Risk Assessment and Risk Management
Procedure for Arsenic in the Tampere Region

Arsenic in the Pirkanmaa Region in Finland: Occurrence in the Environment, Risk Assessment and Risk Management

Layman's Report
RAMAS Project (LIFE04 ENV/FI/000300)

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CONTENTS

1. OBJECTIVES OF THE RAMAS PROJECT

Arsenic (As) is a natural component in bedrock. It ranks twentieth among the elements in abundance in the Earth's crust. Geological processes have dispersed arsenic to locations where it is more susceptible to dissolution and transport to biosphere, such as, water-conducting fractures in bedrock and the soil cover. Human activities have also released arsenic to the environment generating contaminated areas with occasionally very high arsenic concentrations. In early 1990's some alarming findings were published concerning the health effects of arsenic, a known carcinogen. As a consequence of these findings WHO recommended that the human health based limit value of arsenic in drinking water should be reduced from 50 µg/l to 10 µg/l. National authorities in many countries followed this recommendation, including the Finnish Ministry of Social Affairs and Health. Since arsenic is also toxic to biota, the risks owing to its natural and anthropogenic occurrence should be considered.

Since 1980's geochemical mappings conducted in Finland have revealed several areas with elevated arsenic concentrations in bedrock and soil. One wide-spread arsenic anomaly is located in a densely populated area in southern part of the country, in the Tampere Region (Fig. 1). When the analytical methods for water analyses improved in early 1990's excess arsenic was detected also from bedrock groundwater. Combined with the reported adverse health effects arising from rather low arsenic concentration motivated the municipalities and health authorities to launch a number of studies in this region.

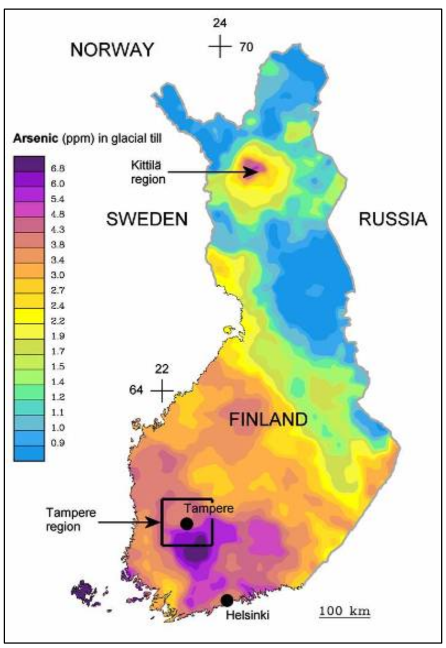

Figure 1. *Distribution of arsenic in glacial till in Finland.*

There has been a lot of interest in arsenic from different perspectives, not only concerning the quality of drinking water. There are numerous potential anthropogenic sources of arsenic in the area, such as wood impregnation plants, power plants, landfills and other waste treatment plants. In this context, the local authorities have monitored arsenic, for example, in fresh waters and sewage around the suspected contaminated areas. The earlier studies have been site or target-specific without any wider consideration of the impact to the whole community or nature. Furthermore, the existing information has been spread to numerous files and registers and is not readily accessible to users. This was the starting point and acted as the promoter for an integrated arsenic project proposal submitted to the LIFE Environment - programme. The proposal was successful and the project "Risk assessment and risk management procedure for arsenic in the Tampere Region" (RAMAS) was implemented in 2004-2007.

In nutshell, the general aims of the RAMAS project were to pull together all the available data on natural and anthropogenic arsenic from the study area, to fill possible data gaps with supplementary studies, to carry out environmental and health risk assessments based on this knowledge, and finally, to identify possible needs for risk management actions arising from the outcomes of risk assessment (Fig 2.).

The responsibilities in the project were divided in such a way that the best available expertise was engaged to the work. The participating organisations had access to a major part of the historical data, whether in the files of research institutes or in the registers of authorities, and they were able to provide almost all the analytical services the project needed. The project partners included the Geological Survey of Finland (beneficiary), the Helsinki University of Technology, the Pirkanmaa Regional Environment Centre, the Finnish Environment Institute, the Agrifood Research Finland, Esko Rossi Oy and Kemira Kemwater. More detailed information about the project and the material produced can be found in the project's website www.gtk.fi/projects/ramas.

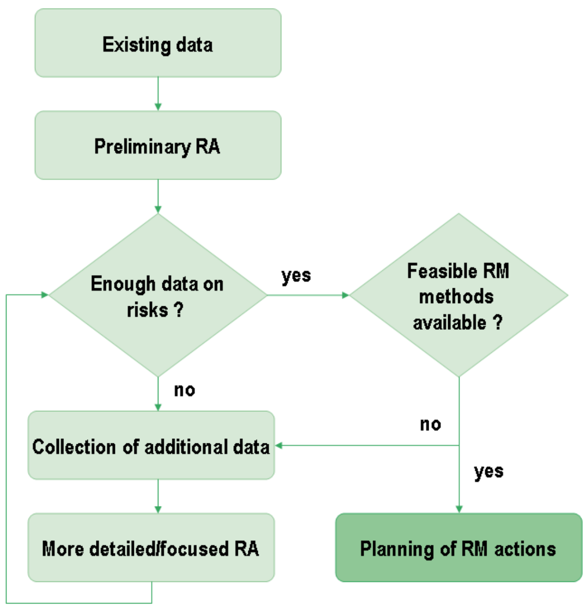

Figure 2*. Generic description of a risk management procedure associated with environmental contamination. RA = risk assessment, RM = risk management*

2. APPROACH AND RESULTS OF THE PROJECT

The RAMAS project was the first in Finland to create an overall, large-scale risk management strategy for a region that has both natural and anthropogenic contaminant sources. The regional risk assessment was based on selected test cases. These included the following: households or farms having been utilizing arsenic-bearing water and soil for a long time, wood impregnation plants and abandoned mine areas. All relevant information was gathered, and for example, assessment of arsenic uptake by crops, ecotoxicological tests and biomonitoring (human exposure) were carried out to obtain better understanding of the exposure-response relationships in the area.

The following sections present a summary of the main project tasks dealing with: natural arsenic sources, anthropogenic arsenic sources, risk assessment, risk management and dissemination of results. The two first mentioned tasks collected and reported the geochemical and other information related to the various arsenic sources, thus providing the input for the risk assessment task. The risk management task, in turn, addressed the needs for preventive and remediation measures identified on the basis of the ecological and health risk assessments.

2.1. Natural arsenic sources

Natural arsenic in the area is derived from the arsenic bearing minerals, which are locally enriched in the metamorphosed, crystalline bedrock. Due to the action of geological and geochemical processes, arsenic has transferred to groundwater and soils. The glaciogenic events were particularly important in dispersing arsenic into the surrounding areas. The study area divides into three units based on geological grounds. In the northern half of the area granitic bedrock dominates and the arsenic concentrations in all geologic media were at the average level encountered in the country. The arsenic problem is clearly focused in the southern part of the Tampere Region (also known as Pirkanmaa), where metamorphosed volcanic rocks are common constituents of the bedrock (Backman *et al*. 2006).

Arsenic concentrations in shallow groundwater and surface waters are generally low, below 1 µg/l. Hence, arsenic is not an issue for the public water supply, which are based on these shallow water reservoirs. The major concern is focused on drilled wells, which are used by private households and other small units. Altogether, 1237 arsenic analyses from drilled wells were available. In 22.5 % of the wells the limit value, 10 µg/l, was exceeded. All these arsenic wells are located in the southern part of the study area. Most of the samples that had arsenic speciation analysis were arsenate (As^{5+}) dominated.

Elevated arsenic concentrations in soils are related to till, which is the main soil type in the region. The regional arsenic anomaly extending from the Tampere Region towards south was already recognized in the nationwide geochemical mapping of till. The median value for arsenic in the study area is double compared to the rest of the country (5.3 mg/kg vs. 2.6 mg/kg). There are areas where the arsenic concentrations exceeded the limit value for contaminated soil (50 mg/kg for residential areas and 100 mg/kg for industrial areas). The highest encountered concentration was 9 280 mg/kg. Arsenic concentrations tend to increase downwards in the soil profile and the highest concentrations are generally in the basal part of the sequence. This observation has important implications for the handling of arsenic-bearing till. Arsenic concentrations in other soil types are generally low, although slightly higher than elsewhere in the country.

Locally high arsenic concentrations in bedrock groundwater may pose a risk for public health in the southern part of the Tampere region. In shallow groundwater and surface water the arsenic concentrations were low. In some cases the high arsenic content in bedrock and soil may give rise to environmental problems and demand careful consideration in land-use planning. RAMAS project produced a series of geochemical maps presenting the arsenic distribution in various geological media. In addition, an integrated geochemical risk area map was compiled, where the observed arsenic concentrations relative to the guideline values for drinking water (10µg/l), soil (50 mg/kg) or bedrock (50 mg/kg) were applied to evaluate the source of the risk (Fig. 3).

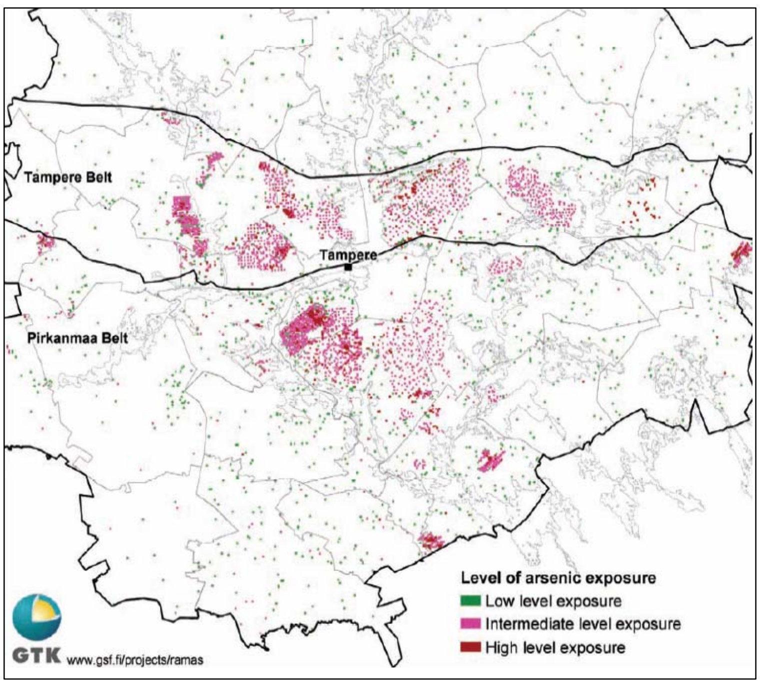

Figure 3. *Integrated geochemical risk area map based on the comparison of observed concentrations and the guide-line values for arsenic in groundwater, soil or bedrock. The northern part of the study area is not shown due to the consistently low risk.*

The contents of arsenic and other elements in arable and forest soils and crops were investigated in selected farms. The 13 farms studied were located in areas where the arsenic concentrations in till were known to be elevated. The aims were to compare arsenic concentrations between the arable and forest soils, between soil layers, between crop species and between the high- and low-arsenic areas. Wheat grains (*Triticum aestivum L.*), potato tubers (*Solanum tuberosum L.*) and timothy grass (*Phleum pratense L.*) were selected crop species because they are important in the human food chain (Mäkelä-Kurtto *et al.* 2006).

Arsenic contents in arable soils ranged from 2.90 to 6.80 mg/kg dry matter (dm) in the plough layer and from 2.84 to 4.82 mg/kg dm in the subsoil. These values are at the national level despite of the elevated arsenic concentrations in the surroundings. Only about 1% of total arsenic was in a soluble form in the soil plough layer. Arsenic content in corresponding forest soils were somewhat higher, but distinctly lower than in till. This is due to the differences in source and transport distance of the geogenic material forming these soil types. The source for clays and other fine-grained soils, typically cultivated in this region, is further away in low-arsenic bedrock areas, while tills represent the local, arsenic-rich bedrock. A major source of arsenic in the arable and forestland seemed to be of geogenic origin. Obviously, the surface layers have received minor amount of additional arsenic from anthropogenic sources, like atmospheric deposition and fertilizer preparations.

Contents of arsenic in the crops were at a low level. Arsenic contents increased in the following order: wheat grains (0.005 mg/kg dm), potato tubers (0.011 mg/kg dm) and timothy grass (0.014 mg/kg dm), on the average. Peeled potatoes contained less arsenic than unpeeled ones. Soil-to-plant uptake factors of arsenic were also low 0.001 for wheat grains and potato tubers and 0.004 for timothy grass, on average. Arsenic had one of the lowest soil-to-plant uptake factors among the elements studied. Limited data on forest berries and mushrooms collected by the project did not evidence any arsenic uptake either.

2.2. Anthropogenic arsenic sources

Data was acquired about chemicals (wood impregnates, pesticides), products (ammunition, fertilizers, fodder), and industrial activities *e.g.* mining and waste treatment sites. RAMAS project also studied the possible role of landfill leachates in mobilizing the naturally occurring arsenic from the surrounding till. The most relevant arsenic sources at Tampere region turned out to be the wood preservative plants and the old mine sites (Parviainen *et al*. 2006).

Altogether 14 wood treatment plants were identified from the study area, two of which were in operation until late 2006, when the use of chromated copper arsenate (CCA) -based wood treatment was banned. The negligent use of CCA products, inappropriate storage of CCA-treated wood and the use of the impregnated wood in the past have caused soil, surface water and groundwater contamination. Concentrations of arsenic in the contaminated soils at CCA plants in the study area range from 3 up to 12000 mg/kg. The majority of harmful elements from the CCA-contaminated soils have already leached and migrated over time and at present the leaching is slow but continuous. The ecotoxicological tests carried out within the RAMAS project showed that the soils heavily contaminated by CCA appeared to be toxic to some organisms. There were also indications that copper rather than arsenic might be the cause of environmental hazards.

Mining of sulphide ores leaves behind waste rock and tailings areas giving rise to acid mine drainage and consequent release of harmful elements. There are five mine sites in the study area two of which, the Haveri Cu-Au mine and the Ylöjärvi Cu-W-As mine, were studied in RAMAS Project. The ore in Ylöjärvi contained 1200-4600 mg/kg of arsenic, while at Haveri the arsenic concentrations were well below 100 mg/kg (Fig. 4).

Figure 4. Sampling of tailings and surface waters in the vicinity of the closed Haveri Cu-Au mine. The upper part of the tailings layer is clearly oxidized. The surface waters contain significant amounts of heavy metals.

The Ylöjärvi mining area has been identified as a potential source for arsenic contamination already years ago and, therefore, the nearby surface waters have been monitored since 1970's. The tailings area has an impact on the quality of surface waters and the active period of the mine can be traced from the lake sediment layers of nearby lakes and streams. The tailings area contains high concentration of arsenic ranging from 1000 to 2200 mg/kg resulting to run-off, which contains up to 250 µg/l of arsenic. The arsenic concentrations in surface water decline gradually downstream so that after seven kilometers, the load to Lake Näsijärvi is 3-14 µg/l. It is evident from the lake sediment profiles that during the mining period much more arsenic has been available along the route. At Lake Näsijärvi the sediment layers accumulated during mining contain 235 mg/kg of arsenic, whereas the natural background level was 17 mg/kg. The recent sediments still contain arsenic twice the amount of the natural background indicating that the tailings area is continuously stressing the environment.

2.3. Risk assessment

To assess the risks of environmental arsenic to human beings and biota, case-specific, quantitative human health risk assessments (HRA) and ecological risk assessments (ERA) were carried out. These risk assessments were focused on the specific site types previously identified in RAMAS – project. In the study area such site types included former wood treatment plants, which had used the CCA chemical, mine sites and areas with high level of natural arsenic in soil or groundwater (Sorvari *et al*. 2007).

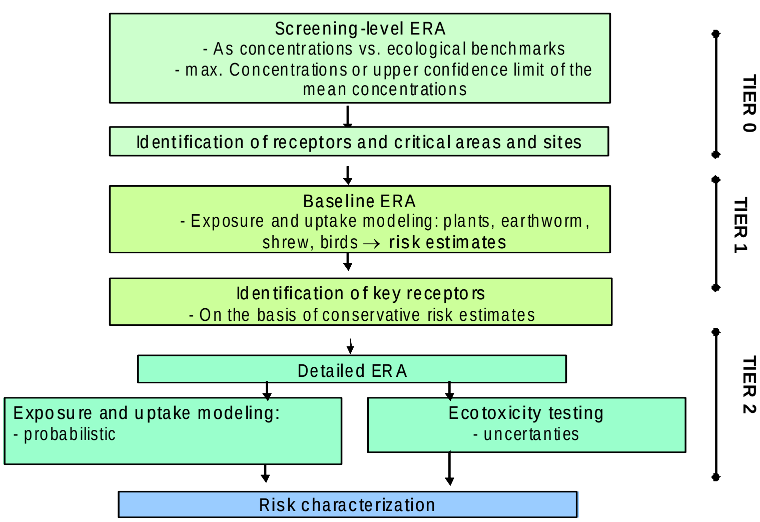

***Figure 5.** Tiered approach followed in the ecological risk assessment.*

The ecological risk assessment followed a tiered approach recommended on international and national levels (Fig. 5). In tier 0, the environmental concentrations of arsenic were compared with various ecological benchmark values, *i.e*. risk-based concentration limits. Exceeding of the benchmarks normally indicates the need for a more detailed i.e., baseline assessment (tier 1). Some uptake and intake models were used to derive risk estimates for the identified key species. In tiers 0 and 1, all available concentration data of arsenic in different media (soil, water, air, sediment) was used. In tier 2 we amended the data with the results of ecotoxicity test (Schultz & Joutti 2007) which measure harmful effects on test species at controlled standard conditions. As test species we used aquatic and terrestrial microbes and plants and soil animals. Besides toxicity of contaminants their environmental fate is of concern when assessing the factual risks. Hence, the combination of leaching tests, measuring the potentially available fraction of a compound, and ecotoxicity test with soil samples allowed the derivation of some estimates of possible environmental risks in the future.

The assessment of human health risks (HRA) was based on exposure modelling, human biomonitoring and epidemiological studies. In exposure modelling all the potential intake routes (food consumption, direct contact with soil and consumption of drinking water) were taken into account. Statistical estimates of intake from drinking water were calculated using Monte Carlo simulation based on the results from analyses of arsenic in well water samples. Exposure from other than site-specific sources was estimated from national level data. The potential exposure arising from the key anthropogenic hot spot areas *i.e.*, mine sites and CCA wood impregnation plants was also considered. In case of anthropogenic sources, the primary calculations were based on the highest arsenic levels in order to cover the "worst case" exposure scenarios. The results from the biomonitoring study (urine analyses) and the epidemiological study (number of the incidences of several cancer types) were used to verify potential human exposure and risks on population scale.

The ***ecological risk assessment (ERA)*** based on chemical data and exposure uptake modelling using conservative assumptions resulted in very high risk estimates, *i.e* hazard quotients (HQs) in the case of the former wood impregnation plant and the mine site. Judged by these results all study sites pose ecological risks varying from moderate to high. However, the ecotoxicological studies produced slightly different results showing high risk only in the case of the CCA plant and low risks in the case of the mine site and areas with high natural arsenic in till. When the results from different study methods were combined, the mine site appeared to pose the highest ecological risks compared with other study sites.

The ERA showed that even naturally occurring arsenic may pose adverse effects to the most sensitive species. Hence, we can expect that some selection of species has occurred at areas with high concentrations of naturally occurring arsenic in soil. The highest natural concentrations in soil are found in the deeper layers which limits the exposure of biota whereas the risks to groundwater quality may be high. In the case of excavations, such material can be brought in to surface layers where it can pose significant risks to biota. Due to the toxicity and steep dose-response effects of arsenic, safety margins need special attention in areas with elevated background levels. The risks to aquatic ecosystem adjacent to the mine site are not expected to decrease with time considering the vast amount of arsenic stored in the tailings area.

The ***health risk assessment*** indicated that the arsenic content in the dug well waters, typically below 1 µg/l, apparently do not pose any significant health risk to consumers. The average total arsenic intake within drilled well water users was estimated to be 0.56 µg/kg/d. The probability of exceeding the safe exposure level was estimated to be 5.9 – 46 % depending on the applied regulatory value. However, differences between the arsenic intake estimates in the different parts of the study area are considerable. The biomonitoring study verified exposure from drinking water, i.e., the concentrations of arsenic excreted in the urine were the highest among the users of water containing elevated concentrations of arsenic. However, in few cases high urinary concentrations were detected even though people were not exposed through drinking water. These elevated concentrations might be associated with occupational exposure or exposure, for example, in hobbies. Some evidence for the increased cancer incidence within Tampere region was obtained, although the results need to be interpreted with caution due to several sources of uncertainty that may bias the results. Nevertheless, this is a clear signal that underlines the need for further studies of the health impacts and preventive actions to reduce the exposure.

2.4. Risk management

In the first phase of the risk management task of the RAMAS project the methods applied in the management of arsenic-related risks were surveyed using literature and expert interviews as information sources (Lehtinen *et al*. 2006). These methods can be classed as policy instruments, informational mechanisms or technical methods. In the second phase, the study was focused specifically on the risk management procedures adopted in the study region and on the identification of possible development needs (Lehtinen *et al.* 2007).

There are no definite or established criteria for a \`good´ risk management (RM) process. However, some factors e.g. adequate connection with risk assessment and sufficient participatory practices, can be identified as being the main contributors of a ‘good’ RM process. The stakeholder involvement during RAMAS was extensive and based on the identification of the key local and regional level actors (Fig. 6).

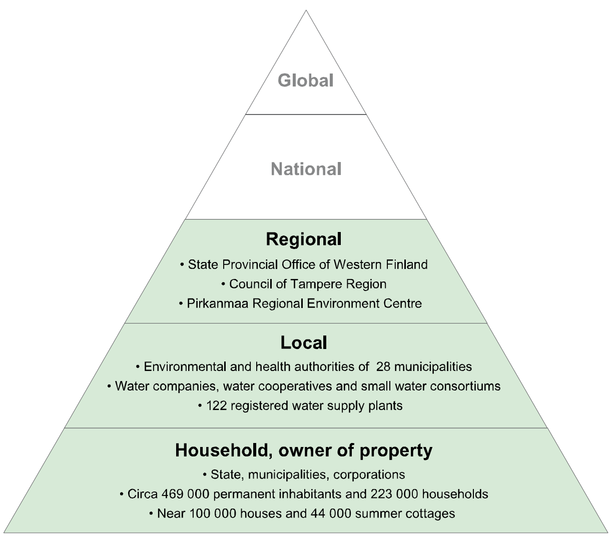

***Figure 6**. Stakeholders in the study area involved in the management of risks associated with environmental arsenic.*

According to the risk assessment carried out within RAMAS the major human health risks in the study region is the arsenic in drinking water originating particularly from drilled wells. These risks have been restricted *e.g.*, by expanding the water supply network. Such activities have also been subsidized by the State. It is important that these expansions are continued in the future. Here the regional land use and water supply planning play an important role. There are also household-specific methods available for the removal of arsenic from drinking water. However, these equipment have not yet been widely used.

In Tampere region, the population centers are focused the arsenic-rich areas and even in the vicinity of the old mine sites hence, posing a risk to human health. Expanding residential areas on, *e.g.* old mine sites or former wood impregnation sites, may result in significant additional risks to human health. It is also necessary to ascertain that in the future, the contamination at former mine sites will not extend to potential new residential areas.

Data on the contaminated sites which might contain arsenic *e.g.*, mine sites and wood impregnation plants, have been collected and are maintained in the national register. So far, remediation measures have been carried out at eight of the existing 14 wood treatment plants in the study area. At present, only few remediation methods are available for soils contaminated with arsenic and other inorganic compounds in Finland. Hence, soil excavation and treatment off site is still the most common remediation method. As an alternative option to remediation measures, the most contaminated hot spots at CCA-plant sites could be marked in field in order to avoid human exposure. Some of the former CCA-plants are located on important groundwater areas (class I). At such areas it is important to consider possible risks to groundwater quality. From the viewpoint of environmental risks, old mine sites in particular, are relevant owing to their large spatial scale. So far, no notable remediation activities have been realized at mine sites in the Tampere region.

It is recommended to restrict human activities particularly at the tailings areas of mine sites in order to eliminate the distribution of arsenic to the environment via air and surface run off. Here, active remediation measures would be one option. The wetlands between mine sites and larger water systems effectively bind arsenic and hence hinder its migration further in the water system. The functioning of such natural ’purification units’ should be maintained.

3. DISSEMINATION

Dissemination has been very active through out the RAMAS Project. The fact that data transfer is the most efficient risk management tool has been the leading idea. This is also the field which has been observed to be very challenging. There are many kinds of problems and improvements are needed at all levels. The data sources are scattered, the quality or the scale of the information is not corresponding the needs and there are also difficulties due to the different educational backgrounds of the people involved in the environmental management. Briefly, the available information does not easily reach the end users.

The RAMAS Project published 11 technical reports covering all the disciplines of the project (see www.gtk.fi/projects/ramas). These reports do not only describe the work carried out and the methods applied, but they also provide the primary, unpublished data collected from different sources and the new data produced by the project. All reports, except for two, are in English. The Final Report, however, was written in Finnish, because it was considered beneficial in order to reach the attention of the authorities in municipalities, regional environmental centres and licensing agencies. The international audience was addressed by 13 presentations in conferences. In addition, more than 40 presentations were given in national forums. The dissemination continues despite of the closing of the RAMAS project.

4. ENVIRONMENTAL BENEFITS AND LESSONS LEARNED

The environment, environmental research, management and decision making are expected to benefit from the outcome of the RAMAS project in several ways. The project produced a lot of information, which was refined to recommendations addressing aspects from initial data collection to risk management procedures. At least the following benefits can be mentioned:

• The spatial distribution of arsenic in natural environment is better understood. The areas with elevated or high arsenic concentrations in bedrock, soil and groundwater were identified in reasonable accuracy. The potential mechanisms of arsenic release from its primary source and the hazard it may pose to ecosystem and human health were reviewed.

• Anthropogenic arsenic contamination was evaluated and the most problematic sites were identified. The data collected from and around a closed sulphide mine showed that arsenic is continuously transported away from the source area and hence, distant ecosystems which are not adapted to elevated arsenic concentrations may be affected. A robust transport model was constructed to quantify the movement of arsenic in a watercourse impacted by a mine site

• It is important to realize that the harmful components may occur in several chemical forms and compounds. In till arsenic was found to be incorporated in primary sulphides derived from the bedrock. Sulphide fragments have preserved under the low-oxic conditions in the basal part of the till bed, while in the upper part of the sequence weathering has disintegrated the primary minerals and released heavy metals and arsenic. Released arsenic is then bound into secondary iron and manganese compounds enveloping other soil particles. Arsenic is remobilized from these phases under different conditions and with different rates. This has implications already in the assessment of risks. Quick standard field or laboratory tests do not necessarily reveal the actual risk related to slowly weathering phases. Another implication is that these aspects must be considered when selecting the remediation methods

• Significant amount of new ecotoxicological data was produced for different types of contaminated and natural soils evidencing the toxicity of the arsenic-bearing soils both to invertebrates and plants used as test organisms. These kind of undisputable arguments are valuable when debated weather remediating measures are needed or not

• Ecotoxicological laboratory methods were used and modified to be better applied to different soil materials. It is important that the results of the ecotoxicity tests are carefully and critically interpreted. Especially, when there are multiple contaminants present, enough data and sophisticated statistical methods are of great value to demonstrate and identify the causative compounds

• Toxicity tests indicated that concentration-effect curve is very steep for arsenic, i.e. the response was very dramatic once certain threshold concentration was exceeded. This observation points to the need of large safety margins regarding permitted arsenic concentrations in soil.

• It is possible, that some local species may be rather tolerant even to high arsenic levels. The balance between the species and the geochemical environment is achieved in time and it results to natural biodiversity. The situation is different, if the ambient geochemical balance is abruptly disturbed by e.g. human activity and the nature does not have enough time to adapt to this change

• Legislation, on national or EU level, does not fully take into account the elevated natural concentrations. The focus is on the anthropogenic contamination, although the adverse effects on organisms may be the same. Furthermore, both natural and anthropogenic sources may occur in the same areas, like in the case of mine sites or at a construction site where natural high-arsenic soils turn into anthropogenic when excavated

• It is strongly recommended that national geochemical mapping or monitoring programmes or other activities producing geochemical information, would consider a wider spectra of elements and not only those which are topical for the particular project itself. During the work of this project it was frequently found that otherwise extensive data sets didn’t include arsenic analyses. Generally, the reason was that arsenic was not considered relevant for the conducted study

• The goal of the RAMAS Project to carry out regional risk assessment and risk management for natural and anthropogenic arsenic and to consider the risks both for ecosystems and human health was quite ambitious. This was the first such attempt in Finland and there are not many examples from other countries either. Normally, the environmental risk assessment is carried out for spatially limited sites and for well-known chemical hazard. The selected approach, despite of being laborious, has also clear synergy benefits. It motivates to form a truly comprehensive view of the problematic issue, arsenic in this case. The concept including the identification of the potential arsenic sources and the compilation of exposure-response scenarios can be directly used for the planning similar activities elsewhere. There are also better changes for compact and more elaborated interpretation of results due to the wide scientific expertise engaged to multi-disciplinary projects. This kind of “screening project”, related to arsenic or other harmful elements, can be recommended for all countries.

5. RAMAS AND THE THEMATIC STRATEGY FOR SOIL PROTECTION

The RAMAS project was planned and realized in the spirit of the Thematic Strategy for Soil Protection (COM(2006)231 final). The multidimensionality of risk management decisions which consider soil contamination was acknowledged in RAMAS. Assessment of the environmental and human risks is a vital element, but other elements also influence risk management decisions such as available policy instruments, resources and technology, pressures on the use of land and other natural resources, existing operational structures (*e.g.* administrative practices, ownerships) or socio-cultural aspects. These other elements were surveyed and briefly discussed also in RAMAS.

Little attention in general has been paid to the protection of other receptors of arsenic compounds than groundwater, which could be used for drinking and other household purposes. During RAMAS project the human health effects and their regional extent, especially the risk of cancer, attracted the greatest attention among the stakeholders. It is clear that food safety and health is tightly interlinked in soil protection as stated in the thematic strategy. However, also the other receptors need attention. As it is stated in the soil strategy; “soil is interlinked with air and water in such a way that it regulates their quality.” In the case of larger contaminated areas, such as historical mining areas, the risk assessment and management should be based on larger drainage areas, even at river basin scale. Therefore, we support the idea of assessing possible synergies between soil protection and measures incorporated in river basin management plans under the Water Framework Directive.

Development needs of the eco-toxicological methodologies were once again confirmed in RAMAS. The task to define the differences on the bioavailability of arsenic originating from different sources, such as natural or anthropogenic sources, proved to be very demanding. In Pirkanmaa, even the separation of the origin of the soil contamination can be very complicated. On the other hand the separation between natural and anthropogenic origin is only needed in the decisions concerning liability issues, no separation is necessary in the planning of risk management.

***Figure 7**. A natural “purification unit” close to the Ylöjärvi mine.*

The mine sites investigated in RAMAS project are far too large for a remediation approach where the contaminated material would be transported to another location. Correspondingly, it is hard to believe, that any constructed arsenic removal facility would be cost-effective in the case of the studied tailings-lake-stream-lake system. Instead it is recommended that the functioning of the natural ’purification units’ (wetlands) should be maintained, maybe even strengthened. Further investigations are needed in order to understand better the mechanisms which bind arsenic in fresh water ecosystems (Fig. 7).

6. TRANSFERABILITY OF THE RESULTS

Arsenic is already an identified problem in many areas and is likely to cause problems in many others, although not yet recognized. This is due to the abundance of arsenic in geologic materials and its relatively common use in industry and agriculture. Presently, the industrial use of arsenic is restricted in many countries, but the historical consumption has left behind sites, which require remediation. Therefore, arsenic is a target for large number of projects worldwide. Due the multidisciplinary nature of the arsenic issue, it is necessary for environmental projects and programmes to learn from each other. This underlines the necessity of transferability, which in turn demands good documentation and the application of standardized methods when relevant. There are features, such as climatic conditions, geology and national legislation or practices, which put limitations for the application of information produced elsewhere. However, many things are also transferable, either as direct solid data or as model approaches applied elsewhere.

RAMAS project has aspired to promote the data transfer in all its actions. The project has published 11 reports, where the methodology has been described in detail and the primary analytical data is given. The reports provide also the geological context, sampling and other features, which may be needed when the representativeness of the information is evaluated. The reporting was planned in such a way that both national and international end users were taken into account. Altogether 13 presentations have been given in international Conferences and even more are to come. Several papers are still planned to be submitted to journals.

The relevancy of the primary, geochemical data is engaged to the geology and somewhat to the climate as well. Countries which have crystalline, metamorphic bedrock and similar glacial history as Finland benefit most from the data sets themselves, but also from the experience gained how to plan and conduct the geochemical sampling campaigns, how the sample treatment affects and which fraction to analyse. The limited transfer of arsenic from soil to crops and wild berries, the presence of arsenic in water ecosystems both in dissolved and solid forms and over all arsenic concentrations in different geologic materials are examples of aspects, which can be found useful in all environments.

One way to improve the transferability is to use standardized methods. There are a number of ISO- and EN-standards, which give guidance to various laboratory methods for environmental samples. This, of course, aims to enhance the applicability of the produced data regardless of its origin. However, the standardisation is not fully comprehensive and if such internationally agreed methods are not available, *e.g*. the Decree on the Assessment of Pollution Level and Remediation Need for Soil (2007), given by Finnish Government postulates the use of otherwise well-established practises. Presumably, this is the case in many other countries as well. Therefore, the transferability is dependent on the detailed documentation of the methodology as the RAMAS Project has done.

In this context it may be useful to question, however, also the principle of standard methods themselves. Are they really optimal for the particular material under investigation? There is no doubt, that there must be generally accepted concepts, but are the results for the low-pH glaciogenic soils typical for northern areas comparable with those for, e.g the Mediterranean soils of different chemistry and origin. What is good for contaminated soils does not necessarily work for natural soils. It might be useful to try somewhat tailored methods to meet the local requirements and if possible, combine the results from different approaches. Clearly, more development and international co-operative research is needed in this field.

In Finland, more sophisticated risk assessment procedures have lately become more common instruments in the decision making of soil remediation. Still, the use of ecotoxicological methods as part of risk assessment is occasional, probably because the ecotoxicological testing is usually time-consuming and expertise is not easily available. However, the wider use of biological tests should be encouraged, since they provide direct information of the effects on biological systems, which are often very difficult to assess by other means. They also pass the basic question about the bioavailable fraction of contaminants always connected to the use of concentration data. The very limited database of ecotoxicity of harmful elements in natural Finnish soils and, especially for the organisms typically used in laboratory tests (earthworm, potworm, ryegrass etc.) complicated the interpretation of the ecotoxicological data in RAMAS Project. This calls for combined efforts to create such databases for international use.

An important outcome from any project, which however is often ignored, is the identification of gaps in data or in understanding processes and obvious defects and shortcomings in methods. If adequately appraised and clearly expressed, these aspects are valuable for future projects and also for the authorities and other end users when they are evaluating the state of knowledge in their fields of responsibility. Therefore, the RAMAS Project has carefully analysed all the steps taken from the collection of historical arsenic data to the risk assessment and risk management procedures and has discussed in length about the development needs in the Final Report directed to the Finnish audience, authorities in municipalities and environmental agencies and other target groups. The topic-specific discussion in English is available in the thematic reports available in the project's website and in a number of conference papers.

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The project has produced a number of Reports. The following reports have been published:

1. Natural Occurrence of Arsenic in the Pirkanmaa Region in Finland
2. Anthropogenic Arsenic Sources in the Pirkanmaa Region in Finland
3. Management of arsenic risks in the Pirkanmaa region – Survey of available risk management instruments and tools (in Finnish)
4. Arsenic and other elements in agro-ecosystems in Finland and particularly in the Pirkanmaa region
5. A transport model of arsenic for surface waters - an application in Finland
6. Arsenic Ecotoxicity in Soils
7. Arsenic removal from groundwater and surface water - Field tests in the Pirkanmaa Region, Finland
8. Risk Assessment of Natural and Anthropogenic Arsenic in the Pirkanmaa Region, Finland
9. Risk Management of Environmental Arsenic in Finnish conditions -case Pirkanmaa region
10. Natural and anthropogenic arsenic contents in the Pirkanmaa region. Arsenic contents in different soil horizons, in tailing sand and dust, in water at quarries, at CCA wood preservative plants, and at landfills and in natural berries, mushrooms and birch sap (in Finnish)
11. Arsenic in the Pirkanmaa regoin in Finland - Ocurrence in the Environment, Risk Assessment and Risk Management. Final results of the RAMAS-project (in Finnish)

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