructure, building, cargo transportation, construction of roads, etc.), deforestation, soil pollution by petroleum products, etc.;
- landfill disposal of drilling waste;
- oil spill emergencies.

In 2002, air emissions from stationary and mobile pollution sources amounted to 35.1 kt (in 2001 the total amount of emissions was 36.6 kt), including 1.47 kt of dust and 36.6 kt of gaseous and liquid pollutants. Gas emissions associated with oil extraction are very high, and methods of utilising the gas have not yet been developed in NAO.

In 2002, 24.5 kt of pollutants were emitted to the atmosphere by stationary pollution sources. The basic components of these air emissions were: ashes (720 t); soot (720 t); SO₂ (3750 t); CO (12200 t); NO₂ (4600 t) and hydrocarbons (2400 t). Although these pollutants cannot be considered as PTS, their emissions are a measure of total environmental stress in the region. The major polluters of the atmosphere are the energy producing companies: 'Total RRR', JSC 'Varandeygaz';

Table 4.25.
Industrial emissions from major enterprises in the NAO in 2002, tonnes.

Enterprise	Total	Dust	SO ₂	CO	NO ₂	Hydrocarbons	Specific contaminants
'Total RRR' (Survey, exploitation, development)	4472.7	0.0	2126.8	1154.8	533.6	158.5	H ₂ S 1.1; methane 2.7
JSC 'Varandeygaz'	2597.7	210.5	50.2	1735.2	183.2	218.7	Acrolein 2.1
JSC 'Arcticneft'	2576.2	101.2	66.6	1718.1	246.3	203.2	Acrolein 2.4; vapours of benzene 33.9; V ₂ O ₅ 1.2; methane 23.2
Company 'Polyarnoye Siyanie' Ltd	1868.0	8.3	10.7	1350.3	304.0	193.7	Acrolein 1.1.
JSC 'Pechoraneft'	1686.2	170.1	5.0	14.8	55.8	1440.0	Acrolein 0.6
'Lukoil-Komi' Ltd	1528.2	59.7	0.0	715.6	332.7	311.1	Xylol 1.3; toluene 1.1; acetone 0.16; butanol 0.23; methane 104.7
Municipal service of the Nenets district	1210.8	324.5	297.6	160.3	379.7	48.7	
State industrial combine 'AMNGRE'	1018.4	7.6	18.2	7743.9	203.5	26.3	Acrolein 2.3; methane 16.5
JSC 'Severgeoldobycha'	957.0	33.2	73.4	178.2	586.0	78.3	Acrolein 7.7
Nar'yan-Mar heat and power plant	617.6	10.0	20.1	315.8	244.4	24.7	Acrolein 2.4; methane 0.3

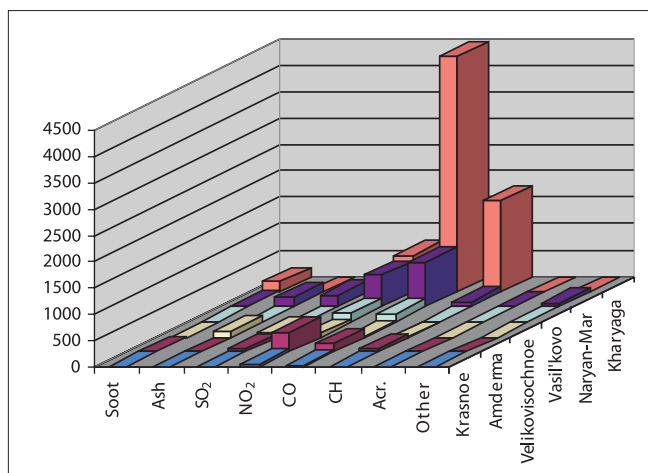


Figure 4.68. Air emissions in major NAO settlements in 1999, tonnes.

JSC 'Arcticneft'; 'Kompaniya Polyarnoye Siyanie' Ltd; JSC 'Pechoranefit'; and 'Lukoil-Komi' Ltd. (Table 4.25). Air emissions from the largest NAO settlements are shown in Figure 4.68.

Official statistics do not document any significant pollution sources in the lower part of the Pechora basin, although wastewater discharges have increased 1.7-fold since 1998, mostly due to water use in oil and gas production and by municipal services.

Nar'yan-Mar port is one of pollution sources and is located on the right bank of a narrow channel, the Gorodetsky Shar, which joins the Great Pechora river 1.5 km upstream of its mouth and 110 km from the Bolvansky cape. The port has no storage tanks and, therefore, wastewater is discharged directly into the Pechora river without treatment.

Levels of pollutants in the Pechora delta tend to be elevated. Contamination is connected, not only with the local activities, but also, to a large extent, with pollution due to wastewater discharges from enterprises located in the Pechora basin involved in gas and oil production (i.e., polluting substances transported with the Pechora flow). However, based on the data and information obtained from project activities concerned with the assessment of riverine pollution fluxes, it may be possible that there are also considerable sources of PTS located between the settlements of Oksino and Andeg (an area which includes Nar'yan-Mar and its suburbs) which contribute to PTS fluxes in the river flow.

The current system of handling solid household wastes in Nar'yan-Mar consists of the collection of waste in containers, cesspools, and auto-dumpers, followed by their transportation to landfill using specialized and other motor transport. In addition, household wastewater is also transported to landfills, since most existing housing is not connected to sewer systems, and the capacity of older treatment facilities is insufficient. However, due to the recently commissioned new treat-

ment facilities, and work to increase the capacity of older sites, the volume of household wastewater entering landfills is decreasing every year. In other NAO settlements, solid and liquid household waste is removed not only to authorized sites, but also, to a large extent, to illegal landfills.

The system of solid household waste collection does not allow the separation of hazardous wastes (e.g., those containing mercury batteries, plastics, etc.) and dumping of such wastes at landfill sites results in environmental contamination by dangerous toxic substances, including dioxins, especially if fires occur. Communal solid waste, together with hazardous waste in landfills is also subjected to the effect of precipitation which washes pollutants down into the soil profile, and subsequently leads to their transport with ground waters. The situation is aggravated by a lack of landfill sites equipped with environmental facilities, and the low capacity of waste treatment facilities in Nar'yan-Mar and other NAO settlements. Existing landfills do not meet environmental or sanitary requirements as:

- they lack sanitary protection zones,
- they lack rainwater filtrate removal and treatment systems;
- they lack waterproof screens.

The most hazardous and widespread waste products are luminescent lamps containing mercury (2.49 t in 2000), obsolete accumulators (4.1 t), used motor oil (119.3 t), drilling sludge (7908 t) and oil-slime (329.2 t).

There are no facilities specifically designed for the processing or incineration of solid communal waste in NAO, and only a small amount of solid communal waste is incinerated at industrial sites, generally those involved in oil and gas development activities.

Processing of medical waste, rubber waste products, and ash-and-slag wastes from boiler-houses, has also not been developed in NAO. The medical institutions of the city of Nar'yan-Mar generated 16.8 t of waste products that were transported to the municipal landfill site in 2001.

4.4.3.2. Inventory of PTS pollution sources

Pesticides

According to information obtained from the Department of Agriculture and Foodstuffs of the NAO Administration, no chlorinated pesticides, insecticides, disinfectants, etc., have been used in the last ten years in the Pechora river flood-plain by any agro-industrial enterprises or related organizations. Hexachlorobenzene (HCB) has not been used as a disinfectant.

Industrial chemical compounds

According to information received, no enterprises exist in Nar'yan-Mar or in territories adjoining the settlement of Nelmin-Nos that could represent a potential

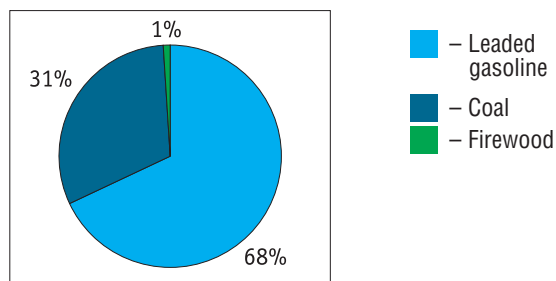


Figure 4.69. Lead emissions from organic fuel combustion in the Nelmin-Nos area.

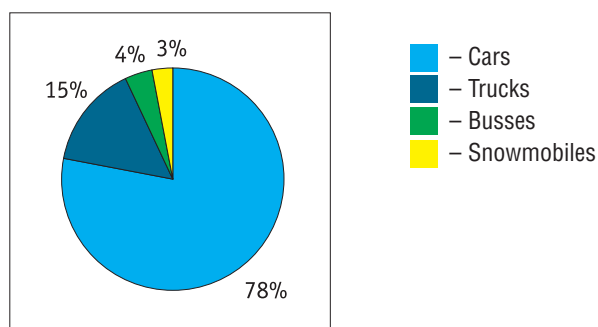
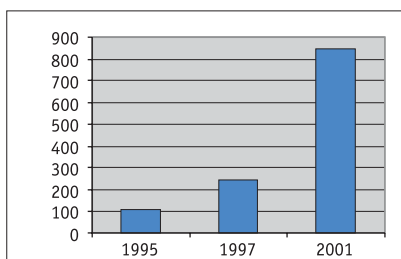


Figure 4.70. Lead emissions resulting from different means of transportation in the Nelmin-Nos area.

Figure 4.71.

Lead emissions from the combustion of leaded gasoline in the Nelmin-Nos area, kg.



source of polychlorinated biphenyls (PCBs), originating from equipment containing PCBs, or brominated flame retardants.

4.4.3.3. PTS mobilization from combustion of fossil fuels

Official statistical data on fossil fuel consumption in the NAO was used to calculate PTS emissions. The fuel amount consumed in the NAO within the Nelmin-Nos area was estimated based on the assumption that the population of this area (including Naryan-Mar, the settlement of Krasny, and Nelmin-Nos itself), comprises 65% of the total NAO population. Account was also taken of the fact that most of the population in the area (27000 out of 29300) live in Nar'yan-Mar.

Lead

In the Nelmin-Nos area, lead emissions from organic fuel combustion arise mainly from leaded gasoline (Figure 4.69) used by vehicles with internal combustion engines (Figure 4.70). However, the total annual emissions of lead from fossil fuel combustion are very low.

It should be noted that, due to a significant growth in the number of motor vehicles in the area in recent years, an increase in lead emissions has been documented, despite the introduction of unleaded gasoline (Figure 4.71).

Mercury

Mercury mobilization from the combustion of fossil fuels in the Nelmin-Nos area is rather small. For example, in 1997 it did not exceed 1 kg. Such low levels of mobilization can be explained by the widespread use of natural gas by major consumers, in particular the Nar'yan-Mar heat and power plant and municipal boilers.

Polyaromatic hydrocarbons (PAHs)

Data on PAH emissions from the combustion of various kinds of hydrocarbon fuels in the Nelmin-Nos area, including Nar'yan-Mar, are presented in Figure 4.72. A major contribution to total PAH emissions is made by the gasoline-fueled motor vehicles. It is notable that the role of gasoline in total PAH emissions has increased drastically in recent years, due to a significant growth in the number of cars in the area, particularly in Nar'yan-Mar. Before that, diesel fuel had played a dominant role (Figure 4.73).

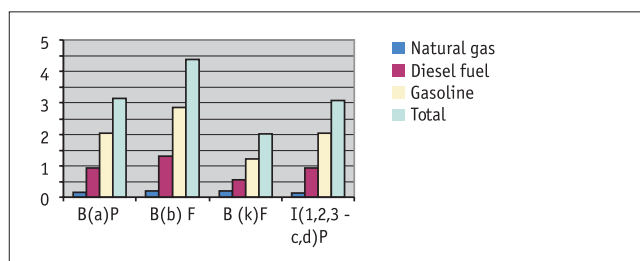


Figure 4.72. PAH (benzo[a]pyrene, benzo[b]fluoranthene, benzo[k]fluoranthene, and indeno[1,2,3-c,d]pyrene) emissions from the combustion of hydrocarbon fuel types in the Nelmin-Nos area in 2001, kg.

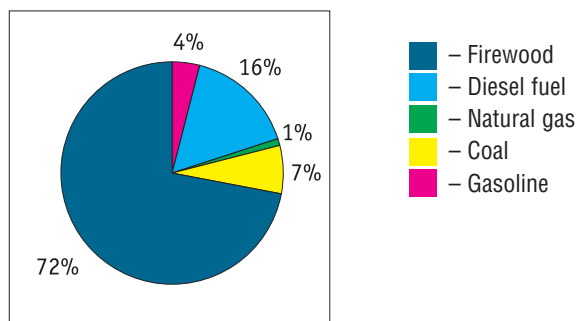


Figure 4.73. Contribution of different types of organic fuel to benzo[a]pyrene emissions in the NAO in 1995.

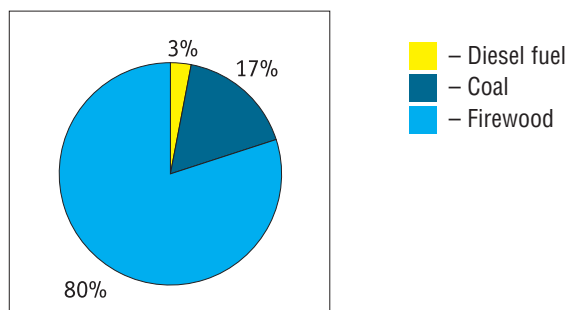


Figure 4.74. Contributions to total dioxin emissions from combustion of major organic fuel types in the NAO in 1997.

The contribution of coal to PAH emissions in this area is much lower than in other project pilot study areas, since petroleum hydrocarbon fuel types dominate in

this oil and gas producing region. However, the largest contribution to PAHs comes from firewood. As firewood is mainly used for domestic heating, this fact is of particular concern in relation to possible impacts on human health.

Dioxins

According to expert estimates, total dioxin emissions in the inventory area in 1997 were 687.15 mg TEQ. Contributions of different types of organic fuel to total dioxin emissions are shown in Figure 4.74. Fuels such as natural gas, gasoline, and kerosine contribute considerably less than 1% of total emissions.

Attention should be paid to the fact that a major contribution to total dioxin emissions arises from the use of firewood for heating and other domestic needs. As these emissions arise from the burning of organic fuels in the home, and particularly from open fires commonly used by indigenous peoples in their traditional dwellings, this fact is a matter of particular concern in the context of possible exposures to humans and related health implications.

4.4.4. Taimyr Autonomous Okrug (TAO)

4.4.4.1. General description

In the TAO, the inventory of local sources covered the vast territory around the city of Norilsk, which forms the main basis for the economy of the entire TAO. Norilsk has a dominating influence on the environment of adjacent territories, including the areas of the settlements Dudinka and Khatanga, which are the centers of residence for the indigenous population.

The TAO population, including the Norilsk Industrial Area (NIA), is 288600 (based on 1996 data). The population of the NIA itself is 44100. The population of the town of Khatanga is about 5000, and that of the town of Dudinka and settlement Dikson more than 31300. Most of the urban population resides in the city of Norilsk, however, this city is formally outside of the TAO jurisdiction, and administered as a subsidiary of the Krasnoyarsk Krai.

Annual industrial air emissions from enterprises located in the TAO territory amount to more than 2 million tonnes of pollutants. Thirty-nine different pollutants are monitored in these emissions. The bulk of the emissions comprise sulphur dioxide, followed by sulphuric acid, inorganic dust, carbon monoxide, and nitrogen dioxide. Emissions from stationary sources are dominant and amount to about 99% of total industrial emissions in the region. This equates to two-thirds of emissions in the Krasnoyarsk Krai, and 14% of all industrial emissions in the Russian Federation. 2309 stationary industrial emission sources have been registered in the TAO territory, of which only 318 are equipped with gas treatment facilities to reduce emissions.

The Norilsk Industrial Area, the largest copper and nickel producer in the Arctic and the Russian Federation, is located about 60 km from Dudinka, to the east of the river Yenisey, covering an area of about 60 thousand km² in the northwestern part of mid-Siberian plateau between longitudes 86–92°E, and latitudes 68–70°N. It is acknowledged as the largest single source of environmental pollutants, not only in the region, but in the whole circumpolar Arctic.

4.4.4.2. Geographical areas of concern

Norilsk Industrial Area (NIA)

The former Norilsk Mining and Metallurgical Combined Plant, now called 'Norilsky Nickel' JSC, is the main polluter in the territory.

In the 1980s, it began operating a number of plants producing elemental sulphur, which through recovery of sulphur (at a maximum recovery of 20%) substantially decreased SO₂ emissions and significantly improved the environment of the region. However, SO₂ is still the main contaminant emitted in the NIA, accounting for 96.7% of total emissions. In addition to SO₂, 'Norilsky Nickel' JSC emits a wide range of contaminants, among which are heavy metals, including those addressed in the project.

Automobiles are acknowledged as an important source of some PTS emissions. In this respect, the NIA is singular because it does not have any extensive railway network for passenger or cargo transport. To compensate for this drawback use of road vehicles is widespread, with associated negative impacts on air quality in residential areas. In winter, when temperature inversions are common, pollution of the lowermost atmospheric layer from vehicle exhausts often exceeds pollution from stationary emission sources.

High levels of sulphur dioxide in air are recorded in the city on about 350 days a year, including 120 to 150 days with levels from 5 to 10 times the Maximum Acceptable Concentration (MAC), and 40 to 60 days with a level exceeding 10 times the MAC.

The total duration of air pollution amounts to around 50% of the year, 80% of this time with a level of under 5 MAC, 15 to 17% of the time with a level from 5 to 10 MAC, and 2 to 4% of the time with levels of 10 MAC or more. Due to the prevailing wind directions, the main pollution sources for the city's atmosphere are the copper plant, the nickel plant, and the sinter plant. In spite of protection measures in place, the atmospheric air pollution level in the city is gradually increasing (Table 4.26).

About 20 million tonnes of solid waste are produced annually in the NIA (23.4 million tonnes in 2000). Over the entire period of industrial activities in the area, more than 400 million tonnes of mining and industrial

Table 4.26.

Average concentrations of air pollutants in the city of Norilsk (mg/m³), and their trend (mean annual change based on linear regression) over the period 1996-2000; and total emissions (thousand tonnes) from the combined smelter, 'Norilsky Nickel' JSC during the same period.

Pollutants	1996	1997	1998	1999	2000	Trend
SO ₂	0.22	0.17	0.13	0.21	0.21	0.002
NO _x	0.03	0.02	0.04	0.05	0.05	0.007
NO	0.04	0.03	0.06	0.07	0.08	0.012
Phenol	0.002	0.003	0.002	0.004	0.006	0.001
Formaldehyde	0.022	0.017	0.006	0.011	0.040	0.003
Cl ₂	0.01	0.03	0.00	0.00	0.00	-0.005
Total emissions from 'Norilsky Nickel' JSC	2155	2185	2139	2171	2145	

wastes have been accumulated, whilst no more than 5% of the existing waste have been recycled. The waste composition is 99% mining and industrial waste (of which 94% are bearing strata and overburden), and 1% waste from domestic consumption.

About 2400 hectares are occupied by rock dumps. In addition, 1500 hectares have been damaged by strip-ping. Tailing dumps occupy a further 1500 hectares. About 10 million tonnes of toxic waste containing more than 50 different components, and more than a million tonnes of slag are stockpiled in the territory each year. Almost no waste-storage sites conform fully to current legal and regulatory requirements.

The NIA drainage system falls mainly within the basin of lake Piasino. The bulk of 'Norilsky Nickel' JSC's wastewater is discharged into this hydrological system. The biggest water course in the region is the river Norilskaya, which connects the lakes Melkoye and Piasino. Secondary rivers, namely the Shchuchya, Kupets, Yergalakh, Ambarnaya, Daldykan, and others, are tributaries of the Norilskaya or flow directly into the lake Piasino, which is the biggest lake in the region (Figure 4.75).

Dudinka area

The town of Dudinka is located on the right bank of the river Yenisey at its confluence with the Dudinka river, 433 km upstream from the mouth of the Yenisey.

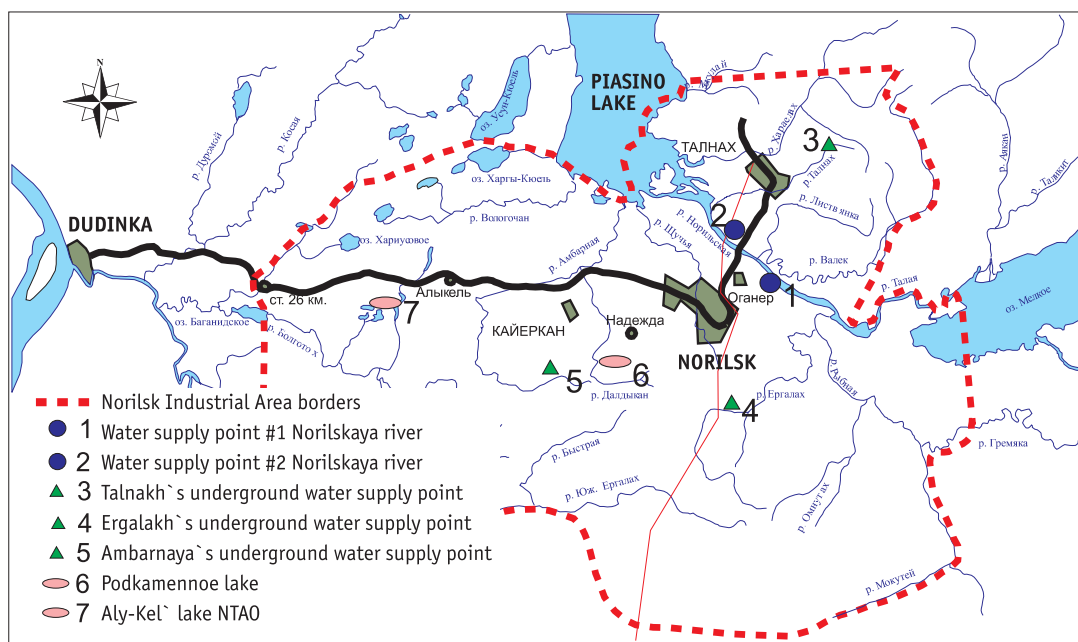
Dudinka port works practically all year round and specializes in the offloading of imported cargo (petroleum products, food stuffs, and construction materials for the Norilsk plant and for the town of Dudinka), and the export of copper-nickel concentrate for the various mining and smelting companies and enterprises. The port is equipped with its own transport infrastructure, a large oil depot, and the facilities necessary for handling of contaminated bilge waters and household wastewater. In total, the port (based on data for the early-1990s) receives about 7600 t of waste products from vessels, including about 300 t of oil-containing waste.

Pollution of water around the port occurs a result of wastewater discharges from both the port, and from entities located nearby. More than two million m³ of wastewater is discharged to the waters around the port each year. A proportion of bilge and domestic wastewater from shipping is released directly into the waters of the port. Some of the polluting heavy metals (copper, nickel, cobalt, etc.) enter the water as a result of the wash-out from bulk copper-nickel concentrates.

Air operations are located in the Dudinsky area, and construction and geological prospecting organizations also operate from the city. The town infrastructure is maintained by the bodies responsible for municipal housing and communal services. These, the road department, trade organizations, and a smoke-house

Figure 4.75.

The drainage network of the Norilsk Industrial Area.



are not formally considered as PTS sources under the inventory of local sources, but as a whole exert a very insignificant influence on the environmental state of the adjoining territories, when compared to the neighboring Norilsk smelter.

Khatanga area

The Khatanga settlement is located on the left bank of the river Khatanga, 110 km from its mouth. The population of the settlement numbers 5000. There are relatively few large enterprises based in the settlement. Those present include an aviation enterprise connected with the local airport, a sea cargo port, a fish-processing factory, housing and municipal services, three oil depots, a base for polar expeditions, and a number of state agricultural producers and co-operative enterprises, etc.

The settlement municipal services share a water supply and sewage network with the industrial enterprises, and water is taken from the river Khatanga upstream of the settlement. Wastewater enters a main settlement collector, and after mechanical treatment, is discharged back into the river Khatanga 1.5 km downstream of the settlement. Water consumption by the settlement and industrial enterprises has reduced over the last few years. According to figures from the Sea Inspectorate of the Krasnoyarsk Krai, wastewater discharge into the river Khatanga from the settlement collector in 1994 was about 1 million m³. There are no data available, however, on the chemical composition of wastewaters.

Khatanga port, which is located at the left bank of the river Khatanga 112 km upstream from its mouth, operates for three to three-and-a-half months during the summer navigation period. There are 5 berths in the port adapted to serve sea vessels up to 5000 tonnes. Handling operations are carried out along the port road, and also along the road in Kozhevnikova bay. The port has no oil depot of its own, however, there are three depots near the harbour area, belonging to other departments.

The port itself consumes up to 400000 m³ of water, including 140000 m³ for industrial needs, and 260000 m³ for economic and household needs. Wastewater is discharged into the main settlement collector. The total discharge of untreated waters is 6-

8 million m³ per year. The port has the technical capability to collect wastewater from sea-going vessels. After fuel and oil separation, remaining oil and slag are incinerated in boiler-houses and operational waste is transferred to landfill.

The main air pollution sources in the settlement are the eleven departmental boiler-houses utilizing local coal, and the airport facilities, which use diesel fuel. In total, heating the settlement of Khatanga requires about 45–50000 t of coal per year. About 3000 t of suspended substances, more than 500 t of sulphur dioxide, more than 750 t of carbon monoxide and approximately 180 t of nitrogen oxides are emitted into the atmosphere. About 85% of emissions deposit directly onto the area occupied by the settlement, over a radius of 3–3.5 km.

4.4.4.3. Inventory results

Pesticides

According to the TAO Veterinary Medicine Administration (pers. comm., letter no. 144 of 10.04.2003), the district veterinary service regularly used the insecticide dichlorodivinyolphosphate (DDVP) against mosquitoes and gadflies in the summer, during the period 1980 to 1991. In total, up to 1270 litres of the insecticide were used on farms in Khatanga, Ust-Yenisey and Dudinka Districts. Currently, no pesticides are used in the TAO for agricultural purposes.

Polychlorinated biphenyls (PCBs)

The PCB inventory carried out in 1999 in the NIA revealed the presence of electric equipment, namely, transformers and capacitors, filled with the dielectric fluids, Sovtol-10, Askarel, and Pyralene. The quantity of these synthetic PCB-containing fluids amounts to 451.5, 145.0, and 10.38 t, respectively (Table 4.27). These figures have not changed since 1999.

Most pieces of equipment containing the above fluids are operative. Among 226 transformers, 222 are in service, three have been decommissioned, and one is held in reserve. Among 643 capacitors, 368 are in service, 246 have been decommissioned, and 29 are held as a reserve stock. Decommissioned equipment contains 5.64 t of Askarel and 0.89 t of

Enterprise	Transformers, pcs.				Capacitors, pcs.				Synthetic PCB-containing transformer oil, tonnes					
	Including				Including				Total	Brandname	PCB content, %	Including		
	Total	In operation	In reserve	Decommissioned	Total	In operation	In reserve	Decommissioned				In operation	In reserve	Decommissioned
'Norilsky Nickel' JSC	226	222	1	3	643	368	29	246	451	Sovtol-10	90%	448.32	3.14	-
									145	Askarel	N/A	139.36	-	5.64
									10	Pyralene	N/A	9.49	-	0.89

Table 4.27.
Inventory of PCB-containing electric equipment located at 'Norilsky Nickel' JSC (data for 1999).

Table 4.28.
Nomenclature and characteristics of PCB-containing waste at 'Norilsky Nickel' JSC (data for 1999). Wastes were generated for 1996-1999 as a result of the decommissioning of 3 transformers and 246 capacitors.

#	Waste type	Amount of waste, t/year	PCB amount, t/year		Kind of waste handling (warehousing, landfill disposal, reprocessing, transfer to the third-part organizations)	Notes
			Content in waste, %	Total, t/year		
1	Askarel	5.64	100%	5.64	Warehousing (two imported transformers)	At the plant site
2	Pyralene	0.89	100%	0.89	Warehousing (1 imported transformer)	At the plant site
3	Sovtol-10	N/A			Warehousing (246 capacitors)	Indoors and at the plant site

Pyralene (Table 4.28), and is still located at the plant sites. There have been no documented discharges or incidents of site pollution from transformer oils.

The inventory of PCB discharges has shown that, during the operation and maintenance of transformers, about 10 litres of PCB per annum on average are spilled from each transformer (AMAP, 2000). According to these estimates, transformers used by the Norilsk Mining Plant discharge 3.33 t of PCB per annum. Over the whole operating period (the service life of transformers is assumed to be 25 years), 83.25 t of PCB will have been discharged to the environment.

Dioxins and furans

Within the TAO, unintentional formation of dioxins and furans is related to industrial production and may occur during thermal processes carried out at the metallurgical plants of 'Norilsky Nickel' JSC, which reprocess sulphurous ores in the production of non-ferrous metals. It is very likely that, regardless of the lack of studies to date on the presence of dioxins and furans in environmental emissions from its production lines, the plant may be a source of pollution in connection with these substances.

Other possible sources of these contaminants may include:

- incineration of fossil fuels in the boilers of public utilities in the studied localities;
- vehicles, mainly those running on leaded gasoline;
- sources related to fossil fuel burning for household heating;
- open uncontrolled burning of solid household waste at dumps.

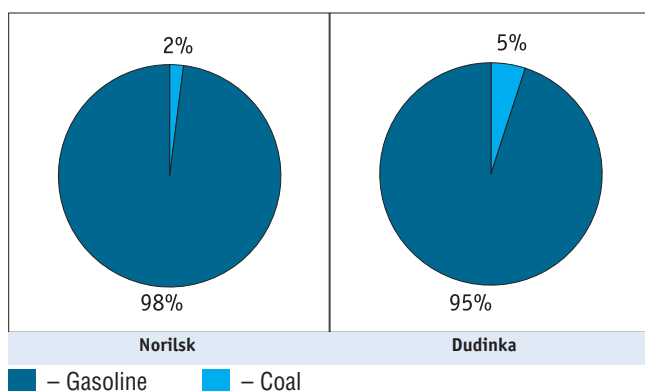


Figure 4.76. Lead mobilization through the combustion of coal and gasoline in the TAO in 1997.

The presence of Cl_2 in the air of Norilsk in previous years (see Table 4.26) could be an indicator of possible dioxin formation in the area, as there is no pulp and paper industry in the TAO territory and no community solid waste incineration plants or production of chlorinated organic products.

Mercury

As stated above, non-ferrous metal production is a significant source in the mobilization of mercury. In 2001, the NIA produced 120000 t of primary nickel and 357000 t of primary copper. According to expert estimates, production of these amounts of non-ferrous metals would be accompanied by the mobilization of 1.7–2.02 t of mercury, emitted to the atmosphere. In addition, 0.65–0.99 t of mercury would have accumulated in captured dust (COWI, 2004).

Lead

According to official statistics, annual emissions of lead in the inventory area vary from 26.5 to 32.8 t.

4.4.4.4. PTS mobilization from combustion of fossil fuels

As in the other pilot areas, estimates of PTS emissions were based on the consumption of different types of organic fuel. It is important to note, that the inventory areas of the TAO, and the NIA in particular, are characterized by high levels of coal consumption, and this essentially determines PTS mobilization associated with fossil fuel combustion.

Lead

Due to high coal consumption, and a decrease in the use of leaded gasoline, lead mobilization from coal dominates, particularly in the NIA (Figure 4.76). It should be noted that the annual amount of lead mobilized through coal combustion in the NIA is higher than lead emissions by the 'Norilsky Nickel' JSC in the production of non-ferrous metals due to lead mobilization from the ores (Figure 4.77). Total lead mobilization through coal combustion in Dudinka and Khatanga comprises about 0.5% of that in the NIA.

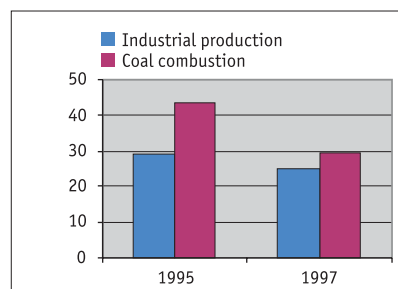


Figure 4.77.
Lead emissions in the NIA from industrial production and coal combustion.

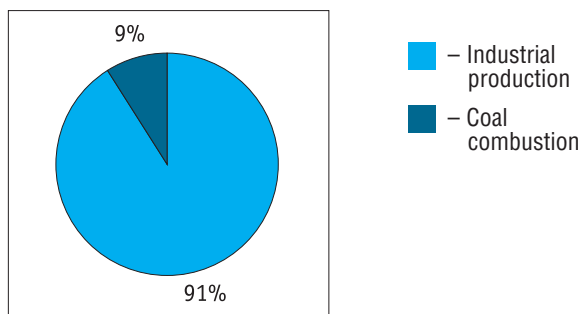


Figure 4.78. Sources of atmospheric emissions of mercury in the Norilsk Industrial Production in 2000.

Mercury

Use of natural gas and other types of petroleum hydrocarbon fuels for energy production produces a relatively minor contribution to mercury mobilization. For example, use of natural gas in the NIA, contributes annually about 10g of mercury. A more significant contribution to mercury emissions is made by coal used for heat and power production. As almost 99% of total coal combustion in the TAO occurs in the NIA, and (in addition to the even more substantial emissions from production of non-ferrous metals) coal contributes 10% of the NAI emissions of mercury to the atmosphere (Figure 4.78), the NIA is clearly responsible for the greater part of the mercury contamination from the TAO.

Polyaromatic hydrocarbons (PAHs)

Total PAH emissions to the atmosphere due to the consumption of hydrocarbon fuels in the TAO, including the NIA, are presented in Figure 4.79. For all PAHs, as in the case of benzo[a]pyrene (Figure 4.80), the main contribution is made by the NIA. It should be noted that contributions from defense-related activities have not been included in the inventory estimates, since this information was not available to the assessment. Because of this, contributions from areas outside of the NIA, for example Khatanga, may be higher. However, the pre-eminent role of NIA will not change.

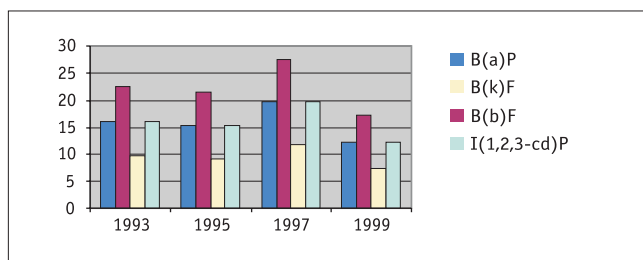


Figure 4.79. PAH (benzo[a]pyrene, benzo[b]fluoranthene, benzo[k]fluoranthene, and indeno[1,2,3-c,d]pyrene) emissions from combustion of hydrocarbon fuels in the TAO (including the NIA), kg.

As a rule, specific PAH emissions occurring through coal combustion are higher than those associated with combustion of petroleum hydrocarbon fuels. As coal consumption in the TAO is higher than, for example, in Murmansk Oblast, and the NAO even more so, coal combustion sources dominate PAH emissions from the TAO (Figure 4.81).

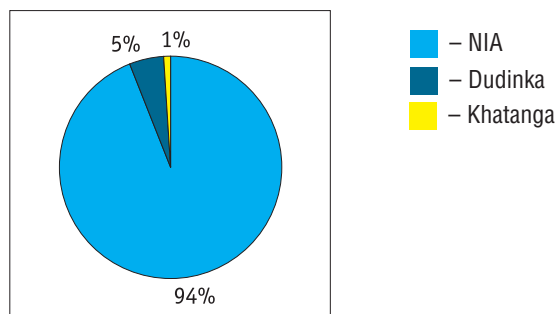


Figure 4.80. Contributions of different source regions to benzo[a]pyrene emissions from the combustion of hydrocarbon fuels in the TAO.

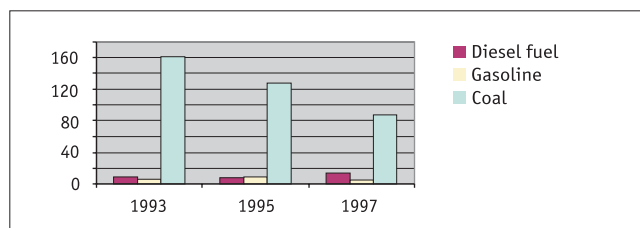


Figure 4.81. Contribution of different types of fossil fuel combustion to benzo[a]pyrene emissions in the NIA, kg.

Dioxins

The use of coal for heat and energy production is a dominant source of dioxin emissions when compared to other types of organic fuel in the TAO. As expected, the NIA is responsible for almost 99.5% of dioxin emissions from coal combustion in the TAO. However, the TAO dioxin emissions from petroleum hydrocarbon fuel combustion (including those from the NIA), are comparable to the dioxin emissions from coal combustion in the TAO when the NIA is excluded.

4.4.5. The Chukchi Autonomous Okrug (CAO)

4.4.5.1. General description

The CAO, which is located in the extreme far north-east of continental Russia, consists of eight districts. These are: Anadyrsky (settlement Ugolnye Kopi); Beringovskiy (settlement Beringovskiy); Bilibinsky (settlement Bilibino); Iultinsky (settlement Egvekinot); Provedensky region (settlement Provedeniya); Chaunsky (town of Pevek); Chukotsky (settlement Lavrentiya); and Shmidtovskiy (settlement Mys Schmidta). The CAO capital, Anadyr, is located in the Anadyrsky District.

According to the census, the population of the CAO was 164783 persons in 1989. In recent years its population has decreased and, by the beginning of 2000, the figure was 72180 persons of whom 49106 are in urban areas and 23074 classed as rural.

The settlements involved in the inventory of local sources are located in three rayons: the city of Anadyr and settlement of Kanchalan in Anadyrsky District, the settlement of Provideniya in Providensky District, and the settlement of Uelen in Chukotsky District. Population characteristics of the inventory areas are presented in Table 4.29.

#	Settlements	Area, km ²	Population
1	City of Anadyr	20	11845
2	Anadyrsky Rayon Settlement of Kanchalan	249610	12500 665
3	Chukotsky Rayon Settlement of Lavrentiya Settlement of Lorino Settlement of Uelen Settlement of Neshkash Settlement of Enurmino Settlement of Inchnown	30247	4657 1079 1404 844 693 293 344
4	Providensky region Settlement of Provideniya	27286	5067 2137

Table 4.29. Population characteristics of areas in the CAO included in the inventory of local sources.

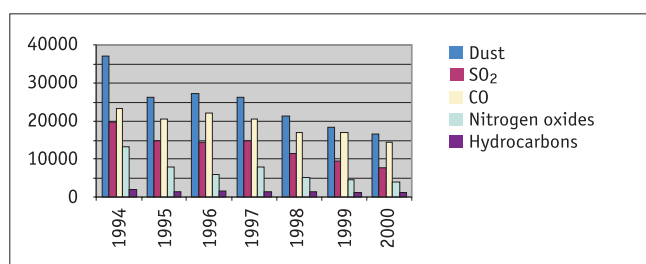


Figure 4.82. Atmospheric emissions of major pollutants from stationary sources in the CAO, t/y.

Main local pollution sources are related to the development of mineral resources such as gold, tin, tungsten, mercury, coal, and lignite. Together, in 1995, industrial entities emitted 72500 t of pollutants into the atmosphere, and discharged 39.3 million m³ of sewage into surface water bodies (including 8 million m³ of polluted wastewater). In 2000, these figures were, respectively, 35500 t, and 20.0 and 5.3 million m³. The main pollution sources are the Pevek Mining and Concentration Plant, the Iultin Mining and Concentration Plant, and also numerous boiler houses.

Provideniya is the biggest settlement inhabited by indigenous peoples in the CAO. The settlement has a seaport, a shipyard terminal, a tannery, and a meat-and-dairy plant. The indigenous population is involved in reindeer-breeding, fishing, the fur trade, and hunting. There are practically no industrial facilities in the settlements of Uelen and Kanchalan where the indigenous population is engaged in reindeer-breeding, hunting, and the fur trade. There are no major pollution sources except for solid household waste and pollution of coastal waters by petroleum products.

Data on air emissions from stationary sources in the CAO are presented in Figure 4.82. Although official statistics do not include data on PTS emissions, there is a well-defined general trend of decreasing emissions. It may be assumed that PTS emissions in this region are also decreasing, in accordance with this general trend. Official statistics on air emissions in the CAO from motor vehicles do not include private vehicles. Based on expert estimates, vehicles used for personal transport exceed the number of vehicles belonging to the state and to the various enterprises by about 50%. Data

Variable	1999	2000	Maximum annual discharge in the previous 7 years
Suspended matter	0.7	0.45	2.46
Dry residue	0.41	0.64	0.87
Organic matter (BOD)	2.22	2.29	3.46
Petroleum hydrocarbons	0.01	0.01	0.01
Chlorides	0.55	0.67	0.73
Sulphates	0.28	0.21	0.5
Ammonia nitrogen	0.11	0.12	0.14
Nitrites	0.002	0.001	0.007
Nitrates	0.013	0.029	0.029

Table 4.30. Discharges of contaminants with wastewater in the CAO, thousands of tonnes.

on air emissions from non-private motor vehicles are presented in Figure 4.83. Official statistics also exclude data on emissions of, for example, lead from the use of leaded gasoline by motor vehicles. This information, based on expert estimates, is provided below.

Official statistical data on pollutants in wastewater discharges in the CAO are presented in Table 4.30. Polluted wastewater is discharged from treatment facilities belonging to the various utilities in the cities of Anadyr and Pevek and the settlements of Bilibino and Iultin. Main areas of pollution were found around the city of Anadyr (affecting 185 km²) and the settlement of Nagorny (affecting 60 km²). Within the inventory area, wastewaters are discharged into natural water bodies without any form of treatment, with the exception of Kanchalan settlement, where effluents are collected from cesspits and transported to the settlement's dump for further partial treatment.

4.4.5.2. Main settlements in the inventory areas

Anadyr

Anadyr is the capital of CAO, and has the most developed infrastructure in the CAO. Emissions for the city of Anadyr, based on State statistical data, are presented in Table 4.31. The city has no wastewater treatment facilities. There are no enterprises registered as potential sources of PCB contamination in the area of Anadyr, and no information on users of PCB-containing equipment. Similarly, there are no industrial wastes in Anadyr which are likely to contain PCB, or hexachlorobenzene (HCB), as there are no activities connected with either their production, or use.

A potential source of brominated flame-retardant compounds (BFRs) is land occupied by municipal landfills, but there are no data currently available on their content due to a lack of information on types of solid household waste dumped at the landfill. In the opinion of experts from the municipal services, household and electronic apparatus that could represent a source of BFRs are seldom found among debris located at the landfills. The Anadyr municipal landfill is located two kilometers from city. The amount of waste dumped annually in the landfill is 28000 m³. It is important to

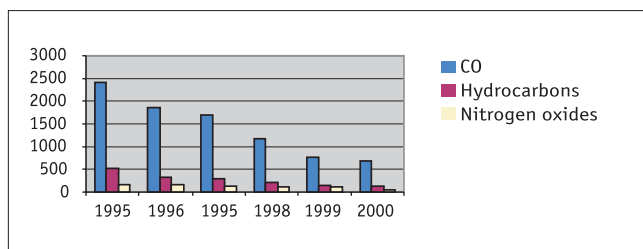


Figure 4.83. Atmospheric emissions from motor vehicles (excluding private cars) in the CAO, t/y.

note that landfills in Chukotka are in a permanently frozen state and therefore among the safest landfills and, as certified by the communal services, has low potential for spontaneous combustion, and percolation from the landfill into groundwater.

Although no special studies have been undertaken, and there are no directly relevant data available, it is possible, on the basis of the information presented above, to infer the possible presence of dioxins and furans in the city. Furthermore, there has been no work associated with organizing an inventory, collection, storage and treatment of mercury-containing luminescent lamps and such equipment.

Kanchalan

The settlement of Kanchalan is located in Anadyrsky District, on the bank of the river Kanchalan, part of the Anadyr river system. At present the settlement has no industry, and agriculture is represented only by reindeer-breeding farms, which only use the settlement as a base. The settlement's housing and municipal services operate a diesel electric power station and a coal-fired boiler-house, which uses coal from the Anadyr deposit.

There is no sewage system in the settlement, and collection is in cesspools, which are periodically cleaned, with the solid waste being removed to the settlement landfill. According to environmental protection authorities, the level of air pollution in the settlement has never been investigated, and therefore available data is limited to potential sources of PTS only.

Provideniya

The settlement of Provideniya is located to the north of the Gulf of Anadyr, in the Emma Bay (Komsomolskaya). Ureliki village directly adjoins the settlement. Infrastructure in the settlement of Provideniya is similar to that of Anadyr city. The main enterprises are the sea trading port, the airport, a meat-and-milk complex, the 'Providensky kozhzavod' JSC, enterprises run by housing and municipal services, construction operations, and military infrastructure. The port is responsible for the water supply for the settlement. Water is taken from lake Istihet and the river Krasiviyi. Effluent discharge amounts to 4.3 million m³. There are no treatment facilities for industrial or domestic wastewater; and practically all waste water from the settle-

Variable	1996	1997	1998	1999	2000	2001
Total	4.26	3.94	4.65	3.07	17.002	4.829
Dust	2.90	2.96	3.43	0.23	15.489	3.662
SO ₂	0.53	0.51	0.56	1.51	0.463	0.509
CO	0.42	0.22	0.3	1	0.432	0.341
Nitrogen oxides	0.27	0.18	0.36	0.29	0.197	0.282

Table 4.31. Trend in air emissions of major pollutants in Anadyr, thousands of tonnes.

ment and port is discharged into the bay of Komsomolskaya. The enterprises listed above are the main water pollution sources.

The following contaminants enter the bay with wastewater: suspended mineral substances (4.32 t), petroleum products (0.13 t), organic matter (24.84 t), chlorides (14.06 t), sulphates (8.33 t), total nitrogen (23 t), surfactants (0.012 t), and phosphorus (0.04 t). Of these pollutants, housing and municipal services release the following: mineral suspensions (3.82 t), organic chemicals (22.31 t), chlorides (12.96 t), sulphates (6.06 t), total nitrogen (2.13 t), and phosphorus (0.04 t).

Air pollution in the settlement of Provideniya and its nearest neighbours, originates from the burning of solid fuel (Beringov coal). In the mid-1990s, about 47500 t/yr were burned in boiler installations. Major pollutant sources include: the thermal power station at the seaport (coal consumption of 9728 t/y), boilers operated by housing and municipal service enterprises (8685 t/y), boilers in the village of Ureliki (7000 t/y), and boiler-houses run by the military infrastructure (7000 t/y).

More than 9600 t of black oil (Mazut) and diesel fuel are burned annually in the settlement. The major pollutant sources include boiler-houses belonging to the seaport and the communal service and diesel-fired power stations.

Annual emissions of pollutants to the atmosphere around Provideniya are: 1390 t of dust, 500 t of sulphur dioxide, 750 t of carbon monoxide and 200 t of nitrogen oxides. Emissions from motor vehicles for the whole of Providensky District include: carbon dioxide (256 t), nitrogen dioxide (11 t), and methane (53 t). Mean atmospheric deposition of mineral salts in the areas of settlement for the last few years have been about 50 kg/ha/y, with wet deposition of sulphur at 4-6 kg/ha/yr and nitrogen at about 2 kg/ha/y.

An additional pollution source is solid household and industrial non-toxic debris, which is stored in planned landfills. In total, 33800 m³ of solid waste are exported to landfills each year from all the enterprises within the settlements of Provideniya and Ureliki, and an additional 858 t/y from neighboring villages. There are no data currently available on PTS sources in the area.

Uelen

The settlement of Uelen is administered under Chukotsky District. Uelen's infrastructure only includes enterprises belonging to the housing and municipal service departments: the Uelen workshop, farm, and social institutions (consisting of the school, medical station, and kindergarten).

Environmental pollution sources are as follows: the diesel-fired power station, coal-fired boiler, landfill for household debris, coal and ash waste repository, and household heating sources. Air emissions in the settlement in 2001 were: dust (939 t), carbon monoxide (1130 t), sulphur dioxide (668 t), and oxides of nitrogen (536 t).

According to information provided by the local authorities, chlorinated pesticides have not been used in the areas of the above settlements.

4.4.5.3. PTS mobilization from combustion of fossil fuels

As for other project pilot study areas, estimates of PTS emissions from the combustion of organic fuel are based on statistical data on fuel consumption and population distribution. About 30% of the population of the CAO reside in or around the city of Anadyr and the settlements of Kanchalan, Provideniya and Uelen. Due to a lack of data on fossil fuel consumption in the these areas, it was assumed that consumption therefore amounts to about 30% of the total fuel consumption in the CAO as a whole.

Estimates of total PTS emissions from the combustion of fossil fuel in the inventory area are presented in Table 4.32.

Contaminant	1993	1995	1997
Lead	1684.75	1160.70	1033.23
Mercury	3.61	3.30	3.23
Benzo[<i>a</i>]pyrene	10.22	6.94	5.61
Benzo[<i>b</i>]fluoranthene	11.46	7.20	5.37
Benzo[<i>k</i>]fluoranthene	9.31	6.13	5.09
Indeno[1,2,3- <i>c,d</i>]pyrene	23.55	18.49	17.42
Dioxins (mg TEQ)	1182.15	1034.29	1004.09

Table 4.32. Estimated emissions of selected PTS from the combustion of fossil fuels in Anadyr, Kanchalan, Provideniya, and Uelen, kg.

Due to the high consumption of local coal, lead emissions to air as a result of coal combustion are far greater than emissions from the use of leaded gasoline, even in the years when leaded gasoline was more widely used.

4.4.6. Conclusions

4.4.6.1. General conclusions

An assessment of official statistics on the environmental release of pollutants, as well as data obtained by environmental protection authorities of the various administrative territories of the Russian Federation under the scope of the project, clearly indicates that existing environmental release control and reporting systems are not ade-

quate for contemporary requirements. That is, a reporting system suitable for documenting the efficiency of actions taken by countries in connection with international measures to reduce environmental releases of PTS, and in particular the 'Stockholm Convention on Persistent Organic Pollutants'.

- The control and reporting systems of the environmental protection authorities do not adequately cover environmental releases from defence-related activities in the Arctic regions.
- The existing environmental monitoring systems, in almost all cases, do not cover secondary pollution sources; that is sources that are not directly linked to environmental pollution by industrial enterprises, although these may strongly influence the state of the environment, and ecosystems and human health. For example, monitoring of anthropogenic sources such as harbours and ports only covers petroleum hydrocarbons and few other contaminants, and not important PTS that can originate from shipping activities and associated wastes, and particularly from scrapping of ships.

4.4.6.2. Murmansk Oblast

Despite the fact that full, representative figures for releases to the environment are missing for some enterprises and that figures for some of the controlled variables have been obtained by calculation; based on the available information, it is possible to note the following:

- The main persistent pollutants emitted to the atmosphere of this area are copper and nickel, with emissions amounting to about 1000 tonnes per year. Compared to the emission of copper and nickel from industrial enterprises, fuel combustion makes a relatively small contribution to the total emissions of heavy metals in this region.
- Industrial enterprises located in the vicinity of the area where the Saami population is most dense, emit a significant proportion of the total industrial air emissions in Murmansk Oblast. Within the project study area, the most significant pollution source is the 'Severonikel' combined smelter in Monchegorsk. There are a number of other important pollution sources in the area, mainly with respect to heavy metals.
- Emissions of benzo[*a*]pyrene from industrial enterprises are approximately equal to those from the burning of organic fuels.
- According to official data, chlorinated pesticides have not been used and are not currently used in Murmansk Oblast.
- PCB-containing transformer fluids are used in only 13 transformers at 'Apatit' JSC. However, taking account of the high concentration of defence-related activities in Murmansk Oblast, it may be assumed that a considerable proportion of PCB-containing paints, varnishes, and lubricants produced in the former USSR have been used there.

- In general, there are a number of dioxin sources that might be relevant to the survey area. Some enterprises, such as the nickel combined smelter 'Severonickel' are considered potential dioxin pollution sources, but no information is available to confirm this assumption.
- Intentional mercury use in industrial production in Murmansk Oblast has not been documented. However, mercury-containing devices, in particular luminescent lamps, contribute to environmental contamination. The enterprise 'Ecord Ltd.' involved in handling of used luminescent lamps and located in the area has outdated equipment and itself contributes to mercury contamination of the environment.
- The 'Severonickel' combined smelter is considered to be a significant source of mercury contamination in the area due to mercury mobilisation during nickel and copper production. Annual mercury emissions from this enterprise are estimated to be about 0.2 tonnes. In addition, about 0.1 tonnes is accumulated annually in captured dust.
- Coal combustion is considered to be the major contributor to lead emissions that result from fossil fuel combustion. Total lead emissions from the combustion of fossil fuels in the Lovozero area have decreased in recent years, mainly due to a reduction in emissions from motor vehicles.
- Mercury contamination from local sources as a result of fossil fuel combustion is significantly less than that due to mercury mobilization from nickel and copper production at 'Severonickel' JSC. However, given that domestic coal burning contributes to contamination of the indoor environment, the role of the latter in human intake may be much greater.
- Releases of PAHs from organic fuel combustion have gradually decreased, possibly, due to changes in the types of fuel used. However, after 1998, PAH emissions stabilized, presumably due to the recovery of the economy after the 1997 crisis.
- Industrial enterprises appear to be the main source of dioxin pollution from fossil fuel combustion in the Lovozero area. The role of municipal services, particularly local boilers used for non-centralized heating, in dioxin emissions has significantly increased in recent years. Although still much less than from industrial enterprises, the three-fold growth in emissions from municipal sources within 7 years should be a matter of concern.

4.4.6.3. The Nenets Autonomous Okrug (NAO)

- Main local pollution sources in the NAO are associated with oil and gas production and shipping.
- In spite of the fact that official statistical data do not document significant PTS pollution sources in the lower part of the Pechora basin, the assessment of PTS fluxes in the river flow indicate a possible input of some PTSs between Oksino and Andeg, i.e. in the vicinity of Naryan-Mar. Pollution levels in the Pechora delta tend to be elevated.

- Gas emissions during oil extraction are very high in the NAO, and methods of utilising the associated gas have not yet been developed or applied.
- The port at Nar'yan-Mar, located in a narrow channel connected to the Great Pechora river, is a source of pollution. The port has no treatment facility or storage tanks for liquid wastes and, therefore, wastewater is discharged directly into the river without treatment.
- The system of solid waste collection does not allow for separation of hazardous wastes, including those containing mercury. Disposal of such wastes at landfill sites results in environmental contamination by dangerous substances, which can include dioxins in the event of uncontrolled burning at the landfill site. Methods for handling of medical waste, rubber waste products, and ash and slag waste from boiler-houses has not been developed in the NAO.
- Automotive vehicles are the main source of lead emissions in the NAO. The total amount of lead mobilized through fossil fuel combustion is relatively low. However, due to a significant increase in the number of motor vehicles in the area in recent years, an increase in lead emissions has been observed, despite greater use of unleaded gasoline.
- Coal consumption in the NAO is relatively low, since use of petroleum hydrocarbon-based fuels predominates in this region. However, use of firewood as a fuel is relatively common, particularly for domestic heating. As the result, this fuel contributes, for example, about three quarters of the total emissions of benzo[*a*]pyrene, and 80% of total dioxin emissions from the combustion of organic fuel.

4.4.6.4. The Taimyr Autonomous Okrug (TAO)

- The Norilsk Industrial Area, the largest producer of copper and nickel in the Arctic and in the Russian Federation, is acknowledged as the largest single source of environmental pollutants, not only in its immediate locality, but in the circumpolar Arctic. It emits a wide range of contaminants, including a number of heavy metals that fall within the scope of the project.
- Automotive vehicles are an important source of some PTS emissions. The Norilsk area in winter is characterized by numerous temperature inversions, and during these periods, pollution of the lower atmosphere by vehicle exhaust fumes often exceeds pollution from stationary combustion sources.
- About 10 million tonnes of toxic wastes containing over 50 different major pollutants, and more than 1 million tonnes of slag are stockpiled in the Norilsk area each year. Almost none of the waste-storage sites conforms fully to current legal and regulatory requirements.
- According to the results of the PCB inventory for the Russian Federation, significant amounts of PCB-containing fluids are used in electric equipment within the various enterprises of the Norilsk Industrial Area. According to estimates, the transformers used in this area discharge 3.33 tonnes of

PCB annually, and over the whole operating period of the transformers, more than 83 tonnes of PCB will have been released to the environment. In addition, an unknown amount of PCB may enter the environment as a result of releases from PCB-containing paints and varnishes, and compounds used in building construction, etc.

- In 2001, the production of non-ferrous metals in the Norilsk area was accompanied by the mobilization of 1.7–2.02 tonnes of mercury, which was emitted to the atmosphere. In addition, 0.65–0.99 tons of mercury were accumulated in captured dust.
- Dudinka port operates practically all year round. In spite of the fact that it is equipped with an adequate transport infrastructure and oil storage depots, large-scale loading activities, and washout of bulk copper-nickel concentrates causes contamination of the Yenisey river with a range of hazardous substances, in particular heavy metals.
- About 1 million m³ of waste waters are discharged annually into the Khatanga river from the collector at the Khatanga settlement. There are no data available regarding the chemical composition of the wastewater discharged. The total volume of untreated wastewater discharged in the Khatanga area amounts to 6–8 million m³ annually.
- The TAO, and the Norilsk Industrial Area in particular, is characterized by high coal consumption levels. Coal burning therefore plays a predominant role in PTS emissions associated with fossil fuel combustion, for example, mobilization of lead. It should be noted that the amount of lead mobilized annually from the combustion of coal in the TAO is greater than the amount emitted by the Norilsk combined smelter during the production of non-ferrous metals.
- Mercury mobilized from coal combustion at heat and power plants contributes up to 10% of atmospheric emissions, the remainder being due to mercury mobilization from ores used in the production of non-ferrous metals.
- Dioxin emissions from the combustion of petroleum hydrocarbon-based fuels in the entire TAO, including the Norilsk Industrial Area, are comparable to dioxin emissions from coal combustion in the TAO when the Norilsk Industrial Area is excluded.

4.4.6.5. The Chukchi Autonomous Okrug (CAO)

- Main local pollution sources in the CAO are related to the development of mineral resources including gold, tin, tungsten, mercury, and coal and lignite. Main pollution areas occur around the city of Anadyr (affecting 185 km²) and the settlement of Nagorny (affecting 60 km²).
- Coal dominates organic fuel consumption within the CAO, and, correspondingly, coal burning is responsible for emissions of a number of PTS.
- Sea ports in Anadyr, Lavrentiya and Provedeniya are considered to be local pollution sources.

4.5. Household and occupational sources of exposure

The knowledge accumulated over the last decade about effects of persistent organic pollutants on health indigenous people of the North has caused much public concern about their traditional food considered to be the major pathway of human exposures to highly toxic chlorinated organic compounds and metals. In the meantime other exposure sources and pathways of PTS were generally ignored.

To clarify potential indoor (household) and occupational sources and pathways of exposure, a targeted survey including human blood sampling among selected families and domestic and workplace matters were carried out. The targeted survey was designed as a case study involving 28 families from 3 selected native settlements. The selection of families was based on those measurements of cord blood concentrations of total PCBs derived from the basic survey of the project.

The work programme included re-interviewing and blood re-sampling of those women shown higher cord blood concentrations of total PCBs (over 500 ng/g lipids) at time of birth as well as interviewing and blood sampling of adult family members living together with target women. The referent group has been represented by families of those women found to have lower cord blood concentrations of total PCBs (below 500 ng/g lipids) living either in the same native community or in the closest vicinity of it. It has been proven that the sufficient number (at least 4) of families of “exposed” and “less exposed” newborns were available by the planning period only in:

- the settlement of Lorino, Chukotka coastal study area;
- the district of Khatanga, Taimyr Peninsula;
- and the settlement of Nelmin Nos, Pechora River Basin;

The invitation and interviewing procedures and blood sampling protocol were identical to the those applied for the general indigenous population in the 2001 survey but supplemented with the extended questionnaire focused on occupational and household sources of exposure to PTS since the treatment of animals against mosquito bites, protection of houses against rodents, bed-bugs and cockroaches are widely occurred in the northern communities. The work programme thereof involved visiting the houses of selected families as well as work places and, where possible, sampling wash-outs and scrapes in home and occupational settings for further analyses for contaminants. Activities potentially associated with the human exposure to PTS are summarized in Table 4.33.

The impression on to what extent the indigenous population is at higher risk of exposure to PTS through the sources other than local foods can be illustrated by following information obtained from the questionnaire study :

Type of exposure	Site of exposure	Percent of pregnant women reported exposure	Per cent of general population reported exposure
Occupational	fishing/hunting, casting of pellets/plummets	0.9	7.3
	Reindeer herding, lather and fur handicrafts, animal treatment, maintenance female worker, veterinary	10.4	4.63
	Nurse, hospital worker	10.0	4.63
	Gardener	19.1	30.5
Vegetable gardening	Any place	41.3	34.1
Use of toxic substances	At home	39.6	30.96
	At work	5.2	2.3
	In vegetable garden	2.6	0.63
	Against rodents	6.1	3.74
Adverse habits	Smoking	35.2	54.1
	Alcohol abuse (including home-made hard liquors)	57.8	69.9

Table 4.33.
Activities associated with risk of PTS exposure (according to questionnaire).

- Casting of shot (plummet) and other hunting and fishing appliances can hardly be accounted as a source of significant lead exposure in surveyed populations. Only 7% indigenous people and below than 1% of pregnant indigenous women have reported activities potentially associated with contacting lead.
Smoking is likely to remain one of the most significant source of cadmium intake in indigenous people, since 54% of adults of general population and 35% pregnant women have reported tobacco smoking habits.
- Household use of toxicants is reported by 34-41% of respondents. However, despite the fact that over 30% of surveyed population grow vegetables in garden plots or greenhouses, only few reported on the use of insecticides to protect cultivated plants.
- 70% respondents of general population and 58 % of pregnant women reported the frequent consuming alcohol. The significant number of respondents reported to consume homemade alcoholic drinks. A specific source of PTS contamination is that the indigenous people frequently use, for economical reasons, the wasted (second-hand) technical barrels and plastic containers to produce and store liquids including homemade alcohols.

HCB, DDT in considerable concentrations (Table 4.34). The chemical named “Medifox super” produced by “Fox Company” (Russia) is the exception. According to its certificate the main constituent is the permithrin concentrate and “is used for pediculosis treatment and for disinfections of rooms against pediculosis and sarcoptoid ticks”. “Medifox” has been found to be used widely in Chukotka kindergartens, schools, health institutions, residential buildings for scabies treatment since early 1990’s.

“Mashen’ka” crayon imported from China and widely used in the North of Russia for cockroach combating does not appear to contain the POPs in question. However composition of this crayon as well as of other protectors may differ significantly from those used 10-20 years ago. Information about the insecticide composition used in the past, is not available.

The wash-outs were taken indoor (mainly from kitchen walls) whereas the scrapes were taken from surfaces of the kitchen furniture and appliances. Results of their POPs measurements are summarized in the Table 4.35. Judging by these results the indoor environment of indigenous residencies is likely to be one of the most common source of exposure to POPs.

Chemical analysis of some insecticides sampled as result of targeted survey shows that the most common household toxicants available in the market in Nenets, Taimyr and Chukchi AOs do not contain PCB, HCH,

The highest levels of DDT, PCB and HCH were found in the native communities of Chukotka. DDE/DDT ratios in wash-outs and scrapes amount to 10-70 % allow to suggest relatively recent contamination of the residencies by

Name	ΣPCB	HCB	ΣHCH	4,4’-DDE	4,4’-DDT	ΣDDT	ΣTox
“Mashen’ka” crayon	28.0	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Anti-cockroach compound	31.0	n.d.	n.d.	7.7	15.0	22.0	n.d.
Medifox (antilice compound)	234	406	n.d.	38.0	480	546	n.d.
Anti-insect compound	8.0	0.5	n.d.	n.d.	n.d.	0.3	n.d.
Anti-gadfly compound	0.3	0.1	n.d.	0.01	n.d.	0.01	n.d.
Anti –mosquito cream	n.d.	1.1	n.d.	n.d.	n.d.	n.d.	n.d.
Anti-mosquito cream	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Skin-tanning fluid	n.d.	n.d.	n.d.	n.d.	0.08	0.08	n.d.
Skin-tanning fluid	n.d.	n.d.	n.d.	n.d.	0.03	0.03	n.d.

Table 4.34.
POPs concentrations in insecticides and in skin-tanning fluids collected in Nenets, Taimyr, and Chukotka regions in 2003, ng/g

Contaminants	Pechora River Basin	Taimyr	Chukotka	
	Wash-outs, $\mu\text{g} / \text{m}^2$	Wash-outs, $\mu\text{g} / \text{m}^2$	Wash-outs, $\mu\text{g} / \text{m}^2$	Scrapes ng/g
	n=6	n=8	n=11	n=4
ΣPCBs	0.18	1.36	2.35	248.1
HCB	0.02	0.18	0.08	0.8
ΣHCH	0.27	0.28	0.49	67.4
4,4'-DDE	0.28	0.57	0.90	126.3
ΣDDT	1.10	1.85	11.19	768.4

Table 4.35. POPs concentrations in wash-outs and scrapes collected inside the dwellings (geometric means)

DDT – containing chemicals. The intensive past use of household insecticides seems to be the major contributor to the persistent pesticide contamination of indoor environment. However, lack of awareness shown by interviewed indigenous people does not permit to specify the exact insecticide(s) which had been applied indoor. The chemical composition of retailed insecticides is generally unknown since these products had been supplied to the market mostly unlabelled.

The potential occupational exposure to POPs was most frequently reported as in form of the treatment of rein-

deer skin by various insecticides to protect the animals against mosquito bites. Blood-sucking insects, especially gadflies, can penetrate into animal's subcutaneous tissues as well as through naso-pharynx, impose a serious problem for animal health, and during the long-range running, the efficiency of insect combating may be a determinant of the deer herd livestock. The current variety of chemicals against mosquitoes and gadflies combating are different to those used in the past. Nowadays the most common are the synthetic piretroids which do not contain organo-chlorines, and they are not persistent and not capable of accumulating in the body at detectable levels. In the early 1970's organophosphines (chlorophos) with ammonium carbonate or with sodium hydroxide, hexamide with spindle oil and emulsifier, DDVP (dimethyldichlorovinyl-phosphate), etacide, trichlorometaphos-3, sulphur dioxide, smoke hexachlorane shells, cryoline-hexachlorane liniment and other hexachlorane compounds were widely used in reindeer collective farms. Among the above-mentioned chemicals only "hexachlorane" has been found to contain HCH at significant levels. Other currently used insecticides are generally free of POPs containing an array of organo-chlorine compounds, and are readily degradable in the nature.