FEASIBILITY STUDY FOR LOJANE MINE, MACEDONIA

FINAL REPORT

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Client: UNDP-Bratislava Regional Centre
Tel: + 421/259 337 176,
Fax: + 421/259 337 450
E-mail: radka.konderlova@undp.org

- Contact Address: Grosslingova 35
811 09 Bratislava, Slovak Republic

- Contact Persons: Mrs. Radka Konderlová, Programme Associate

Contract: **Consulting services for preparation of a feasibility study for Lojane Mine, Macedonia**

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Contractors:

Lot 1 **University "Ss. Cyril and Methodius"- Skopje**

Contact Data: Faculty of mining and geology - Stip
Goce Dlecev 89
2000 Stip, Republic of Macedonia
www.rgf.edu.mk

Contact Person: *Dejan Mirakovski, project manager*
mirakovskid@yahoo.com

Lot 2 **DEKONTA, a.s.**

Contact Data: *Headquarters:* Podhoří328/28
400 10 Ústí nad Labem , Czech Republic
Contact address: Volutova 2523, 158 00 Prague, Czech Republic
Tel: +420 2 355 222 52-5
Fax: +420 2 355 222 54
E-Mail: cermakova@dekonta.cz ,vana@dekonta.cz
www.dekonta.cz

Contact Persons: Hana Čermáková, foreign projects coordinator
Jan Váňa, project manager

Elaborated by: Mr. Jan Váňa, project manager

Reviewed by: Jan Vaněk, head of environmental division

Approved by: Mr. Robert Raschman, managing director

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Confidentiality statement

The data, observations, determinations, and recommendations presented in this report are the work product of Contractors and UNDP and are, as well as any other information contained herein, the confidential information of Contractors and UNDP, (collectively referred to hereinafter as "Confidential Information") and are provided solely with the understanding and agreement that he Confidential Information will be treated as such, and the Confidential Information will be provided and/or disclosed only to Companies/ Institutions and their contractors and agents, solely on a need-to-know basis and with each being apprised of the nature of the Confidential Information and with the agreement of each party to maintain such in confidence.

Acronyms and abbreviations used

AMD – acid mine drainage
AP – acid producing potential
ARD – acid rock drainage
DCF – discounted cashflow
EnvSec – Environment and Security Initiative
EPA – Environmental Protection Agency, USA
ERP – Emergency Response Plan
FS – Feasibility Study
FSP – Field Sampling Plan
HASP – Health and Safety Plan
HHE – Human health effects
HM – heavy metals
ICP – inductive coupled plasma
MOEPP – Ministry of Environment and Physical Planning
MSDS – material safety data sheet
NATO – North Atlantic Treaty Organization
NP – neutralization potential
OSCE – Organization for Security and Co-operation in Europe
OSHA – Occupational Safety and Health Agency, USA
PCBs – Polychlorinated Biphenyls
PIMS – phosphate induced metals stabilization
ppb – parts per billion (= µg.kg^{-1})
ppm – parts per million (= mg.kg^{-1})
PRB – permeable reactive barrier
QA/QC – Quality Assurance/Quality Control
TA – toxicity assessment
TC – Toxicity Characteristic
TLV – Threshold limits value
ToR – Terms of Reference
UNDP – United Nations Development Program
UNEP – United Nations Environment Program
ZVI – zero valent iron

Glossary of specific terms

Adit: A nearly horizontal passage from the surface by which a mine is entered and drained.
Aerobic: In the presence of oxygen.
Alkalinity: The capacity of water to accept protons (acidity). Alkalinity is imparted to natural waters by bicarbonate, carbonate, or hydroxide anions.
AMD: Acid mine drainage, characterized by low pH, high sulfate, and high iron and other metal species.
Anoxic: In the absence of oxygen.
ARD: Acid Rock Drainage.
Beneficiation: Physical treatment of crude ore to improve its quality for some specific purpose. Also called mineral processing. Beneficiation is restricted to the following activities: Crushing; grinding; washing; dissolution; crystallization; filtration; sorting; sizing; drying; sintering; pelletizing; briquetting; calcining to remove water and/or carbon dioxide; roasting, autoclaving, and/or chlorination in preparation for leaching; gravity concentration; magnetic separation; electrostatic separation; flotation; ion exchange; solvent extraction; electro winning; precipitation; amalgamation; and heap, dump, vat, tank, and in situ leaching.
Cation exchange: A reversible exchange process, that uses a resin, mineral or other exchange medium, in which one cation is removed from solution and replaced by another cation displaced from the exchange medium without destruction of the exchange medium or disturbance of electrical neutrality. The process is accomplished by diffusion.
Cationic species: Ions with a positive charge.
Classification: Separation of particles in accordance with their rate of fall through a fluid (usually water). The hydrocyclone is the most commonly used classification machine.
Comminution: Crushing and/or grinding of ore by impact and abrasion. Usually, the word "crushing" is used for dry methods and "grinding" for wet methods. Also, "crushing" usually denotes reducing the size of coarse rock while "grinding" usually refers to the reduction of the fine sizes.
Concentrate: The concentrate is the valuable product from mineral processing, as opposed to the tailing, which contains the waste minerals. The concentrate represents a smaller volume than the original ore.
Contamination source zone - A source zone is a saturated or unsaturated subsurface zone containing hazardous substances, pollutants, or contaminants that acts as a reservoir that sustains a contaminant plume in groundwater, surface water, or air, or acts as a source for direct exposure. This volume is or has been in contact with separate phase contaminant (non-aqueous phase liquid or solid). Source zone mass can include sorbed and aqueous phase contaminants as well as contamination that exists as a solid or non-aqueous phase liquid.
The redox potential. A measure of the ability of a natural environment to bring about any oxidation or reduction process by supplying electrons to an oxidizing agent or accepting electrons from a reducing agent.
Extraction: The process of removing ore from the ground.
Flotation: Separation of minerals based on the interfacial chemistry of the mineral particles in solution. Reagents are added to the ore slurry to render the surface of selected minerals hydrophobic. Air bubbles are introduced to which the hydrophobic minerals attach. The selected minerals are levitated to the top of the flotation machine by their attachment to the bubbles and into a froth product, called the "flotation concentrate." If this froth carries more than one mineral as a designated main constituent, it is called a "bulk float". If it is selective to one constituent of the ore, where more than one will be floated, it is a "differential" float. The

remaining slurry left after flotation is called the "flotation tailing." Flotation is the dominant method of mineral concentration currently in use.

Gangue: The fraction of ore rejected as tailing in a separating process. It is usually the valueless portion, but may have some secondary commercial use.

Grade: Percentage of a metal or mineral composition in an ore or processing product from mineral processing.

Metallurgy: The science and art of extracting metals from their ores, refining them, and preparing them for use. Metallurgy consists of three major disciplines: mineral processing metallurgy, extractive metallurgy, and physical metallurgy.

Mill: Includes any ore mill, sampling works, concentration, and any crushing, grinding, or screening plant used at, and in connection with, an excavation or mine.

Mine: An opening or excavation in the earth for the purpose of extracting minerals.

Mineral: A naturally occurring, solid, inorganic element or compound, with a definite composition or range of compositions, usually possessing a regular internal crystalline structure.

Mineral processing: Preparation of ores by physical methods, a subcategory of metallurgy. Methods of mineral processing include comminution, classification, flotation, gravity separation, etc.

Open Stope: In competent rock, it is possible to remove all of a mineralized ore body, resulting in an opening of considerable size. Such large, irregularly-shaped openings are called stopes. The mining of large inclined ore bodies often requires leaving horizontal pillars across the stope at intervals in order to prevent collapse of the walls.

Ore: A natural deposit in which a valuable metallic element occurs in high enough concentration to make mining economically feasible.

Overburden: Material of any nature, consolidated or unconsolidated, that overlies a deposit of ore that is to be mined.

Oxidizing: Increasing in oxidation number (valence charge). The process of oxidation involves a loss of electrons.

Passive treatment systems: Systems that do not require periodic or continual maintenance or upkeep to maintain system effectiveness. Examples include aerobic or anaerobic wetlands, anoxic limestone drains, open limestone channels, alkalinity producing systems, and limestone ponds.

pH: The negative logarithm of the hydrogen ion concentration, in which $pH = -\log [H+]$. Neutral solutions have pH values of 7, acidic solutions have pH values less than 7, and alkaline solutions have pH values greater than 7.

Reducing: Decreasing in oxidation number (valence charge). The process of reduction involves a gain of electrons. Reduction-oxidation potential: The redox potential or Eh.

Roasting: The oxidation of ore or concentrate (usually of sulfide concentrates) at an elevated temperature in order to obtain metal oxides. The material is not melted. Roasting is usually used to change metallic compounds into forms more easily treatable by subsequent processing.

Room and Pillar: This method is suitable for level deposits that are fairly uniform in thickness. It consists of excavating drifts (horizontal passages) in a rectilinear pattern so that evenly spaced pillars are left to support the overlying material. A fairly large portion of the ore (40%-50%) must be left in place. Sometimes the remaining ore is recovered by removing or shaving the pillars as the mine is vacated, allowing the overhead to collapse or making future collapse more likely.

Shaft: An excavation of limited area compared with its depth, made for finding or mining ore or coal, raising ore, rock or water, hoisting and lowering men and materials, or ventilating underground workings.

Stoping: In this method, mining is carried out from the bottom of an inclined or vertical ore body upwards, as in open stoping. However, most of the broken ore is allowed to remain in the stope in order both to support the stope walls and to provide a working platform for the overhead mining operations. Ore is withdrawn from chutes in the bottom of the stope in order to maintain the correct amount of open space for working. When mining is completed in a particular stope, the remaining ore is withdrawn, and the walls are allowed to collapse.

Slag: A mixture of oxides (sometimes halides) of metals or nonmetals formed in the liquid state at high temperatures. A flux is usually added to encourage slag production, where the slag represents the undesirable (waste) constituents from smelting and refining an ore or concentrate.

Smelting: Obtaining a metal from an ore or concentrate by melting the material at high temperatures. Fluxes are added that, in the presence of high temperatures, reduce the metal oxide to metal resulting in a molten layer containing the heavy metal values and form a slag layer containing impurities. Smelting is usually performed in blast furnaces.

Spoil: Debris or waste material from a mine.

Stope: An excavation in a mine, other than development workings, made for the purpose of extracting ore.

Tailings: Residue from milling processes (e.g., flotation tailings, gravity tailings, leach tailings, etc.).

Vein: A mineralized zone having a more or less regular development in length, width, and depth to give it a tabular form.

Executive summary

This report presents findings from preliminary investigations described as Lot 1 - Baseline Study and findings/recommendations from Lot 2 – Feasibility Study that have been completed for UNDP office in Macedonia and UNDP Regional office in Bratislava respectively.

The Lot 1-Baseline Study has been carried out by specialists of University "Ss. Cyril and Methodius", Faculty of mining and geology Stip.

The data of Lot 1 are complied and presented in the form of Environmental Impact Assessment study in order to provide high-resolution description of the environment on the site affected, sources of pollution and impacts and risks associated.

Considering the tasks stated in ToR as much as nature of works associated a full investigation of the local conditions, available written data and specially designed sampling program were preformed, starting in February 2006 and completed in June 2006.

Collection of relevant data started with reviewing, evaluation and compilation of relevant data (physical, biological and socio-cultural data) for the study area:

- Soil/water quality sampling/analyses
- Hydrogeology/Hydrology sampling/measurements
- Geotechnical sampling/analyses
- Terrestrial measurements
- Biological data collection/sampling/analyses
- Multiple forms of assessment of public perception of the proposed actions will be conducted and (if possible) realistic approach to the future land usage will be defined.

The Lot 1- Baseline Study provides comprehensive information on:

- Description of the Lojane Mine site and its existing settings, through the maps, site plans, aerial photographs and other graphic aids and images as appropriate, including general layout, size, location, physical characteristics, biological environment and socio-cultural setting.
- Identification of sources of contamination, specification and quantification of contaminants involved; routes of exposure and zone affected,
- Soil/water/air quality sampling/analyses
- Geochemistry/Hydrogeology sampling/measurements
- Environmental Impact Assessments
- Environmental Risks Assessment (including relevant stability issues)
- Documentation and storage of the results/findings in a form of project progress reports and Baseline study.

The Lot 2 – Feasibility Study has been carried out by Dekonta a.s. (Czech Republic) within the period June 22 – July 25, 2007. The FS summarizes data acquired from the field work and laboratory tests performed - site reconnaissance, samples collection, laboratory work, mineralogical study, geomechanic tests, solidification/stabilization tests, and tests of contaminated water treatability.

Based on the field works and laboratory tests the waste characterization is provided – the mining/ore processing wastes within the area of interest are mostly classified as hazardous waste due to high concentrations of contaminants identified (i.e. As, Sb, Ni, and Tl potentially) as well as due to their high leachability (except some waste rocks). Based on the data collected within the frame of Baseline Study completion and complementary data acquired within the frame of Feasibility Study preliminary human health Risk Assessment has been carried out. This RA indicates unacceptable risks posed by the mining/ore processing wastes insecurely dumped in both the contamination source zones – i.e. the tailings dump at Rudnicka kolonija and the area of former roasting facility at Tabanovce.

The broad search in the internet sources served as basis for description of prospective remediation/cleanup techniques, case studies, unit costs estimation and finally selection of applicable methods for the corrective measures. On the basis of the investigation of local conditions (economic, legal) the proposal on mitigation/corrective measures is provided. With respect to the financial demandingness of the site remediation/rehabilitation it is recommended to split the works proposed into five phases that are further broken down into partial stages/tasks that can stand alone from environmental and engineering feasibility perspectives should the next funding increment be delayed or unavailable.

The Feasibility Study also presents recommendations for the development of Emergency response Plan and recommendations for the development of Monitoring Plan.

The cleanup method proposed for the short term risk reduction is excavation and transport of mining/ore processing waste from the area of former roaster to the tailings dump where the dump would be capped with geosynthetic liner and recultivated.

1 Introduction and project background

1.1 Introduction

The Feasibility Study for Lojane Mine, represents a first step within the targeted program of the Environment and Security Initiative (UNDP, UNEP, OSCE and NATO), “Reducing Environment and Security Risks from Mining in South-Eastern Europe”, to decrease trans-boundary environmental and safety risk posed by sub-standard mining and mineral processing operations in the past, as well as to reduce the significant risk associated with non-operational, abandoned site where large quantities of physically and chemically unstable and poorly contained mine wastes are stored.

The project is a pilot under the project “Reducing Environment and Security Risks from Mining in South-Eastern Europe” described above and a follow up to the 2000 UNEP Post-Conflict Environmental Assessment, which focused, among other things, on severely polluted “hot spots” and industrial mines in Republic of Macedonia requiring immediate attention.

The main objective of the project is to produce a Feasibility Study for the Lojane Mine aiming to recommend short-term risk reduction and long-term remediation and environmental protection measures for the Lojane Mine which was identified as mining related hot spot threatening the environment as well as public health and safety, both in local and transboundary context.

1.2 Project background

Lojane Chromium and Antimony Beneficiation Plant and Mine is an abandoned mine site located north of Kumanovo, near the border with Serbia & Montenegro and Kosovo. This mine was active in the period 1923 till 1979 when antimony, chromium and arsenic were extracted. Originally the mine was started and operated by Italian Joint Venture Company until start of the II WW when mine was operated under control of occupational forces. After the war ending the mine and all facilities where nationalized and new State owned company was formed to control and operate the mine. The headquarters of this company where located in Bujanovac, today Serbia. In mid 60's this company was associated to State owned Zajaca Metal Company from Zajaca, Serbia.

Until 1964 the ore concentrate was exported to the London Metal Exchange, but the export was stopped after it was confirmed that the concentration of arsenic was too high, and not in accordance with environmental laws. Starting from 1964, the ore concentrate was exported to the Zajaca metal facility in Serbia.

Under not completely explained reasons (most probably unfavorable economic circumstances) mine stop the activities in 1979.

Due to fact that all operators of the mine were located in Serbia, very limited amount of official documents concerning the mine activities, including mine plans, were available. After indications that copies of mine plans and documents are preserved in State Archive in Kumanovo, working group tried to contact and obtain the documentation, but from unexplained reasons no official answer was received. Un-official information point that all documentation about the mine was taken for review by some company (no name was disclosed) interested to re-open the mine. During the project activities the working group was unable to asses/ reviews this documentation.

Since no original documentation about mine activities was available, all data disclosed are based on limited terrestrial measurements, review of other available documentation and estimation and conclusion form the on site recognition. Due to fact that some facilities were not accessible (like underground facilities) only limited estimations about them are disclosed. After the cessation of mining activities in 1979, complete infrastructure i.e. production facilities (underground workings), beneficiation (flotation and smelting -ore frying) facilities, ore waste dump and tailings ponds, as much as storage yards, silos and workshops were abandoned without undertaking any conservation measures. The old adits, dumps, roads and ruined objects become very dangerous sources of contamination with heavy and toxic metals (As, Hg, Cr^{6+} and Sb).

The most affected area is between the villages Lojane, Vaksince and Tabanovce.

The old Lojane Mine Site is located between the villages Lojane, Vaksince in area called Rudnicka Kolonija (Mine colony). The total mine site area is about 10 km^2. The area of consideration includes several locations where old production, storage and transportation facilities existed.

Specifically, in the adjacent area of the former arsenic-antimony mine Lojane (along the flow of the River Suva) old mine shafts and adits are located (4 mine adits and 3 ventilation shafts were identified, scattered on both sides of the valley). In the higher part of the valley, along the south foot of the hill a ruins from small mining settlement and mine office/service buildings are scattered on the area of approximately 1.000 m2. In the same area 3 waste rock dumps and mined ore stockpiles are located. Waste rock dump are relatively small and each contains 20.000 to 50.000 tons waste rocks from mining operations. Additionally ore stock pile containing 5.000 tons of high grades Sb, Cr ore is located over the one of the waste rock dumps. This dumps were left unprotected and are prone to the mechanical disintegration, wind and water erosion so they presents a significant source of contamination in the areas between villages of Lojane and Vaksince.

Also, along the road connecting villages of Vaksince and Lojane in the close proximity of the locality named Mining Colony there are remains of the old arsenic-antimony beneficiation plant (ruins from the processing plant as much as some administrative and service building area). Dry tailings pile and arsenic concentrate storage pond are situated in this area just near the old flotation plant. The tailings pile covers a surface of app. 17,500 m^2, between the old processing plan and the road. It’s estimated that tailings pile contains around 450,000 tons of fine sized material with an average concentration of arsenic and antimony up to 1-2 % As±Sb. Concentrate storage pond is a stone build structure with estimated volume of app. 5,000 m^3, and its estimated that contains around 15,000 tons high grade concentrate (>50% arsenic sulphides). At the same location a local school and few residential and commercial objects are located.

The next source of contamination with toxic metals is so called arsenic-antimony ore smelting-frying facility, located 4,5 kilometers east of the flotation facility, North West of village of Tabanovce and near the international railway station Tabanovce where custom and police control buildings are also located. The facility ruins and storage yard cover surface of 8,800 m^2. Estimated quantity of 5,000 tons arsenic concentrate (realgar) is stored at the open storage yard, left completely unprotected. In addition, near the smelting-frying facility there are around 2,500 barrels (almost disintegrated) filled with As_2O_3 and some other unknown substances.

The concentrates from the flotation facility to the smelting-frying facility were transported along a narrow railway track. Along the transport track, material that was lost during the transports due to its content presents a dangerous source of contamination. Nowadays this track is completely disintegrated and area is turned into agricultural land.

All the above-mentioned factors indicate without any doubt that the area of the Lojane Mine has been contaminated with heavy and toxic metals.

Only very limited amount of data about the level, intensity and aureole of contamination were available, with exemption of only few papers/reports and Local Environmental Action Plan which briefly describe the site and issues associated.

Based on the data mentioned afore, following issues concerning site surrounding contamination were reported;

- surface water contamination with HM and As;
- groundwater contamination with HM and As;
- soil pollution with direct impact on quality of food produced
- fugitive dust emission/ low air quality;
- reduction of commercial value of the properties and food produced in adjacent area.

It must be noted that, although discussed, no valid data (like toxicological data, HHR data) on the issues concerning human health effects of supposed contamination with HM were found.

1.3 Project objectives

1.3.1 General objectives

Generally, the scope of work, as defined in the ToR, consists of:

a) clear identification of sources of contamination; specification and quantification of contaminants involved; routes of exposure and zone affected, and the associated risks;

b) identification of available technologies (procedures) for closure, clean up and rehabilitation according to planed future land usage, including cost estimation for each and selection of optimal technology/ies through the diverse criteria analyses, as well as the new risks associated with remediation works;

c) exploring the feasibility of cost-effective clean up, closure and rehabilitation measures in site specific conditions, and to draft plans for return of the disturbed land to a stable, productive and self-sustaining condition, taking into account beneficial uses of the site and surrounding lands.

The study should incorporate baseline data collection (environmental site assessments, public hearings and interviews, database and literature review) to the level of extent which will be sufficient to define applicable closure, cleanup and rehabilitation measures, landscape models (maps) according to the (proposed) future land use, pilot scale tests of selected technologies in labs or real term conditions, basic plans drafting, costs analysis, implementation scheduling (action plans), benefits and monitoring performance plans. Assessment of risks and planning for accidents related to the site should be included that will help the stakeholders to understand why this is to be done and what the results can be.

The feasibility study should help to set up guidelines (at national level) for abandoned sites rehabilitation, and preparation of emergency response plans (early warning systems and emergency awareness and preparedness).

During the process of bids selection and considering available funding and the nature of works associated, the tasks were clearly separated and works was performed in two separate lots:

Lot 1 - Baseline study - complete Environmental Impact Assessment (EIA) for the area of consideration, which will provide high-resolution and accurate quantitative/qualitative data describing the environment on the site affected, sources of pollution and impacts and risks associated.

Lot 2 - Rehabilitation/Remediation plans – description of applicable cleanup and remediation measures, selection of possible methods for site cleanup and rehabilitation, pilot tests of selected methods, design of clean up, closure and rehabilitation measures for site specific conditions, plans drafting, costs analysis, implementation scheduling (action plans), and monitoring performance plans.

1.3.2 Terms of reference

The following summarized terms of references were given by the implementing agency - UNDP.

Task 1: Description of the proposed project site – A full description of the Lojane Mine site and its existing setting.

Task 2: Description of the Environment - Assemblage, evaluation and presentation of data on the relevant characteristics of the study area, including physical, biological, and socio-economic & cultural information.

Task 3: Description of Applicable Cleanup and Rehabilitation Measures**:** Comprehensive review of cleanup and rehabilitations techniques should be given. This section should include:

a) Site cleanup:

- Selection of disposal area (if needed) and description of protective measures to be taken at the disposal area. Special attention should be given to long term water impermeability and stability of selected disposal site;
- Description of cleanup methods, necessary equipment and transportation routes to move the toxic wastes from the uncontrolled environment of the impacted site to a controlled treatment or disposal area. Special measures must be proposed to reduce possible negative impacts on the environment as much as health and safety risks on the personnel involved during the clean up operations.

b) Landscape modeling:

- Detailed 2D and 3D models of area involved should be developed according to the proposed future land use, drainage pattern and aesthetic value of the area.

c) Soil rehabilitation:

- Description of possible containment technologies for soil (cover, cap, liner and cap/cover).
- Description of immobilization technologies (solidification and fixation).
- Description of treatment technologies (recycling, thermal and soil washing processes);
- Description of stabilization technologies.

d) Water treatment (rehabilitation)

- Description of possible water treatment technologies to remove toxic contaminants from the water streams. Special emphasis on passive treatments technologies allowing the naturally occurring chemical and biological reactions that aid treatment to occur in the controlled environment of the treatment system, and not in the receiving water body.

- Alternative low tech or low cost/low maintenance systems could also be proposed.

Task 4: Pilot scale tests of selected technologies: Selected rehabilitation (treatment) technologies should be tested in real conditions is order to prove their feasibility for site specific conditions, as much as to determine exact operational parameters. All tests (treatability studies) should be fully documented and results should incorporate in Final FS report. Alternatively, if the same pilot scale works have been done elsewhere i.e. at the sites similar to the project site, experiences gained by others could be used.

Task 5: Plans drafting: Based on baseline data and results from the real condition tests, or alternatively from the experiences gained in other pilot scale tested technologies at similar sites, detailed plans for clean up and rehabilitation of the Lojane Mine site should be drafted. The plans should include cost analysis (discounted cash flow), implementation schedule, detailed maps (including models and photographs) and drawings. The plan should also include the risks associated with the clean and remediation activities.

Task 6: Recommendations for the development of an Emergency Response Management Plan: Recommendations should be made for the development of an Emergency Response Plan to ensure that procedures are in place to handle any emergency. The Plan should be based on the assessment of risks and planning for accidents related to the site.

Task 7: Recommendations for the development of a Monitoring Plan: Recommendations for the development of a Monitoring Plan to ensure successful implementation of cleanup and rehabilitation measures and setup of performance evaluation criteria's should be given.

Task 8: Workshops organization: In order to present the results of the study and to share the experience and knowledge gained throughout the project realization with other similar projects in the region, a workshop will be held. Also, at the beginning of the project workshops will be organized to inform the affected communities on the objective of the feasibility study and the planned activities. The workshop will be organized by the Macedonian company in collaboration with UNDP Country office in Skopje and the Ministry of Environment and Physical Planning. Representative(s) of the Czech organization is expected to participate at the workshop and present the results of the study together with the Macedonian company.

Task 9: Knowledge capture and documentation: Throughout the entire project, experiences will be recorded / documented so that learning can be disseminated.

1.4 Legislation, regulations, policy and administrative framework

The main governmental body in charge of specific matters is Ministry of Environment and Physical Planning. Additionally, some portions of the works could require involvement of State Technical Inspection, Ministry of Agriculture, Forestry and Water Resources, Ministry of Transportation and Ministry of Health.

The following are some of the extracts from the legislation related and relevant to the actual conditions on site, as much as planed works on the project.

The Constitution of Macedonia

The Constitution of The Republic of Macedonia (1992) recognizes the right to private property and to protection by the State of property. Part II of the Constitution enshrines the fundamental rights and freedoms of the individual to access land and to protect and conserve the environment.

The Law for Environment - (Jun 2005)

Passed in June 2006 this piece of legislation is the principal Act governing and regulating environmental issues in Macedonia. The Act's main functions include the protection of the environment and control of pollution in particular to provide for the health and welfare of people, animals, plants and the environment in general. The act is in general compatible with EU directives and is followed with several attendant Regulation's.

The Law of Mineral Resources Extraction (Official gazette of R.M. 19/98)

The legal framework for mining and mineral resources development in Macedonia is the Law of Mineral Resources Extraction of 1998. The Act stipulates regulations in acquiring prospecting licenses and mining and mineral rights. This law arranges conditions and manners for conducting exploration and extraction of mineral resources, explorations concessions, mining concessions, building, maintenance and operation of mining and mineral processing plants, machines, instrumentation, health and safety protection, exploration and mining measurements and plans. It also deals with environmental issues pertaining to prospecting and mining with specific reference to obligation for rehabilitation of the affected area.

An entire set of laws and regulations applied to specific area of interest follows:

Law on Nature Protection (“Official Gazette of RM” No: 67/04);

Low on Waters (“Official Gazette of RM” No: 4/98, new draft law proposed January 2005)

Low on Air quality (“Official Gazette of RM” No: 67/04);

Law on Technical Inspection (“Official Gazette of RM” No: 48/99);

Law on Waste (“Official Gazette of RM” No: 37/98, and 16/04)

Law on Investment Buildings Development (“Official Gazette of RM” No:15/90);

Law on Spatial and Urban Planning (“Official Gazette of RM” No: 45/05);

Law on Occupational Health and Safety (“Official Gazette of SRM” No: 18/98);

Law on the Maintenance of Public Hygiene, Collection and Transportation of Communal Solid and Industrial Waste (“Official Gazette of RM” No: 37/98);

The Law on Harmful Noise Prevention (“Official Gazette of SRM” No: 28/84;10/90; and 62/93);

Criminal Code of RM (“Official Gazette of RM” No: 37/96);

The Law on Public Works (“Official Gazette of RM” No: 45/97);

The Law on Toxic Matters Production (“Official Gazette of SRM” No: 4/78);

The Law on Trade in Toxic Matters (“Official Gazette of RM” No: 13/91);

The Law on Transportation of Toxic Matters (“Official Gazette of RM” No: 27/90);

Regulations:

Book of Regulations on the maximum permissible concentrations and quantities harmful matters in ambient air (MOEPP 10/05).

Book of Regulations on the maximum permissible concentrations and quantities of other harmful matters that may be released into the air from individual sources of pollution (“Official Gazette of SRM” No: 3/90).

Book of Regulations on the manner and the terms for submitting the reports on performed measurements, control and recording of measurements of released harmful matters into the air (“Official Gazette of SRM” No: 9/76).

Book of Regulations on the manner and the terms for measurements, control and recording of measurements and of released harmful matters into the air from facilities, plants and devices that could pollute the air above the maximum permissible concentrations (“Official Gazette of SRM” No: 13/76).

Book of Regulations on the methodology of monitoring and identification of harmful matters in the air (“Official Gazette of SRM” No: 9/76) .

Considering the fact that the some laws and regulations are rather old dated and contain certain system out-of-date solutions, there is an ongoing process for adoption of the new versions compatible with EU legislative.

1.5 Project team

The project team completing the Feasibility Study comprised of local specialist from University "Ss. Cyril and Methodius", Faculty of mining and geology Stip, and Czech specialists from company Dekonta a.s.

The project team comprised of specialists understanding the regulatory factors and technical issues involved in investigation and remediation of contaminated areas.

Brief profiles of the team members are presented in the following tables.

University "Ss. Cyril and Methodius", Faculty of mining and geology Stip

The members of team completing the Baseline Study are listed in table 1.1 further.

Table 1.1 – Team of the Baseline Study

Name	Position in team / Role	Task Assignment / Responsibility
Expert staff		
Todor Delipetrov Dean of the Faculty, Geology Dept.	Team leader	Project development Overall Quality control and Quality assurance Geophysics Hydrogeology
Dejan Mirakovski Mining Dept.	Project Mananger	Project initiation and coordination of working group Environmental Impact Assessment Risk Assessment Rehabilitation/pollution control
Tena Shijakova-Ivanovska Geology Dept.	Expert	Geochemistry Mineralogy and petrology Geochemical sampling and mapping
Vlado Gicev Mining Dept.	Expert	Geodesist Stability issues Risk Assessment
Emilija Nakova Biologist	External expert	Biology/Biochemistry
Dejan Milanov Agriculture	External expert	Soils/agriculture
Pance Arsov Inorganic chemistry	External expert	Chemical processes
Assistant staff		
Zoran Despodov	Logistic Manager	Organization and logistics
Riste Popovski	Assistant	Terrestrial measurements, maps, landscape modeling
Vesna Zajkova	Assistant	Lab analyses
Gorgi Dimitrov	Assistant	Data collection/sampling
Marjan Delipetrov	Assistant	Data processing and compiling
Blagoj Delipetrov	Assistant	Landscape modeling, data processing

Dekonta a.s.

Members of Dekonta's team, completing the Feasibility Study, are listed in table 1.2.

Table 1.2 – Team of the Feasibility Study

Name	Position in team / Role	Task Assignment / Responsibility
Expert staff		
Robert Raschman Prague Centre Director	Team leader	-monitoring of overall contract performance – technical, schedule, cost and administrative
Jan Váňa	Project Mananger	-deliverables of all tasks, technical staffing, schedule adherence, budget compliance - use of specialists coordination -communication with local partners and authorities
Ondřej Urban	Expert	- bench tests performance and evaluation
Pavel Veselý	Expert	environmental consultant
Jakub Kanta	Expert	-Emergency Response
Hana Čermáková	Expert	- projects development -administrative and logistical support, -focal point for UNDP program associates
Assistant staff		
Petra Žáčková	Assistant	Labs

1.6 Report organization

In respect of documents that completion of the project has been divided into two separate lots the following documents are prepared and presented in the relevant Chapters:

Chapter 1 - Introduction

It presents general background to the project and the specific project objectives. In addition, the organization of the project team is presented.

Chapter 2 - Baseline Study – Lot 1

This chapter presents the description of the Lojane Mine site and its existing setting. Assemblage, evaluation and presentation of data on the relevant characteristics of the study area, including physical, biological, and socio-economic & cultural information is provided, too.

Chapter 3 – Feasibility Study – Lot 2

In this chapter, description of applicable cleanup and remediation measures, selection of possible methods for site cleanup and rehabilitation, bench tests of selected methods, proposal on clean up, closure and rehabilitation measures for site specific conditions, plans drafting, costs analysis, implementation scheduling (action plans), and monitoring performance plans are described.

Chapter 5 – Conclusions and recommendations

This chapter summarizes the findings of Baseline Study and feasibility Study. The main conclusions and recommendations are presented too.

2 Lot 1 - Baseline Study

2.1 Site description

2.1.1 Site location

The abandoned Lojane Mine Site and associated processing facilities are located north of city of Kumanovo (see fig. 2.1) on the territory of Lipkovo municipality. Lipkovo municipality is located in the northern part of Republic of Macedonia with area of about 270 km^2. The territory of Lipkovo municipality borders with Serbia on north and Kumanovo municipality on the East, Aracinovo and Gazi Baba on south and west. In the eastern part of the municipality passes highway and railway of international meaning, as main infrastructural objects for connection in north-south direction through flows of rivers South Morava and Vardar.

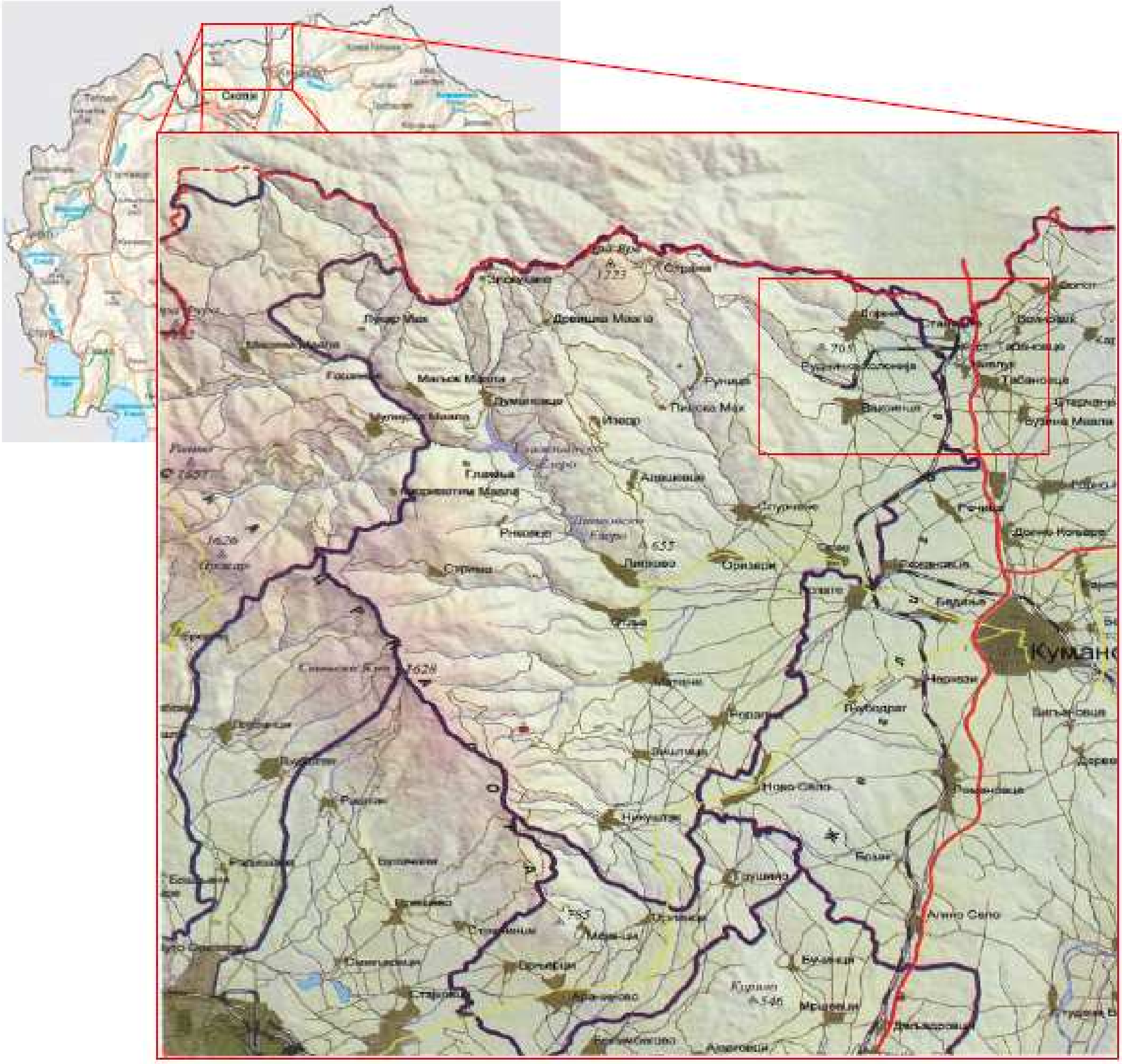


Fig. 2.1 – Lipkovo municipality map

2.1.2 Climatic characteristic

2.1.2.1 Climate

According the climatic- vegetation parameters and basic elements regime (G. Filipovski, R. Rizovski and P. Ristevski, MANU 1996) the Lipkovo area is classified as a continental submediterranean region. The climate is strongly influenced by moderate eastern continental climate or cold masses coming from the north, particularly during the winter period. These masses lower the air temperature. On the other hand, along the River Vardar the Mediterranean influence comes to the north as witnessed by some typical Mediterranean plants. Considering that fact that there is not meteorological station in the Municipality, data has been inferred based on stations in Kumanovo and Skopje.

2.1.2.2 Temperature

Temperatures given in the chart below refer to the monthly average temperatures calculated form mean daily temperatures, measured in 3 intervals during each day.

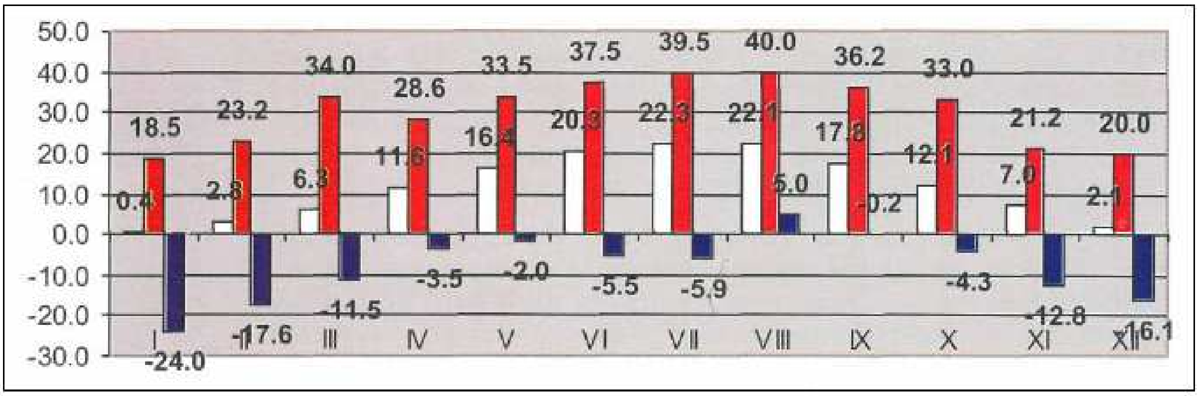


Fig. 2.2 – Air temperature (1961 – 1980, MS Kumanovo)

white color – mid monthly; red color – absolutely maximal temperature; grey color – absolutely minimal temperature

The coldest month is January with 0.4° C, the warmest being July with 22.3°C. The lowest temperature of –24°C has been recorded in on 27 January 1954. The low temperatures have a negative effect on the human environment especially in agriculture.

2.1.2.3 Precipitation

Precipitation regime is analyzed based on frequency of occurrence, length, monthly and annual averages, aggregate conditions, intensity etc. The precipitation is most variable climatic parameter, and is conditioned with a lot of natural and recently eve anthropogenic factors.

Annual precipitation in the Lipkovo area amounts to 549.2 mm and the area has higher rainfalls than the Skopje valley, but much less than the region of Kriva Palanka. The rainiest seasons are spring and autumn with highest average in May of 72.1 mm. On the other hand, summer period is dry, the lowest average of rainfall being in August of only 30.2 mm.

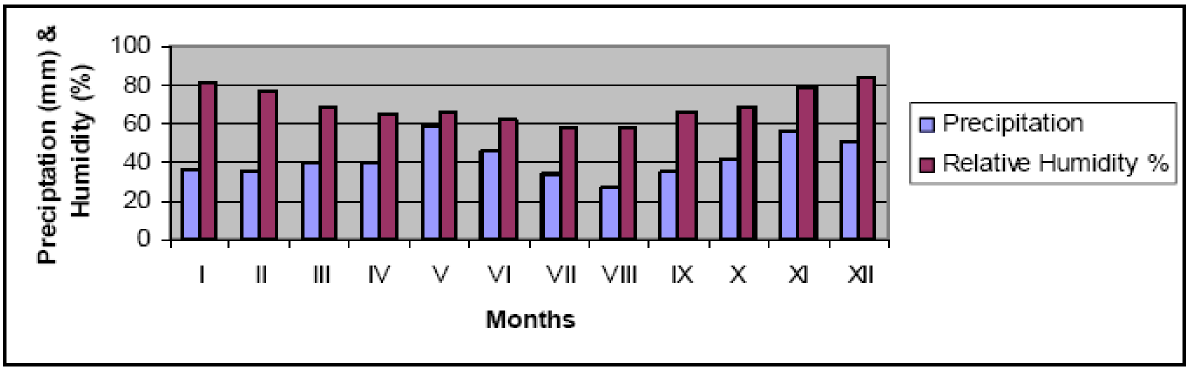


Fig. 2.3 – Average monthly precipitations (1961-2001),

Precipitation and relative humidity refer to data measured in mm and % at the meteorological station.

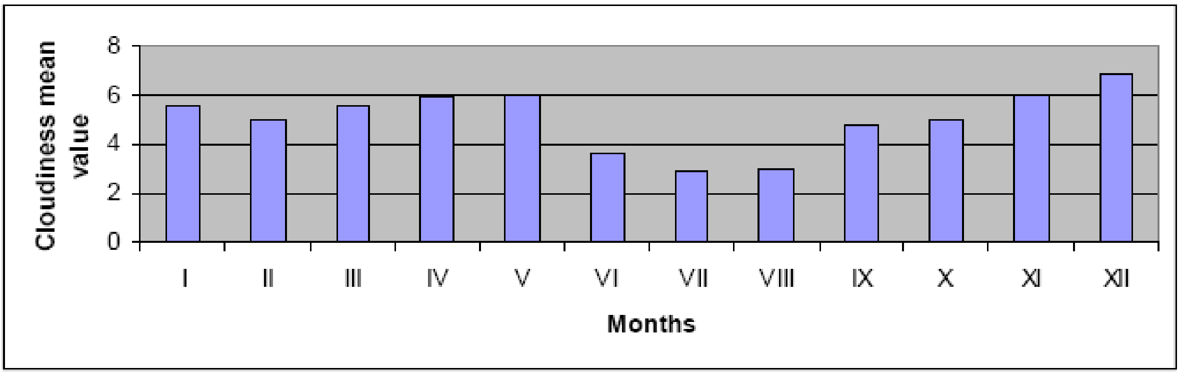


Fig. 2.4 – Cloudiness mean values (2003)

Cloudiness value is determined visually in a scale from 0 to 10, where 0 denote utterly clear, and 10 utterly cloudy.

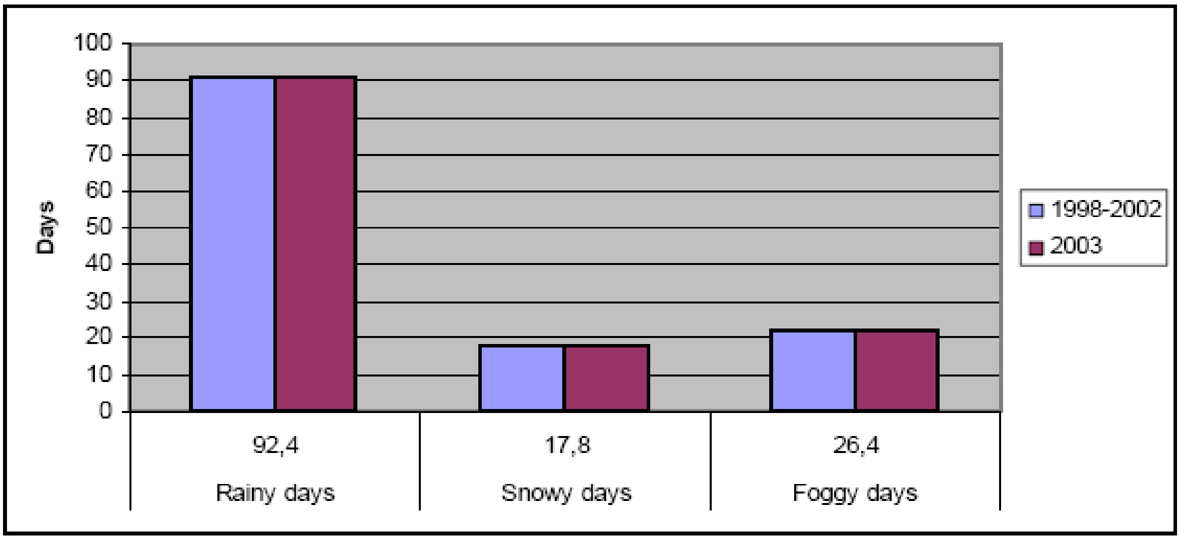


Fig. 2.5 – Number of rainy, snowy and foggy days (1998-2002 versus 2003)

Numbers of rainy and snowy days are considering being day with more that 0.1 mm precipitation or more then 1 cm snow.

2.1.2.3.1.1.1 Winds

Data on the winds refer to the frequency of winds measured in eight directions.

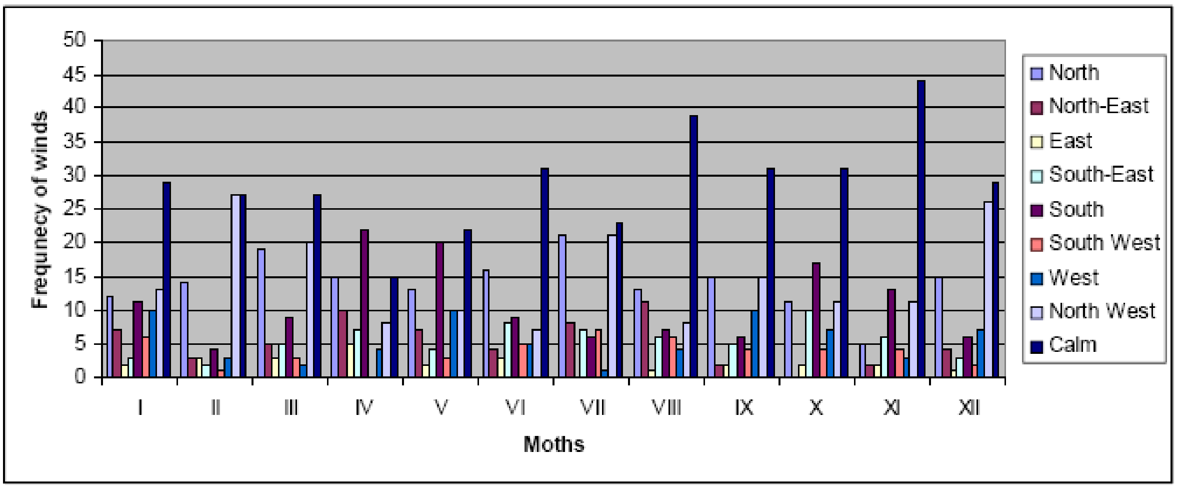


Fig. 2.6 – Frequency of winds (2003)

All data presented are complied from Hydro-meteorological service, measurement station Kumanovo and Skopje (Statistical yearbook 2004).

2.1.3 Geological settings

2.1.3.1 General geology of the area

The area under investigations consists of a complex of Precambrian rocks, of Paleozoic metamorphic rocks and magmatites, a complex of Mesozoic sediments and magmatites, a complex of Tertiary sediments and volcanics as well as Quaternary layers and volcanics (Fig. 2.7).

Schists of the transition zone (Sse) are present of the Precambrian. The schists are the zone between the Serbo-Macedonian and the Vardar zones and have the characteristics and degree of metamorphism close to both zones. The zone is built of various schists such as quartz-chlorite, muscovite-chlorite, sericite-chlorite, graphite etc. that alternate occasionally by mica schists and leptinolites. They are green and of pronounced schistose texture.

The Paleozoic occupies an important part of the area and is present as lithologic occurrences as follows:

Marbles (M) are common in the schists of the Veles series. It occurs as chert layers and large masses with some regularity. Marbles are white and grey. They are made up of large calcite grains with small limonite admixtures. Occasionally schistose texture can be seen in marbles with marked mica indicating to the gradual transition to adjacent mica schists. They do not contain micro fauna, but some macro fauna forms have been noticed, entirely deformed by recrystallization that hampers their determination.

Sericite and phyllitic shists (F) are the most widespread of all Paleozoic schists and under the Tertiary sediments they emerge on the surface as erosion windows. The schists are of earlier origin, most probably formed by pelite and psamite metamorphosis. Today are present quartz-sericite, chlorite-sericite schists, mica and sericite schists, argilloschists and phyllites.

The mineral composition is simple: quartz, chlorine, muscovite and a little albite and zircon. The percentage of clayey material is often large. Interlayers and lenses of white and grey thin-platy marbles and marbalised limestones alternate the mentioned schists.

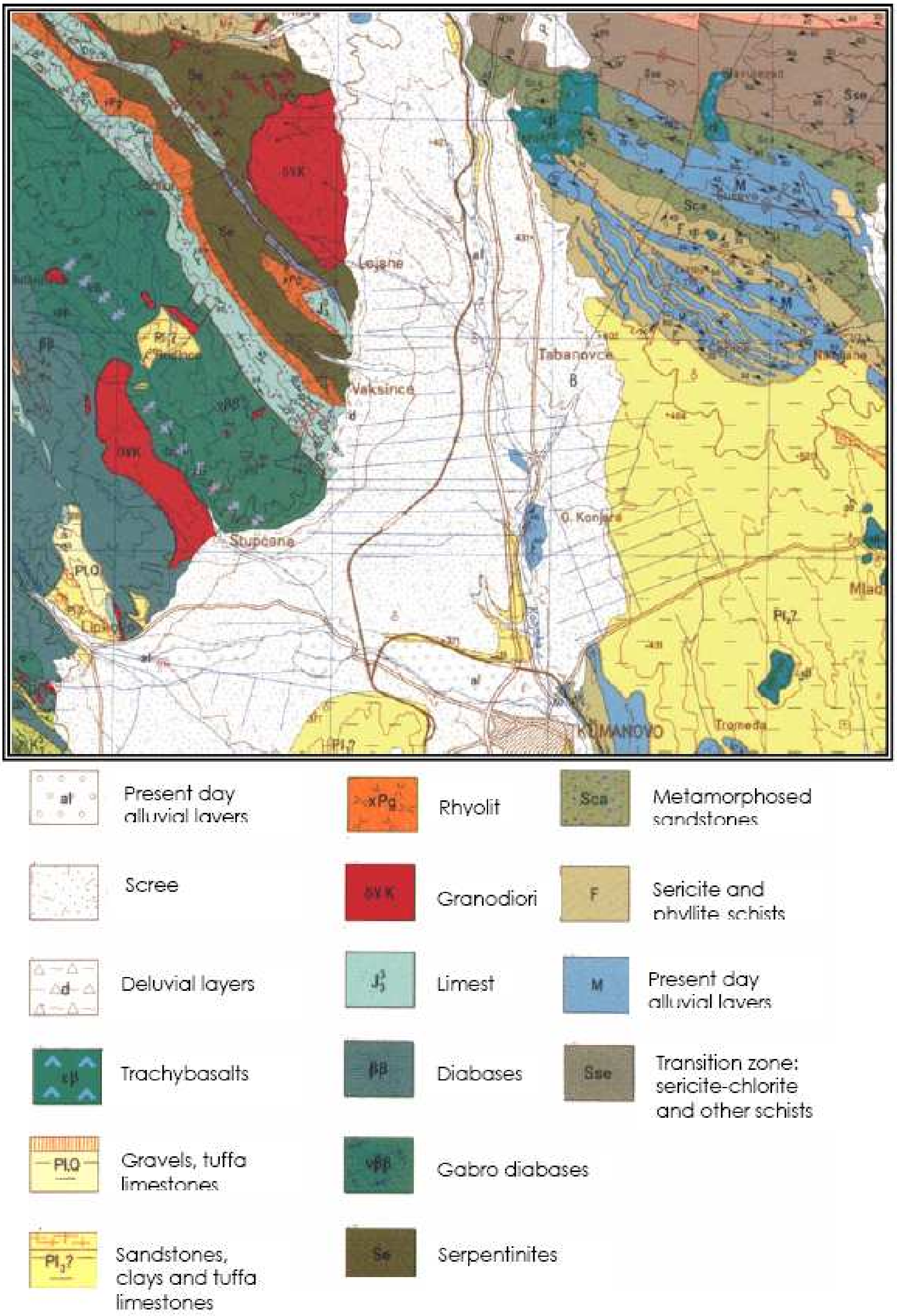


Fig. 2.7 – Geological map of Lojane Mine vicinity

Metamorphic sandstones (Sca). The sandstones mare made up of 65% quartz grains (0.1 – 0.9 mm), muscovite of over 30%, other component parts being feldspar grains and ferruginous material (goethite and hematite), cement is calcite.

Serpentinite (se). The Lojane serpentinite massif is one whole with several ruptures separated in several masses extending to north-west as tectonic interwoven serpentine lenses in Paleozoic and Jurassic rocks. It is obvious that the entire massif in the past was an olivine ultramafite, that later serpentinised totally. Serpentinite are present as dunites and harzburgites. Olivine is the primary component part and chromite secondary. The secondary minerals are serpentinite and magnetite, seldom chlorite and carbonate. Most of the mass is serpentinised. Serpentine is a dense aphanate rock of dark green to dark color and shell like fracture.

The Mesozoic complex of sediments and magmatic rocks is present as:

A gabbro-diabase (ßß) zone is a zone of mixture of diabase veins in gabbro and vice versa, gabbro loads in diabases.

Diabases (ßß) are weathered, broken and cracked. Fresh samples can seldom be seen. It can also be seen that they are dark green, fine-grained structure and massive texture.

They are made up of plagioclase grains of idiomorphic shape. The inter space is filled with pyroxene grains that poicilitically include the plagioclase crystals. Magnetite and limonite occur as accessory minerals.

A facies of ***reef limestones*** (J33), the facies possesses the largest regional penetration of all Jurassic sedimentary rocks. Limestones are grey-white. They are cracked and filled with calcite veins. The rock is fine-grained, of carbonate composition and pselite to psephite structure. It also contains some clayey substance. The fragments are connected with fine-grained carbonate that gives the rock breccious structure.

Granodiorites (..K) occur in two places as large masses, near the villages of Lojane and Slupcane. They are medium sized, grey to greenish color conditioned by the feldspar color. The rock is mostly fresh except in the parts affected by tectonics where it is cataclised. Owing to surface weathering a large arenite cover occurs. The major minerals are plagioclase, orthoclase and quartz. Orthoclases occur as large fresh grains with fine plagioclases in them. Plagioclases are zonal and stronger altered than orthoclase.

Rhyolites (xPg) are effusive rocks and belong to the Paleocene complex. They occur as intrusions through the gabbro diabase massif. They are of porphyry structure with quartz, orthoclase and plagioclase and the colored representatives are biotite and amphibole. They are light or dark grey depending on the alteration type.

Upper Pliocene is present as ***sandy-clayey series*** (Pl3). The series consists of sands, clays, loams, lenses of sandstones, tuffa limestones and thick gravel layers. The lihtologic members are of undefined stratigraphic level are alternate in different intervals horizontally and vertically. However, it can be seen that they are mostly sands. The sands are grey-white to yellowish and quite unbound. They are seldom clean owing to the presence of variable amount of clayey material.

Clays alternate with sands irregularly occurring as large and longer but thin lenses without defined stratigraphic level.

The Gravel series (Pl,Q) overlies the sand series in most of the terrain and the tuffa limestones that occupy the top most part of the sand series. Gravels are poorly bound, their composition being sands and seldom-clayey sands. They are made up of well-rounded pebbles of quartz, quartzite, amphibole etc. Transparency is poor so that diameter of pebbles is from 1 x 2 cm to 10 x 20 cm. Interspaces are filled with sandy clay. If carbon is higher in the cement, semi bound carbonates develop.

Trachybaslats (.ß) are volcanics of the younger effusive phase. They are grey to dark grey. Under a microscope it can be seen up to 1 cm olivine phenocrystals and many biotite flakes. They possess porphyry structure. They also include plagioclases, diopside, sanidine and some leucite. Magnetite and apatite occur as accessory and hematite, limonite and seldom calcite as secondary minerals. In the groundmass can also be seen volcanic glass of up to 5 – 10%.

Deluvial layers (d) are transition zones in the mountain massifs in other Quaternary layers (proluvial, alluvial etc.). The base is of unworked pieces of various materials but they are filled with clay humus material.

Weathered surface material overlies the Pliocene and Quaternary layers. It is made up of variable sandy-clayey-gravel material. It contains rare and unworked pieces of Pliocene sandstones and tuffa limestones. The material is the most fertile in the area. It formed under conditions of exogene factors that have transformed the soil.

Present day ***alluvial layers*** have formed at the divide of all major rivers. They are present as gravels. The allusions of gravel material are rare occurring in the lower river courses.

2.1.3.2 Ore occurrences

Since the area of interest was for long time in history mining area the spatial distribution of all metal and non-metal occurrences in the area are given.

Ore occurrences in the area consist of ***antimony and arsenic*** deposits. Antimony has been found in two localities – Nikustak and Lojane. At Nikustak antimony occurs in Paleozoic schists as monomineralization along the vein type. In the Lojane mine both antimony and arsenic have been found in the serpentinite which is in contact with rhyolites. Ore bodies are complex ore veins. Major ore minerals are antimony and realgar of 6.5% As and 4% Sb.

Nickel has been found at Nikustak in Paleozoic schists only as a mineralogical occurrence as a mineral chrysopras and nickel-bearing pyrite.

Mineral occurrences of ***mercury*** have been seen in the locality.

Chromite has been found in all serpentinite massifs and represents intramagmatic crystallization differentiates. However, its per cent is of no importance except for Lojane massif where it was exploited for a long time.

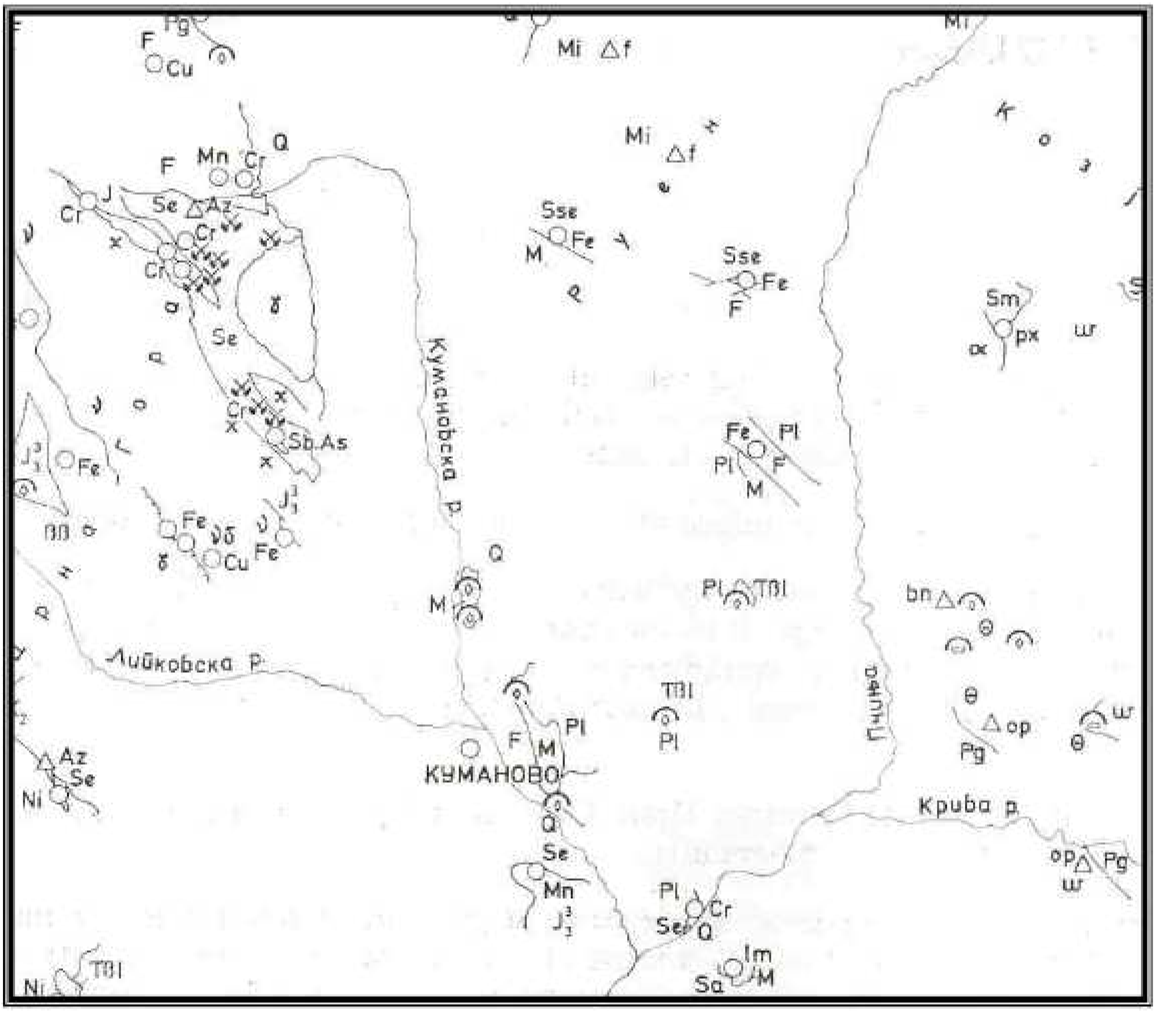


Fig. 2.8 – Ore occurrences in the area

2.1.3.3 Tectonics

In terms of the geology the area belongs to the Vardar zone, only a small part (in the northeast) being part of the Serbo-Macedonian massif (fig. 2.9).

The tectonic composition of the Vardar zone (A) consists of various formations, beginning with Paleozoic rocks and all younger formations, the Quaternary inclusive. In terms of its tectonic evolution the zone is characterized with high instability. As a result complexes of Old Paleozoic and Albian and inherited forms are present.

Very important structures occur in the contact between schists of the transition zone and those of the Veles series where the Celopek faults occur (7). The schists of the transition zone comprise a large anticline structure called Celopek anticline (6) of WNW – ESE extension. The schists of the Veles series are strongly altered east of Tabanovce where with the marbles they comprise symmetric folds (8) of NW-SE strike. The folds are strongly deformed by several faults with dentic strike, as are the folds. It is on these faults that extrusion of younger effusive near Slavujevc east of Tabanovce took place. Intense tectonic movements occurred in the Lojane serpentinite massif owing to the plasticity of serpentinite. Primary layering and cracks can seldom be seen, whereas zones of parallel schistosity are well pronounced. The latter mark the ruptures inside the serpentinite.

Granitoide bodies inside serpentinite occur as lens-like bodies that received their orientation due to tectonic movements after they were impressed into serpentinite. This can be seen from fractured zones and fractures that crosscut both the granodiorite bodies and serpentinite. These granitoids are probably mobile today owing to the difference in density compared to the density of plastic serpentinite and owing to the active tectonics of today.

The Tertiary sediments are poorly dislocated and the structures in them are rare and slight. Deposition of Paleogene sediments terminated in Mid Oligocene. After deposition an imbricated tectonics occurred that caused older rocks overthrust the Paleogene sediments.

The Miocene sediments discordantly overlie older formations with slight monocline dip towards wets and southwest. They are discordantly overlain by Pliocene sediments and are of almost horizontal position. They have been affected by disjunctive tectonics. Along faults extrusion of younger effusive rocks took place. The area under investigations consists of a complex of Precambrian rocks, of Paleozoic metamorphic rocks and magmatites, a complex of Mesozoic sediments and magmatites, a complex of Tertiary sediments and volcanics as well as Quaternary layers and volcanics (Fig. 2.10).

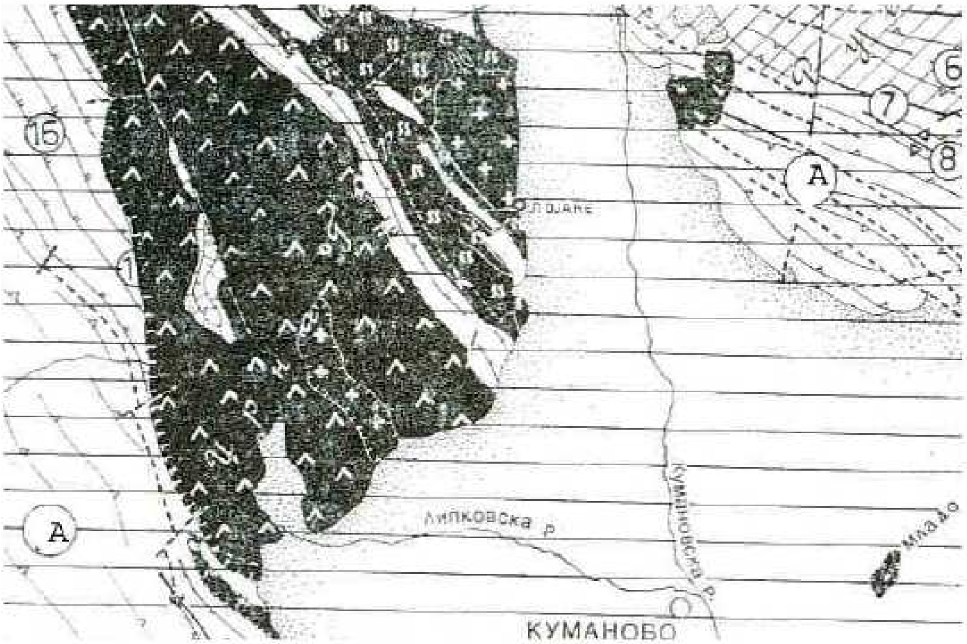


Fig. 2.9 – Tectonic map of the area

2.1.3.4 Hydrogeology

Hydrogeological conditions have been analyzed in order to see possible practical aspects in the implementation of the elaborate. In that regard the following aspects have been analyzed:

- hydrogeolocigal function of the rocks,
- kinds of hydrologic-hydrogeologic occurrences.

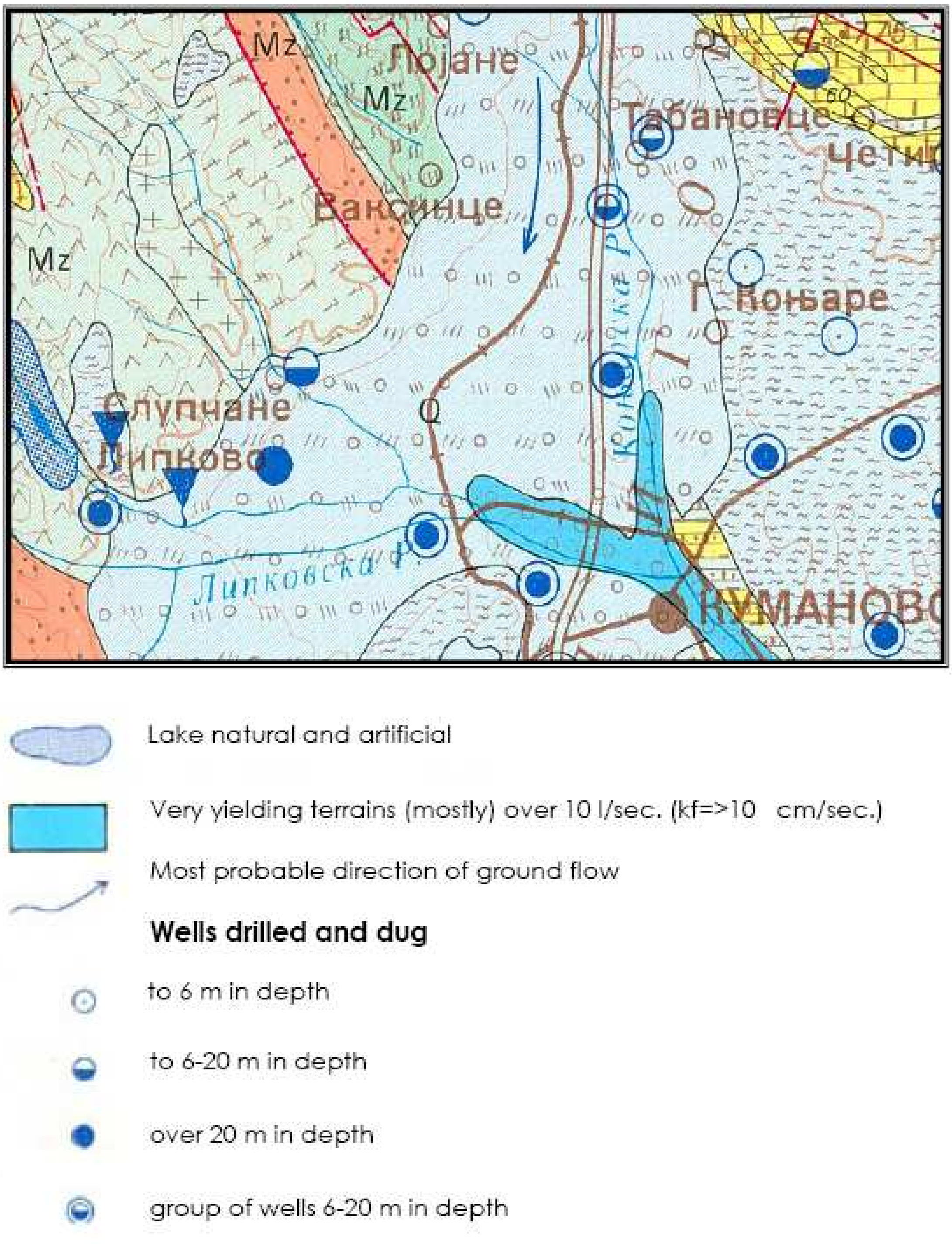


Fig. 2.10 – Hydrogeological map of the area

Taking in consideration the geological conditions in the terrain, the rocks in the area, in terms of their hydrogeology can be classified as:

-hydro geological collectors of fracture-karts porosity with marble layers,

-hydro geological collectors of intergranular porosity with alluvial layers,

-hydro geological insulators with delluvial occurrences,

-relative hydrogeolocigal insulators with schists, diabases, granodiorites and serpentinites.

Typical collectors are the alluvial layers of intergranular porosity and the marble layers which, owing to their fissuration and local cavernosity, are of characteristic structural type of porosity that makes possible the infiltration of surface waters through the massif as far as the zone where permanent level of ground water is present.

Deluvial sediments owing to their fine-grained fractions as clayey binding material that envelops fracture grains can be regarded as typical hydro geological insulators with intergrain porosity.

Schistose occurrences, diabases, granodiorites and serpentinites are regarded as relative insulators with fracture type of porosity. This classification indicates that, generally, in these occurrences one should not expect typical aquifer zones and that possible occurrences of wetting can be expected along fault structures and locally.

The Pliocene layers have been separated as separate hydro geological complex made up of sands, clays and sandstones. Clays are hydro geological insulators; sandstones are collectors of fracture porosity, whereas sands are collectors of in-between porosity.

The weathered surface material covers the Pliocene and Quaternary layers. It is made up of variable sandy-clayey-gravel material. These weathered masses are very important to us since they are the fertile lands, being at the same time the most densely populated places. Such are the large places Vaksince, Lojane, Lipkovo, Tabanovce etc. They are located just at the border between deluvium and the weathered surface material.

From hydrogeologic aspect the weathered material, owing to its clayey material and humus possesses pronounced hydro insulator features that prevents infiltration of surface waters to deeper horizons of the Pliocene complex from where people receive their potable water. This is a kind of natural protection from As, Sb and other heavy and toxic metals (present in several open waste dumps) that dissolved and transported from surface enter the deeper parts of the earth’s crust and join drinking waters.

2.1.3.5 Hydrology

The area of the consideration is part of the Lojanska and Lipkovska Rivers river basins that flow into the Tabanovska which joins the Pcinja. There are two water reservoirs on the Lipkovska River called Lipkovo and Glaznja.

The river basin of the Lipkovska is one of the largest in the Lipkovo-Karadak region and Skopska Crna Gora. It is formed by numerous small rivers, stream and temporal brooks. The waters from the upper course collect in Kamena, Vodenicka and Dumanosvka Rivers, which at Glaznja join and form the River Lipkovska. As far as the entrance to Lipkovo valley it possesses a gorge like characteristic, with deep cuts and narrow sides. After excess to Lipkovo valley it collects the Strumsla and Vuksanska rivers and the waters of Slupcanska.

The Lojanska River that is formed by Mala and Golema Rivers possesses a separate river basin and empties into the Tabanovska. It is of dips steeply towards Lojansko Pole- flats and due to the granite-diabase riverbed its water is clear as far as the village of Lojane. The river provides good conditions for the construction of a water reservoir for the water supply system and irrigation of agricultural flat land for which technical documentation has been prepared.

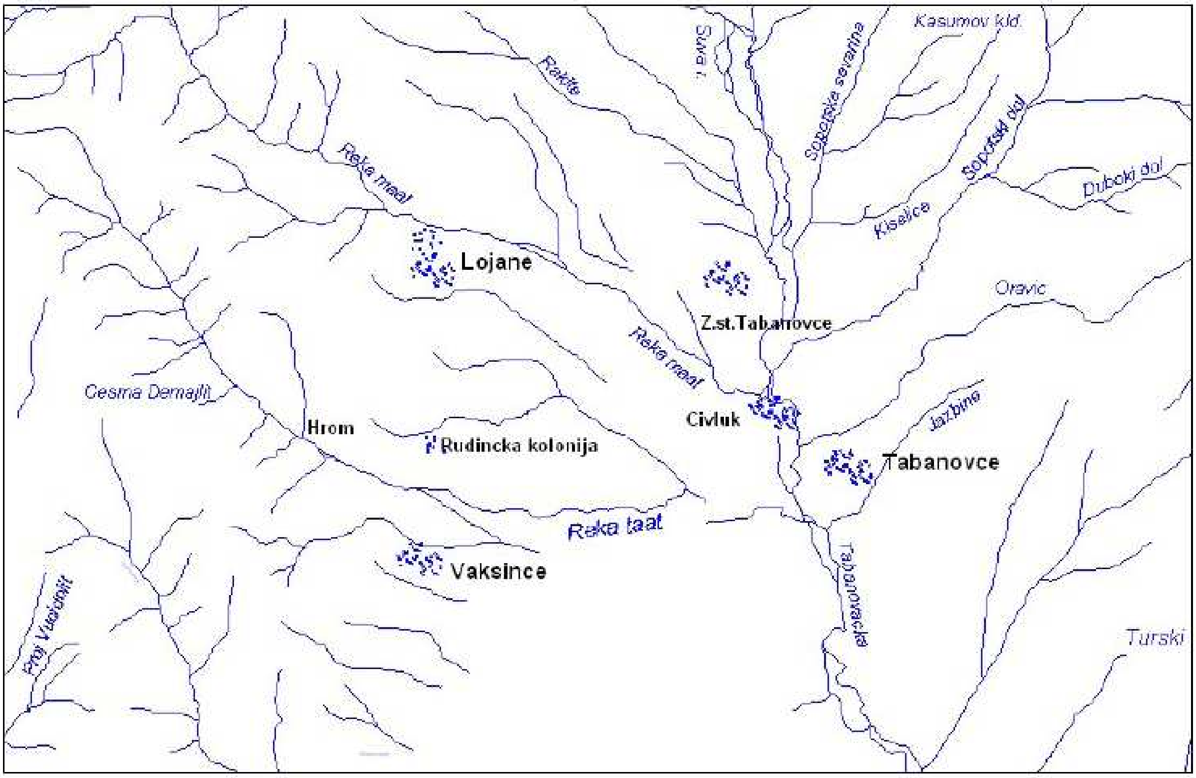


Fig. 2.11 – Rivers and stream in the area

Despite the fact that area is relatively reach with good quality water sources, drinking and irrigation water supply isn't satisfactory. Only 36.5 % of agrarian area on the territory of the Municipality is cultivable land irrigated with the water from the Lipkovo system.

Much bigger problem represents a fact that none of the rural settlements is supplied with safe drinking water and equipped with water supply network. The population is supplied with water through individual wells and springs from hilly and mountainous areas. This means that villages are not connected to public water supply networks, while those that have such partial networks (parts of the village, and not entire village) are of temporary nature of poor quality of the water. Such partial water supply networks of poor quality exist only in 5 villages in the plane area, excluding the village of Otla, while other villages do not have any network at all. The water used by the population in Lojane and Vaksince area is of particular concern, because it is contaminated with heavy metals (As, Cr, Sb ...) due to present pollution sources from abandoned mine site, as much as relatively high natural background of this metals of subsurface environment.

Additional problem, for all settlements certainly are fecal wastewater (septic tanks), etc, which often pollutes or endangers drinking water source. Drinking water in the area is not controlled by sanitary or health institutions.

2.1.4 Biological conditions

2.1.4.1 Vegetation

As we already mention the area belongs to continental sub Mediterranean climatic zone of the country. Oak forests are most widely spread in this (ass. Quercetum frainetto cerris macedonicum Obred. Emend. Ht). Grass and forest vegetation prevail in the area of Lojane compared with the other part of the Kumanovo region with predominance of forest species.

The forest consists of oak can be seen as a belt along the edge of the Kumanovo valley on some 800 m above sea level entering both sides of the gorge of the river Lipkovska as far as the village of Dumanovce. Association is thermoxerophile with predominance of white oak ash tree, black ash tree with xerophile pastures in the lower parts.

Woods of lumber can be seen near Belanovce (1950 - 1137 m above sea level). It grows on limestone terrain with predominance of dark oak. Beech and cerris can be found in small areas around the villages Dumanovce and Otlja.

Forests of several kinds of local trees can be found in several places in the Lipkovo -Karadak region. Dominant tree species in these forest communities are Quercus pubescens and Carpinus orientalis.

Associated species of trees and bushes are:

Fraxinus ornus
Syringa vulgaris
Buxus sempervirens
Cornus mas
Ostrya carpinifoli
Pistacia terebinthus
Acer monspessulanum
Juniprerus oxicedrus
Paliurus aculeatus...

From lower vegetation, following species can be found:

Silene viridiflora
Symphytum bulbosum
Evonymus verrucosa
Geranium sanguineum
Cyclamen neapolitanum
Carex halleriana
Aristella bromoides
Iris sintenisii
Ranunculus sp.
Tamus communis
Saxifraga buldifera
Philostachys

Photo 2.1 – Local vegetation

2.1.4.2 Wildlife

A typical represents of vertebral fauna are Ponto Mediterranean and Syrian arboreal elements, like worm water snake (Typhlops Vermicularis), cat snake (Typhlops Fallax), Balkan snake (Coluber Gemonesis), Balkan green frog (Pelobates yuriasly balcanicus), Eripaseiy concolor, Mustela Nivalis and others. Also varies birds could be found in the area.

Some predators and other important hinting species in spite of intense hunting are also noted. There can be seen bear, fox, wolf, etc.

According to the list of natural rarities (Statistical Yearbook 2004), this area is not defined as important for preserving bio-diversity of the country. Also, it should be noted that there are no records of special eco-systems with extraordinary biodiversity, habitats of endangered or endemic species, as much as routes of migratory species in the area.

2.1.5 Social setting and economic conditions

2.1.5.1 Population

There are no urban settlements on the territory of the Municipality, with 21 rural settlements which have population of various demographic dynamics and structure. The central settlement of the Municipality is the village of Lipkovo towards which other rural settlements incline. The closer urban settlement in the area is city of Kumanovo with population of around 120.000.

First data about population in Lipkovo municipality go back to the beginning of XX century, collected by travel writers, teachers and registers of that time authorities. According that data, in 1900 number of population was 14.678 inhabitants, in 1913 there was 11.453 inhabitants, in1921 - 12.234 inhabitants and in 1931 - 13.450 inhabitants.

After the World War II, in 1948, firs official registration of inhabitants was done. It showed that in the area of today's Lipkovo municipality lived total of 18.135 inhabitants. In 1971 number of inhabitants increased to 20.899 inhabitants and in 1994 to 22.861 inhabitants. In the period between 1948 and 1971 number of inhabitants has positive trend of 2.764 inhabitants or 13 %, but in the next period, from 1971 to 1994, birthrate was 1.962 inhabitants or 8,5 %.

But, in the mountains settlements in the period 1971 -1994, number of inhabitants decreased, for example, in Alesevci for 52.7 %, in Belanovce for 95 %, Glaznja 69.9 %, Dumanovce 98.6 %, Zlokukane 63.4 %, Izvor 89.8 %, Rankovce 82.6 %, Runica 74.2 % and Strima 67.9 %. The inhabitants moved out in prairie's settlements in that area, bun also in Kumanovo and Skopje, and Turkey. Only in period between 1953 and 1966, around 4.450 inhabitants immigrated to Turkey.

Straza village is only settlement which is displaced from 1978.

In prairies settlements, which are characterized with better conditions for living, number of inhabitants increased natural and with mechanical influx. In the period between 1971 and 1994, increasing of inhabitants appeared in Otlja for 82.6 %, Lipkovo for 51 %, Orizare for 44.1 %, Vaksince for 37.9 %, Slupcane for 38.1 %, Ropalce for 30.1 % and Lojane for 27.5 %.

Average population density is 110 inhabitants per 1 km2. It is bigger in prairie's settlements in spite of mountain's settlements which enclose bigger area, but with small number of inhabitants (Dumanovce, Alesevce, Fosince, Strima, Rankovce etc.). Administrative center of the municipality is village Lipkovo, with 2,126 inhabitants, to which gravies the other village settlements. Largest settlement in the municipality is village Matejce, with 3,126 inhabitants.

Data about settlements in Lipkovo municipality are given in the table 2.1 below.

According nationalities, the biggest part of the population is composed of Albanians - 96.13 % and Serbians - 1.77 % (see fig 2.12). The number of other nationalities is negligible. In every household (3.599) in the municipality live in average 6.4 members. Men are more than women with ratio 52:48 (see fig. 2.13).

Until 1964 Lipkovo was independent municipality, but in 1965 it was joined to Kumanovo. According territorial separation in 1996, it is independent again.

Table 2.1 – General data about the settlements in Lipkovo Municipality

Settlement	Height a. s. l. [m]	Area [m^2]	Inhabitants		
			1948	1971	1994
Lipkovo	420	13,4	1418	1542	2331
Alesevce	450	27,7	496	334	157
Belanovce	940	9,4	407	241	11
Vaksince	480	17,5	1024	1627	2242
Vistica	580	6,8	553	732	938
Glaznja	560	10,5	482	252	76
Gosince	910-1040	12,9	631	512	643
Dumanovce	580	13,0	477	605	14
Zlokukane	820	2,2	163	71	29
Izvor	810	5,8	304	293	30
Lojane	440	18,6	943	1784	2267
Matejce	480	34,1	2657	2616	3126
Nikustak	500-590	20,4	1331	1411	163
Opae	365	3,3	1123	1684	1880
Orizari	400	4,9	817	1282	1841
Otla	500	17,1	1543	1638	2677
'Rnkovce	780	2,8	213	201	35
Ropalce	460	4,9	516	815	1085
Runica	600	13,0	654	705	181
Slupcane	415	16,8	1571	2249	3037
Strima	1050	8,5	365	305	98
Straza	1020	7,0	447	0	0
Total		**270,6**	**18.135**	**20.899**	**22.861**

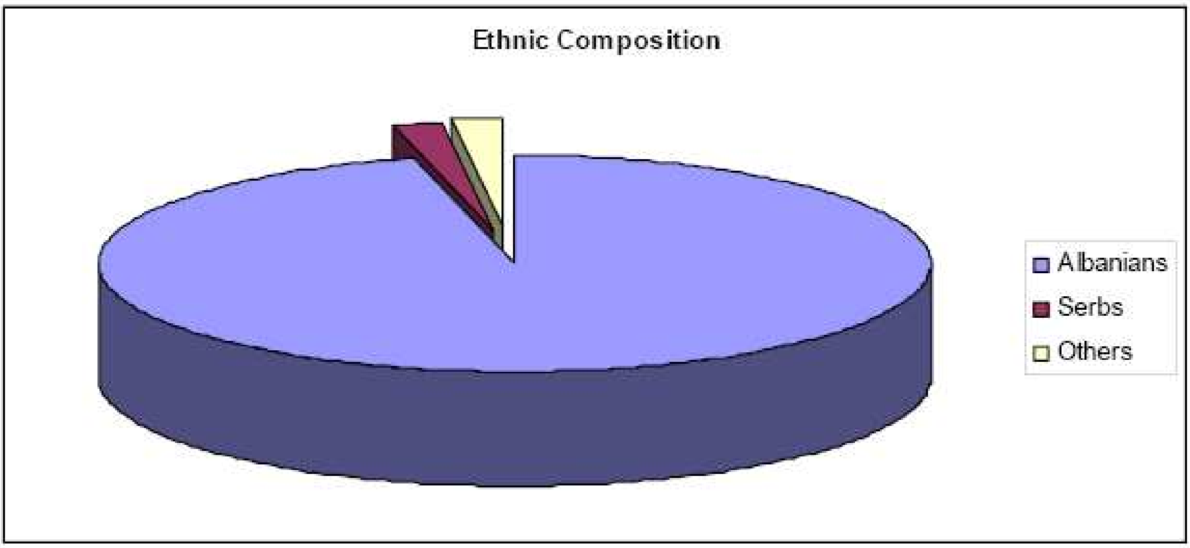


Fig. 2.12 – Ethnic composition of Lipkovo Municipality population

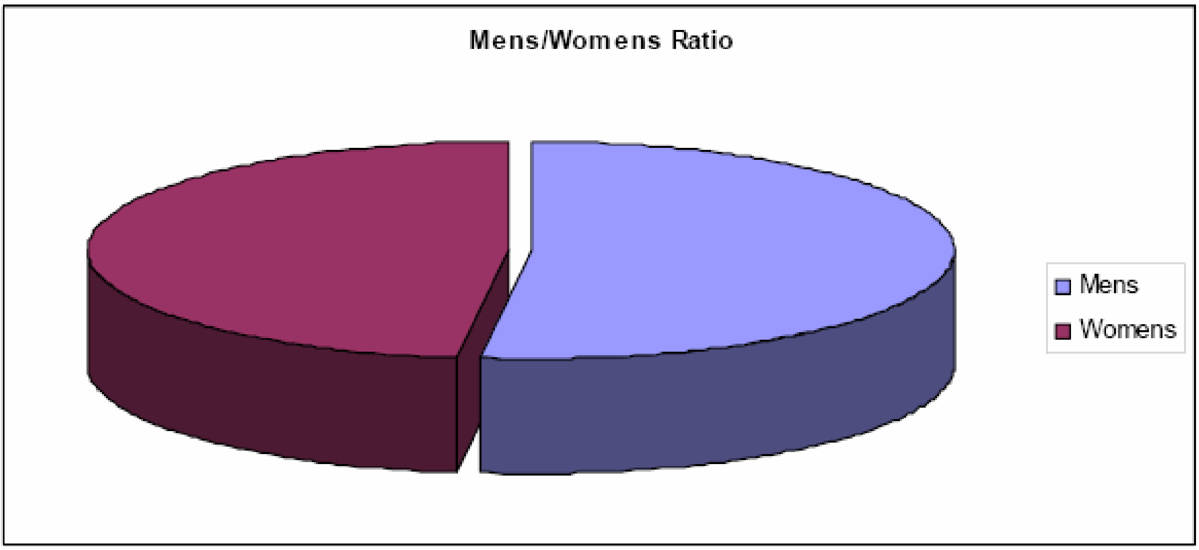


Fig. 2.13 – Men/women ratio of Lipkovo Municipality inhabitants

2.1.5.2 Socio-economic conditions

2.1.5.2.1 Employment and distribution of incomes

Lipkovo municipality is one of poorly developed regions and there are no industrial objects on its territory. Main economic activity is agriculture and 95 % of active population is involved in it. There is area of 22,599 ha for agriculture, from which 8,256 ha or 36.5 % is cultivable soil which is irrigated by Lipkovo hydro system. Pastures has an area of 4,375 ha or 19.3 %, and forests are the most spread on area of 9,968 ha or 44.2 %.

There is traditionally agricultural production with predominance of cereals and little vegetable for own needs and for the green markets in Kumanovo and Skopje. Agricultural areas are parcel out and with one - crop economy. About 20 years ago sheep rising were wide spread, but today sheep are rarity. There are milk cows for home needs, while cow farms are rare.

The private sector involves small number of population, with predominance in trade and some small private firms for cement blocks. There are no conditions for employing of the population in the Municipality and because of that there are 2,500 unemployed persons, and some of them receive social welfare. 15 persons work in public administration and public companies in Kumanovo. The same number is employed in local administration and some private firms in Municipality.

2.1.5.2.2 Community infrastructure and services

Urbanization in municipality is on low level. Only three from 19 village settlements has urbanism documentation, but competent authorities can't realize it because of insufficient conditions.

All settlements are connected with asphalt roads which are narrow and damaged from use and inadequate maintenance. Additional problem comes from dirt and dust on the streets, from the vehicles entering the roads directly from the fields, as much as from sedimentation material due to uncontrolled run off waters.

Although all settlements are connected with electricity network, there are lot problems with electricity supply due to old infrastructure and inadequate maintenance.

There is no water supply system. Although there is accumulation for drinking and irrigate water in the territory of Lipkovo municipality with capacity of 27 billions m^3, Lipkovo has no system for drinking water supply. This reservoir supplies Kumanovo and other populated places. The Government permits using of this water with quantity of 25 liters per second which is enough only for two places Lipkovo and Orizare.

Function of this system has elementary problems, too. In most time it is not used rationally, and on the other hand used technology is very old and amortized.

Drinking water is supplied from local small and individual springs, which are without sanitary control. Institutional and technical possibilities in Lipkovo are not enough to carry out sanitary analyses of the water. All chemical analyses show high bacteriological pollution.

Only few populated places (five from 11 settlements) are joined to water supply system, and none from the mountain settlements.

There is no sewage system, so in all settlements fecal wastewater from the households are usual drained through the septic holes and open channels direct to the rivers, in soil, to open roads, in yards etc. Practically, waste waters in populated places flow through the roads.

Drinking water in the area is not controlled by sanitary or health institutions.

There are ten primary schools in the municipality, predominant located in prairies settlements and one secondary school, opened in 1999 (there are several classes from the secondary school "Goce Delcev" from Kumanovo. Conditions for modern teaching are on very low level.

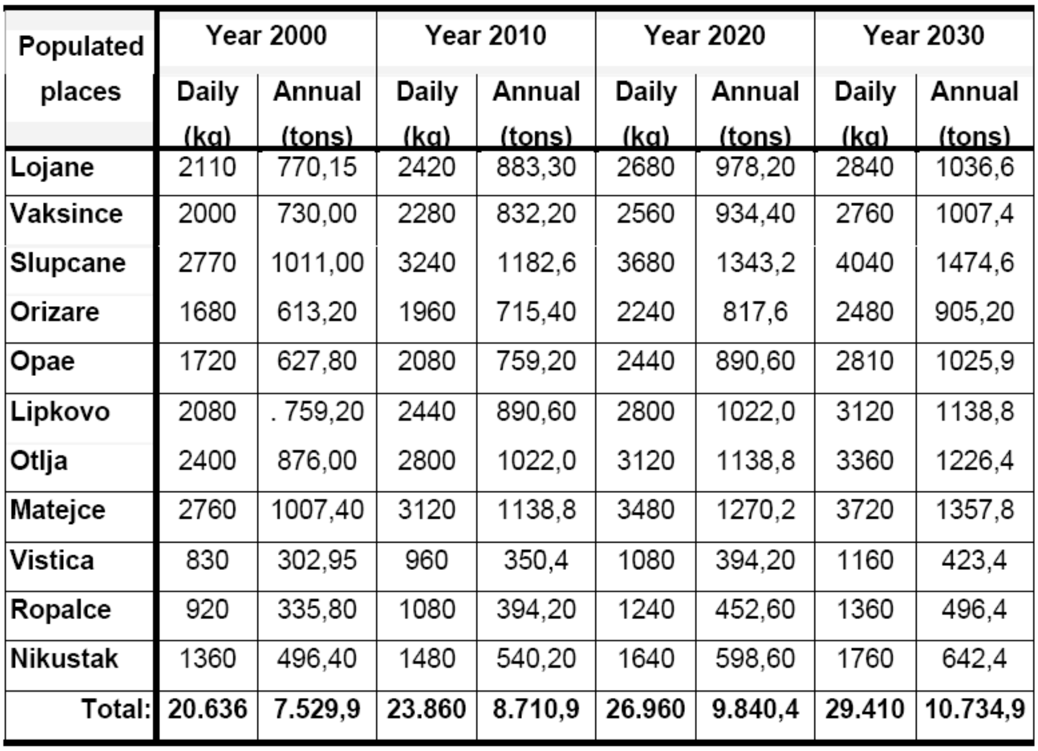
Many of the schools, including the biggest with 1000 pupils, have no drinking water. Only four from ten schools has normal water supply, and only three has toilets.

There are 4 national and 6 private health organizations. In populated places, there is relatively good medical care.

Lipkovo municipality, as specific urban - rural environment, doesn't have appropriate system for communal solid waste disposal. Solid waste is the most produced by households and usually it's disposed in valleys, river flows, near the roads and present serious problem quality of living.

There are 5 bigger waste dumps in the municipality for communal waste. Bearing in mind number of population in all populated places, solid waste producing is changeable depend on characteristics of living, geographical location, seasons etc., so there is oscillations from 1.2 to 2.5 times. Because of that, average daily producing of solid waste per year is 0.8 kg/person/day, or 4.0 kg/household/day. The quantity of solid waste production per day or per year in the municipality is shown in the next table.

Table 2.2 – Solid waste production per day and year for different periods



Populated places	Year 2000		Year 2010		Year 2020		Year 2030	
	Daily (kg)	Annual (tons)	Daily (kg)	Annual (tons)	Daily (kg)	Annual (tons)	Daily (kg)	Annual (tons)
Lojane	2110	770,15	2420	883,30	2680	978,20	2840	1036,6
Vaksince	2000	730,00	2280	832,20	2560	934,40	2760	1007,4
Slupcane	2770	1011,00	3240	1182,6	3680	1343,2	4040	1474,6
Orizare	1680	613,20	1960	715,40	2240	817,6	2480	905,20
Opae	1720	627,80	2080	759,20	2440	890,60	2810	1025,9
Lipkovo	2080	. 759,20	2440	890,60	2800	1022,0	3120	1138,8
Otlja	2400	876,00	2800	1022,0	3120	1138,8	3360	1226,4
Matejce	2760	1007,40	3120	1138,8	3480	1270,2	3720	1357,8
Vistica	830	302,95	960	350,4	1080	394,20	1160	423,4
Ropalce	920	335,80	1080	394,20	1240	452,60	1360	496,4
Nikustak	1360	496,40	1480	540,20	1640	598,60	1760	642,4
Total:	**20.636**	**7.529,9**	**23.860**	**8.710,9**	**26.960**	**9.840,4**	**29.410**	**10.734,9**

Solid waste production per day in 2003 was about 23,740 kg, and annual 8,660 tons on municipality level. In summer and autumn solid waste production is two times bigger related to average production.

There is municipal public services company JP "PISA", formed in 1997. Company has no motor pool. From the beginning works with three rented tractors with trailers and three tons dump track. In May 2003, by humanitarian organizations, company received 10 tons tuck Rotopres. In this time, there are 13 employees in the company.

Many households don't pay communal services because of many reasons, disagreement, political grouping etc. Payment of a debt per household is 1.7 euros, which is less than Kumanovo (5 euros per month). Special dangerous for environmental quality are toxic wastes as sanitary waste from the private health organizations in villages.

2.1.5.2.3 Planned development activities

Current negative economic conditions, as much as ecological problems present in the municipality, have adversely affect on economical development. In that regard, there are ideas for local management and state institutions to make more efforts for correct economic development of the region.

Current efforts of local authority's works in the direction of providing conditions for eco-agriculture development as important measure for realization of coordinate environmental and economic development. Additional efforts are made in expanding of forest reserves (economic use of forests) and increasing quality of the pastures (increasing farm's production, and capacity).

There are conditions for development of tourism, but the possibilities of the two hydro accumulations Lipkovo and Glaznja are not used. Periodically monastery in the village Matejce is used in this function.

2.1.5.3 Land use

2.1.5.3.1 Agricultural land

Agriculture is primary activity in the municipality. Main economic activity is agriculture and 95 % of active population is involved in it. There is area of 22,599 ha for agriculture, from which 20 % is cultivable soil which is irrigate by Lipkovo hydro system. Pastures has an area of 4,375 ha or 19.3 %, and forests are the most spread on area of 9,968 ha or 44.2 %. Main activities on this area are agriculture and cattle rising.

Individual producers use agrochemicals in agricultural production (artificial fertilizers and plant preservatives). Mineral fertilizers consumption is 1,800 tons. The most used are phosphoric fertilizers, about 1,150 tons, and nitrogen fertilizers consumption is 650 tons per year. Organic fertilizers consumption is smaller related to mineral fertilizers. Insecticides are used for peppers, potatoes and cabbage production, about 22 kg/ha.

2.1.5.3.2 Forests

Today's bare places are result of large felling of trees and destroying forests. With forests from this region operate Forest Economy from Kumanovo, company which almost 30 years use these forests and gradually destroy and reduce forest vegetation. Per year, area of about 1.2 ha is cut with total wooden mass of 14,900 m^3.

Pasture vegetation and forests are very important for the practical life and possibilities for cattle raising, beekeeping and for lumber industry and firewood.

Although in this area huge quantity of wood is exploiting, there is no economic activity on local level for using the wood. Woods are transported for other area production.

2.1.5.3.3 Urban development and spatial planning

Because of the emigration in prairie settlements, there is reduction of fertile soil in the municipality which is evident today too.

In that regard, we should mention the example with Lojane village after 1975 when 1/3 houses were built in the Vresta and Dolno Maalo, and that was the most fertile soil in the region. Same problems are evident in village Vaksince which is divided in two parts: Gorno Vaksince, placed on serpentines and the bigger part placed on fertile soil of field Vaksinsko.

Slupcane, the second village according population, in the last 20 years is spread toward fertile soil through the individual building. The same dynamics have villages Otlja, Matejce, Vistica, Nikustak, Opae, Orizari, in other words in all plains.

Main reason for this uncontrolled village spreading through the fertile agricultural areas is lack of data in global and detail urban plan. Space spreading of rural places is actual problem which have affect on reducing fertile areas and their degradation. On the other hand, it impose other serious problem, in other words, opening wells polluted with heavy metals of arsenic, antimony, chromium, iron, copper, etc.

2.1.5.4 Cultural and archaeological resources

2.1.5.4.1 Landscape

The area of concern is rough hilly terrain crossed with narrow valley's which opens into a big flat area of Kumanovsko Pole. 3 D model of the area is given below.

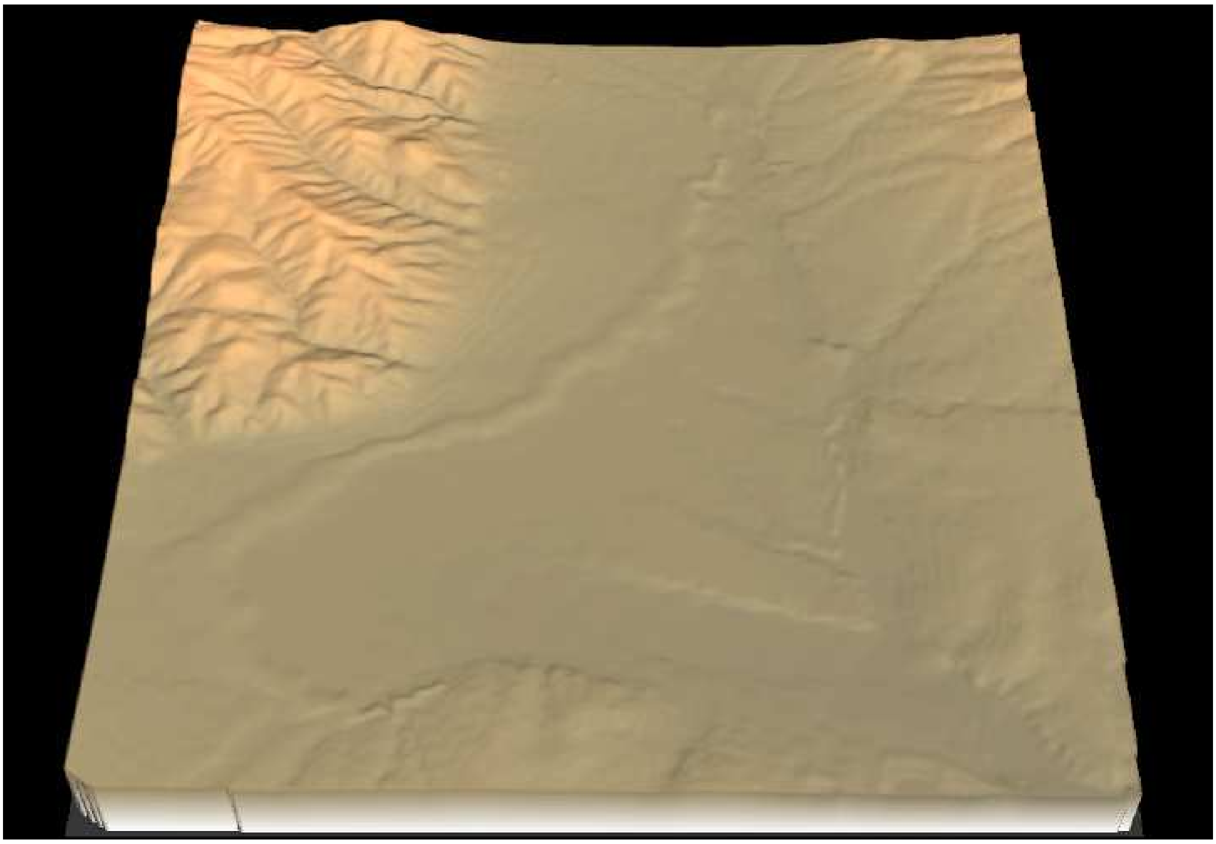


Fig. 2.14 – 3 D model of the area

Hill slopes are covered with dense trees and bushes, which gives non affected and very natural perspective. At the foot hills where rural settlements are located, residential houses are scattered. On the opposite, flat fertile lands are cultivated, and so visually changed by anthropogenic effects. It should be noted that due to relatively small dimensions, mine facilities and associated structures didn't significantly change natural landscape.

2.1.5.4.2 Cultural and archaeological heritage

In addressing the cultural and archaeological resources of the proposed site three aspects were examined:

- Archaeology
- Historic resources
- General archaeological potential of the area.

In the study area there are no cultural and archaeological sites that are of historic interest within the zone of visual influence of the proposed development.

Detailed review of available data was performed in order to gather further information on other important or contentious archaeological resource of the area. The investigation revealed that no information was available on the study area.
Also, this area dose not has any natural or anthropogenic sites with extraordinary aesthetic, recreational or tourist values which are mentioned in the List National Rarities (Statistical Yearbook 2004).

2.2 Current environmental conditions

Since no data about the pre-mining conditions were available, all descriptions given below refer to the current conditions, which are certainly in some form affected by mining activities. The data presented are result of available literature data as much as data collected for on site recognition.

2.2.1 Air quality

There are no industrial polluters on air so in biggest part of the municipality the air quality could be consider as good. Households use woods for heating, but that can’t be treated as serious source for pollution. There is serious and very dangerous air pollution from the unclean streets/roads, especially in summer months, when there is lot of dust.

Clear exemptions from previous conclusions are areas nearby abandoned Lojane Mine facilities. Only issue concerning the air quality is fugitive dust from abandoned mine facilities of old Lojane mine. Intensive fugitive dust emissions are reported from dry tailings piles and arsenic concentrate storage ponds located in place called Mining Colony between villages of Vaksince and Lojane. These structures are completely unprotected and very prone to wind erosion, thus endangering nearby local school, as much as wider area of villages Vaksince and Lojane.

The same situation occurs from the old roasting (smelting) facilities, although in this case there are not residential or public object in immediate vicinity.

2.2.2 Water quality

One of the most serious problems in the area of Lipkovo municipality is lack of quality drinking water, since there is no water supply system. Drinking water is supplied from local small and individual springs, which are without sanitary control. All chemical analyses performed, indicate very high bacteriological pollution.

Biggest problem for all settlements, according the LEAP document, are fecal wastewaters from the households which are usually drained through the septic holes and open channels direct to the rivers, in soil, to open roads, in yards etc. Practically, waste waters in populated places flow through the roads, often polluting or endangers public or residential surfaces and drinking water sources. According to same document, epidemic from drinking bio-polluted water were frequently registered.

There are no industrial waste waters because there are no industrial objects.

The water used by the population in Lojane and Vaksince area is of particular concern. According to data presented in available documentation, its pointed that the surface and groundwater in this area are contaminated with heavy metals (As, Cr, Sb ...) due to present pollution sources from abandoned mine site, as much as relatively high natural background of this metals of subsurface environment.

2.2.3 Soil quality

Soil quality is mostly affected by improper use of agrochemicals, communal solid waste and certainly from pollution with heavy metals disseminated through different pathways from abandoned mine facilities.
There is no professional use of agrochemicals, so the overdose or wrong use of the chemicals is common. Also, some times, these means are bought by individual traders and are with suspicious quality.

Since there is no organized system for communal solid waste collection and disposal, produced solid waste is disposed in valleys, river flows, and near the roads, thus making it significant source of environmental pollution with all consequences which results from it. Problem of soil pollution with HM is not mentioned or recorded in documents reviewed, including LEAP as most detailed documents concerning the quality of the environment in Lipkovo Municipality.

2.2.4 Effects of environmental conditions on living quality and people’s health

According the available documentation, main problems in this region with effects on people health are:

- polluted air,
- polluted surface and underground waters,
- polluted fertile soils,
- non quality agricultural products because of spray with insecticide and use of chemical fertilizers,
- low standard of living,
- no recreation and sport activities,
- low quality of living due to social status of the population, low level of education, etc.

According the Lipkovo municipality LEAP, main reasons are minimum quality and quantity of drinking water and waste waters, as well as dust from the dry tailings pile.

In practice, it is proved that main reason for contagious diseases (hepatitis) are uncontrolled communal waste dumps.

According to the same document its noted that people in Lojane and Vaksince have many diseases as a result of non quality drinking water, because of not controlled used of wells in serpentines which contain arsenic, antimony and chromium.

2.2.4.1 Public perception of the environment

Due to very specific conditions and sensitivity of the area public perception concerning environmental issue, although planed was not conducted. The data concerning perception are collected from published reports (Lipkovo municipality LEAP), as much as from discussions with local authorities and inhabitants of settlements visited.

In general the documents reviewed present the fact that level of ecological conscience of local population is very low. Reasons are seen in lack of information, living culture, social - economic conditions (unemployment), as well as non functional law system.

According to LEAP document on question about what part of the environment is biggest problem, tested people answer that is drinking water quality (28.3 %), air quality (26.0 %), soil quality (22.2 %), flora and fauna (16.9 %) and 6.2 % don't know. Probably, these answers are because of fact that villages in Lipkovo region have problems with water supply.

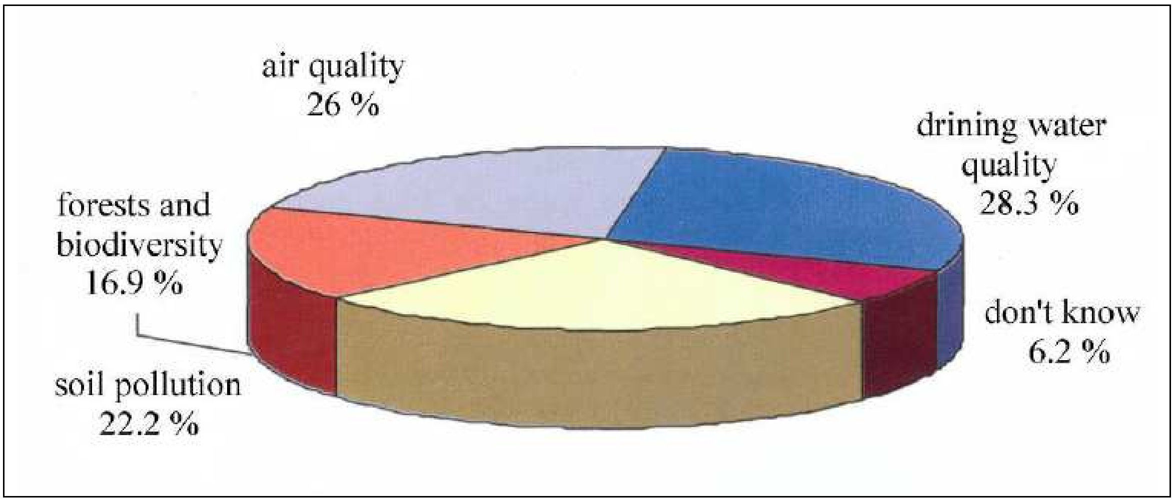


Fig. 2.15 – The biggest ecological problems - Lipkovo Municipality population opinion

It should be noted that for most people only problem with abandoned mine facilities is dust from dry tailings pile (probably due to visibility of the dust clouds), while the water and soil pollution were not mentioned. Concerning the water and soil quality, according to the local population, issues with communal waste waters and solid waste are more important.

2.3 Abandoned mine facilities description

2.3.1 Description of mining/mineral processing technology used

As previously mentioned no original mine plans, documentation was available, so discussion below is based only on data collected on site, as much as on assumptions and conclusion from on the site observations as much as literature data for operations, waste streams, and waste management practices typical of historic mine sites and mineral processing facilities.

It should be noted that knowledge of the operating history of the site is essential for site scoping and characterization and the cleanup alternative selection process, so a special efforts were done to clearly identify and describe mining/processing technology used at the site.

Since from obvious reason, underground workings as much as some surface remaining from the mine were not accessible, and in order to determine type of mining technology used as much as extent underground workings, following points are reviewed:

- technology available at the time when mine was active,
- surface objects (shafts and mine adits),
- surface disturbance – footprint (subsidence...),
- quantities of non-ore materials removed and disposed as waste,
- amount of tailings produced (usually biggest portion of total material excavated)

Based on this, following conclusions were drawn:

- Primitive technology (in today terms) was used, probably human works with limited application of mechanical tolls (powered by compressed air) and horses.
- Most probably some kind of room and pillar mining method was applied (since no subsidence was spotted in the area). It also obvious that underground workings are limited in extent (small size of the adits and no significant water drainage).
- Total quantity of material excavated during the period when mine was active (1923-1979) is estimated to amount of app. 1,300,000 tons, so the annual production capacity

was between 25,000 to 30,000 tons, thus classifying the operation as relatively small (in today terms very small).

- Total quantity of wastes generated by extraction operations (waste rocks) are estimated to app. 90,000 tons. No significant water drainage from the mines was noted.

Total number of 4 mine adits and 3 ventilation shafts are located in the area, scattered on both sides of the valley. In the higher part of the valley, along the south foot of the hill ruins from small mining settlement and mine office/service buildings are scattered on the area of approximately 3,000 m^2. In the same area 4 waste rock dumps and mined ore stockpiles are located.

Considering the beneficiation facilities, remains found on place clearly indicate that flotation process was used. The ore excavated was transported in processing plant by narrow rail line to the processing plan where ore was reduced in size by the crushing and/or grinding circuit (see photo 2.10). Antimony and arsenic minerals were concentrated by flotation process. As for all flotation systems, a complex system of reagents was most probably used, including, pH conditioners (regulators, modifiers), collectors, frothers, activators, and depressants. The wastes generated by this process, known as tailings were disposed in dry form on the pile created just in front of the plant. The tailings pile covers a surface of app. 17,500 m^2, and contains app. 450,000 tons of tailings. A concentrate storage pond (stone structure with estimated volume of app. 5,000 m^3) build near the plant contains app. 15,000 tons of 50% As concentrate.

At the end concentrates were transported to the roasting plant, used to prepare ores for smelting. The facility ruins and storage yard covers surface of 8,800 m^2.

Summarized data about all facilities mentioned before are given in following table. Chemical composition of all waste dumps, tailings and concentrates left are also determined.

Table 2.3 – Compiled data for abandoned mine facilities

Location	**Objects**	**Chemical/Mineral composition**	**Quantities**
Along the river Suva (Masugguri hill)	Office/Service Buildings	/	3.000 m^2
Along the river Suva (Masugguri hill)	Shafts , Adits	/	3 shafts, 4 adits
Along the river Suva (Masugguri hill)	Waste rock dump 1		20.000 tons
	Waste rock dump 2		20.000 tons
	Waste rock dump 3		50.000.tons
	Waste rock dump 4		100.000 tons
	Ore stockpile	High grade ore (app. 5-6 % Sb, 4 % As)	5.000 tons
Mining colony	Plant/Office Buildings	/	2.000 m^2
Mining colony	Tailings Dump		450.000 tons
Mining colony	Arsenic concentrate	realgar (As>50%)	15.000 tons
Roasting facility Tabanovce railway station)	Open Stock Yard	realgar (As>50%)	5.000 tons
Roasting facility (Tabanovce railway station)	Drums	As_2O_3	500 pcs

2.3.2 Locations of abandoned mine facilities

The old Lojane Mine Site is located between the villages Lojane, Vaksince in area called Rudnicka Kolonija (Mine colony). The total mine site area is about 10 km^2. The area of consideration includes several locations where old production, storage and transportation facilities existed. It is worthwhile to mention that relatively large size of the mine site is due to fact that operations are not co-located. The processing (flotation) plant is located at a convenient and safe location so ore from all mine adits (transported on narrow tracks railway) can be collected and processed. From this plant the concentrate was further transported to roasting facility or a remote smelter.

Mine Facilities - old mine shafts and adits are located in Valley of Suva River on the softly inclined sides of Masguri Hill. Total number of 4 mine adits and 3 ventilation shafts are located in the area, scattered on both sides of the valley. In the higher part of the valley, along the south foot of the hill ruins from small mining settlement and mine office/service buildings are scattered. In the same area 3 waste rock dumps and mined ore stockpiles are located. Photos of all structures mentioned are disclosed below.

Mineral Processing Facilities – ruins from processing plant (crushing and flotation) as much as some administrative and service building are located along the road connecting villages of Vaksince and Lojane, at the locality called Rudnicka Kolonija. Also a dry tailings pile and arsenic concentrate storage pond are situated in the same area just near the old flotation plant, between the old processing plant and the road. At the same location a local school and few residential and commercial objects are located (see the photos disclosed).

Smelting (ore frying) Facility – old roasting/smelting facility and open storage yard are located in North West of village of Tabanovce, near the international railway station Tabanovce where custom and police control buildings are also located.

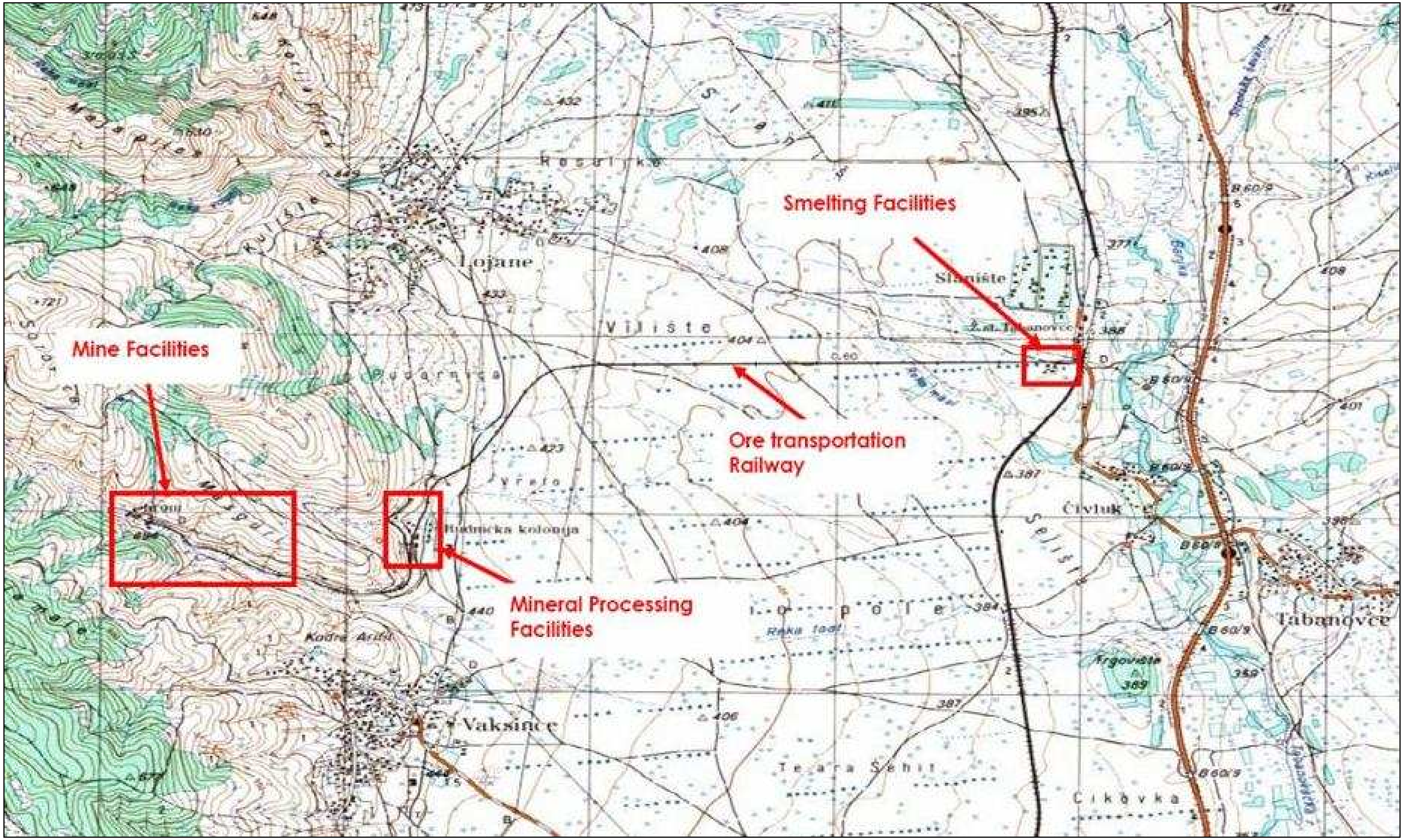


Fig. 2.16 – Map of area of consideration (1: 25.000)

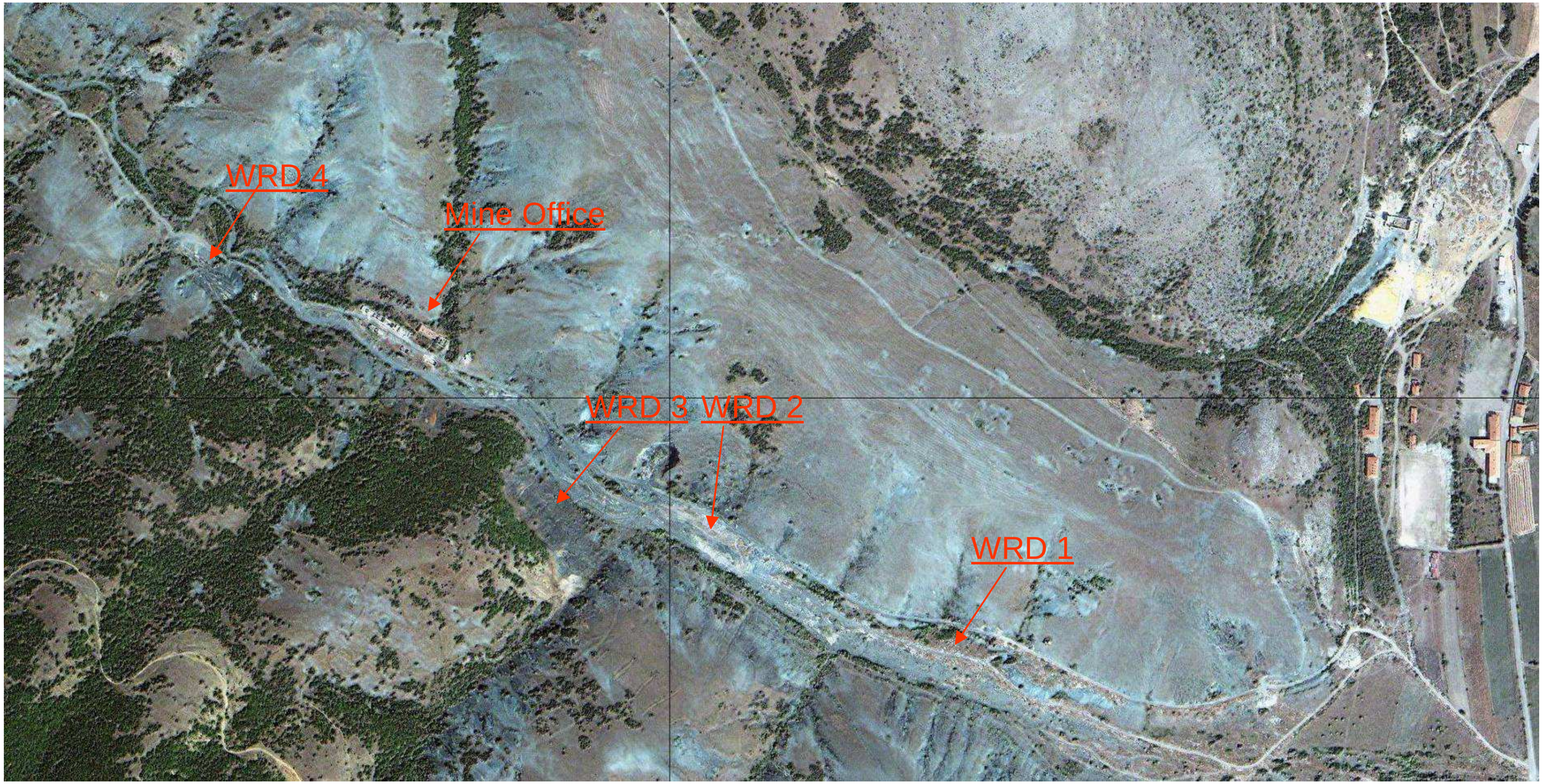


Fig. 2.17 – Mining facilities in Suva River valley

Photo 2.2 – Mine structures

Photo 2.3 – Mine structures – adit No. 1

Photo 2.4 – Mine structures – adit No. 2

Photo 2.5 – Mine structures – old mining buildings

Photo 2.6 – Mine structures

Photo 2.7 – Processing facilities – tailings dump (top view, south side)

Photo 2.8 – Processing facilities – tailings dump (top view north side)

Photo 2.9 – Processing facilities – side view (south side)

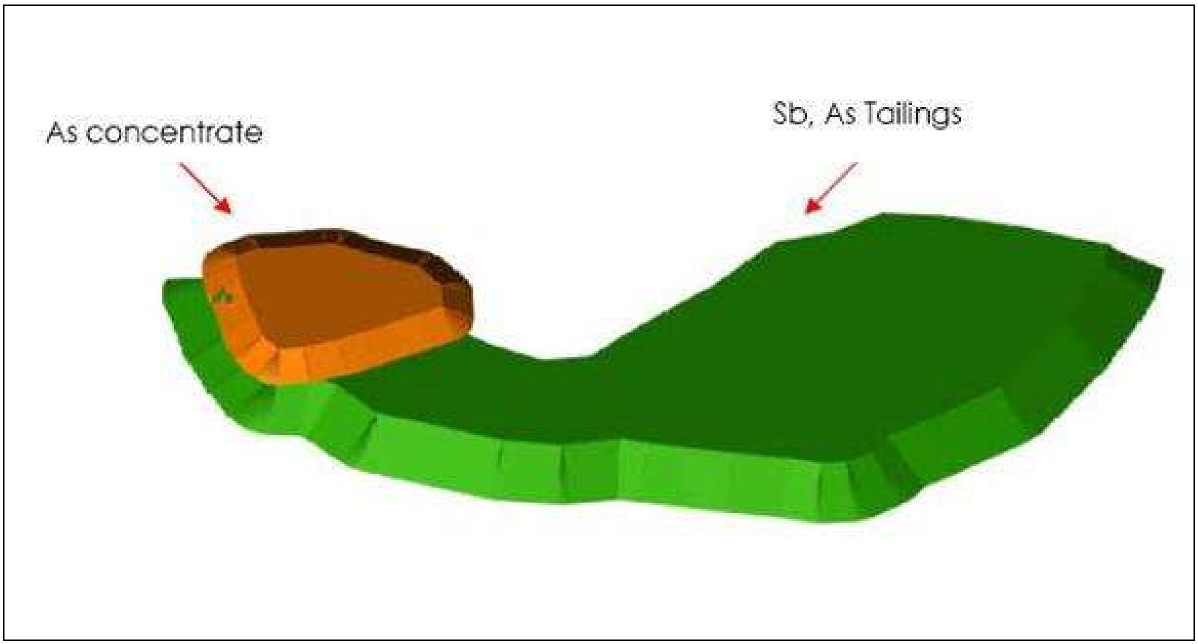


Fig. 2.18 – Processing facilities – 3D model of tailings dump and As-concentrate

Photo 2.10 – Processing plant ruins

Photo 2.11 – Arsenic concentrate storage pond (side view)

Photo 2.12 – Arsenic concentrate storage pond (top view)

Photo 2.13 – Roasting/smelting facilities – plant ruins

Photo 2.14 – Roasting/smelting facilities – open storage yard

2.4 Environmental impacts

2.4.1 Introduction

Mining is one of the industrial activities with high potentials for adverse impacts on the human health and overall quality of the environment, especially in cases with abandoned mine sites, like Lojane mine is.

Knowledge of these impacts will be important during site scoping, characterization, and alternative selection. This background information provides valuable insight into the contaminants that may be present, potential threats to human health and the environment, and feasibility of response actions.

A variety of environmental impacts may occur at an abandoned mine site. Major categories of abandoned mine site impacts are listed below:

- Metals contamination of ground/surface water and sediments;
- Sedimentation;
- Air emissions;
- Physical impacts.

Effects from process like leakage from underground storage tanks or solvent disposal from mechanical shops, involving contaminants like PCBs, solvents, petroleum, chemicals used in processing, are not addressed, since no indications for them are found on site and if they exists, their extent is probably limited in intensity and area.

2.4.1.1 Metal contamination of groundwater and surface water

Mining operations can affect surface and ground water quality in several ways. The most obvious occurs in mining below the water table, either in underground workings or open pits, which provides a direct conduit to aquifers. Ground water quality is also affected when waters (natural or process waters or wastewaters) infiltrate through surface materials (including overlying wastes or other material) into ground water.

Contamination can also occur when there is a hydraulic connection between surface and ground water. Any of these can cause elevated pollutant levels in ground water. In addition, contaminated ground water may discharge to surface water down gradient of the mine, as contributions to base flow in a stream channel or springs.

In case of Lojane Mine Site, due to existence of underground mine workings as much piles of waste materials, its clear that there is a great risk of pollution of surface and ground waters, although due to specific site geology/hydrogeology connection between surface waters and aquifers is limited. Anyway, this risk are seriously investigated and described in the text below.

Further, disturbance in the ground water flow regime may affect the quantities of water available for other local uses.

Considering the fact that Lojane Mine was small scale underground operation, as much as fact that currently there are no activities for workings dewatering, channels for re-direction of flow or other active or passive water control objects, it can be concluded that impact of abandoned mine facilities on surface and ground water flow directions, intensity and availability are minimal in extent.

In addition, since the Lojane Mine was closed almost 30 years ago, it is certain that the ground and subsurface water regime reach new equilibrium which can be noticed in present. Since there are no available records of previous drainage patterns, it's impossible to conclude about extent and intensity of changes occurred. These are the reasons why this issue will not be addressed in future discussion.

Primary sources of dissolved pollutants from metal mining operations include underground mine workings, overburden and waste rock piles and tailings piles. Dissolved pollutants at a mine site are primarily metals but may include sulfates, nitrates, and radionuclides; these contaminants, once dissolved, can migrate from mining operations to local ground and surface water (contamination of surface water may also occur as contaminated soil or waste materials are eroded and washed into water bodies). While AMD/ARD can enhance contaminant mobility by promoting leaching from exposed wastes and mine structures, releases can also occur under neutral pH conditions. Discharges of mine waters, storm and snowmelt runoff, and seepage are the primary transport mechanisms to surface water and ground water. Naturally occurring substances in the site area are the major source of these pollutants.

Considering the Lojane specific site geology dissolved metals most probably will include arsenic, antimony, chromium, lead, copper, manganese, cadmium, iron, nickel, beryllium and zinc. It's to be expected that elevated concentrations of these metals in surface and ground waters preclude their use as drinking or irrigating water. Also high metal concentrations have detrimental effects on aquatic life/biota. Qualitative and quantitative parameters of dissolved pollutants, mechanisms of contamination and transportation of pollutants, as much as pollutant effects on human health and life/biota, were in details investigated and are in details elaborated in this report.

Sediments in receiving streams can also be contaminated when dissolved pollutants are discharged to surface waters partition to sediments in the stream. In addition, fine grained waste materials eroded from mine sites can become sediments. Sediment contamination may affect human health through the consumption of fish and other biota that bioaccumulate toxic pollutants. Finally, sediment contamination provides a long-term source of pollutants through potential re-dissolution in the water column. This can lead to chronic contamination of water and aquatic organisms.

As a result of this processes, some toxic constituents associated with discharges from mining operations may be found at elevated levels in sediments, while not being detected in the water column or being detected at much lower concentrations. Similar mechanism, can contribute to pollution of food produced on the soils irrigated with contaminated water, due to bioaccumulation of some contaminants in the plants.

As a result of site specific conditions and long term uncontrolled pollution sediment contamination which may affect human health, its expected to occur at Lojane mine site. Based on these assumptions, all issue regarding sediment contamination is assessed and results of this assessment are discussed below.

2.4.1.2 Sediments

Because of the large land area disturbed by mining operations and the large quantities of earthen materials exposed at sites, erosion may cause significant loading of sediments and any entrained chemical pollutants to nearby streams, especially during severe storm events and high snowmelt periods.

Water erosion may be described as the process by which soil particles are detached, suspended, and transported from their original location. Sedimentation is the byproduct of erosion, whereby eroded particles are deposited at a different location from their origin. The main factors influencing erosion include rainfall/snowmelt runoff, soil infiltration rate, soil texture and structure, vegetative cover and slope length.

Major sources of erosion/sediment loadings at mining sites include, waste rock and overburden piles, tailings piles, haul and access roads and ore stockpiles. Other non-mining sources also may contribute to erosion impacts in the watershed. At smelter sites historic air emissions may have caused toxicity to local vegetation, increasing erosion potential in impacted areas.

Particulate matter is detrimental to local fish populations. Decreased densities of Macroinvertebrate and benthic invertebrate populations have been associated with increased suspended solids. Enhanced sedimentation within aquatic environments also has the effect of inhibiting spawning and the development of fish eggs and larvae, as well as smothering benthic fauna. In addition, high turbidity may impair the passage of light, which is necessary for photosynthetic activity of aquatic plants.

Exposed materials from mining operations, such as mine workings, wastes, and contaminated soils, may contribute sediments with chemical pollutants, including heavy metals. Contaminated sediments in surface water may pose risks to human health and the environment as a persistent source of chemicals to human and aquatic life and those non-aquatic life that consume aquatic life. Human exposure occurs through experiencing direct contact, eating fish/shellfish that have bioaccumulated toxic chemicals, or drinking water exposed to contaminated sediments.

Beyond the potential for pollutant impacts on human and aquatic life, physical impacts are associated with the sedimentation, including the filling of deep pools resulting in the loss of habitat for fish and an increase in temperature. The sedimentation can also result in the filling of downstream reservoirs reducing the capacity for flood control. The sedimentation can also cause the channel to widen and become shallower, which may increase the frequency of over bank flow.

In the area of Lojane mine site, except Suva River, there are no larger surface water streams which could be endangered with process of sedimentation. For this reason sedimentation is in general assessed from standpoint of contamination of sediments only. Since the Suva River is short and small volume stream which during the low water level dissipate in the flats of Kumanovsko Pole and only in high water level periods reach stream of Tabanovska River, the sedimentation is limited to the Suva River and dose note present significant risk from standpoint of increasing flood capacity or loss potential for energy production.

2.4.1.3 Air emission and downwind deposition

At abandoned mine sites, the processes that were the source of the emissions typically have ceased operation, therefore continued deposition is unlikely. Fugitive dust usually is still emitted from unstabilized waste management units and contaminated sites or from transportation and remediation activities.

Fugitive dust is produced from wind entraining dust from dumps and spoils piles, roads, tailings, and other disturbed areas. Dust problems from tailings, due to high levels of metals (arsenic, for example) trigger concerns.

Tailings and waste rock at metal mines usually contain trace concentrations of heavy metals that may be released as fugitive dust and present respiratory hazard or contaminate areas downwind as coarse particles settle out of suspension in the air. Although deposition at any distance may have been at a relatively low concentration, the long period of deposition (i.e.

from decades) and the biostability of metals have created soil contamination problems of significant proportions.

Fugitive dust from tailings and waste piles at the Lojane mine site, due to visibility issues are reported as one of the biggest problems associated with the site. It's clear that wind erosion especially at the tailings pile significantly contributes to public surfaces and soil pollution due to downwind aero-sedimentation of contaminants and pose respiratory hazards to exposed population. For this reason, air emissions are also elaborated in future discussions.

2.4.1.4 Physical impacts

Mine structures and waste management units pose a unique set of problems from a perspective of both ensuring the safety of remediation workers and alleviating environmental impacts that would result from structural failure and a subsequent release of contaminants.

Slopes at mine sites usually have a several hazards associated with each. No properly reclaimed sloped may create environmental problems associated with increased erosion, rapid runoff, changes in wildlife patterns and the exposure of potentially reactive natural materials. Slopes created with dumping or piling of overburden, tailings, waste rock or other materials (which can be toxic, acid forming, or reactive) are usually very unstable. Slope failure can result in direct release or direct exposure of these materials to the surrounding environment. Saturation of waste material can also trigger slope failure.

At Lojane mine site several so called filled slopes are identified, including waste and tailings piles as much as concentrate/ore piles. All this structures are relatively small in dimensions and quantities of materials stored. Only dry tailings pile contains bigger amount of material (app 1.000.000 tons), but slopes are note higher than 10 m. Based on the onsite visit of our geomechanic expert, it is concluded that structural stability of the piles is not an issue which posse immediate risk for structural failure, and its not discussed in this report. Of course if any remediation works on the slopes are taken, depending on the action planed re-assessment of the stability has to be performed.

Mining subsidence is the movement of the surface resulting from the collapse of overlying strata into mine voids. The potential for subsidence exists for all forms of underground mining. Subsidence may manifest itself in the form of sinkholes or troughs. Sinkholes are usually associated with the collapse of a portion of a mine void (such as a room in room and pillar mining); the extent of the surface disturbance is usually limited in size. Troughs are formed from the subsidence of large portions of the underground void and typically occur over areas where most of the resource has been removed.

Effects of subsidence may or may not be visible from the ground surface. Subsidence can contribute to increased infiltration to underground mines, potentially resulting in increased AMD generation and a need for greater water treatment capacity in instances where mine drainage must be treated. Impacts to ground water include changes in water quality and flow patterns (including surface water recharge).

Since the underground mining activities were very limited in intensity and extent, as much as the fact that on site visits did not reveals any indications of subsidence, this issue will not be considered in future assessment.

Structures at mining and mineral processing sites can be a physical hazard for investigative and remediation workers and contain quantities of contaminates. For example, buildings at many mining and mineral processing sites were just shut down when the facility stopped production with the hope that production would be restarted. Because of this many buildings may contain both chemicals used in the process in containers that are no longer intact or quantities of material, such as flue dust or feed product that contains high concentrations of contaminates. In addition to the materials contained in the structure, the structure may be unsafe due to time, weather, and the exposures that occurred during operations.

The site visits reveal that all buildings and other structures are demolished and all equipment, installations and material inside are taken. Still the ruins pose physical treat for people or animals entering them and they should be completely removed and site cleared. Since there are no other impacts expected, this issue should be included for consideration when remediation actions are planed, and will not be further discuss in this report. Mine openings, both horizontal and vertical, can be a significant physical hazard at an abandoned mine site. These mine openings may harbor a number of physical hazards that can injure or kill those who enter, including unstable ground that could collapse or bad air, either insufficient oxygen or containing poisonous gases, such as carbon monoxide. The other physical hazards from mine openings are those that are unknown, particularly vertical shafts. If the opening has been covered, either by an old collapsed building or vegetation, they may pose the threat of falling, to individuals or wildlife that may get to close to the obscured opening.

All mine openings (adits and shafts) are out of the populated area and but of course they can be a treat for persons or animals enter them, so the proper isolation or fencing to prevent the access should be considered. Again this should be considered when remediation actions are planed.

2.4.2 Toxicological profiles of contaminants of concern

Based on the data collected in preliminary research activates, contaminates of concern are determined. The data are updated after the finishing of filed investigations. Following metals are included in this section - antimony, arsenic, cadmium, cobalt, copper, lead and nickel.

2.4.2.1 Antimony

Antimony is a naturally occurring metal that is used in various manufacturing processes. It is generally found as a sulfide or oxides. The natural sulfide of antimony, stibnite, was known and used in Biblical times as medicine and as a cosmetic. The most important use of antimony metal is as a hardener in lead for storage batteries. The metal also finds applications in solders and other alloys. Antimony trioxide is the most important of the antimony compounds and is primarily used in flame-retardant formulations. These flame retardant applications include such markets as children's clothing, toys, aircraft and automobile seat covers.

2.4.2.1.1 Pharmacokinetics

Exposure to antimony may be via inhalation, oral and dermal routes (ATSDR, 1990). Antimony is sparingly absorbed following ingestion or inhalation (Felicetti et al., 1974; Gerber et al., 1982; US EPA IRIS, 1998a,b). Both gastrointestinal and pulmonary absorption are a function of compound solubility. Trivalent antimony is more readily absorbed than pentavalent forms. Antimony is transported in the blood. Antimony is not metabolized but may bind to macromolecules and react covalently with sulfhydryl and phosphate groups (ATSDR, 1990). Excretion of antimony is primarily via the urine and feces (Cooper et al., 1968; Ludersdorf et al., 1987; ATSDR, 1990).

2.4.2.1.2 Non-cancer effects

Acute oral exposure of humans and animals to high doses of antimony or antimony-containing compounds (antimonials) may cause gastrointestinal disorders (vomiting, diarrhea), respiratory difficulties, and death at extremely high doses (Bradley and Frederick, 1941;

Beliles, 1979; ATSDR, 1990). Subchronic and chronic oral exposure may affect hematologic parameters (ATSDR, 1990). Long term exposure to high doses of antimony orantimonials has been shown to adversely affect longevity in animals (Schroeder et al., 1970). Limited data suggest that prenatal and postnatal exposure of rats to antimony interferes with vasomotor responses (Marmo et al., 1987; Rossi et al., 1987). Acute occupational exposure may cause gastrointestinal disorders (probably due to ingestion of airborne antimony) (ATSDR, 1990). Exposure of animals to high concentrations of antimony and antimonials (especially stibine gas) may result in pulmonary edema and death (Price et al., 1979). Long term occupational exposure of humans has resulted in electrocardiac disorders, respiratory disorders, and possibly increased mortality (Renes, 1953; Breiger et al., 1954). Antimony levels for these occupational exposure evaluations ranged from 2,200 to 11,980 µg Sb/m3. Based on limited data, occupational exposure of women to metallic antimony and several antimonials has reportedly caused alterations in the menstrual cycle and an increased incidence of spontaneous abortions (Belyaeva, 1967). Reproductive dysfunction has been demonstrated in rats exposed to antimony trioxide (Belyaeva, 1967).

No data were available indicating that dermal exposure of humans to antimony or its compounds results in adverse effects. Eye irritation due to exposure to stibine gas and several antimony oxides has been reported for humans (Stevenson, 1965; Potkonjak and Pavlovich, 1983).

2.4.2.1.3 Cancer effects

The US EPA has not evaluated antimony or antimonials for carcinogenicity. IARC (1989) has classified antimony trioxide as possibly carcinogenic to humans (Group 2B) by inhalation. Antimony trisulfide was not classifiable as to its carcinogenicity to humans (Group 3) (IARC, 1989).

2.4.2.1.4 Susceptible populations

No studies were located regarding unusual susceptibility of any human subpopulation to antimony. A susceptible population will exhibit a different or enhanced response to antimony than will most persons exposed to the same level of antimony in the environment. Reasons include genetic makeup, developmental stage, health and nutritional status, and chemical exposure history. These parameters result in decreased function of the detoxification and excretory processes (mainly hepatic and renal) or the preexisting compromised function of target organs. For these reasons the elderly with declining organ function and the youngest of the population with immature and developing organs are expected to be generally more vulnerable to toxic substances than healthy adults (ATSDR, 1992).

2.4.2.1.5 Current exposure limits

Oral Exposure Limits - The US EPA (US EPA IRIS, 1998a - oral RfD assessment last revised 1991) has calculated subchronic and chronic oral reference doses (RfDs) of 0.4 µg/kg-day based on decreased longevity and alteration of blood chemistry in rats chronically exposed to potassium antimony tartrate in the drinking water (5 ppm equivalent to 350 µg Sb/kgday) (Schroeder et al., 1970). More recently, the NRC (2000) has proposed an oral RfD for antimony trioxide of 200 µg/kg-day based on increases in serum enzymes and liver weight in female rats from a study conducted by Hext et al., (1999). Because there is an inadequate toxicity database, the NRC's confidence in this derived RfD is low to medium. Use of the US EPA's RfD is a more conservative approach.

Inhalation Exposure Limits - The US EPA (US EPA IRIS, 1998b - inhalation RfC assessment last revised 1995) has calculated a reference concentration for chronic inhalation exposure

(RfC) of 0.2 µg/m3 based on pulmonary toxicity and chronic interstitial inflammation in a one year inhalation toxicity study in rats exposed to antimony trioxide (Newton et al., 1994). This RfC was also proposed by the NRC (NRC, 2000).

2.4.2.2 Arsenic

Arsenic (As) is a brittle, gray metal that tarnishes in air. It is a natural component of the earth's crust and occurs in small amounts in rock, soil, water and underwater sediments. It is commonly found in combination with sulphur and iron in minerals such as arsenopyrite. Arsenic is used mainly to preserve wood and to control insects and weeds. Elemental arsenic is not soluble in water; calcium arsenate, and calcium arsenites are sparingly soluble in water; the remaining arsenicals are soluble in water. Arsenic, arsenic pentoxide, arsenic trioxide, the calcium arsenites, lead arsenate, and potassium arsenate are soluble in various acids (ATSDR, 1993).

2.4.2.2.1 Pharmacokinetics

The oral bioavailability of arsenic compounds is dependent on the chemical species and on the matrix (e.g., soil or dust) in which it is administered. Based on published literature, the absorption of water-soluble inorganic arsenic compounds in an aqueous solution is about 95 percent (ATSDR, 1993). For soil and house dust impacted by operating smelters containing arsenic, the oral bioavailability in Cynomolgus monkeys is about 14 and 19 percent, respectively (Freeman et al., 1995). The bioavailability of inorganic arsenic for exposure via inhalation would be in the range of 30 – 34 percent (ATSDR, 1993). Dermal absorption through human skin in vitro ranged from 0.8 to 1.9 percent (Wester et al., 1993). Distribution of arsenic within the body is affected by the route through which exposure occurs. Given sufficient time for equilibration, arsenic generally tends to be evenly distributed amongst tissues within the body. The interaction of arsenic with various tissues is dependent on the chemical form of the arsenic. The primary pathway of elimination of inorganic arsenic is excretion via the urine. Because of the importance of urinary excretion as the primary route of elimination of arsenic, concentrations of arsenic compounds in the urine is considered to be a reliable index of recent exposure to arsenic (ATSDR, 1993).

2.4.2.2.2 Non-cancer effects

There are numerous studies that have looked at human exposures to inorganic arsenic in the air, but there are no reports of fatalities associated with short term occupational exposures to arsenic levels as high as 100 mg As/m3 (ATSDR, 1993). Inhalation exposures to inorganic arsenic dusts in the workplace have been reported to cause irritation of the nose and throat, laryngitis, bronchitis and cases of very high exposures have been reported to result in perforation of the nasal septum (ATSDR, 1993). However, respiratory effects have not been noted at exposure levels that range between 0.1 and 1.0 mg/m3 (ATSDR, 1993). There is some limited evidence of respiratory tract effects following oral exposure to inorganic arsenic, but this is thought to be a secondary effect that is due to the vascular damage which results from the ingestion of arsenic (ATSDR, 1993). There is limited and equivocal epidemiological evidence that suggests that inhalation exposures to arsenic trioxide dust may result in cardiovascular effects. However, there are a number of studies that indicate that oral exposures to inorganic arsenic can lead to serious damage of the cardiovascular system (ATSDR, 1993). Both acute and long-term exposures can result in myocardial depolarization and cardiac arrhythmias. Long term exposures to low levels of arsenic can also result in damage to the vascular system, characterized by a progressive loss of circulation in the hands and feet (ATSDR, 1993). In areas of Taiwan, with elevated levels of arsenic in the drinking water, evidence of circulatory effects related to arsenic exposures were seen at a dose of approximately 0.014 mg As/kg-day (ATSDR, 1993).

There are several studies that have indicated that inhalation exposures to inorganic arsenic can lead to a number of neurological effects in humans, including peripheral neuropathy of sensory and motor neurons that are manifested as numbness, loss of reflexes and muscle weakness. In extreme cases, frank encephalopathy including hallucinations and memory loss have been reported (ATSDR, 1993). These effects generally cease once exposures have ended (ATSDR, 1993). Acute effects of oral arsenic exposure include vomiting, nausea, diarrhea, gastrointestinal hemorrhage and death. There are a large number of cases of human fatalities following the ingestion of inorganic arsenicals. In most cases, the doses resulting in death have been difficult to quantify. However, two reports, indicate that doses ranging between 1 and 22 mg As/kg body weight per day (mg/kg-day) have resulted in death. Although similar effects are often seen with long-term exposures to lower doses of arsenic, effects are not generally reported at doses lower than 0.01 mg As/kg-day (ATSDR, 1993). There is a large number of studies that indicate that the acute ingestion of large amounts of inorganic arsenic can cause a number of injuries to the nervous system including; headache, lethargy, mental confusion, hallucination, seizures and in extreme cases, coma (ATSDR, 1993). Chronic exposures to lower levels of arsenic, ranging between 0.019 and 0.5 mg/kg-day, are typically characterized by a peripheral neuropathy similar to that seen with inhalation exposures. Neurological effects have not been detected in populations chronically exposed to arsenic levels of less than 0.01 mg/kg-day (ATSDR, 1993). A number of hematological effects including anemia and leucopenia have been reported in humans as a result of acute, intermediate and chronic oral exposures to arsenic (ATSDR, 1993). These effects are usually not seen in persons exposed to levels of arsenic lower than 0.07 mg/kg/day (ATSDR, 1993). Oral exposures to inorganic arsenic have been reported to cause several toxic effects in the liver including, elevated levels of hepatic liver (ATSDR, 1993). These effects are generally seen in cases where chronic exposures range between 0.019 to 0.1 mg/kg-day (ATSDR, 1993). It has been suggested by several researchers that these effects are secondary to the damage of hepatic blood vessels resulting from the damaging effects that inorganic arsenic has on the circulatory system. However, there is insufficient clinical information available to confirm this (ATSDR, 1993). There is little clinical evidence of renal damage following oral exposures to inorganic arsenic compounds (ATSDR, 1993). A few cases of renal failure have been reported in cases of arsenic poisoning, but this is felt to be due to fluid imbalances of vascular damage caused by arsenic, and not directly attributable to arsenic (ATSDR, 1993). The most common dermal effect associated with the ingestion of inorganic arsenic is the development of a pattern of skin changes which include hyperkeratosis, the development of hyperkeratosis warts, areas of hyper pigmentation and hypo pigmentation (ATSDR, 1993). Numerous studies have shown that dermal effects are common in humans exposed to inorganic arsenic levels that range between 0.01 and 0.1 mg As/kg-day. These studies have also demonstrated that, below a dose level of 0.01 mg As/kg-day, dermal effects are not reported (ATSDR, 1993).

2.4.2.2.3 Cancer effects

There is sufficient convincing epidemiological evidence to show that inhalation exposure to inorganic arsenic can increase the risk of developing lung cancer. Many studies provide only qualitative evidence of an association between the duration of and/or level of exposure to arsenic and the increase in the rate of lung cancer. There is sufficient epidemiological information available from occupational studies for the US EPA to develop cancer potency estimates for inhalation exposures to inorganic arsenic (US EPA IRIS, 1998 - carcinogenicity assessment last revised 1998). Health Canada (1996) classified inorganic arsenic compounds as Group (carcinogenic to humans). There are a large number of epidemiological studies that provide convincing evidence that the ingestion of inorganic arsenic increases the risk of developing skin cancer. The most common effect is the development of squamous cell carcinomas. Basal cell carcinomas also occur. In the majority of cases, skin cancer only develops after prolonged exposure (ATSDR, 1993). There is sufficient human epidemiological data available for the US EPA to develop estimates of cancer risk associated with oral exposure to inorganic arsenic (US EPA IRIS, 1998 - carcinogenicity assessment last revised 1998).

2.4.2.2.4 Susceptible populations

No studies were located regarding unusual susceptibility of any human subpopulation to arsenic. A susceptible population will exhibit a different or enhanced response to arsenic than will most persons exposed to the same level of arsenic in the environment. Reasons include genetic make-up, developmental stage, health and nutritional status, and chemical exposure history. These parameters result in decreased function of the detoxification and excretory processes (mainly hepatic and renal) or the pre-existing compromised function of target organs. For these reasons the elderly with declining organ function and the youngest of the population with immature and developing organs are expected to be generally more vulnerable to toxic substances than healthy adults (ATSDR, 1993).

2.4.2.2.5 Current exposure limits

Oral Exposure Limits - The US EPA IRIS (1998 - oral RfD assessment last revised 1993) calculated an oral RfD of 0.3 µg As/kg-day based on epidemiological studies of chronic exposure to arsenic through drinking water. This limit was selected for non-carcinogenic effects. Arsenic exposure via the oral route was considered to be carcinogenic to humans, based on the incidence of skin cancers in epidemiological studies examining human exposure through drinking water. The cancer slope factor of 0.0015 (µg As/kg-day)-1 and corresponding risk specific dose (RSD) of 0.00067 µg As/kg-day are based on an acceptable risk level of one-in-one million. On January 22, 2001, the US EPA established an enforceable Maximum Contaminant Level (MCL) of 10 µg/L for arsenic (Fed. Reg. 66: 6976-7059). On March 23, 2001, US EPA issued a delay of the effective date for this Final rule (Fed. Reg. 66: 16134-16135). On May 22, 2001 EPA announced that it would delay the effective date for the rule until February 22, 2002 allowing time to complete the reassessment process and to afford the public a full opportunity to provide further input. Following a request from US EPA to the National Academy of Sciences' (NAS) National Research Council's subcommittee on arsenic to review the science and update its 1999 Arsenic in Drinking Water report, a revised Arsenic in Drinking Water, 2001 Update report was prepared. This update report assessed new information on arsenic exposure in Taiwan and northern Chile. At this time the US EPA IRIS file for inorganic arsenic has not been updated, so the current IRIS file oral cancer slope factor is as described above. WHO (1996) calculated an arsenic in drinking water risk of 10-5 (µg/L)-1 based on prevalence of skin cancer in Taiwanese studies and the US multistage model.

Health Canada (Health Canada, 1996; CEPA, 1996) developed a TC05 of 840 µg/L for drinking water based on the Taiwanese studies and the US EPA's 1988 model (US EPA, 1988, as cited in CEPA, 1996) adjusted for Canadian ingestion volumes.

Inhalation Exposure Limits - The US EPA (US EPA IRIS, 1998 -carcinogenicity assessment last revised 1998) calculated an inhalation unit risk for arsenic of 0.0043 (µg/m3)-1 based on epidemiological studies of lung cancer in workers at arsenic smelters. WHO (2000) calculated an inhalation unit risk for arsenic of 0.0015 (µg/m3)-1 based on epidemiological studies of lung cancer in workers at arsenic smelters in Sweden and the USA. Health Canada (1996) developed a TC05 of 7.8 µg /m3 based on occupational exposure data at the Anaconda copper smelter in Montana and a relative risk model.

2.4.2.3 Cadmium

Cadmium is a natural element that is usually found as a mineral combined with other elements such as oxygen, chloride and sulphur. Cadmium forms both organic and inorganic compounds. It is extracted mostly during the production of other metals, and is used in batteries, pigments, metal coatings and plastics.

2.4.2.3.1 Pharmacokinetics

Following inhalation, the major site of cadmium absorption in humans is the alveoli of the lung.

Human data are not available for absorption in the lung. A kinetic respiratory tree model has been developed to predict cadmium particle deposition in the lung (Nordberg et al., 1985). This model suggests that only 5% of the particles that are greater than 10 µm in diameter will be deposited and that about 50% of the particles less than 0.1 µm will be deposited. The respiratory tree model also predicts that 50 to 100% of the cadmium deposited in the alveoli will be absorbed. The majority of ingested cadmium tends to pass through the gastrointestinal tract without being absorbed and is excreted in the feces. Absorption of ingested cadmium is influenced by nutritional status, with absorption increased by low intake of calcium, iron, zinc and copper (Nordberg et al., 1985). Absorbed (from the lungs and gastrointestinal tract) cadmium tends to be excreted very slowly and is found in equal proportions in the urine and feces. The main target organ for cadmium following ingestion is the kidney. The half life of cadmium in the human body is very long. An estimated half life for cadmium in the kidney ranges from 6 to 38 years and the liver from 4 to 19 years (ATSDR, 1998).

The placenta may act as a partial barrier to fetal cadmium exposure. Cadmium is not metabolized, rather it binds to proteins and other molecules. In particular it binds to the protein, albumin in the bloodstream which transports cadmium to the liver. Once cadmium enters the liver it becomes bound to another protein called metallothionein and is released to the bloodstream. The metallothionein bound cadmium is then filtered by the kidney glomerulus and is then reabsorbed by the proximal tubule cells. Lysozymes degrade the cadmium-metallothionein complex and cause free cadmium to be released in the kidney. The free cadmium initiates the synthesis of metallothionein in the proximal tubule cells and can also cause damage to the kidneys in excessive amounts. Currently, information to determine the potential absorption of cadmium via the dermal route of exposure is limited (ATSDR, 1998). Dermal absorption factors have been recommended (US EPA, 1992, 2001) based on a human skin in vitro study of the dermal absorption of cadmium chloride from soil and water (Wester et al., 1992).

2.4.2.3.2 Non–cancer effects

Cadmium and cadmium compounds possess moderately acute toxicity via both ingestion and inhalation. Cadmium is slowly excreted by the body, and therefore bioaccumulates in humans. Chronic cadmium poisoning can be associated with both inhalation and ingestion. Effects Based on studies of cadmium production workers, the route of entry for cadmium with the most immediate health effects is inhalation of fumes or dust. Localized health effects caused by cadmium exposure include irritation to the respiratory tract and to the mucous membrane lining of the inner surface of the eyelid. This is often accompanied by dyspnea (severe difficulty in breathing) and general weakness. Troubled breathing may become more pronounced as pulmonary edema and tracheobronchitis develop. The most common result of acute systemic cadmium exposure is emphysema, but in some instances, mortality may occur. Prolonged exposure may also result in anosmia (loss of sense of smell) and discoloration of the teeth. Ingestion of high acute doses of cadmium may cause gastrointestinal effects such as nausea, vomiting, and abdominal pain (Nordberg et al., 1973). Cadmium causes kidney damage, particularly to the proximal renal tubules in the early stages and as the disease progresses, or the dose increases, glomerular damage is also observed. Renal dysfunction has been demonstrated to be a consequence of chronic low level exposure to both inhaled and ingested cadmium (Bernard et al., 1994). Chronic cadmium exposure coupled with poor nutrition can lead to changes in the way which the kidney metabolizes vitamin D. This can result in painful bone diseases such as osteomalacia and osteoporosis, mainly in women. There is limited data to suggest that cadmium exposures in pregnant women may result in decreased birth weight in their babies. Epidemiologic studies have found an association between cadmium exposure and osteoporosis. Findings in a study on workers exposed to cadmium for up to five years suggest dose-response relationships between cadmium dose and bone mineral density and between cadmium dose and osteoporosis (Järup et al., 1998). In a study on residents living within known proximities to zinc smelters, low to moderate environmental exposure to cadmium was associated with skeletal demineralization and incidence of fractures and height loss (Staessen et al., 1999). Cadmium appears to have a relatively low dermal toxicity based on studies that showed that workers who were occupationally exposed to high levels of cadmium dust, did not report any dermal effects. Cadmium does not appear to cause sensitization by repeated dermal contact.

2.4.2.3.3 Cancer effects

Epidemiological studies demonstrate increased incidence of lung cancer in workers exposed to cadmium via the inhalation route, however, the studies did not control for factors such as smoking and simultaneous exposures to other metals so the causal relationship is somewhat controversial. Oral exposure to cadmium has not been associated with cancer in humans or animals. The United States Environmental Protection Agency has classified cadmium as a probable human carcinogen (Group B2) when inhaled, based on limited human and sufficient animal data (US EPA IRIS, 1998 -carcinogenicity assessment last revised 1992). Health Canada (Newhook et al., 1994) has classified cadmium as a Group II carcinogen.

2.4.2.3.4 Susceptible populations

Populations which may be unusually susceptible to cadmium exposure are those with a genetic predisposition to lower inducibility of metallothionein, the enzyme which sequesters cadmium. Dietary deficiencies which lead to depleted levels of calcium or iron in individuals may result in increased absorption of cadmium from the gastrointestinal tract. Infants and children may have increased uptake of cadmium via the gastrointestinal tract and higher concentrations of cadmium in the bone.

2.4.2.3.5 Current exposure limits

Oral Exposure Limits ATSDR (1998) has developed a chronic oral minimum risk level (MRL) of 0.2 µg/kg-day for cadmium. The chronic MRL is derived from a NOAEL (no observed adverse effect level) of 2.1 µg/kg-day from a study of cadmium accumulation in the kidneys of Japanese farmers living in an area of Japan with highly elevated cadmium levels (ATSDR, 1998). An uncertainty factor of ten was used to account for variability in the human population. The United States Environmental Protection Agency has developed oral reference doses for cadmium for food and water. The oral reference dose for food is 1.0 µg/kg-day and for water is 0.5 µg/kg-day (US EPA IRIS, 1998 - oral RfD assessment last revised 1994). The highest cadmium level in the human kidney which does not produce proteinuria (excretion of low weight molecular proteins into the urine) has been determined to be 200 µg cadmium/g of wet kidney cortex. A toxicokinetic model was used to determine the level of chronic oral exposure that would result in a cadmium kidney concentration of 200 µg cadmium/g of wet kidney cortex. The toxicokinetic model assumes that 0.01% of the body cadmium kidney burden is eliminated daily and that absorption of cadmium from food and water are 2.5% and 5% respectively. A No-Observed-Adverse-Effect Level (NOAEL) for chronic cadmium exposure was determined to be 5.0 and 10 µg/kg-day. An uncertainty factor of ten to account for human variability was applied to the NOAELs to develop the reference doses for food and water. Joint FAO/WHO Expert Committee on Food Additives (WHO, 1993) proposed that the total daily intake of cadmium should not exceed 1 µg/kg body weight/day. This intake was designed to keep the cadmium levels in the renal cortex below 50 µg/g, and assumed an absorption rate for dietary cadmium of 5% and a daily excretion rate of 0.005% of body burden (WHO, 1996). Health Canada has not determined a tolerable daily intake for cadmium (Health Canada, 1996).

Inhalation Exposure Limits The US EPA (US EPA IRIS, 1998 -carcinogenicity assessment last revised 1992) has developed an inhalation unit risk of 1.8 x10-3 (µg/m3)-1. This unit risk is based on lung and upper respiratory tract cancers in cadmium production workers (Thun et al., 1985). The air concentration at the 10-6 life-time cancer risk level (1-in-1,000,000) is 0.0006 µg/m3. The WHO has an annual guideline value (non-cancer) of 0.005 µg/m3 (WHO, 2000). Health Canada has calculated a TC05 of 5.1 µg/m3. This TC05 is based on lung tumor incidence in an inhalation exposure bioassay with rats exposed to cadmium chloride for 18 months (Takenaka et al., 1983, Oldiges et al., 1984). This TC05 was amortized over the standard life-time of a rat, and converted to an equivalent concentration in humans using standard values for breathing volumes and body weights of rats and humans. It can be divided by 50,000 to obtain a 10-6 life-time cancer risk air concentration of 0.0001 µg/m3.

2.4.2.4 Cobalt

Cobalt exists in nature as a brittle hard metal, closely resembling iron and nickel in appearance. It has two valence states (Co(II) and Co(III)), which form numerous organic and inorganic salts. It is alloyed with iron and nickel to make Alnico. Cobalt is used in Stellite alloys, and stainless steel alloys used in jet and gas turbines. Cobalt salts have been used for centuries for the production of brilliant and permanent blue colors in porcelain, glass, pottery and enamel. Cobalt is an essential nutrient for humans as it is needed to make vitamin B12. Vitamin B12 is a coenzyme in many biological reactions including the production of red blood cells. Cobalt has, therefore, also been used to treat anemia. As cobalt is an essential element, it is found in most body tissues with the highest concentrations occurring in the liver, kidney and bones.

2.4.2.4.1 Pharmacokinetics

Inhaled cobalt particles accumulate in the respiratory tract depending on particle size. From the lungs, cobalt particles either dissolve into the bloodstream or are transferred to the gastrointestinal tract by mucocilliary action and swallowing. Approximately 50% of the cobalt transferred to the gastrointestinal tract is actually absorbed and the rest is eliminated in the feces. About 50% of the portion of the initial lung burden can remain up to six months after exposure (Foster et al., 1989 as cited in ATSDR, 1992). Cobalt consumed by the oral route of exposure is absorbed by the gastrointestinal tract. The amount of cobalt absorbed ranges from18 to 97% in humans and is dependent upon the dose and type (form) of cobalt as well as the nutritional status of the individuals involved. Cobalt absorption tends to increase in subjects which have iron deficiencies in their diet. Elimination in the feces is the primary excretion method for oral cobalt exposures. Absorption of cobalt through intact, or unbroken skin does not generally occur (ATSDR, 1992). However, cobalt may be absorbed through broken or injured skin.

2.4.2.4.2 Non-cancer effects

Acute effects of exposure to cobalt-containing dust occupationally are typically inflammation of the nasopharynx. Inhalation of cobalt can affect the respiratory system and if sufficient quantities are inhaled (3µg cobalt/m3), irritation, wheezing, asthma and pneumonia can result. The occupational exposure levels noted here are approximately 10,000 times the typical outdoor air concentration. Individuals can also develop sensitivity to cobalt if exposed continually in an occupational setting to concentrations of about 7 µg cobalt/m3 and subsequent exposures can result in skin rashes or asthma attacks (ATSDR, 1992). Oral exposure to cobalt has occurred in humans who consumed beer containing cobalt salts. In the 1960s, cobalt salts were added to beer to improve its foaming qualities. This practice has been discontinued as it led to several deaths amongst heavy beer drinkers (8 to 30 pints per day) who consumed doses ranging from 3 to 10 mg cobalt per day ("beer drinkers cardiomyopathy"). Less serious effects associated with the consumption of beer containing cobalt compounds included nausea, vomiting and diarrhea. Increased production of red blood cells also occurs in humans after oral exposure to cobalt. Decreased uptake of iodine by thethyroid gland has been observed in humans exposed to short term doses of 1000 µg cobalt/kg-day or longer term doses of 540 µg cobalt/kg/day (ATSDR, 1992). Developmental effects were not observed in babies born to mothers who were taking medication containing cobalt to regulate anemia while pregnant (Holly, 1955 as cited in ATSDR, 1992). Reproductive effects were not observed in the people who died after exposure to high cobalt levels in beer. Some effects have been observed in animals (adverse effects on the testes and increased length of the estrous cycle). However, the significance of these effects for humans is not clear as the cobalt doses used in these studies were much higher than those to which humans are usually exposed. Contact dermatitis has also been consistently reported as an outcome of acute dermal exposure to cobalt compounds in occupational settings.

2.4.2.4.3 Cancer Effects

Hamsters exposed to cobalt oxide dust did not develop an increased incidence of lung tumors in comparison to the control population. Intramuscular injection of cobalt oxide resulted in the production of tumors in rats but not in mice (Gilman 1962 as cited in ATSDR, 1992). Based on animal data, the International Agency for Research on Cancer (1991) has classified cobalt as 2B; possibly carcinogenic for humans. There is insufficient evidence to implicate cobalt or cobalt compounds as human carcinogens. Cobalt has not been shown to cause cancer in humans.

2.4.2.4.4 Susceptible Populations

People who are already sensitized to cobalt may be unusually susceptible because subsequent cobalt exposure may trigger an asthma attack. Cobalt sensitization can be determined by cobalt specific changes to serum antibodies (IgE and IgA).

2.4.2.4.5 Current Exposure Limits

Oral Exposure Limits - the recommended daily intake of cobalt as vitamin B12 is 2 µg/day for adults and 0.3 µg/day for children less than two years old (Health Canada, 2000). The US EPA Region III derived an oral RfD of 20 µg/kg-day for cobalt based on cobalt intake levels in food (US EPA, 2001). This RfD was based on the upper range of average intake for children, that is below the levels of cobalt needed to induce polycythemia in both renally compromised patients. However, the current US EPA IRIS list of chemicals does not include cobalt.

Inhalation Exposure Limits An intermediate minimal risk level (MRL) of 0.03 µg cobalt/m3 is proposed by the Agency for Toxic Substances and Disease Registry (ATSDR, 1992). This inhalation RfC is based on a Lowest-Observed-Adverse Effect Level (LOAEL) of 110 µg/m3 (as cobalt sulfate) for squamous metaplasia of the larynx in rats and mice exposed for 13 weeks in the NTP (1991) and Bucher et al., (1990) studies. This dose was adjusted for intermittent exposure, converted to an equivalent concentration in humans, and a safety factor of 1000 was applied. No regulatory dermal exposure limits for cobalt were identified in the literature reviewed for the current assessment.

2.4.2.5 Copper

Copper is a natural element that is also an essential nutrient for the human body. It is used as a conductive agent in electrical equipment, reducing agent, catalyst, as wire material, and can be found in some pesticides. Copper can be ingested from drinking water or eating certain foods. Another possible route of exposure includes the inhalation of roadway dust containing copper from the use of car brakes. It could also be ingested from foods that have absorbed it from copper cookware. Copper sulfate is used as a pesticide, fungicide and nutritional supplement in animal feed and fertilizer. Copper is an essential element for humans and is found widely throughout the body. Adverse health effects can be linked to both copper deficiency as well as excessive copper levels. Copper deficiency is demonstrated by anemia, neutropenia and bone abnormalities, but is rarely observed in clinical situations. Copper is considered essential for the development of structural and enzymatic proteins. Enzymes regulating cellular respiration, free radical detoxification, iron metabolism, neurotransmitter function and synthesis of connective tissue contain copper.

Regulation (activation and repression) of gene transcription also requires copper. Copper concentrations are regulated in the body by a process called homeostasis (ATSDR, 1990). Copper regulates the mechanism which controls its intracellular homeostasis. Copper enters the liver where it is reduced and then complexes with glutathione. Metallothionein is the primary protein to which copper binds and these proteins are involved in the detoxification and binding of excess copper. Copper binds to the transcription factor which causes the production of metallothionein. When cellular copper levels are high then copper will bind to the metallothionein transcription factor causing metallothionein production, thereby detoxifying excess copper concentrations. If cellular copper levels are low, it is unlikely that there will be enough copper to bind to the metallothionein transcription factor, thereby limiting the production of metallothionein so that the copper can be used for metabolism (Gollan et al., 1973).

2.4.2.5.1 Pharmacokinetics

No studies were found which document absorption, distribution or elimination of copper following inhalation exposure. Absorption of copper occurs primarily through the gastrointestinal tract. Copper absorption is related to the amount of copper in the diet. For example, when adults were administered a low copper diet (780 µg copper per day), 55.6% of the administered copper was absorbed by the gastrointestinal tract as determined by the use of isotopes. For adults who were administered an adequate dose of copper in their diet (1,680 µg copper per day), 36.3% absorption was observed and for adults with a high daily copper intake (7,530 µg copper per day), only 12.4 % absorption was found. Copper absorption in adults is saturable and the percentage of copper absorbed decreases as the daily intake of copper increases. Total retention of copper increased with dietary intake and appropriate balance was maintained even at the lowest concentration studied (780 µg copper per day). Copper absorption and metabolism decreases as a result of competition with high levels of other metals such as iron and zinc for binding sites on metallothionein. Molybdenum inhibits copper retention. Recent studies with an isotopic tracer indicate that infants absorb sufficient copper to meet their growth needs (Ehrenkranz, 1989). Infants appear to reduce copper intake at high dietary concentrations by increasing fecal elimination and decreasing absorption. The liver is the major organ involved in the distribution of copper throughout the body. Distribution of copper to other tissues throughout the body occurs through the blood stream. The highest concentrations of copper are found in the brain, kidney, heart, liver and pancreas. Ceruloplasmin (a protein which can bind six to eight Cu(II) atoms) and serum albumin appear to be the major carriers of copper through the bloodstream. Bile is the major elimination pathway for liver copper as it accounts for approximately 80% of the copper leaving the liver. Pregnancy is associated with increased copper retention likely due to decreased biliary excretion resulting from the hormonal changes which typically occur. Urinary excretion and sweating are minor contributors to copper removal. The use of topical medications containing copper compounds can increase dermal absorption of copper (Eldad et al., 1995). Components of topical medication such as salicylic acid or phenylbutazone facilitate the transport of copper through the skin.

2.4.2.5.2 Non-cancer effects

Inhalation exposure information is limited to studies on factory workers who have been exposed to significantly higher copper air concentrations than the general public. Copper dust is considered a respiratory irritant as factory workers experienced irritation of the mucosal membranes of the mouth, nose and eyes. Metal fume fever has also been observed in workers exposed to high concentrations of fine copper dust in air. Gastrointestinal effects such as nausea, anorexia and occasionally diarrhea were also experienced by factory workers and it is thought that the gastrointestinal effects are primarily due to swallowing a portion of the airborne copper (i.e., would be classified as an oral exposure). Copper is rarely toxic unless very large amounts are ingested. The available toxicity data associated with oral consumption of copper are limited to ingestion of water with very high copper concentrations or suicide attempts involving copper sulfate.

Chronic exposure to drinking water containing approximately 60 µg copper/kg-day (equals 4,200 µg copper/day for a 70 kg adult), resulted in nausea, vomiting and abdominal pain shortly after consumption of the water. The gastrointestinal difficulties stopped after an alternate water supply was found for the affected persons. Chronic copper poisoning is very rare, since the capacity for healthy human livers to excrete copper is considerable. Any reports of chronic copper poisoning that do exist involve patients with liver disease. Developmental effects have not been observed in children of mothers with Wilson’s Disease (a metabolic disorder which causes accumulation of copper in the liver) or healthy humans. Developmental toxicity has been found in mice, mink and hamsters that were fed a high copper diet or were injected with copper. Reproductive effects have not been observed in human populations exposed to high copper levels. Copper containing intrauterine devices are used as a method of birth control and animal studies have shown that the copper wires contained within these devices are the contraceptive agent. Dermal exposure to copper can result in allergic contact dermatitis.

2.4.2.5.3 Cancer effects

The United States Environmental Protection Agency has classified copper and copper compounds in Group D which indicates that they are substances for which inadequate data are available to make a carcinogenicity assessment. Specifically, for copper and copper compounds there are no human carcinogenicity data, animal bioassay data is inadequate and mutagenicity tests are equivocal (US EPA IRIS, 1998 -carcinogenicity assessment last revised 1991).

2.4.2.5.4 Susceptible populations

Infants and children under one year old are unusually susceptible to copper toxicity because they have not developed the homeostatic mechanism to remove copper from the body. Wilson’s Disease is a genetic disorder associated with impaired transport of copper from the liver to the bile, thereby resulting in increased copper concentrations in the liver as they are not able to maintain homeostasis. Another genetic condition which increases the susceptibility to copper toxicity is a deficiency in the enzyme glucose-6phosphate dehydrogenase. Individuals with liver disease are also susceptible to copper toxicity because of the critical role the liver plays in eliminating copper from the body.

2.4.2.5.5 Current exposure limits

Oral Exposure Limits - As copper is considered an essential element for humans there are two types of exposure limits that are considered: (a) the minimal daily intake so that a person will not suffer from copper deficiency; and (b) the maximal permissible daily intakes so that a person will not suffer from copper toxicity. The World Health Organization (WHO, 1998) has determined the minimal daily copper intake for adults to be 20 µg copper/kg/day which is equivalent to 1,400 µg copper per day for the average 70 kg adult. For children, the World Health Organization concluded that the minimal daily copper intake should be 50 µg copper/kg/day (equivalent to750 µg copper per day for a 15 kg child). The minimal daily copper intake was determined as the amount of copper needed for a child or adult to function properly while accounting for variables such as differences in copper absorption, retention and storage. The Recommended Dietary Allowance (RDA) for US adults is 900 µg copper/day or about 13 µg/kg/day (IOM, 2001). This RDA is a combination of indicators, including plasma copper and ceruloplasmin concentrations, erythrocyte superoxide dismutase activity and platelet copper concentration in controlled human depletion/repletion studies. The US Reference Daily Intake (a term which replaces “US RDA”) for copper is 2,000 µg/day or about 30 µg/kg/day for adults (US FDA, 1999). The tolerable upper intake level for US adults is 10,000 µg/day or about 140 µg/kg/day, and is based on protection from liver damage (IOM, 2001).

Inhalation Exposure Limits - A chronic non-cancer Reference Exposure Level (REL) of 2.4 µg/m3 is listed for copper compounds in the California Air Pollution Control Officers Association Air Toxics “Hot Spots” Program, Revised 1992 Risk Assessment Guidelines. This REL is based on respiratory effects (CAPCOA, 1993, CARB, 1998). The United States

Environmental Protection Agency (US EPA) has not established a Reference Concentration (RfC) for copper compounds (US EPA IRIS, 1998 inhalation RfC assessment last revised 1991). A2-7.3.3 Selection of Exposure Limits The estimates of the carcinogenic potencies of inhaled copper and non-cancer effects of ingested copper, developed by the Institute of Medicine (IOM) and the California Air Resource Board (CARB) will be used to assess potential human health risks associated with exposure to copper at this site.

2.4.2.6 Lead

Lead is a bluish-white lustrous metal. It is very soft, highly malleable, ductile and a relatively poor conductor of electricity. It is very resistant to corrosion but tarnishes upon exposure to air. Lead pipes bearing the insignia of Roman emperors, used as drains from the baths, are still in service. Alloys include pewter and solder. Tetraethyl lead was used in some grades of petrol (gasoline).

2.4.2.6.1 Pharmacokinetics

The absorption, distribution, metabolism, and elimination of lead has been extensively studied in both animals and humans. Available data can be used to quantify the uptake and disposition of lead in the human body for various populations of children and adults. Lead absorption is influenced by the route of exposure, chemical speciation, the physicochemical characteristics of the lead and exposure medium, and the age and physiological states of the exposed individual (e.g., fasting, nutritional calcium and iron status). There is a significant body of data available in the scientific literature evaluating lead absorption from soil (summarized in NEPI, 2000). The primary sites for inorganic lead absorption are the gastrointestinal and respiratory tracts. The bioavailability of ingested soluble lead in adults may vary from less than 10% when ingested with a meal to 60 – 80% when ingested after a fast. Immediately following absorption, lead is widely distributed to blood plasma and soft tissues, then it redistributes and accumulates in bone (ATSDR, 1993). Bone lead accounts for approximately 73% of the total body burden in children, increasing to 94% in adults due to changes in bone turnover rates with age. Transplacental transfer of lead has been demonstrated based on measurements of lead in umbilical cord blood in humans, as well as tissue concentrations in offspring of mice. Lead that is not retained in the body is excreted principally by the kidney as salts or through biliary clearance into the gastrointestinal tract in the form of organometallic conjugates. Excretion rates measured in infants, children, and adults are highly variable, although available data suggest that the fraction of absorbed lead that is retained in humans decreases with age (ATSDR, 1993). Dermal absorption of lead compounds is less significant than either oral or inhalation routes of exposure (ATSDR, 1993). Information on the dermal absorption of lead containing compounds is limited to a single study, which applied a lotion containing lead acetate to the forearms of male volunteers and reported a dermal absorption rate of approximately 0.06% over a 12 hour period (ATSDR, 1993). The toxicokinetics of lead seem to be affected by the polymorphism of the enzyme deltaaminolevulinic acid dehydratase (ALAD) (Smith et al., 1995). ALAD is a polymorphic enzyme with two common alleles, ALAD*1 and ALAD*2 (Petrucci et al., 1982).

Gerhardsson et al., (1999) investigated the mobilization of lead by use of the chelating agent 2-3-meso-dimercaptosuccinic acid in male lead smelter workers. Two workers with the ALAD*2 allele seemed to mobilize less chelatable lead in relation to their blood, plasma, and urine concentrations of lead than the other workers. Smith et al., (1995) suggest that ALAD*2 in circulating red blood cells bind lead more avidly than ALAD*1, thus increasing the blood lead level, but at the same time decreasing the amount of lead delivered to soft tissues.

2.4.2.6.2 Non-cancer effects

The potential for lead to impair neurobehavioral development in children is the subject of much concern. Acute inhalation and oral exposures to lead often results in central nervous system effects including; dullness, restlessness, irritability, poor attention span, headaches, muscle tremors, hallucination and loss of memory (Health Canada, 1992). Encephalopathy has been reported at very high lead exposure levels (100 µg lead/deciliter of blood in adults and 80 µg/dL in children) (Health Canada, 1992). Chronic exposure to elevated levels of lead can result in a number of nervous system effects. Tiredness, sleeplessness, irritability, headaches, joint pain and gastrointestinal symptoms have all been reported (Health Canada, 1992). In adults, these effects are seen at blood lead levels of 50 80 µg/dL. Occupationally exposed persons have been found to suffer from muscle weakness, mood disruptions, and peripheral neuropathy when blood lead levels reached 40 - 60 µg/dL. At levels of 30 - 50 µg/dL, significant reductions in nerve conductive velocities were also reported (Health Canada, 1992). Renal disease has also been reported, but nephropathy has not been detected in adults or children whose blood lead levels were below 40 µg/dL (Health Canada, 1992). There is substantial human evidence in both adults and children which demonstrates that both the central and peripheral nervous system are the primary targets of lead toxicity. Subencephalopathy, neurological and behavioral effects in adults and electrophysiological evidence of nervous system damage in children have been reported at blood lead levels as low as 30 µg/dL (Health Canada, 1992). A number of epidemiological studies have examined the effects of lead exposure in young children. The studies were able to demonstrate no clear threshold below which the detrimental effects of lead on child neurological development does not occur (Health Canada, 1992). Epidemiological studies have indicated that non-cancer neurological effects may occur at very low exposure levels. Therefore, an exposure level based on these effects will provide against the possible carcinogenic effects of lead. Health Canada (1996) recommended a provisional tolerable daily intake (PTDI) for lead of 3.57 g/kg-day. This value was based on technical reports from annual meetings of the Joint FAO/WHO Expert Committee on Food Additives (WHO/ JECFA, 1993), and epidemiological studies associating lead exposure with neurological effects in infants and children. The WHO value was established to prevent increases in blood lead levels in children. Studies with young children have shown that daily exposures to lead in the 3 - 4 µg/kg- day range do not alter the blood lead level in the children. Intakes at or above 5 µg/kg-day resulted in significant increases in blood lead levels (WHO / JECFA, 1993).

2.4.2.6.3 Cancer effects

Epidemiological studies of occupationally exposed adults were not able to demonstrate an increase in cancers among an exposed cohort compared to control. The International Agency for Research on Cancer (IARC, 1987), considers the overall evidence of lead carcinogenicity in humans to be inadequate. Animal studies have reported renal tumors in rats exposed to 1,000 µg lead salts/g in the diet. While exposures to lead acetate, subacetate and phosphate salts produced renal tumors in rats, equivalent exposures to other lead salts did not result in the production of renal tumors (Health Canada, 1992). Health Canada has classified lead as a Group IIIB (possibly carcinogenic to humans) compound based on a lack of adequate human data and limited evidence of carcinogenicity in animals. The US EPA (US EPA IRIS, 1998 - carcinogenicity assessment last revised 1993) has classified lead as a probable human carcinogen based on sufficient animal evidence. However, the Carcinogen Assessment Group (US EPA IRIS, 1998) did not recommend derivation of a quantitative estimate of oral carcinogenic risk, due to a lack of understanding pertaining to the toxicological and pharmacokinetic characteristics of lead. In addition, the neurobehavioral effects of lead in children were considered to be the most relevant endpoint in determining an exposure limit. Health Canada (1992) classified lead in Group IIIB (possibly carcinogenic to humans) by ingestion. Lead and inorganic lead compounds have been placed in Group 2B (possible human carcinogen) by ingestion under IARC (1987).

2.4.2.6.4 Susceptible populations

There is a very large database which documents the effects of acute and chronic lead exposure in adults and children. Extensive summaries of the human health effects of lead are available from a number of sources including Health Canada, the US EPA IRIS database and the ATSDR. These reviews show that infants, young children up to the age of six and pregnant women (developing fetuses) are the most susceptible (Health Canada, 1992).

2.4.2.6.5 Current exposure limits

Oral and Inhalation Exposure Limits - Health Canada (1996) recommended a provisional tolerable daily intake (PTDI) for lead of 3.57 µg/kg-day. This value was based on technical reports from annual meetings of the Joint FAO/WHO Expert Committee on Food Additives (JECFA) (WHO, 1993 - as cited in Health Canada, 1996), and epidemiological studies associating lead exposure with neurological effects in infants and children. Based on a critical blood lead level of 100 µg/L for cognitive deficit, hearing impairment and disturbed vitamin D metabolism in children, the annual average air lead level should not exceed 0.5 µg/m3 (WHO, 2000). The Ontario Ministry of Environment and Energy recommended an IOCpop (intake of concern for populations) of 1.85 µg/kg-day which incorporated the population-based significance of the health effects and attempted to minimize the predicted number of children with individual blood lead levels of concern (MOEE, 1994). Sub-clinical neurobehavioral and developmental effects were the critical effects appearing at the lowest levels of exposure (MOEE, 1994). The IOCpop was based on an LOAEL (lowest observed adverse effects level) in infants and young children of 10 µg/dL, converted to an intake, with an applied uncertainty factor of two for the use of an LOAEL (MOEE, 1994).

2.4.2.7 Nickel

Pure nickel is a hard, silvery-white metal, which has properties that make it very desirable for combining with other metals to form mixtures called alloys. Some of the metals that nickel can be alloyed with are iron, copper, chromium and zinc. These alloys are used in making metal coins and jewelry and in industry for making items such as valves and heat exchangers. Most nickel is used to make stainless steel. Compounds of nickel combined with many other elements, including chlorine, sulfur and oxygen exist. Many of these compounds dissolve fairly easily in water and have a characteristic green color. Nickel and its compounds have no characteristic odor or taste. Nickel compounds are used for nickel plating, to color ceramics, to make some batteries, and as substances known as catalysts that increase the rate of chemical reactions (ATSDR, 1997). The physiological role of nickel in animals and humans has not yet been determined. It is believed, based on plants and microorganisms, that nickel is involved as a cofactor in metalloenzymes/proteins or as a cofactor which facilitates iron absorption in the intestine (Nielsen, 1985). Nickel may also affect endocrine function regulating prolactin levels. Nickel deficiency has not been observed in humans, but has been induced in animals, indicating that nickel is an essential element for animals (Schnegg and Kirchgessner, 1975). An important issue relating to nickel toxicity is its speciation. Its form (metallic, salt, oxide, etc.) and solubility strongly influence its toxicology. The solubility (in water) of different nickel compounds ranges from the highly soluble nickel salts (nickel chloride - 642 g/L, nickel sulfate 293 g/L) down to the insoluble nickel oxide (1.1 mg/L) and the sparingly soluble nickel subsulfide (517 mg/L) (ATSDR, 1997). Some of the more insoluble nickel compounds (i.e., nickel oxide, nickel subsulfide) may have higher solubility in biological fluids (Yamada et al., 1993; Ishimatsu et al., 1995; Oller et al., 1997). The predominant nickel species in Rodney Street soils is the relatively insoluble nickel oxide (Results section of Part A). The toxicity of nickel can be classified into four separate categories: (1) non-cancer respiratory and other disorders, due to the inhalation or ingestion of nickel compounds; (2) cancer, due to inhalation of nickel compounds; (3) allergy, a hypersensitivity to nickel manifested by contact dermatitis and asthma; and (4) iatrogenic poisoning which may have occurred in the past in patients undergoing hemodialysis, corrosion of stainless steel prostheses, and nickel-contaminated medication, or medication such as disulfiram that caused increased nickel concentration in the blood (not discussed).

2.4.2.7.1 Pharmacokinetics

Inhalation Exposure - Following inhalation exposure, nickel may deposit in the lungs depending on the size of the particle inhaled. Larger particles (5 - 30 µm) tend to accumulate in the upper respiratory tract while smaller particles are deposited in the lower respiratory system (see section A 29.2.1.1).
Absorption of nickel compounds deposited in the lung into the blood stream depends upon their form and solubility. Soluble nickel compounds such as nickel chloride and nickel sulfate are absorbed readily (up to 100%) from the respiratory tract, while almost none of the less soluble nickel compounds such as nickel oxide and nickel subsulfide (as demonstrated by urinary nickel levels in exposed workers (ATSDR, 1997) are absorbed. Inhaled nickel that is absorbed is excreted through the urine. Studies conducted on nickel workers show that nickel urinary excretion increased towards the end of the shift and also towards the end of the work week, indicating that one fraction is removed quickly, but that there was also a fraction which was removed more slowly (Ghezzi et al., 1989; Tola et al., 1979; as cited in TERA, 1999). No reliable estimates are, however, found in the literature for retention and uptake of nickel from solely nickel oxide inhalation exposure in humans. Recently, Yu et al., (2001) have developed a dosimetry model for inhaled nickel compounds using occupational exposure data and information from studies of rats inhaling nickel. Occupational exposure to nickel results in higher nickel lung burdens than the general population. Workers exposed to insoluble forms of nickel (such as nickel oxide and nickel sulfide) have higher nickel levels in the nasal mucosa than those workers exposed to more soluble forms of nickel (this may be related to larger inhalable dust particles being trapped in the upper respiratory tract). Less soluble nickel compounds, therefore, appear to remain in the nasal passage following inhalation exposure. Serum nickel levels are higher in workers exposed to soluble nickel compounds in comparison to those exposed to insoluble nickel compounds (Torjussen and Andersen, 1979, as cited in ATSDR, 1997). Nickel sensitized individuals had similar nickel levels in blood, urine and hair relative to non-sensitive individuals (Spruit and Bongaarts, 1977, as cited in ATSDR, 1997). Pulmonary exposure to green nickel oxide in rats resulted in nickel excretionin the feces, but not in the urine, indicating that the primary removal mechanism of nickel oxide involved clearance from the lungs rather than by dissolution-absorption processes (Benson et al., 1994 as cited in ATSDR, 1997). The observed excretion could also reflect mucociliary clearance (being brought up in mucus and then being swallowed), in addition to macrophage clearance. Benson et al., (1994) also found that nickel subsulfide is cleared relatively rapidly (half life of four days) from the lungs of rats. They concluded that nickel subsulfide is relatively insoluble in water, but dissolves rapidly in lung fluid.

Oral Exposure Studies examining the absorption of nickel by humans found that nickel sulfate was up to 40 times more bioavailable if administered in water than in food (Sunderman et al., 1989). The bioavailability of nickel also increased when administered in a soft drink, but not when given in milk, coffee, tea or orange juice (Solomons et al., 1982). Serum nickel levels were found to be elevated in subjects who had fasted prior to the administration of nickel in drinking water, but this was not the case for those who were administered nickel in food. Food tends to decrease the bioavailability of nickel. Some nickel sensitive individuals were found to have decreasing nickel serum concentrations and increasing nickel urinary concentrations with increased administered nickel concentrations (Santucci et al., 1994). This may be an indication that some nickel sensitive individuals can decrease nickel absorption in response to increased nickel intake. In non-occupationally exposed people, nickel concentrations tend to be highest in lungs, thyroid and adrenal glands, kidney, heart and liver (Rezuke et al., 1987, as cited in ATSDR, 1997). The total amount of nickel estimated to be present in the human body is about six mg for a 70 kg adult (Sumino et al., 1975, as cited in ATSDR, 1997). Quantitative absorption data for unspecified forms of soluble nickel are as follows: 1 - 27% of ingested nickel is absorbed (depending on whether food is consumed); approximately 1 - 6% of nickel administered with food or during a meal is absorbed; 12 - 27% of nickel absorbed after a fast (data from Diamond et al., 1998, as cited in TERA, 1999). Bioavailability and bioaccessibility of nickel is further discussed in Appendix 5. Nickel metabolism occurs via a series of nickel exchange reactions (Sarkar, 1984, as cited in ATSDR, 1997). In human blood, nickel binds to a blood protein called albumin. Nickel competes with copper for a binding site on the albumin (Hendel and Sunderman, 1972, as cited in ATSDR, 1997). Nickel is then transferred from the albumin to L-histidine, an amino acid. The nickelhistidine complex has a low molecular weight and can easily cross biological membranes (Sarkar, 1984, as cited in ATSDR, 1997). Nickel is also tightly bound to a nickeloplasmin human blood which is not available for exchange and hence not transported across biological membranes (Sunderman, 1986, as cited in ATSDR, 1997). Most ingested nickel is excreted via feces, although the nickel absorbed by the gastrointestinal tract is excreted in the urine. In comparison, studies of nickel doses administered with food or water, 26% of the dose given in water was eliminated in the urine and 76% in the feces by the fourth day following administration (Sunderman et al., 1989). In contrast, 2% of the nickel dose administered in food was eliminated in the urine and 102% was eliminated in the feces during the same time period. Nickel can also be eliminated through hair, sweat, milk and skin. No reliable estimates are, however, found in the literature for retention and uptake of nickel from nickel oxide ingestion exposure.

2.4.2.7.2 Toxicology

In two year inhalation studies of nickel oxide, nickel subsulfide, and nickel sulfate in rats and mice, respiratory lesions observed for all compounds included increased lung weights, focal alveolar/bronchiolar hyperplasia, inflammation and/or fibrosis of the lung, and lymphoid hyperplasia of the lung-associated lymph nodes (Dunnick et al., 1995; NTP 1996a, 1996b, 1996c). The investigators noted that qualitatively the inflammatory responses in the lungs were similar with all three compounds, however, the effects were more severe after exposure to nickel oxide and nickel subsulfide. In addition to lung effects, atrophy of the olfactory epithelium was also observed after exposure to nickel sulfate. Compared to rats, mice were more resistant to the development of lung lesions following nickel exposure.

The only data available for chronic nickel inhalation exposure for humans is limited to occupational data. One of the limitations associated with the epidemiological data available is that the workers were exposed to several different forms of nickel as well as other metals and irritant gases at the same time. As a result, the observed effects can not be attributed to a particular type of nickel. Other lifestyle factors, such as smoking, which affect disease outcomes, are also not always accounted for, thereby limiting the conclusions that can be drawn. One death has been reported as the result of exposure to very high metallic nickel concentrations (382 mg/m3) of a small particle size (Sunderman, 1993, as cited in ATSDR, 1997). Workers who were chronically exposed to nickel oxide or metallic nickel at concentrations greater than 0.04 mg/m3 had a greater incidence of death from respiratory disease (Cornell and Landis, 1984; Polednak, 1981, as cited in ATSDR, 1997). Other respiratory effects found included chronic bronchitis, emphysema, and reduced vital capacity. These workers were also exposed to other metals, so it can not be concluded that nickel is the sole causative agent of the effects observed. Asthma from primary irritation and as the result of dermal sensitization has also been documented among nickel workers (Dolovich et al., 1984; Novey et al., 1983; Shirakawa et al., 1990; as cited in ATSDR, 1997). Increased incidence of cardiovascular related deaths has not been found in nickel workers. Nickel refinery workers with elevated urinary nickel concentrations also showed a significant increase in urinary $2-microglobulin levels, which is indicative of tubular dysfunction in the kidneys (ATSDR, 1997). However, marked differences are seen between the results using single urine samples (“spot samples”), and sampling conducted over a 24 hour period (TERA, 1999). Although male and female workers were exposed to the same average nickel (nickel chloride and nickel sulfide) air concentrations, the women had twice the nickel urinary concentrations of the men (Sunderman and Horak, 1981, as cited in ATSDR, 1997). A study of nickel production workers has found significant increases in levels of immunoglobulin G (IgG), IgA, and IgM as well as a significant decrease in IgE. Serum proteins involved in cell-mediated immunity also increased, suggesting stimulation of the immune system by nickel (Bencko et al., 1983; 1986; as cited in ATSDR, 1997). The TERA (1999) report concluded that “the overall epidemiological database regarding potential kidney effects of inhalation exposure to soluble nickel is weak. However, the available data do provide suggestive evidence that the kidney can be affected under exposure conditions below those causing acute toxicity.” Studies show that pregnant female workers at a nickel refining plant in the Kola region in Russia had a 15.9% increase in spontaneous abortions in comparison with a control population of pregnant female construction workers (who were not occupationally exposed to nickel) who had a spontaneous abortion rate of 8.5% (Chashschin et al., 1994). The Russian metal refinery workers were exposed to nickel sulfate concentrations of approximately 0.08 to 0.196 mg nickel/m3 and corresponding urinary nickel concentrations were 3.2 to 22.6 µg/L. Nickel urinary concentrations in persons not occupationally exposed ranged from <0.1 to 13.3 µg/L. Heavy lifting and heat stress are also associated with nickel refining. A preliminary study of pregnant Russian nickel refinery workers also indicated that babies born to these women had a 16.9% increase in development effects (primarily cardiovascular and musculoskeletal defects), relative to the children of construction workers who had a 5.8% increase in developmental effects. It is not clear whether the fact that the Russian workers also were exposed to heavy lifting and heat stress contributed to the observed abortions. No indications of fetal toxicity (birth weight of first child) in the general population in nickel smelter cities in the Kola region in Russia (Nikel and Zapoljarnij) were found in a large comparative study of pollution and health in the Norwegian-Russian border area. Further studies are in progress (Smith-Sivertsen et al., 1997; Odland, 1999). A significant increase of gaps in the chromosomes was found in white blood cells of nickel workers who were exposed to nickel monosulfide and nickel subsulfide. Breakage or exchange of the chromosomes was not observed. The study did not find any correlation between the incidence of the chromosome gaps, blood nickel concentration, duration of nickel exposure, or age of workers (Waksvik and Boysen, 1982, as cited in ATSDR, 1997). It should be noted that the effects discussed in these paragraphs require absorption from the lungs and systemic distribution of nickel, which would be unlikely to occur following inhalation exposure to nickel oxide alone.

2.4.2.7.3 Current exposure limits

It should be noted that the Health Canada (1996) exposure limits for nickel compounds cited below are based on toxicological literature reviewed up to 1993. Several key studies have been published since 1993 (TERA, 1999, WHO, 1998, WHO, 2000 and IOM, 2001).

Inhalation - Health Canada (1996) classified metallic nickel as Group IV (unclassifiable with respect to carcinogenicity in humans). Health Canada (1996) reports a provisional non-cancer tolerable concentration (inhalation) of 0.018 µg/m3.

Ingestion - No ingestion exposure limits for metallic nickel were located. Dermal Exposure Limits- Contact dermatitis caused by nickel exposure is discussed in section above. The European Directive 94/27/EC (European Union, 1994) of June 30, 1994 addresses the issue of (metallic) nickel in certain objects (mainly jewelry, but including clothes fasteners) coming into direct and prolonged contact with the skin and causing sensitization and allergic responses in humans. This directive requires that:

(1) jewelry that pierces the skin must contain less than 0.05% nickel (500 µg/g) on a mass basis;
(2) products coming into direct and prolonged contact with the skin are restricted to release nickel at a rate of less than 0.5 µg/cm2/week; and
(3) products listed in (2) with a non-nickel coating must also ensure that the nickel release rate not exceed 0.5 µg/cm2/week for at least two years normal usage of the product.

This directive is not directly applicable to the situation where soil nickel gets on the skin.

To assess the potential for cancer effects related to inhalation of nickel oxide, the annual average ambient air concentration (TSP sampler) from MOE monitoring station 27047 (at Davis and Fraser Streets) data was compared to inhalation life-time cancer risk factors from various agencies. These inhalation unit risks may not be based on respirable nickel compounds since total airborne nickel was measured in the workplace. TSP sampler data is the most comparable data for use with workplace exposure data.

For the purposes of this risk assessment, the US EPA RfD for soluble nickel was selected to assess potential non-cancer effects from estimated nickel intakes from all exposure routes. This is essentially the same exposure limit as the tolerable upper intake level for soluble nickel recently derived by IOM (2001). Animal studies show that the absorption of orally administered nickel compounds is closely related to the solubility of the compound (Haber et al., 2000). The only studies indicating a lower bioavailability and corresponding lower toxicity of insoluble forms of nickel are Mastromatteo (1986), Ishimatsu et al., (1995) and Griffin et al., (1990). There is some suggestion that some insoluble nickel forms, e.g., nickel subsulfide, have limited solubility in body fluids, however, this appears to be in the context of inhaled insoluble nickel forms being taken into the lung tissue by phagocytosis (Yamada et al., 1993). Even though the predominant form of nickel in Rodney Street community soils is the insoluble nickel oxide, it is anticipated that the main way that nickel is absorbed is by diffusion as the soluble nickel (II) ion moiety which mainly occurs under acidic conditions. As the acidic stomach contents empty into the small intestine, the first few centimeters of the small intestine constitute the optimum location for metal absorption. As the pH becomes alkaline, the metal ions become less available due to formation of less soluble compounds and will pass through to the colon without being absorbed. Since the scientific evidence suggests that it is likely that only soluble nickel forms are absorbed from the ingested soil, the use of a soluble nickel RfD is appropriate. This preferential uptake of soluble nickel forms from the digestive and respiratory systems with subsequent excretion in the urine is well documented for humans and animals. There is difference of opinion on the suitability of some reproductive studies involving nickel chloride administered in drinking water for use in deriving exposure limits. Recent literature suggests that the animal reproduction study and the uncertainty factors used to derive the Health Canada TD05 for nickel chloride and the WHO TDI should be reviewed. Each toxicity study used to support exposure limits (RfD, TDI, etc.), has been subjected to detailed evaluation and review by the agency involved and some discussion of the reliability, strengths and weaknesses and confidence rating of the studies can be found (US EPA, 1998c - oral RfD assessment last revised 1996, CEPA, 1994, Hughes et al., 1994, WHO, 1996, 1998, IOM, 2001). For the chronic toxicity and reproductive toxicity studies selected to support exposure limits, the NOAEL/LOAEL range is 1.3 mg/kg/day (LOAEL, Smith et al., 1993) to 5 mg/kg/day (NOAEL, Ambrose et al., 1976, ABC, 1988). Other assessments have considered basing RfDs on values ranging from 2.2 mg/kg/day (NOAEL, Springborn, 2000) to 7.6 mg/kg/day (LOAEL, TERA, 1999 and Vyskocil et al., 1994). In conjunction with UFs of ten fold for inter and intra species extrapolation, additional UFs have been used to account for other shortcomings or deficiencies in the supporting study selected. For the studies selected to develop ingestion exposure limits for soluble nickel, the NOAEL for chronic toxicity of 5 mg/kg/day is well established (Ambrose et al., 1976). This NOAEL value was recently endorsed by IOM (2001). Lack of a defined NOAEL for reproductive toxicity is a data gap which has required the use of an additional UF (uncertainty factor) due to uncertainty about the NOAEL for this endpoint (WHO, 1996, Health Canada, 1996). The new unpublished study of Springborn (2000) is currently under review by US EPA as part of a re-assessment of the 1988 RfD for soluble nickel ingestion on IRIS (Ambika Bathija - personal communication). Springborn (2000) demonstrates a clear NOAEL for reproductive toxicity. This suggests that a UF to account for this data gap may no longer be necessary or that the magnitude of the UF adjusting for lack of this information can be revised resulting a smaller overall UF. Consequently, the NOAEL and UFs used in the US EPA RfD for soluble nickel continue to provide an adequate margin of safety to protect human health. Other considerations include: Other oral exposure limits below this value are directed towards intake, e.g., drinking water intakes, and may be unsuited for total exposure considerations. Any exposure limit for soluble nickel has to consider the oral hypersensitivity of some nickel sensitized people. This may be offset by other studies showing that nickel supplements can lead to hyposensitization of other sensitized people.

2.4.3 Work plan

Based on the ToR as much as the data collected trough detailed on site investigations and documentation and literature review, detailed Work Plan was developed. Work Plan comprises two main documents; Sampling and Analysis Plan (SAP) and Health and Safety Plan (HSP).

The SAP ensures the consistency of sampling and data collection practices and activities over time, and ensures that data needs and quality objectives developed in the work plan are met. SAP consists of two parts: (1) a quality assurance project plan (QAPP), which describes the policies and activities necessary for achieving data quality objectives for the site; and (2) the field sampling plan (FSP), which provides guidance for all field work by defining in detail the sampling and data-gathering methods to be used in the project. Short discussion on the plan is given below.

The HSP includes a health and safety risk analysis for existing site conditions; employee assignments; personal protective equipment used by employees; medical surveillance requirements; personnel monitoring, site control measures; decontamination procedures;

standard operating procedures for the site; and entry procedures for confined spaces. Specific HSP issues for this site include explanations of physical hazards such as open shafts, subsidence, landslide potential and chemical hazards from contaminants. Due to specific nature of the plan and data contained, HSP is proprietary document of Faculty of Mining and Geology and will not be further discussed. Review of this plan (in Macedonian) is available only at faculty quarters and after confidentiality agreement.

2.4.3.1 Sampling and analysis plan

2.4.3.1.1 Field sampling plan

Sampling plan was developed after the initial review of geology/hydrogeology site conditions, catchments of run-off waters, drainage patterns, terrain configuration and climate data. The plan also considers the level of investigations required by ToR as much as budget limitations for planed activities. Due to very specific conditions, sampling program was developed in two phases intended to:

> Phase – I, to determine environmental media and area affected, type and level of contaminants and developed conceptual model for mechanisms of pollution, receptors and routes of exposure.
>
> Phase – II, to confirm the finding and precisely define the levels of contaminants in media analyzed.

Because the zone of the mine site (as defined by ToR) was very large (10 km2), development of classic sampling networks with mash 200 m x 200 m would require amount of works which significantly overcome level required by ToR as much as the budget assigned. Also due to large number possible pollution source limited in size and scattered over the entire area, sampling mesh of this size could result with errors by simply skipping some of the structures or occurrences of pollution.

As an alternative, directed field sampling plan was develop. The plan was based on the specific site conditions and directed in the areas of abandoned mine structures, as much as in surrounding areas where contamination of environmental media was expected. Additionally and in order to determine the level of background (natural) "contamination" of the site, samples form media are also taken from locations with similar characteristics, that are considered to be out of zone of influence of identified pollution sources.

All media were included in the sampling, through the process of sampling of:

- -surface waters (rivers and streams),
- -ground waters (well's and springs),
- sediment's, and
- soils.

Map of proposed areas of sampling for Phase -I is given below.

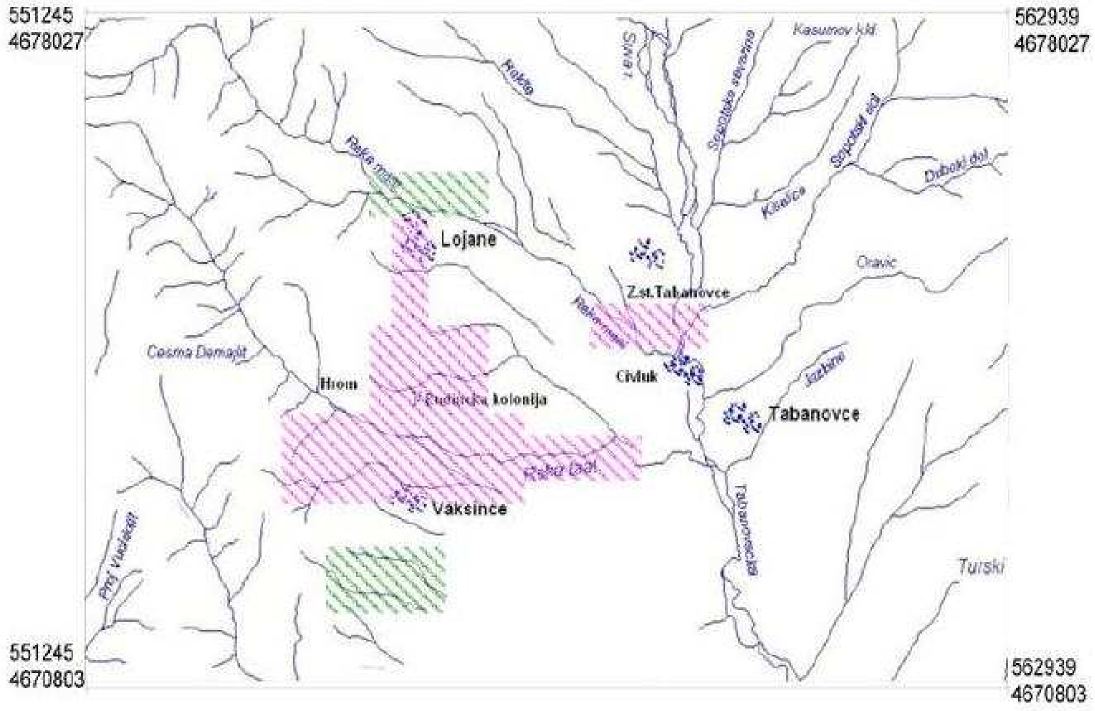


Fig. 2.19 – Map of proposed sampling areas
(red color areas with expected pollution, green color areas selected for background sampling).

On site samples are taken in selected areas and depending from site conditions, under supervision of geologist and hydrogeologist in charge. During the Phase – I, total number of 190 samples are taken. All samples are located by GPS in UTM – WGS 84 coordinates and indicated on the map given below.

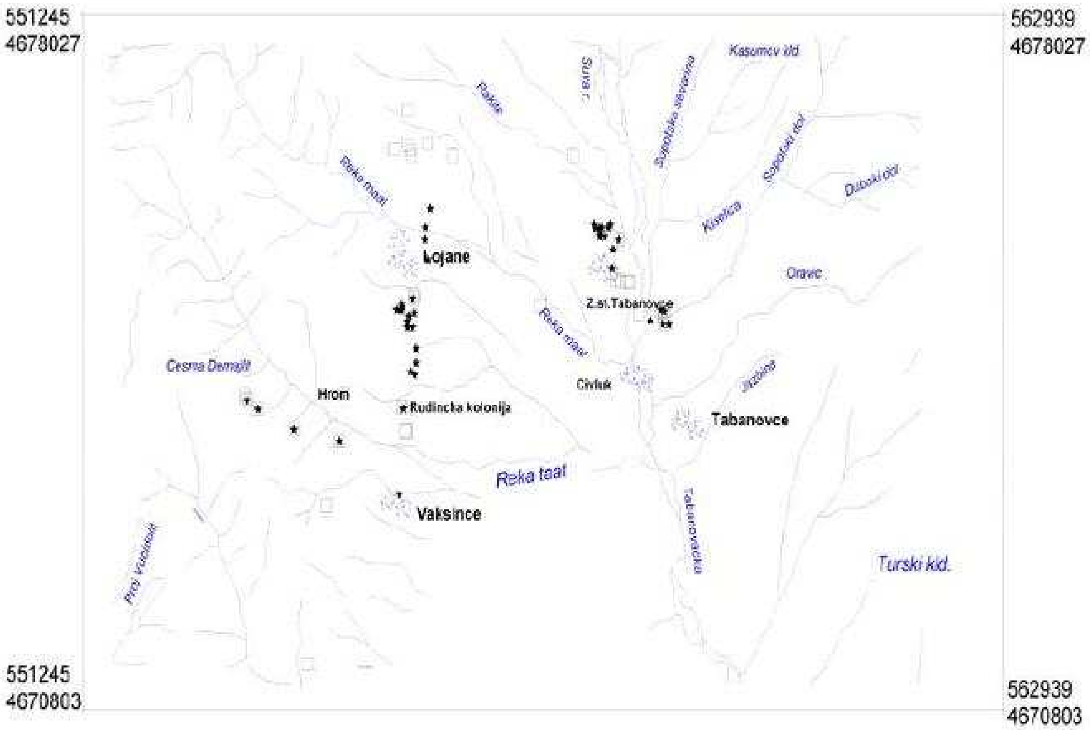


Fig. 2.20 – Map of samples taken in Phase-I

(soil and sediment samples are marked with star, water samples are marked with rectangle) in UTM – WGS 84, coordinates)

Based on the data collected in the Phase – I, and in order to confirm the findings and precisely define the levels of contaminant's in media analyzed additional sampling process (Phase-II) was initiated. In addition, this sampling was scheduled in dry period (July) in order to define the possible difference from the higher water levels period, since the samples in Phase – I were taken in February – March. Total numbers of 50 samples are taken. Map of samples taken in Phase – II are marked on the map give below.

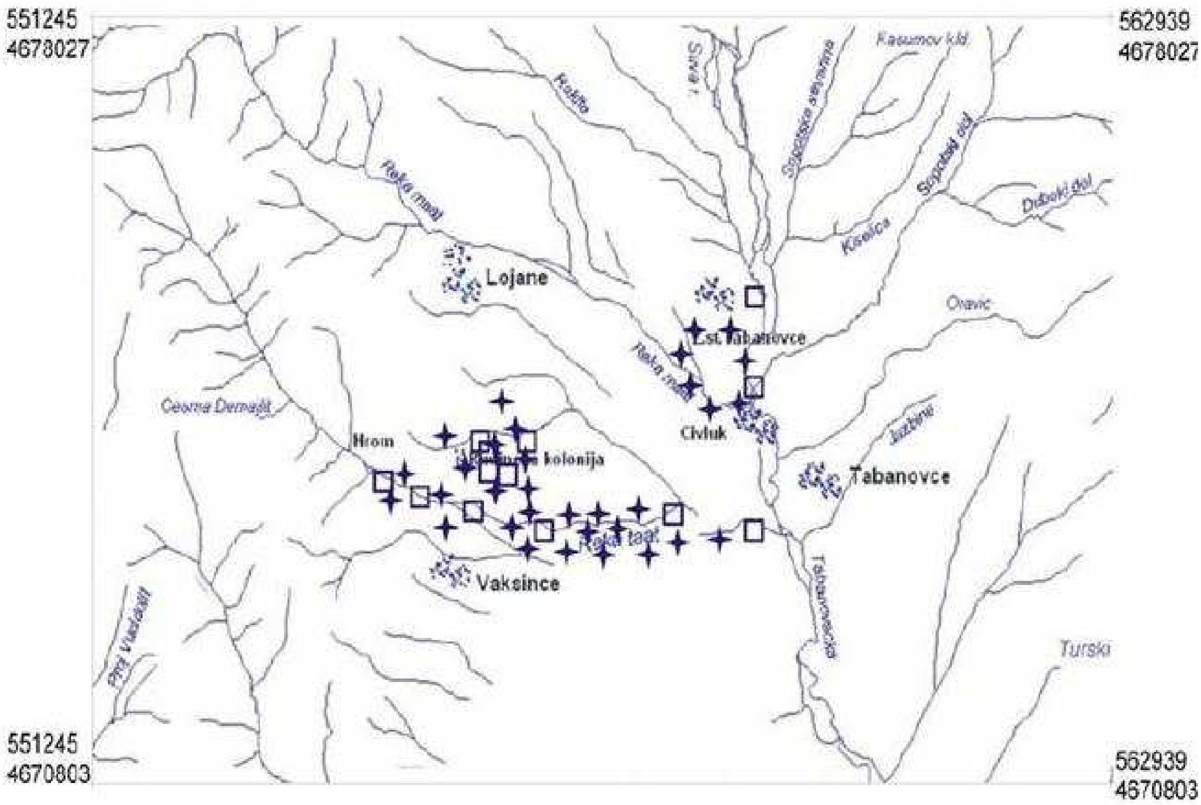


Fig. 2.21 – Map of samples taken in Phase-II

(soil and sediment samples are marked with star, water samples are marked with rectangle) in UTM – WGS 84 coordinates)

Soil and sediment sample were taken by use of hard plastic/metal show, by digging surface of app. 15 x 15 cm and up to 20 cm in depth. Collected material was packed in plastic PE bags and appropriately marked.

Water samples were collected in 3/4 litters plastic bottles previously washed by special solution. All bottles were appropriately sealed and marked.

2.4.3.1.2 Analysis plan

In order to provide required data quality, a special set of procedures was applied. Development of Analyses plan was part of these procedures.

All samples were prepared and analyzed according to the internal procedures and international standard requirement including ISO 190/SC3 for soils and sediments, and ISO 147/SC2 for water quality tests.

Based on the data assessed in preliminary phase possible contaminates of concern were determined. This include following metals; As, Sb, Cr, Cd, Cu, Ni, Pb, Zn, Mn and Fe. In order to avoid possible error in both phases, samples were additionally analyzed for following elements Co, Be, Al, K, P, Ca, Na and Mg.

Soil and sediment samples were drayed at room temperature, grinded and divided according to ISO 11464. Prepared samples were digested in HF and $HClO_4$ (ISO 14869-1) and analyzed on ICP – Inductively coupled Plasma (ISO 11885-1).

Water samples were prepared and analyzed on ICP according to ISO 147/SC2 standards.

2.4.4 Environmental Impact Assessment

2.4.4.1 Impacts on groundwater and surface water

As already mentioned before, mining operations can affect surface and groundwater quality in several ways. In the case of abandoned Lojane mine site, contamination of water with metals is certainly one of the most important issues. Primary sources of dissolved contaminants are:

- underground mine workings,
- waste rock piles, and
- tailings pile.

Detected contaminants reflect the content of the sources and generally elevated concentrations of arsenic, antimony and chromium are observed. Other metals in different concentrations are also detected, including lead, copper, manganese, cadmium, iron, nickel, beryllium and zinc.

Pollutants are mobilized by leaching from exposed waste rock and tailings piles and mine openings. Discharges of mine waters, storm and snowmelt runoff loaded with sediments contaminated by heavy metals, and seepage from waste and tailings piles are the primary transport mechanisms to surface waters and ground waters. Additionally Suva River waters are directly contaminated from one of the mine waste rock's pile's, located inside the river valley, so the water stream wash the banks of the waste rocks pile.

2.4.4.1.1 Surface water

All surface waters in the area were subjects of detailed sampling, including Suva (Taat) River, Lojanska and Tabanovska Rivers. Sampling with the highest frequency was directed to the Suva River, although the flow quantity of this river is much smaller compared with two others and only during the very high water levels the Suva River stream reach the Tabanovska River (during the summer this stream dissipate in the flats). This decision was based on the fact that Suva River passing the mining zone, so total number of 28 samples were taken (app. every 100 m from the mine site down water). Also 15 samples from each (Lojanska and Tabanovska) rivers were taken. Data obtained from the analyses of surfaces waters in the area discussed below.

Results obtained clearly indicates extremely elevated concentrations of As only in Suva River Flow, while in Lojanska and Tabanovska Rivers, although increased concentrations of As are detected, the values are significantly lower.

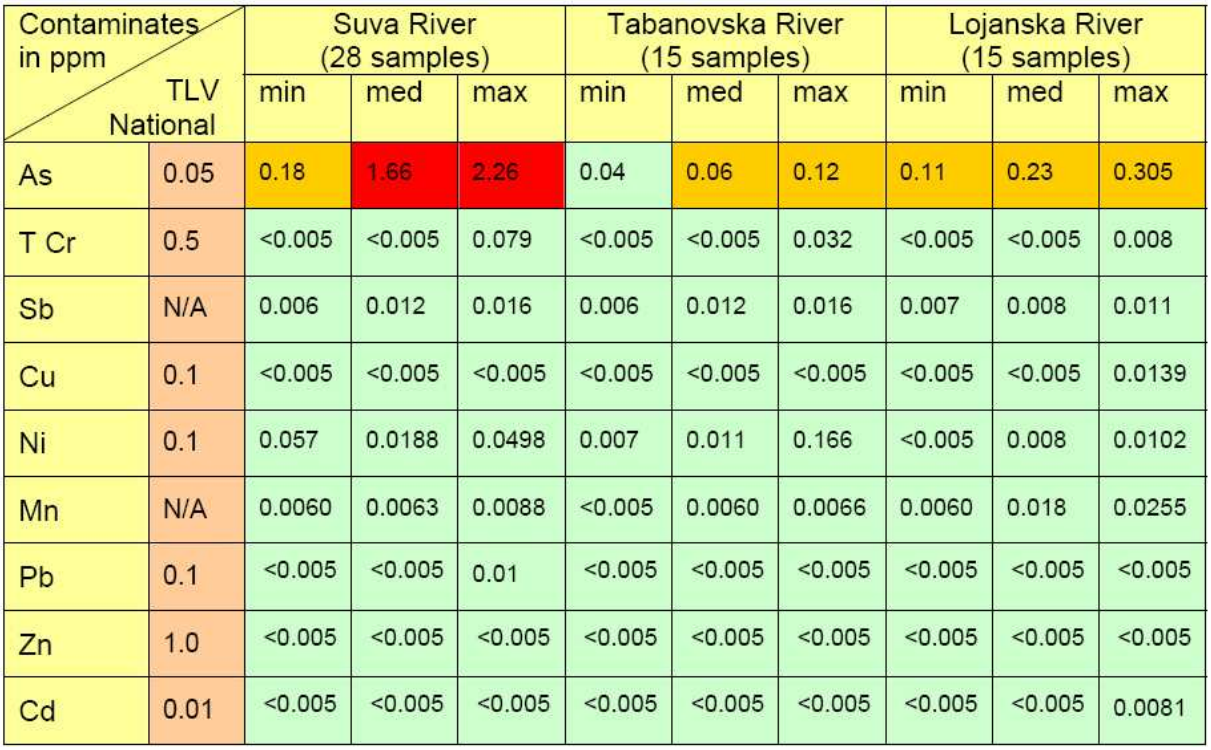
As already mentioned, elevated concentration of As in Suva River waters are result of;

-leaching processes from exposed waste rock and tailings piles and mine openings.
-mine waters, storm and snowmelt runoff loaded with sediments contaminated by heavy metals from the waste rocks and tailings,
-seepage from waste and tailings piles.
On the other side, concentrations of contaminants in Lojanska and Tabanovska Rivers, although increased are much lower, so it can be concluded that due to favorable hydrology/hydrogeology conditions, the contaminated waters of the Suva River flow are naturally contained. Elevated concentrations of As in Lojanska and Tabanovska Rivers, are

most probably result's of with higher background concentrations of As in the area, as much as contamination of sediments (in case of Tabanovska River).

Extremely elevated As concentrations in Suva River waters have certainly detrimental effect on aquatic life/biota in this waters. Additionally these waters are occasionally used for irrigation, thus polluting the plants/food produced, as much as the soil irrigated.

Table 2.4 – Results of surface water streams analyzes



Contaminates in ppm	TLV National	Suva River (28 samples)			Tabanovska River (15 samples)			Lojanska River (15 samples)		
		min	med	max	min	med	max	min	med	max
As	0.05	0.18	1.66	2.26	0.04	0.06	0.12	0.11	0.23	0.305
T Cr	0.5	<0.005	<0.005	0.079	<0.005	<0.005	0.032	<0.005	<0.005	0.008
Sb	N/A	0.006	0.012	0.016	0.006	0.012	0.016	0.007	0.008	0.011
Cu	0.1	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.0139
Ni	0.1	0.057	0.0188	0.0498	0.007	0.011	0.166	<0.005	0.008	0.0102
Mn	N/A	0.0060	0.0063	0.0088	<0.005	0.0060	0.0066	0.0060	0.018	0.0255
Pb	0.1	<0.005	<0.005	0.01	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Zn	1.0	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Cd	0.01	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.0081

Note: red filed – extreme elevation, orange -medium elevation, green below TLV;.data are compared against TLV recommended in National regulations for water quality.

Since the Suva River dose not has the aquatic life of importance for human consumption, most probable routes of exposures of humans are:

-through direct contact with contaminated water;
-consumption of food grown on contaminated soils or irrigated with contaminated water;
-consumption of meet or diary product from the farm animals exposed the contaminated water;
-inhalation of dust from contaminated soil during the agricultural land preparation.

Considering the routes of exposure, this issue will be in details discussed in the text below (Soil Quality).

Wildlife in the area is even more exposed on the negative effects of these waters since the wild animals can more easily come in contact with the waters and use the water for drinking. Similar is situation with farm animals kept in open.

The waters from the Lojanska and Tabanovska Rivers are more widely used for irrigation and even as a drinking water (Lojanska River), although the concentrations of As detected are in most cases are higher than TLV as prescribed in National regulations. It's certain that the use of these waters also could have negative effect on exposed human's health, especially in prolonged use or contact.

2.4.4.1.2 Groundwater

As already mentioned, most obvious risk for contamination of ground waters occurs in mining below the water table, which provides a direct conduit to aquifers. Ground water quality is also affected when surface waters (natural or wastewaters) infiltrate through surface materials (including overlying wastes or other material) into ground water. Contamination can also occur when there is a hydraulic connection between surface and ground water. Any of these can cause elevated pollutant levels in ground water.

In order to clearly investigate the possible contamination of ground waters a total number of 55 samples from the well's in the area of consideration are taken. The well's depth ranges from 12 m to over 80 m.

The data from the analysis are presented in two separate tables. In first table (tab.2.5) results from the samples taken in the villages of Lojane, Vaksince and Tabanovce are given. In the second table (tab. 2.6) results from one well and natural spring, nearby and below the tailings pile are given. In this table are also presented data for 5 wells considered to be out of the range of possible contamination in villages of Tabanovce (on the right side of the International Road) and Vaksince (in the upper part of the village).

Because the waters from the wells sampled is in most cases used as a drinking and water for domestic use, the data obtained are compared against national standards for drinking water.

Table 2.5 – Results of groundwater analyses

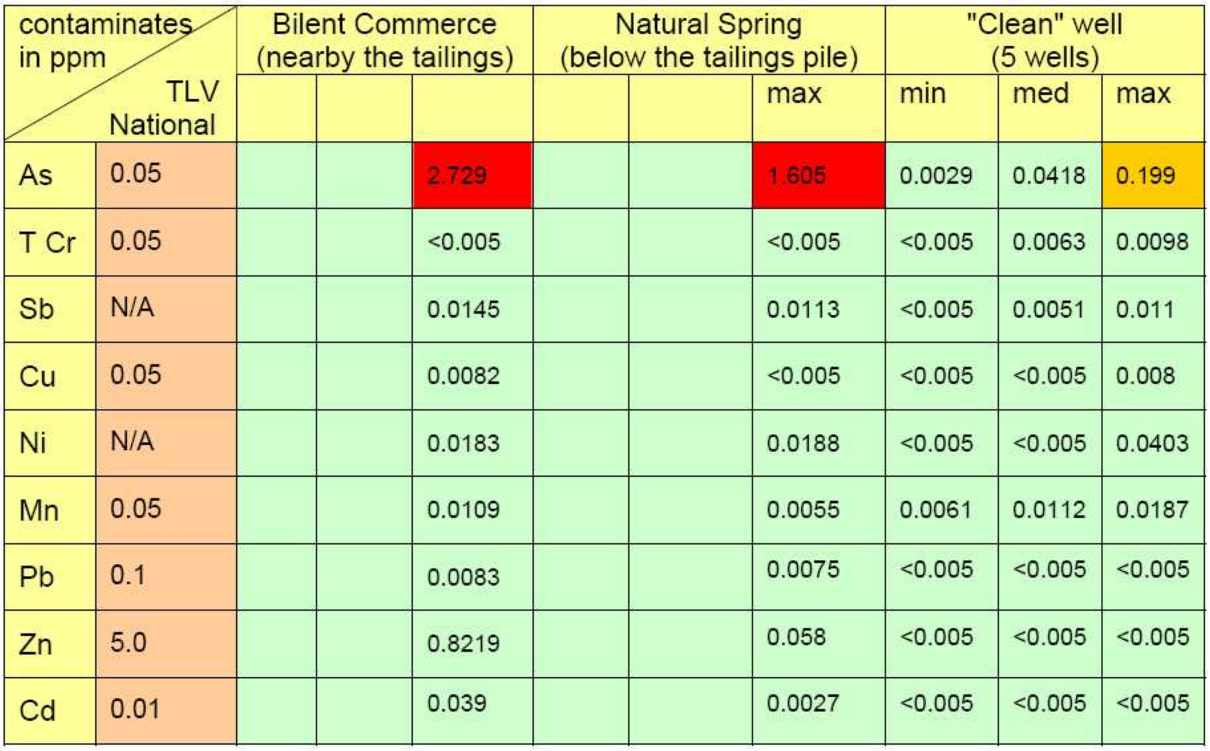
contaminates in ppm	TLV National	Lojane Village (21 wells)			Tabanovce Village (19 wells)			Vaksince Village (8 wells)		
		min	med	max	min	med	max	min	med	max
As	0.05	0.08	0.118	0.3706	0.022	0.041	0.124	0.11	0.23	0.305
T Cr	0.05	<0.005	0.0068	0.0192	<0.005	<0.005	0.032	<0.005	0.007	0.0162
Sb	N/A	0.0055	0.0075	0.0145	<0.005	0.0092	0.0113	0.007	0.008	0.011
Cu	0.05	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.0087
Ni	N/A	<0.005	0.0233	0.0487	<0.005	0.0079	0.016	<0.005	0.0067	0.0403
Mn	0.05	<0.005	0.0072	0.0128	<0.005	0.0060	0.0078	0.0062	0.0091	0.0187
Pb	0.1	<0.005	0.0052	0.0083	<0.005	0.0056	0.0075	<0.005	<0.005	0.0057
Zn	5.0	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Cd	0.01	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005

Note: red filed – extreme elevation, orange - medium elevation, green below TLV;.data are compared against TLV recommended in National regulations for water quality.

It's clear that in huge majority of the samples taken, the waters quality is satisfactory and only slightly increased (up to 5 times) concentrations of As are determined. This data confirm the thesis that there is no direct connection between contaminated surface waters and ground waters, posed by preliminary hydrogeolocigal survey. It's also certain that increased concentrations of As are results of high natural background of this element, and all wells drilled in serpentine are naturally contaminated. Even in the wells from the zones considered to be none affected with former mining activates, similar concentrations are detected.

Although currently to favorable conditions there is no indication extensive contamination of groundwater, there is certainly a big risk of this contamination to occur, especially due to anthropogenic activities which may provide conduit of contaminated surface waters to the groundwater.

Table 2.6 – Results of additional groundwater analyses



contaminates in ppm	TLV National	Bilent Commerce (nearby the tailings)			Natural Spring (below the tailings pile)			"Clean" well (5 wells)		
							max	min	med	max
As	0.05			2.729			1.605	0.0029	0.0418	0.199
T Cr	0.05			<0.005			<0.005	<0.005	0.0063	0.0098
Sb	N/A			0.0145			0.0113	<0.005	0.0051	0.011
Cu	0.05			0.0082			<0.005	<0.005	<0.005	0.008
Ni	N/A			0.0183			0.0188	<0.005	<0.005	0.0403
Mn	0.05			0.0109			0.0055	0.0061	0.0112	0.0187
Pb	0.1			0.0083			0.0075	<0.005	<0.005	<0.005
Zn	5.0			0.8219			0.058	<0.005	<0.005	<0.005
Cd	0.01			0.039			0.0027	<0.005	<0.005	<0.005

Note: red filed – extreme elevation, orange - medium elevation, green below TLV; data are compared against TLV recommended in National regulations for water quality.

Since the concentration of As exceeds TLV values for drinking water, their use for this purpose could pose a health risks. Since this water quality is not associated or influenced with contamination from mining activities, a separate plan for health effects assessment and possible protective measures should be developed.

At only two locations, extremely high concentrations of As are detected. These locations are natural spring below the tailings and positive pressure well nearby tailings pile (Bilnet Komerce well). In both cases, ground water due to positive pressure coming to the surface and wash the tailings before exiting to the surface, thus collecting huge amount of contaminants. Water from the spring creates a stream flow through the field and enters the Suva River. It's clear that use of this water for any purpose could seriously affect exposed humans and animals. Also these waters contribute to increased pollution of already contaminated Suva River, as much as the farm land where this stream passing. Considering the amount of this flow, possible human health effects are limited to very small area. Routes of human exposure include;

- -drinking of contaminated water;
- -direct contact with contaminated waters;
- -consumption of food grown on contaminated soils or irrigated with contaminated waters;
- -consumption of meet or diary products from the farm animals exposed on contaminated waters;

Special concern for risk posed by this water, present a fact that a school is located nearby and children could easily come in contact with this water.

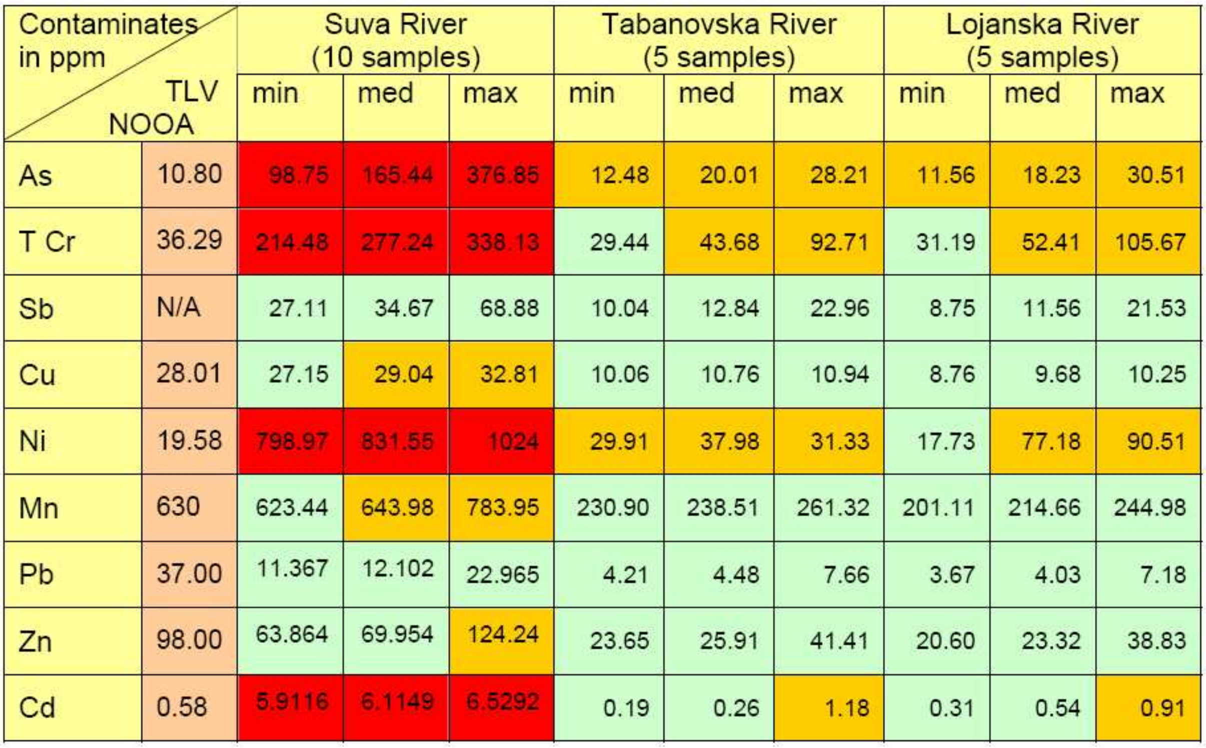
2.4.4.1.3 Sediments

Sediments in receiving streams can be contaminated when dissolved pollutants are discharged to surface waters partition to sediments in the stream. In addition, fine grained contaminated materials eroded from mine sites can become sediments.

Sediments contamination has detrimental effects on aquatic life and can affect human health through the consumption of fish that bioaccumulate toxic pollutants. In addition, sediment contamination provides a long-term source of pollutants, through the potential re-dissolution of contaminants in the in the water column.

To identify the level of contamination of sediments in river beds in the area of consideration, total number of 20 samples are taken, including 10 samples from Suva River, and 5 of each others (Lojanska and Tabanovska Rivers). Data collected are given in the table below.

Table 2.7 – Results of sediments analyzes



Contaminates in ppm	TLV NOOA	Suva River (10 samples)			Tabanovska River (5 samples)			Lojanska River (5 samples)		
		min	med	max	min	med	max	min	med	max
As	10.80	98.75	165.44	376.85	12.48	20.01	28.21	11.56	18.23	30.51
T Cr	36.29	214.48	277.24	338.13	29.44	43.68	92.71	31.19	52.41	105.67
Sb	N/A	27.11	34.67	68.88	10.04	12.84	22.96	8.75	11.56	21.53
Cu	28.01	27.15	29.04	32.81	10.06	10.76	10.94	8.76	9.68	10.25
Ni	19.58	798.97	831.55	1024	29.91	37.98	31.33	17.73	77.18	90.51
Mn	630	623.44	643.98	783.95	230.90	238.51	261.32	201.11	214.66	244.98
Pb	37.00	11.367	12.102	22.965	4.21	4.48	7.66	3.67	4.03	7.18
Zn	98.00	63.864	69.954	124.24	23.65	25.91	41.41	20.60	23.32	38.83
Cd	0.58	5.9116	6.1149	6.5292	0.19	0.26	1.18	0.31	0.54	0.91

Note: red filed – extreme elevation, orange - medium elevation, green below TLV; data are compared against TLV recommended in NOOA standards.

As can be seen from the table in Suva River sediments, highly elevated concentrations of As are detected. In addition, elevated concentrations of other metals are detected like extreme values for Ni and Cd. It must be noted that due to long term contamination and erosion of fine grained waste materials, it's not unusual other constituents associated with discharges from mining operations to be found at elevated levels in sediments, while not being detected in the water column or being detected at much lower concentrations.

Although elevated concentrations of contaminants are detected in sediments of Lojanska and Tabanovska Rivers, the values are again much lower, and are probably connected with natural contamination.

As already mentioned elevated concentrations of toxic metals in sediments may pose risks to human health and the environment as a persistent source of chemicals to human and aquatic life and that non-aquatic life that consume aquatic life. Human exposure occurs through:

- experiencing direct contact,
- drinking water exposed to contaminated sediments,
- eating fish or other products that have bioaccumulated toxic chemicals,
- inhalation of dust form dry sediments.

Certainly the biggest risk is posed by the fact that sediment contamination provides long-term source of pollutants through potential re-dissolution in the water column, acting as persistent source of chemicals to human and aquatic life.

2.4.4.2 Impact on air quality

Possible impacts on air quality associated with abandoned mine sites generally include; fugitive dust emissions, gaseous emissions and odors. Usually because of its visibility dust emissions area most frequently reported.

On site investigations reveal that in case of Lojane Mine site, only fugitive dust emissions from dry tailings pile presents a risk for air quality, while odors coming from the processes of oxidation of waste material disposed are with low intensity and usually contained in small areas.

As the material disposed at the dry tailings pile and arsenic concentrate pond located near the pile is very fine graded, dry surface particles are easily mobile. So during the wind periods, particles are entrained by air movement and clouds of dust are created. It should be noted that this process of wind erosion is intensified over the time due to other atmospheric influences. This is also case with the open storage yard near the ore-frying facility at Tabanovce railway station.

Quantification of fugitive dust emission is always very complex task, associated with long term observations and measurements and use of sophisticated computer models. Considering the time frame of the study as much as availability of the data the work group approached to the process of estimation of the emissions. In order to provide satisfactory data quality for different methodologies were used:

-USEPA, AP-42: Compilation of Air Pollutant Emission Factors (www.epa.gov/ttn/chief/ap42),
-California Air Resources Board (www.arb.ca.gov/ei/areasrc/areameth.htm),
-Clark County, Nevada (www.co.clark.nv.us/air_quality)
-Maricopa County, Arizona (www.maricopa.gov/envsvc/air)

Unfortunately the results obtained could not be accounted as realizable as the one of the main inputs in the estimations, surface exposed was to not available. Since the biggest part of the tailings pile surface was covered by communal or construction waste, it was impossible to obtain exact surface exposed. Data obtained by calculation give significantly lower values, compared to values expected, so it was decided that data could not be accounted as satisfactory and so will not be included in the report.

Although quantitative data concerning fugitive dust emission are not available, considering the chemical composition of the dust and assumed intensity of the fugitive emissions, it is more than certain that this fugitive emissions present significant respiratory hazard for humans exposed. Especially since elementary Scholl and residential objects are located within the radius of only 100 m from the tailings.

In addition, fugitive dust emissions significantly contribute to contamination of areas downwind as coarse particles settle out of suspension in the air. Although deposition may have been at a relatively low concentrations, the long period of deposition have significantly contaminate communal surfaces, commercial and living areas, as much as nearby agricultural lands and water courses public surfaces the area.

In order to define the risk of inhalation of dust by the school children, a sample of aero-sediments from the schoolyard was taken. The sample was taken by wiping the surface of the playground.

Table 2.8 – Results of aero – sediments analysis.

Contaminates in ppm	TLV	Schoolyard (aero-sediment)		
		min	med	max
As	N/A			384.24
T Cr	N/A			174.30
Sb	N/A			131.02
Cu	N/A			44.59
Ni	N/A			330.26
Mn	N/A			1053.69
Pb	N/A			34.29
Zn	N/A			132.11
Cd	N/A			6.42

Data are not compared with any standard values since no standard was available for aero-sediments. Although no standards were available, this values can be considered as very high, especially since the particles of dust could be easily re-entrained and inhaled or ingested by the children playing in the yard. For this reason they are marked with red color.

Level and extent of soils contamination will be discussed below (see the chapter 2.4.4.3 Impact on soil).

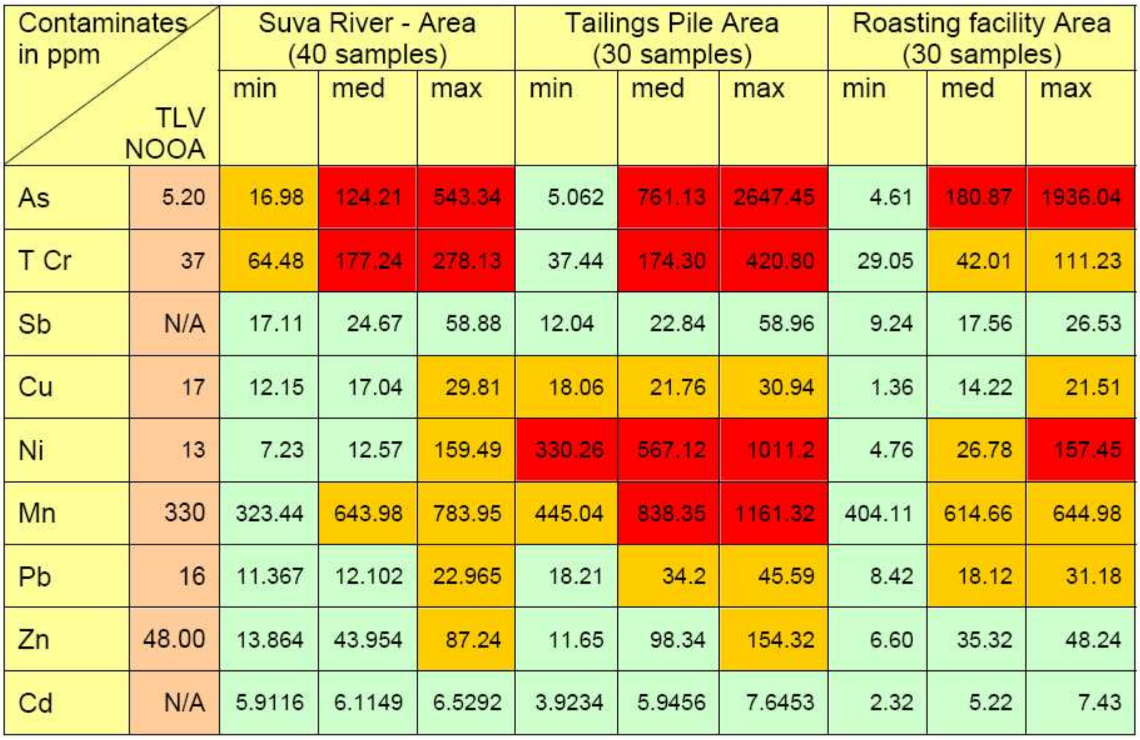
2.4.4.3 Impact on soil

Mining industry can affect soils in several way's, by disturbing the soils through excavation works, structures building and most significantly by polluting the soil with contaminants associated with the process.

In case of abandoned Lojane mine site, certainly the most important issue is soil contamination. Soil is polluted through water and air which serve as transportation mediums of contaminants. In order to identify the level of pollution of soils, and considering the possible mechanisms of pollution of the soils, a total number of 105 soils samples are taken.

In the area of Suva River 40 river flow are taken. Additionally 30 samples from each area, soil around dry tailing pile and roasting facility at Tabanovce railway station are taken. At the Suva river area the samples are taken in the range of 50 m from both sided of the river flow. In the area of tailings pile (Mining Colony) and roasting facility (Tabanovce railway station) the samples are taken from the field along the tailings/ facilities in parallel lines 50, 150 and 300 m from the pile. In addition 5 samples from the area are taken.

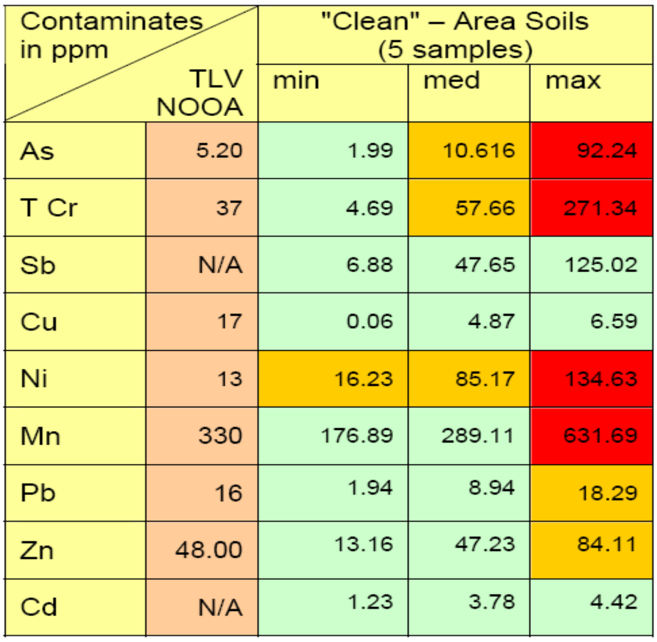
Table 2.9 – Results of soil analyzes – contaminated soil



Contaminates in ppm	TLV NOOA	Suva River - Area (40 samples)			Tailings Pile Area (30 samples)			Roasting facility Area (30 samples)		
		min	med	max	min	med	max	min	med	max
As	5.20	16.98	124.21	543.34	5.062	761.13	2647.45	4.61	180.87	1936.04
T Cr	37	64.48	177.24	278.13	37.44	174.30	420.80	29.05	42.01	111.23
Sb	N/A	17.11	24.67	58.88	12.04	22.84	58.96	9.24	17.56	26.53
Cu	17	12.15	17.04	29.81	18.06	21.76	30.94	1.36	14.22	21.51
Ni	13	7.23	12.57	159.49	330.26	567.12	1011.2	4.76	26.78	157.45
Mn	330	323.44	643.98	783.95	445.04	838.35	1161.32	404.11	614.66	644.98
Pb	16	11.367	12.102	22.965	18.21	34.2	45.59	8.42	18.12	31.18
Zn	48.00	13.864	43.954	87.24	11.65	98.34	154.32	6.60	35.32	48.24
Cd	N/A	5.9116	6.1149	6.5292	3.9234	5.9456	7.6453	2.32	5.22	7.43

Note: red filed – extreme elevation, orange medium elevation, green below TLV; data are compared against TLV recommended in NOOA standards.

Table 2.10 – Results of soil analyzes – background values



Contaminates in ppm	TLV NOOA	"Clean" – Area Soils (5 samples)		
		min	med	max
As	5.20	1.99	10.616	92.24
T Cr	37	4.69	57.66	271.34
Sb	N/A	6.88	47.65	125.02
Cu	17	0.06	4.87	6.59
Ni	13	16.23	85.17	134.63
Mn	330	176.89	289.11	631.69
Pb	16	1.94	8.94	18.29
Zn	48.00	13.16	47.23	84.11
Cd	N/A	1.23	3.78	4.42

Note: red filed – extreme elevation, orange medium elevation, green below TLV; data are compared against TLV recommended in NOOA standards.

Results obtained show elevation of contaminants in almost all soils sampled. Concentrations of the contaminants like arsenic, chromium nickel and manganese are extremely elevated in soils near the sources of pollution, while their concentration decrease as the distance is increased, and although elevated concentration of some toxic metals are found in soil samples at larger distances, they have much lower values. Since the similar values of As. Cr, Ni, Mn are determined in the "clean" soils from Vaksince area, considered to be out of influence of pollution sources, it clear that slightly increased elevation of this contaminants could be explained with high background of this elements in the area.

Areas with higher concentrations of contaminants are marked wit hatching on the following map. Total surface with extremely elevated pollution is estimated to app. 50 ha.

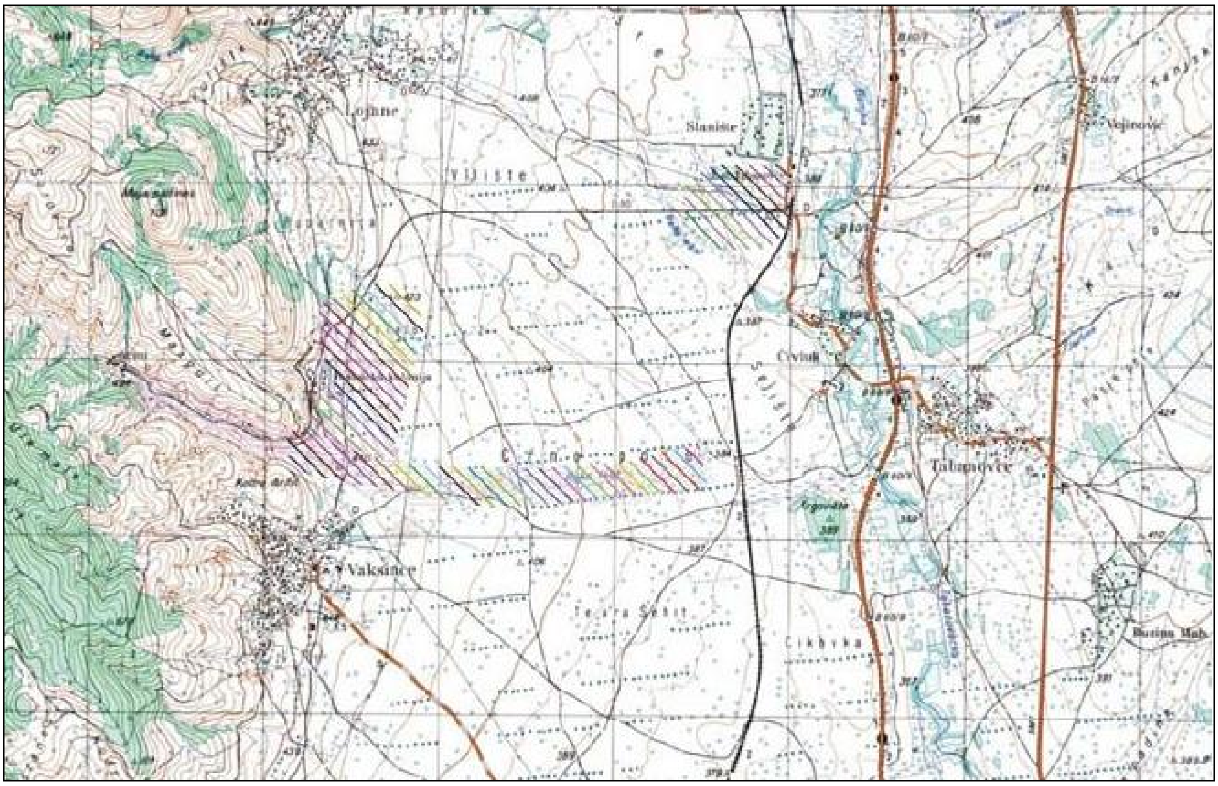


Fig. 2.22 – Map of polluted soils in the area

It should be noted that frequency of sampling performed did not allow exact definition of the borders and areas could be treated rather as estimations only.

Considering the elevation of the contaminants, it's also clear that much higher values are determined in area of dry tailings pile (Mine colony) and roasting facility (Tabanovce Railway station). This can lead to conclusion that most important mechanism of pollution is down wind deposition of contaminants (aero sedimentation), while contamination of soils with waters is less intensive and limited in area.

Soil pollution, especially with higher elevation of this contaminates could poses a serious risk to humans exposed. The effects of these contaminants on the human health are explained in theirs toxicological profiles.

Possible routes of exposure include:

- consumption of products grown on contaminated soils that can bioaccumulate the contaminants,

- accidental ingestion or direct contact with the soils,
- inhalation of dust from dry soils.

Special concern is posed by the fact that contaminated soils can serve as a persistent long term pollution source even if no new contamination is entrained. This could cause long term contamination of all products grown in the soil, especially those which can bioaccumulate the contaminants. In this way through entering the chain of food, soil contamination could have much wider area of influence, since these soils are used for production of vegetables sold in green markets in Kumanovo and Skopje.

2.5 Conclusions of the Baseline Study

This report titled as Baseline Study present all data collected during the LOT 1 of activities for preparation of Feasibility Study for Lojane Mine. The Feasibility Study represents a first step within the targeted program of the Environment and Security Initiative (UNDP, UNEP, OSCE and NATO), “Reducing Environment and Security Risks from Mining in South-Eastern Europe”.

As defined by TOR, the report includes 5 main chapters as flow; General Data, Site Description, Current Environment Conditions, Abandoned Mine Facilities Description, Environmental Impact Assessment.

Site Description comprises all data concerning existing setting of the site including natural and socioeconomic settings.

Third chapter present current environmental conditions include, air, waters and soils quality, as much as population perception of current environmental issues.

Description of abandoned mine facilities give a detailed explanation about, mining/mineral processing technologies used, facilities and structures location. Also quantitative and qualitative description of materials disposed is given.

Environmental impact assessment includes general description of possible impacts, toxicological profile of the contaminants of concern, detailed description of mechanisms of contamination, intensity and extent of contamination, effects on human's health and possible routes of exposure.

In general data present provide a solid base for planning of response actions including proper rehabilitation measures. These measures should comprise pollution mitigation techniques, cleanup measures and site access and usage limitations.

Brief summary of data reported is given below.

General Data
The Feasibility Study for Lojane Mine, represents a first step within the targeted program of the Environment and Security Initiative (UNDP, UNEP, OSCE and NATO), “Reducing Environment and Security Risks from Mining in South-Eastern Europe”, to decrease trans-boundary environmental and safety risk posed by sub-standard mining and mineral processing operations in the past, as well as to reduce the significant risk associated with non-operational, abandoned site where large quantities of physically and chemically unstable and poorly contained mine wastes are stored.

Location
The abandoned Lojane Mine Site and associated processing facilities are located north of city of Kumanovo (see fig. 1), on the territory of Lipkovo municipality. Lipkovo municipality is

located on the northern part of Republic of Macedonia with area of about 270 km^2. The total mine site area is about 10 km^2.

Climate

According the climatic- vegetation parameters and basic elements regime (G. Filipovski, R. Rizovski and P. Ristevski, MANU 1996) the Lipkovo area is classified as a continental submediterranean region.

Geology

The area under investigations consists of a complex of Precambrian rocks, of Paleozoic metamorphic rocks and magmatites, a complex of Mesozoic sediments and magmatites, a complex of Tertiary sediments and volcanics as well as Quaternary layers and volcanics.

In terms of the geology the area belongs to the Vardar zone, only a small part (in the northeast) being part of the Serbo-Macedonian massif.

Taking in consideration the geological conditions in the terrain, the rocks in the area, in terms of their hydrogeology can be classified as: hydrogeolocigal collectors of fracture-karts porosity with marble layers, hydrogeolocigal collectors of intergranular porosity with alluvial layers, hydrogeolocigal insulators with delluvial occurrences, relative hydrogeolocigal insulators with schists, diabases, granodiorites and serpentinites.

Hydrology

The area of the consideration is part of the Lojanska and Lipkovska Rivers river basins that flow into the Tabanovska which joins the Pcinja. There are two water reservoirs on the Lipkovska River called Lipkovo and Glaznja.

Vegetation

As we already mention the area belongs to continental sub Mediterranean climatic zone of the country. Oak forests are most widely spread in this (ass. Quercetum frainetto cerris macedonicum Obred. Emend. Ht). Grass and forest vegetation prevail in the area of Lojane compared with the other part of the Kumanovo region with predominance of forest species.

Wildlife

A typical represents of vertebral fauna are Ponto Mediterranean and Syrian arboreal elements, like worm water snake (Typhlops Vermicularis), cat snake (Typhlops Fallax), Balkan snake (Coluber Gemonesis), Balkan green frog (Pelobates yuriasly balcanicus), Eripaseiy concolor, Mustela Nivalis and others. Also varies birds could be found in the area.

Social settings

There are no urban settlements on the territory of the Municipality, with 21 rural settlements which have population of various demographic dynamics and structure. The central settlement of the Municipality is the village of Lipkovo towards which other rural settlements incline. The closer urban settlement in the area is city of Kumanovo with population of around 120,000. According to the 1994 census total 22,861 inhabitants are recorded. Lipkovo municipality is one of poorly developed regions and there are no industrial objects on its territory. Main economic activity is agriculture and 95 % of active population is involved in it. There is area of 22,599 ha for agriculture, from which 8,256 ha or 36.5 % is cultivable soil which is irrigated by Lipkovo hydro system. Pastures has an area of 4,375 ha or 19.3 %, and forests are the most spread on area of 9,968 ha or 44.2 %. Urbanization in municipality is on low level. Current negative economic conditions, as much as ecological problems present in the municipality, have adversely affect on economical development. In that regard, there are ideas for local management and state institutions to make more efforts for correct economic development of the region.

Cultural and archeological resources

In the study area there are no cultural and archaeological sites that are of historic interest within the zone of visual influence of the abandoned mine site. Detailed review of available data was performed in order to gather further information on other important or contentious archaeological resource of the area. The investigation revealed that no information was available on the study area.

Abandoned mine facilities

Most probably some kind of room and pillar mining method was applied. It is also obvious that underground workings are limited in limited extent.

Total quantity of material excavated during the period when mine was active (1923- 1979) is estimated to amount of app. 1,300,000 tons, so the annual production capacity was between 25,000 to 30,000 tons per annum, thus classifying the operation as relatively small (in today terms very small).

Total quantity of wastes generated by extraction operations (waste rocks) are estimated to app. 90,000 tons.

In the higher part of the valley, along the south foot of the hill ruins from small mining settlement and mine office/service buildings are scattered on the area of approximately 3,000 m^2.

In the same area 3 waste rock dumps and mined ore stockpiles are located. Considering the beneficiation facilities, remains found on place clearly indicate that flotation process was used.

The ore excavated was transported in processing plant by narrow rail line to the processing plant where ore was reduced in size by the crushing and/or grinding circuit. Antimony and Arsenic minerals were concentrated by flotation process. The wastes generated by this process, known as tailings were disposed in dry form on the pile created just in front of the plant. The tailings pile covers a surface of app. 17,500 m^2, and contains app. 450,000 tons of tailings. A concentrate storage pond (stone structure with estimated volume of app. 5,000 m^3) build near the plant contain app. 15,000 tons 50% As concentrate. At the end concentrates were transported to the roasting plant, used to prepare ores for smelting. The facility ruins and storage yard covers surface of 8,800 m^2.

Impact on waters

Results obtained clearly indicates extremely elevated concentrations of As only in Suva River Flow, while in Lojanska and Tabanovska Rivers, although increased concentrations of As are detected, the values are significantly lower.

Extremely elevated As concentrations in Suva River waters have certainly detrimental effect on aquatic life/biota in this waters. Additionally these waters are occasionally used for irrigation, thus polluting the plants/food produced, as much as the soil irrigated.

In huge majority of the ground water samples taken, the waters quality is satisfactory and only slightly increased (up to 5 times) concentrations of As are determined. This data confirm the thesis that there is no direct connection between contaminated surface waters and ground waters, posed by preliminary hydrogeolocigal survey.

It's also certain that increased concentrations of As are results of high natural background of this element, and all well's drilled in serpentine are naturally contaminated. Even in the wells from the zones considered to be none affected with former mining activates, similar concentrations are detected.

At only two locations, extremely high concentrations of As are detected. These locations are natural spring below the tailings and positive pressure well nearby tailings pile (Bilnet

Komerce well). In both cases, ground water due to positive pressure coming to the surface and wash the tailings before exiting to the surface, thus collecting huge amount of contaminants. Water from the spring creates a stream flow through the field and enters the Suva River.

Samples of Suva River sediments, shows highly elevated concentrations of As. In addition, elevated concentrations of other metals are detected like extreme values for Ni and Cd. Although elevated concentrations of contaminants are detected in sediments of Lojanska and Tabanovska Rivers, the values are again much lower.

The biggest associated with the sediments is posed by the fact that sediment contamination provides long-term source of pollutants through potential re-dissolution in the water column, acting as persistent source of chemicals to human and aquatic life.

Impacts on air quality

Although quantitative data concerning fugitive dust emission are not available, considering the chemical composition of the dust and assumed intensity of the fugitive emissions, it is more than certain that this fugitive emissions present significant respiratory hazard for humans exposed. Especially since elementary Scholl and residential objects are located within the radius of only 100 m from the tailings.

In addition, fugitive dust emissions significantly contribute to contamination of areas downwind as coarse particles settle out of suspension in the air. Although deposition may have been at a relatively low concentrations, the long period of deposition have significantly contaminate communal surfaces, commercial and living areas, as much as nearby agricultural lands and water courses public surfaces the area.

Impacts on soil

Results obtained shows elevation of contaminants in almost all soils sampled. Concentrations of the contaminants like arsenic, chromium nickel and manganese are extremely elevated in soils near the sources of pollution, while their concentration decrease as the distance is increased, and although elevated concentration of some toxic metals are founded in soil sample at larger distances, they have much lower values. Most important mechanism of soils pollution is down wind deposition of contaminants (aero sedimentation), while contamination of soils with waters is less intensive and limited in area.

Soil pollution, especially with higher elevation of this contaminates could poses a serious risk to humans exposed. The effects of these contaminants on the human health are explained in theirs toxicological profiles.

Special concern is posed by the fact that contaminated soils can serve as a persistent long term pollution source even if no new contamination is entrained. This could cause long term contamination of all products grown in the soil, especially those which can bioaccumulate the contaminants. In this way through entering the chain of food, soil contamination could have much wider area of influence, since these soils are used for production of vegetables sold in green markets in Kumanovo and Skopje.

3 Lot 2 - Feasibility Study

3.1 Work carried out

Dekonta a.s. has been awarded with Contract for Professional Services – PS 2007-03 “Preparation of a Feasibility Study for Lojane Mine, Macedonia, presentation of the results at a workshop” on January 22, 2007.

The work has been performed within the period January 22 – July 25, 2007.

The work carried out within the frame of Lot 2 completion consists of:

- Site related waste characterization
    - Reconnaissance
    - Samples collection
    - Laboratory work
    - Mineralogical study
    - Geomechanic tests
- Treatability bench tests
    - Solidification/stabilization tests
    - Tests of contaminated water treatability
- Preliminary human health Risk Assessment
- Description of applicable remedial/treatment techniques
    - Applicable methods for treatment of solid wastes
    - Applicable methods for treatment of contaminated water
- Case studies
- Selection of remedial/treatment methods
- Proposal on measures to be adopted
    - Short term risk reduction measures
    - Long term remedial measures
- Recommendations for the development of Emergency response Plan
- Recommendations for the development of Monitoring Plan
- Workshop
- Completion of final report on the Feasibility Study

The work performed and the results obtained are depicted in detail in subsequent chapters.

3.2 Site-related contaminants and waste characterization

3.2.1 Site reconnaissance

With the aim to get full scale information on the site of interest and to collect samples of various waste and contaminated media present within the considered area, the site reconnaissance has been carried out. The site visits were very useful because of lack of detail maps of the site as well as lack of data on mining. Photo log of important features has been kept (see appendix 7).

The first site visit has been performed on January 25th, 2007 and it last half a day and Dekonta's representatives were accompanied by geologists from the Faculty of Geology and Mining, Stip. The tailings dump and ruins of beneficiation plant at Rudnicka kolonija have been visited and the remnants of mining activities in the valley of Suva River were also visited on January 25th. The third source of contamination – former smelter – has not been visited during this site visit because it is located within a border zone where the entry permit is requested.

Bulk sample of the arsenic concentrate, freely stored in an unsecured pond, has been collected, and sample of waste rock (serpentinite – gangue of the Cr ore) has been collected from the pile located in the slope above the tailings and the As concentrate pond nearby the former beneficiation plant – see photo 3.1.

Photo 3.1 – Waste rock and As concentrate pond at Rudnicka kolonija

In the valley of Suva River, three gangue (waste rock) dumps were visited and samples were collected, too. It has been realized that the numerous gangue dumps consists mainly of serpentinite (see photo 3.2), traces of ore minerals appear on some of the dumps – realgar (As_4S_4), chromite ($FeCr_2O_4$). Frequent joints in the serpentinite are rarely filled with pyrite (FeS_2). Abundance of secondary white minerals (sulfate?) has been noted, too. Obviously, the gangue, being dumped into the valley, is eroded by the Suva River during the periods of high water level and thus the dumped gangue pose a risk of spreading the contamination (heavy metals + As, Sb).

Photo 3.2 – Gangue dump in the valley of Suva River

The second site visit has been performed by Dekonta’s representatives on February 14th, 2007. The visit last all day long. The permit to enter the border zone has been issued by police and thus the former roasting facility has been visited firstly. Samples of various waste/material occurring at the roasting facility’s ruins were collected (details on samples collected – see chapter 3.2.2). Quite a wide spectrum of waste has been noted at the roasting facility – As concentrate, As oxide, Sb concentrate, mixed waste containing rock fragments, ore, slag, etc., and slag, regardless of construction debris and littered municipal waste (see photo 3.3).

Photo 3.3 – Various waste at former roasting facility

On the top of it, one well (or a sump?) cased with perforated concrete shaft rings has been found at the roasting facility (see photo 3.4). This well neighbors the unsecured freely stored ore processing waste and may serve as an “open gate” through which the contaminants may easily enter into the groundwater. The groundwater in this alluvial plain may be expected in a low depth beneath the surface and within the permeable alluvial sediments the contamination can be widespread and affect the groundwater quality with all the consequent impacts on the environment and human health.

Photo 3.4 – Unprotected well at former roasting facility

Rudnicka kolonija has been visited again during the second site visit. Bulk sample of tailings was collected for chemical assay, bench tests and mineralogical study. The spring arising beneath the tailings at the road connecting Vaksince and Lojane villages has been visited and sample of water has been collected. Likely, this spring represents a consequence of a recent anthropogenic activity – improperly developed well located within the tailings dump (see appendix 7). The water stream, likely originating in this spring, has no natural bed and flows within an unpaved cart way (see photos 3.5 and 3.6) and dissipates among fields about 300 m apart from the spring. One sample of stream sediment has been collected from this watercourse (SS-1) and one sample of topsoil, potentially affected by the contaminated water, was taken from the close vicinity of this brook.

With respect to indispensable spring-discharge (about 1 Lsec^{-1}) and very high concentration of As (1.605 ppm – see table 2.6), exceeding 32 times the Macedonian limit for potable water, this spring represents additional contamination source. Most likely the contaminated water penetrates into a shallow aquifer in the Quaternary sediments of the plains eastern from Rudnicka kolonija with all the consequences for the environment and human health.

Photo 3.5 – Spring below the tailings

Photo 3.6 – Watercourse from the spring below tailings

Additionally, Masguri ridge (eastwards the Rudnicka kolonija) and the valley beginning southwards the hill Maja padine and having its mouth at Rudnicka kolonija just below the tailings (see photos 3.7 and 3.8) have been shortly visited, too.

Photo 3.7 – View from Masguri ridge

Numerous dumps of gangue (serpentinite) have been found at Masguri ridge – likely, those dumps represent remnants after the ore exploration – exploration trenches, shafts. Again, the dumps are littered with plenty of municipal waste, even sanitary waste (syringes, gauze, etc.). These dumps may also pose a risk of generation of acid drainage and subsequent spreading of the contamination.

Photo 3.8 – This valley drains Masguri ridge and subsequently the contamination source

Finally, the valley of Suva River has been visited again and 3 samples of gangue have been collected as well as 3 samples of stream sediments. The gangue samples are intended for assessments of potential origin of acid drainage (pyrite present in the joints in serpentinite) while the samples of stream sediments are intended for mineralogical study and assessment of the influence of the gangue dumps on the water quality.

During the site visits we have realized that the watercourse of Suva River frequently changes its appearance – there are variable sections in the valley where the flow is visible and sections where the flow is hidden in the sediments. At the mouth of Suva River valley, where the road from Vaksince to Lojane crosses the riverbed, the water rises from the sediments and flows over the road down to the flats (see photo 3.9). So, there is a permanent (not only periodical) flow of contaminants (heavy metals + As, Sb) infiltrating into the flats below the former mining area.

Photo 3.9 – Suva River crosses the road Vaksince - Lojane

The third site visit has been performed in the period May 15 – 17, 2007. Dekonta a.s. obtained information that a subsidiary of Serbian private company Pharmakom MB Zajaca has been awarded with exploration concession in the area of interest. So, the site has been visited with the aim to check up the site status – remnants of exploratory works have been found out – several diggings and boreholes (see photo 3.10). The open diggings, having maximum depth 1.8 m) brought new information – the As concentrate pond is not completely filled with As concentrate (the orange layer) – the As concentrate creates only an upper layer having thickness about 30 – 50 cm. Below this layer, grey claylike material appears, covered with secondary minerals. Samples of this material have been collected for the identification of mineralogical composition as well as for the chemical analyzes. The mineralogical study identified the mineral phases as realgar, epsomite, stibnite, and quartz (details see in chapter 3.2.5.2.).

Photo 3.10 – Digging in As concentrate pond

To conclude, the important findings of the site reconnaissance are:

- the area of interest is heavily littered with municipal waste and construction debris and their separation, collection, treatment and disposal of must be taken into account of the FS;
- there are several sources of contamination within the area considered disregarding the ubiquitous municipal waste and various debris:
    - gangue dumped in the valley of Suva River – possible ARD,
    - gangue dumped on Masguri ridge and its slopes – possible ARD directed by the valley on northeastern slope of Masguri to the tailings,
    - tailings and As concentrate at Rudnicka kolonija,
    - spring below the tailings at Rudnicka kolonija,
    - and As oxide, As concentrate, slag and other hazardous material freely dumped at former roasting facility.
- Suva River appears to be a permanent watercourse and thus a solution for treatment of its water prior entering into an aquifer and/or joining other watercourse has to be found and mitigation measures are to be taken in order to minimize transport of contaminated stream sediments;
- the valley, beginning on the South slope of Maja padine hill and entering the flats at Rudnicka kolonija (see photo 3.8), poses a risk – the runoff water flows around the foot of the As pond and tailings and thus it can spread the contamination (see photo log in appendix 7);

- abandoned limestone quarry has been found at the northern limits of the tailings, this quarry might serve as source of aggregate for use in the site remediation (e.g. temporary roads construction, drainage layers in case of capping, filling of permeable reactive barriers, etc.).

3.2.2 Samples collection

In respect to the site history – i.e. abandoned mine with former extraction of chromite and sulfide ore, ore beneficiation (crushing, milling, flotation) and ore processing (roasting facility) – a wide range of waste streams, resulting from ore extraction, beneficiation and processing, was expected. In order to gather detail information, necessary for the bench scale tests, selection and design of the cleanup and remediation measures, a set of bulk samples of various material/waste has been collected (except the littered municipal waste and various construction debris) at Lojane Mine during the site visits performed in the early stage of FS. Two samples of water were collected, too. The review of samples collected on the site is given in table 3.1.

Table 3.1 – Review of samples collected at Lojane mine

Sample	Matrix	Sample type	Number of samples	Location	Sample weight kg	Date of collection
Lojane - T	Tailings	bulk sample	1	Rudnicka kolonija	45	14.2.2007
Lojane - AsC	As concentrate - surface	bulk sample	1	Rudnicka kolonija	25	25.1.2007
Lojane -AsCD	As concentrate - depth	composite sample	1	Rudnicka kolonija	1	17.5.2007
Lojane - SbC	Sb concentrate(?)	composite sample	1	smelter	3	14.2.2007
Lojane - AsO	As oxide	composite sample	1	smelter	2	14.2.2007
Lojane - S	Slag	composite sample	1	smelter	2	14.2.2007
Lojane - MW	Mixed waste	composite sample	1	smelter	5	14.2.2007
Lojane - SS	Stream sediments	composite sample	4	Rudnicka kolonija -1 s. Suva River valley - 3 s.	2	14.2.2007
Lojane - WR	Waste rock (gangue)	composite sample	4	Rudnicka kolonija -1 s. Suva River valley - 3 s.	9	25.1.2007 14.2.2007
Lojane - O	Ore minerals (As ore)	composite sample	1	Suva River valley	3	14.2.2007
Lojane - TS	Topsoil	composite sample	1	Rudnicka kolonija	1	14.2.2007
Lojane - GW-1	Groundwater	individual sample	1	Rudnicka kolonija	4	14.2.2007
Lojane - PW-1	Pluvial water	individual sample	1	Kumanovo	2	March 2007

Collection of solid samples

The method of composite samples has been used for collection of samples of solid waste materials. Compositing simply refers to physically mixing individual samples to form a composite sample. Composite sampling can substantially reduce analytical costs because the number of required analyses is reduced by compositing several samples into one and analyzing the composite sample. Compositing is common practice for simply increasing the representativeness of a measurement.

The samples were taken using vinyl gloves and a plastic shovel, put into plastic containers and labelled with unique sample number. After taking the samples, the equipment was decontaminated.

Tailings

Bulk sample of tailings has been obtained by compositing of numerous individual samples (50) of uniform volume taken from southeastern slope of the tailings pile (see photo 3.11) which was not covered with soil and vegetation. The individual samples were dug out from the depth 0.20 m beneath the surface.

Photo 3.11 – Tailings dump – sampled area

As concentrate

Bulk sample of the arsenic concentrate (Lojane AsC) has been obtained by compositing of 20 individual samples of even volume. The individual samples were collected from the As concentrate at Rudnicka kolonija and from As concentrate pile at former roasting facility. The ratio was 15 : 5 individual samples collected at Rudnicka kolonija and at the roasting facility, this ratio was deduced from the tonnage of As concentrate dumped at the particular localities (see table 2.3).

Photo 3.12 – As concentrate at Rudnicka kolonija (left) and at the roasting facility (right)

Sb concentrate

Composite sample of the material considered as antimony concentrate has been obtained by compositing of 5 individual samples of even volume. The individual samples were collected from the remnants of presumed Sb concentrate at former roasting facility.

Photo 3.13 – Presumed Sb concentrate at the roasting facility

As oxide

Composite sample of the arsenic oxide has been obtained by compositing of 5 individual samples of even volume. The individual samples were collected from the scattered heaps of As oxide at former roasting facility.

Photo 3.14 – Heaps of As oxide at the roasting facility

Slag

Composite sample of the slag has been obtained by compositing of 5 individual samples of even volume. The individual samples were collected from the heap of As slag at former smelter.

Photo 3.15 – Slag at the roasting facility

Mixed waste

Composite sample consists of 5 individual samples of unidentified waste – likely mixture of slag, ore, and other materials.

Photo 3.16 – Mixed waste at the roasting facility

Stream sediments

Totally, 4 composite samples of stream sediments have been collected at Lojane mine – 1 sample from the bed of brook arising from the spring below tailings at Rudnicka kolonija (sample SS-1). The sample has been taken in distance 250 m from the spring. Three stream sediments samples have been collected in the Suva river valley – sample SS-4 has been collected 250 m up gradient from the mouth of the valley, sample SS-3 has been collected 500 m above the sample SS-1 (i.e. below the waste rock dump at former mine), and sample SS-2 has been taken from the river bed 500 m above the former mine. Only fraction below 2 mm has been collected for the analyses. Each sample consists of 3 individual samples.

Waste rock

Four composite samples of waste rock (gangue) have been collected in the area of interest. Sample WR-1 has been collected from the dump above tailings at Rudnicka kolonija (see photo 3.1). Sample WR-2 has been collected from a small dump nearby the Suva River valley mouth, sample WR-3 has been collected from dump at former shaft, and the sample WR-4 has been collected from a huge waste rock dump up gradient from the former shaft.

Ore minerals

One sample of ore minerals (realgar) for mineralogical study has been collected from the waste rock dump at former shaft in the Suva River valley. No traces of Sb sulfides have been found on the waste rock dumps.

Photo 3.17 – Sulfides (brown strips) on waste rock dump in Suva River valley

Topsoil

In addition, one topsoil sample has been collected in the area where the brook originating in the spring below tailings at Rudnicka kolonija dissipates in grassland 300 m apart of the spring.

Collection of water samples

One water sample (GW-1) has been collected at the site in the course of the site reconnaissance – sample of groundwater arising in the spring beneath the tailings dump (see photo 3.5). Totally, 4 liters of groundwater have been collected and placed into 2 plastic containers. Water in one container has been stabilized by addition of pure hydrochloric acid to maintain pH value 2 – to stabilize the heavy metals. During the sample collection field parameters were measured with portable multimeter – pH, conductivity, temperature and ORP – see table 3.2.

Table 3.2 – Groundwater field parameters

Parameter	Value	Unit
Conductivity	521	µS/cm
t	14.2	^{o} C
pH	7.91	
E_H	83	mV

The sample has been cooled and transported via express mail to Czech Republic for laboratory analyses.

3.2.3 Laboratory works

With the aim to get a detail insight in the wastes and contaminated media composition the samples collected were analyzed by independent accredited laboratories for a wide spectrum of contaminants and chemical composition. Attention has been paid also to assessment of potential acid generation which is one of the largest problems from hardrock metal mining. Commonly referred to as acid rock drainage (ARD) or acid mine drainage (AMD), acid drainage may be generated from mine waste rock or tailings (i.e. ARD) or mine structures like pits or underground workings (i.e. AMD). Acid generation can occur rapidly, or it may take years to appear. That is why even a long time abandoned mine site can intensify in regard to its environmental impacts.

Impacts from AMD/ARD depend on the mineralogy of the rock material, availability of water and oxygen. While acid may be neutralized by the receiving water, some of the dissolved metals may remain in solution and elevated concentrations of these metals in groundwater and/or surface water can rule out its use.

Acid is generated at mine site when metal sulfide minerals are oxidized and sufficient water is present to mobilize the sulfur ion. Metal sulfide minerals are common constituents in the host rock associated with metal mining activity. Prior to mining, oxidation of sulfides and formation of sulfuric acid is naturally occurring process – i.e. weathering. Oxidation of ore bodies, with subsequent release of acid and mobilization of metals, is slow and natural discharge from such deposits threatens a little the receiving water. Ore extraction and beneficiation highly increase the rate of the natural chemical reactions by removing great volume of sulfide rock material and exposing its increased surface area to air (oxygen) and water. The potential of mine associated waste to generate acid and release contaminants (heavy metals) depends on many factors and is site-specific – these factors can be categorized as:

1. ***Generation factors*** – determine the ability of the material to produce acid – water and oxygen are necessary for acid drainage generation, certain bacterial strains enhance acid generation. Water serves as a reactant, a medium for bacteria, and the transport medium for the products of oxidation. A ready supply of oxygen is required to drive

the oxidation – oxidation of sulfides is significantly reduced when the concentration of oxygen in the pore spaces of mining waste is less than 1 – 2 %.

2. ***Chemical control factors*** – determine the products of oxidation reactions, these factors include the ability of the generation rock or receiving water to either neutralize the acid or to change the effluent character by adding metal ions mobilized by acid. Products of oxidation reactions (hydrogen ions and metal ions) may also react with other constituents and dissolution of other minerals contributes to the contaminant load in the acid drainage.
3. ***Physical factors*** – include the physical characteristics of the waste or structure, the way in which the acid-generating and acid-neutralizing materials are placed, and the local hydrology. The physical nature of the material – particle size distribution, permeability, physical weathering characteristics – is important to the acid generation potential. Particle size is a fundamental concern because it affects the surface area exposed to weathering and oxidation. Surface area is inversely proportional to grain size – very coarse grain material (e.g. found in waste rock dumps) exposes less surface area but on the other hand it may allow air and water to penetrate deeper into the material dumped and ultimately producing more acid. Fine grained material (e.g. tailings) may impede air and water flow; however, finer grains expose more surface area to oxidation.

Detail description of laboratory works (chemical analyzes, mineralogical study, geotechnical tests) is provided in subsequent chapters.

3.2.4 Chemical analyzes

3.2.4.1 Scope of chemical analyzes performed

Samples of solid materials (mining and ore beneficiation/processing wastes, stream sediments, topsoil) collected were assayed for a wide spectrum of recalcitrant contaminants in dry matter – i.e. heavy metals (Cd, Co, Cr, Cu, Ni, Pb, Tl, V, Zn) and As, Sb. Usually, Tl concentration is not assayed, but Macedonia is well known metallogenic area rich with this metal, which is highly toxic, and thus because of some similar features with Alsar deposit Tl has been determined in a few samples, too.

In order to characterize the bioavailability of contaminants, leachates from samples collected were prepared and analyzed in accordance with Czech legislation. The leachate analyses are used for assessment and classification of waste – i.e. the values of contaminants in the leachate determines the type of landfill where the waste may be disposed of.

To asses potential for acid generation a simple screening tests were performed too that provides an indication of the extent of readily soluble salts, including those which are acidic and/or contain trace metals, stored in mine waste dumps. This test can be used for screening by qualitatively characterizing waste rock dump material. Fifty grams of material less than 2 mm in diameter is placed into one liter of deionized water, shaken vigorously for five minutes, and allowed to settle for 10 minutes. Aliquots are analyzed for pH, specific conductance and for dissolved components. Tests results are comparable to those for the Synthetic Precipitation Leaching Procedure (US EPA).

Laboratory analyses were performed by independent accredited Czech laboratories Research Institute of inorganic chemistry, Ústí nad Labem.

3.2.4.2 Results of chemical analyzes performed

Findings of laboratory analyses of solid materials are presented in table 3.3 further. Obviously, the materials found within the area of interest are contaminated – mainly with As, Ni and Sb. The results of the laboratory analyses are further discussed in chapter 3.2.7.3.

Results of screening tests for assessments of potential acid generation are presented in table 3.4. Obviously, the materials tested are not prone to produce ARD – with the only exempt, i.e. As concentrate.

Analyses of water sample are presented in table 3.5 – the water from spring below tailings dump has parameters of drinking water – except As content. The water composition indicates its origin in limestones.

Table 3.3 – Results of laboratory analyzes - solid materials

Material →			Sample																
			Tailings		As concentrate			Stream sediments				Slag	As oxide	Sb conc.	Mixed waste	Waste rock				Topsoil
Analyte	**Analysis**	**Unit**	**T - 1/1**	**T - 2/1**	**AsC - 1/1**	**AsC - 2/1**	**AsCD - 1**	**SS - 1/1**	**SS - 2/1**	**SS - 3/1**	**SS - 4/1**	**S- 1/1**	**AsO - 1/1**	**SbC - 1/1**	**MW - 1/1**	**WR - 1/1**	**WR - 2/1**	**WR - 3/1**	**WR - 4/1**	**TS-1/1**
As	d.m.	%	0.84	0.99	51.1	50.5	22,06	0.41	0.027	0.003	0.005	0.25	69.8	57.7	0.39	0.007	1.3	0.59	<0.001	0.023
	leachate	mg/l	10.5	11.6	570	773	536	1.43	1,60	<0.05	0.05	2.51	4,203	3,110	<0.05	<0.05	36.1	15.3	<0.05	1.36
Cd	d.m.	mg/kg	<5	<5	<15	<15	2	7	<5	<5	<5	<5	<15	<15	17	5	9	<5	<5	<5
	leachate	mg/l	<0.005	<0.005	<0.005	<0.005	0.019	<0.005	<0.005	<0.005	<0.005	<0.005	<0.05	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Co	d.m.	mg/kg	66	88	4	5	24	40	51	70	66	40	3	19	5	79	100	67	83	45
	leachate	mg/l	<0.01	<0.01	0.05	0.08	0.072	0.44	<0.01	<0.01	0.01	<0.01	<0.01	0.05	0.25	<0.01	<0.01	<0.01	<0.01	<0.01
Cr_{total}	d.m.	mg/kg	150	160	37	29	122	370	300	350	290	110	1	19	92	320	320	160	110	150
	leachate	mg/l	<0.005	<0.005	0.029	0.032	0.002	<0.005	<0.005	<0.005	0.010	0.006	0.008	<0.005	0.033	<0.005	<0.005	<0.005	<0.005	0.018
Cr^{6+}	d.m.	mg/kg	NA	NA	NA	NA	8	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	leachate	mg/l	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Cu	d.m.	mg/kg	280	41	4	4	27.5	150	24	39	36	17	2	8	330	12	13	15	7	54
	leachate	mg/l	<0.02	<0.02	0.04	0.04	0.007	0.03	<0.02	<0.02	<0.02	<0.02	0.03	0.04	2.74	<0.02	<0.02	<0.02	<0.02	0.03
Hg	d.m.	mg/kg	0.12	0.12	0.60	0.48	<3	0.04	0.04	0.05	0.03	0.05	0.11	0.38	0.1		1.18	0.08	0.22	0.26
	leachate	mg/l	<0.01	<0.01	<0.01	<0.01	<0.05	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01		<0.01	<0.01	<0.01	<0.01
Ni	d.m.	mg/kg	1200	1500	80	60	3358	330	840	1100	940	660	5	310	90	1600	1900	1300	1400	630
	leachate	mg/l	0.53	0.58	1.22	1.80	3.71	1.48	0.02	0.02	0.08	0.05	0.02	0.94	2.45	<0.01	0.02	0.01	<0.01	0.09
Pb	d.m.	mg/kg	150	240	19	15	8.8	210	12	10	12	40	<5	25	230	4	8	24	5	42
	leachate	mg/l	<0.05	<0.05	<0.05	<0.05	0.008	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Sb	d.m.	%	0.66	0.68	6.35	6.86	6.19	0.72	0.013	<0.0004	<0.0004	0.2	7.15	17.1	3.21	<0.0004	4.4	0.46	<0.0004	0.026
	leachate	mg/l	8.36	9.70	3.03	4.41	156	5.50	0.58	<0.07	<0.07	3.24	4.96	11.8	<0.07	<0.05	14.60	4.41	<0.07	0.62
Tl	d.m.	mg/kg	30	NA	100	120	198	<5	<5	<5	<5	NA	8	110	190	<5	130	27	<5	NA
	leachate	mg/l	<0.01	NA	0.3	0.3	0.088	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
V	d.m.	mg/kg	18	19	2	2	38.8	39	22	19	23	19	2	3	23	9	20	22	3	45
	leachate	mg/l	<0.01	<0.01	<0.01	<0.01	0.095	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	0.02
Zn	d.m.	mg/kg	44	44	6	6	49	500	44	41	39	40	3	14	230	40	55	40	37	110
	leachate	mg/l	0.047	0.064	0.26	0.21	0.042	0.53	0.009	0.027	0.019	0.022	0.11	0.13	2.11	<0.005	0.01	0.008	<0.005	0.046

Note: The concentrations of As and Sb are presented in % because of high concentrations of these elements in dry matter

Table 3.4 – Results of screening test of potential acid generation

Parameter	**Material**	**Tailings**		**As conc.**	**Stream sediments**			**Waste rock**			**As ore**	**Topsoil**
	Unit	**T-3**	**T-4**	**AsC 3**	**SS-2/2**	**SS-3/2**	**SS-4/2**	**WR-1/2**	**WR-3/2**	**WR-4/2**	**O-2**	**TS-2**
pH	-	7.92	7.55	2.97	7.27	8.62	8.64	9.85	10.19	10.01	8.39	9.06
conductivity	µS/cm	664	661	1512	185	18	21	139	68	101	199	36
$ANC_{4.5}$	mmol/l	0.22	0.7	pH 2.97	1.35	0.22	0.16	1.85	0.85	1.32	0.3	0.9
$BNC_{8.3}$	mmol/l	0.15	0.12	3.85	0.15	0.05	0.05	pH 9.85	0.05	pH10.01	0.2	0.25
SO_4^{2-}	mg/l	350	320	500	18.6	2	2	8	3	3	0.2	0.25
As	mg/l	4.5	4.1	181	0.053	0.007	0.007	0.01	<0.005	0.065	3.23	1.81
Fe	mg/l	0.05	0.16	0.76	0.59	0.71	0.9	<0.005	0.27	0.05	0.14	51
Cd	mg/l	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
Co	mg/l	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.1
Cr tot.	mg/l	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.4
Cr^{6+}	mg/l	<0.01	<0.01	0.01	≤0.05	≤0.05	≤0.05	<0.01	0.02	<0.01	0.01	0.60
Cu	mg/l	<0.01	<0.01	0.03	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.29
Hg	mg/l	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mn	mg/l	<0.02	<0.02	0.08	0.04	0.04	0.07	<0.01	0.01	<0.02	0.03	0.46
Ni	mg/l	0.12	0.18	0.64	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	2.9
Pb	mg/l	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Sb	mg/l	2.54	2.65	2.6	0.04	<0.005	<0.005	0.018	<0.005	0.006	0.46	3.11
Zn	mg/l	<0.01	<0.01	0.1	0.06	0.05	0.03	<0.01	<0.01	<0.01	<0.01	0.61

Table 3.5 – Results of laboratory analyses - water

parameter	***unit***	***Sample*** **GW - 1**
pH		7.5
conductivity	*mS/m*	53
dissolved matter (105℃)	*mg/l*	320
BNC 8,3	*mmol/l*	0.64
ANC 4,5	*mmol/l*	5.1
COD-Cr	*mg/l*	< 5
S^{2-}	*mg/l*	< 0.01
NH^{4+}	*mg/l*	< 0.01
NH^{3+}	*mg/l*	< 0.01
NO^{3-}	*mg/l*	3.58
NO^{2-}	*mg/l*	< 0.01
F^-	*mg/l*	0.11
Cl^-	*mg/l*	2.62
SO_4^{2-}	*mg/l*	23.8
PO_4^{3-}	*mg/l*	0.19
HCO^{3-}	*mg/l*	311
CO_2 free	*mg/l*	28.2
DOC	*mg/l*	1.11
As_{total}	*mg/l*	0.28
As^{3+}	*mg/l*	<0.01
Ca	*mg/l*	82.6
Cd	*mg/l*	< 0.004
Co	*mg/l*	< 0.02
Cr	*mg/l*	< 0.05
Cr^{6+}	*mg/l*	< 0.01
Cu	*mg/l*	< 0.01
Hg	*mg/l*	< 0.001
Fe	*mg/l*	< 0.05
K	*mg/l*	0.98
Mg	*mg/l*	24.5
Mn	*mg/l*	< 0.02
Na	*mg/l*	5.06
Ni	*mg/l*	< 0.02
Pb	*mg/l*	< 0.05
Sb	*mg/l*	0.019
Tl	*mg/l*	< 0.1
V	*mg/l*	< 0.01
Zn	*mg/l*	< 0.01

3.2.5 Mineralogical study

3.2.5.1 Methods used for minerals identification

With respect to the lack of basic data on the mineralization exploited at Lojane mine, a limited mineralogical study has been performed with the aim to identify mineral phases present in the gangue dumps and various wastes – specifically focused on identification of sulfides and sulfates that contribute to acid drainage above all.

The mineralogical techniques applied to mine waste are X-ray diffraction (XRD) and optical microscopy (OM). Samples analyzed are presented in the table 3.6 below.

The results of X-ray diffraction study are summarized in table 3.7. Semi-quantitative proportions of identified mineral phases are also presented in graphs below (see figures 3.1 – 3.7). Semi-quantitative proportions are calculated from XRD reflections d_{001} (values =100 in the table below) and their intensity in XRD spectrum.

Table 3.6 – Overview of mineralogical samples

Sample	Visual description	Description	Requested determination	Method
Lojane - AsC	realgar, auripigment ?	orange powder	determine the mineral composition	XRD, OM
Lojane - SbC	Sb concentrate ?	grey clay-like clumps	determine the mineral composition	XRD, OM
Lojane - T	fine quartz sand	silty fine sand	find whether sulfides are present	XRD, OM
Lojane - AsO	As oxide	white clay-like plastic material	determine the mineral composition	XRD, OM
Lojane - SS - 3	traces of chromite and sulfides	stream sediment, fraction >2.0 mm	find whether ore minerals and sulfides are present	OM
Lojane - O	realgar, auripigment ?	gangue with As sulfides	characterize the gangue	XRD, OM
Lojane - WR - 4/M	sulfates ?	white coats of secondary minerals	determine the mineral composition	XRD, OM
Lojane - Min - 1	sulfates ?	white coats of secondary minerals	determine the mineral composition	XRD
Lojane - Min - 2	secondary minerals of As, Sb ?	white coats of secondary minerals	determine the mineral composition	XRD
Lojane - Min - 3	As, Sb concentrate ?	grey-brown fine grained material	determine the mineral composition	XRD

3.2.5.2 Results of mineralogical study

Data presented in table 3.7 and figures 3.1 – 3.7 clearly identify the mineral composition of the main contaminants present in source zones at Lojane Mine.

Table 3.7 – Results of XRD analyzes

Mineral composition	Sample							
	T	WR-4/M	AsC	SbC	AsO	Min - 1	Min - 2	Min - 3
quartz SiO_2	100		55			55		4
dolomite $CaMg(CO_3)_2$	54							
magnezite $MgCO_3$	8							
gypsum $CaSO_4 . 2 H_2O$	35		38			35		
kaolinite $Al_2Si_2O_5(OH)_4$	10							
hydromagnesite $Mg_5(CO3)_4(OH)_2$		100						
clinochryzotile $Mg_3Si_2O_5(OH)_4$		99						
magnetite Fe_2O_3		36						
realgar As_4S_4			100			5		
arsenolite As_2O_3				100	100			
stibnite Sb_2S_3							10	11
epsomite $MgSO_4 . 7 H_2O$							55	43
Mg sulfate $MgSO_3 . H_2O$							25	
ploslerite $MgAsO_3(OH) . 7 H_2O$						5		

The biggest portion of the waste – tailings – consists of stable mineral phases (quartz, dolomite, magnezite, gypsum and kaolinite) which do not contribute to acid drainage. The tailings have a good potential for successful treatment with the S/S method. No acid drainage producing minerals have been also identified in the waste rock (serpentinite).

Important finding of the XRD study is that at former roasting facility a toxic waste is stored in unsafe manner – **As_2O_3**, which is very soluble and toxic in a small dose. The material estimated as antimony concentrate during the site reconnaissance has been identified also as arsenic oxide (see table 3.7 – sample SbC and fig. 3.5) – although this material is not likely pure As oxide – it has relatively high content of antimony – about 17% (see table 3.3 – Sb conc. column).

Only by the means of OM the stream sediments from Suva River (sample SS-3) have been studied and prevailing minerals/rocks identified are magnetite > dolomite > quartz > serpentinite. Traces of chromite and sulphidic ore minerals were identified too. In sample of realgar, presence of arsenopyrite has been found by OM. The results and photos of OM study are presented in details in appendix 5.

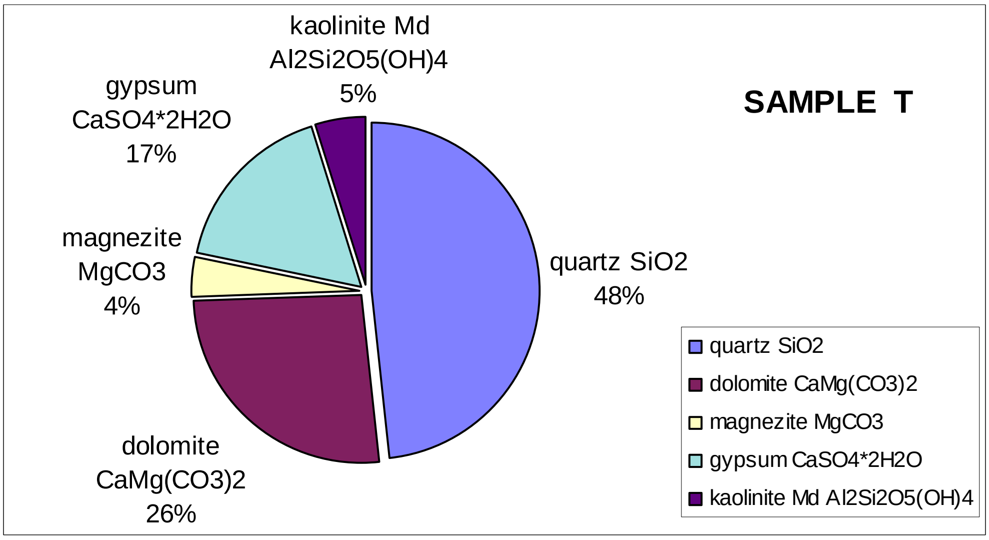


Fig. 3.1 – Mineral composition of the tailings

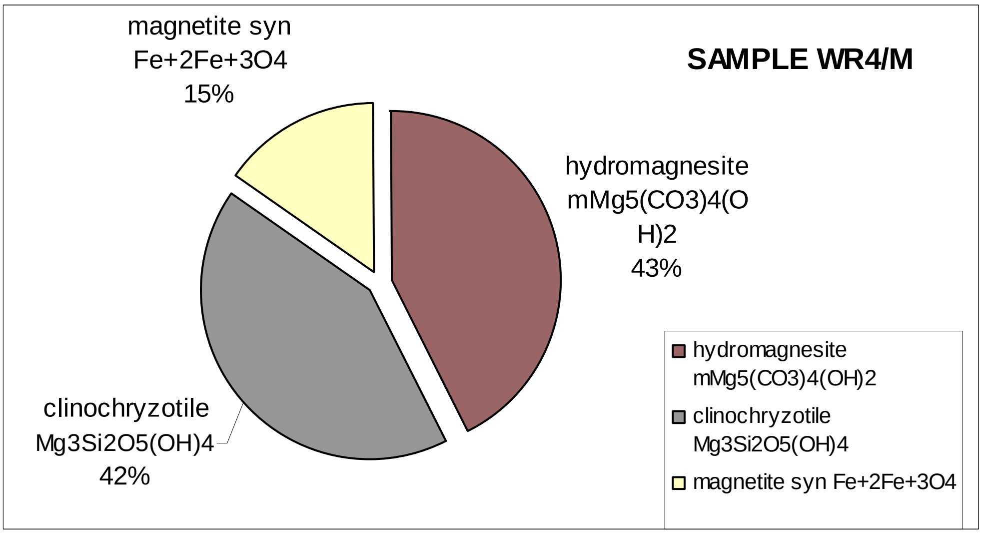


Fig. 3.2 – Mineral composition of waste rock

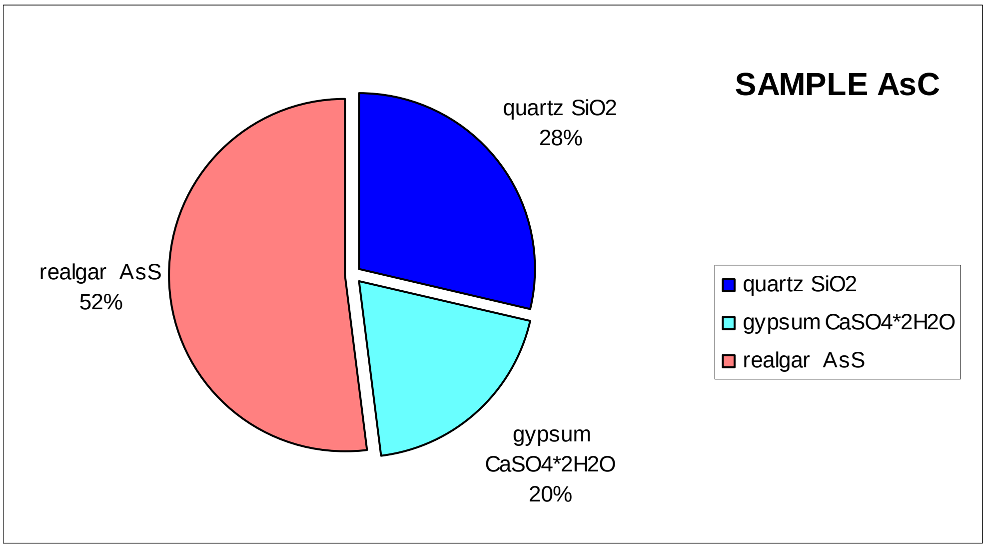


Fig. 3.3 – Mineral composition of As concentrate (surface layer)

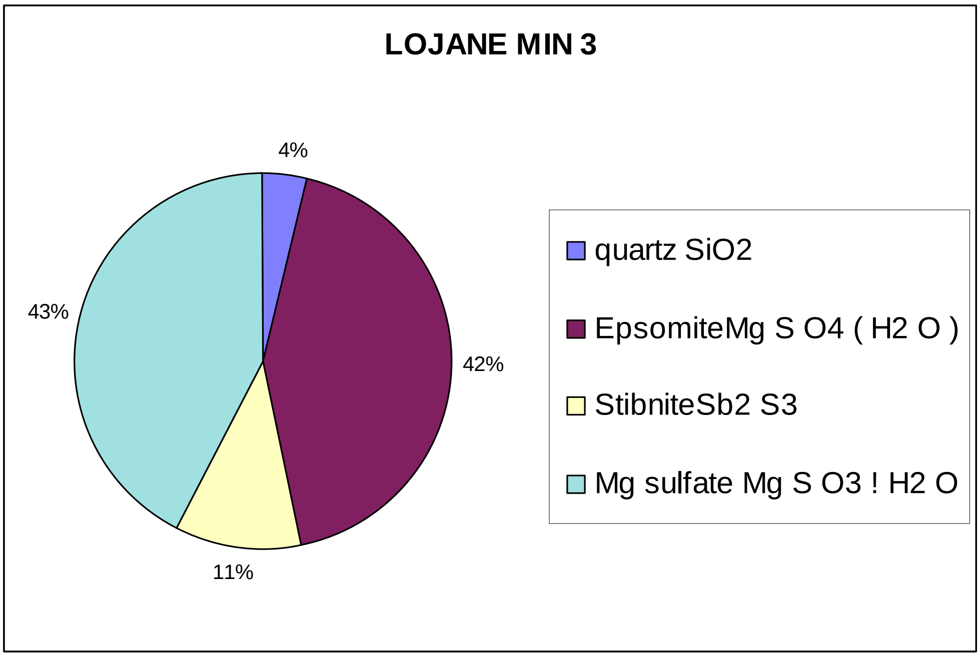


Fig. 3.4 – Mineral composition of As concentrate (depth 1.5 m)

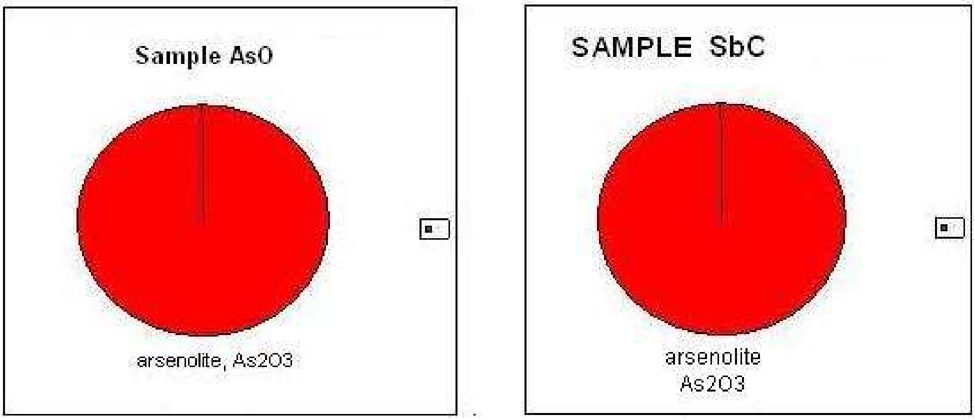


Fig. 3.5 – Mineral composition of As oxide and presumed Sb concentrate

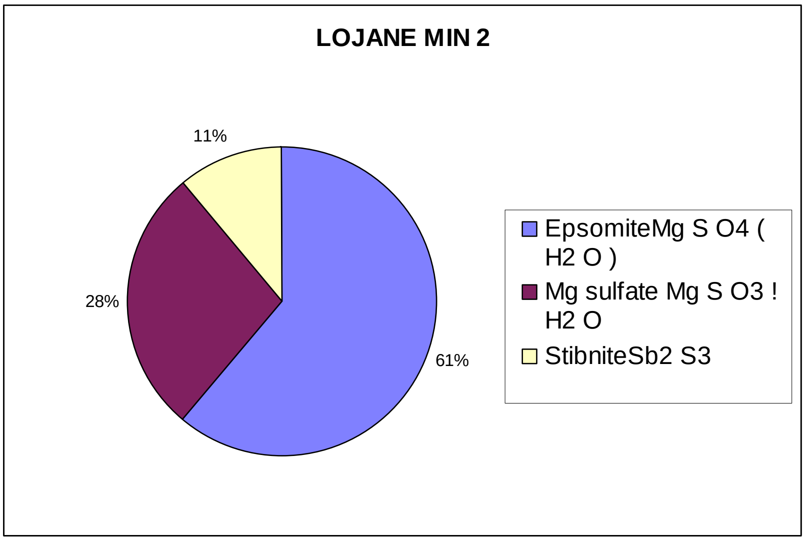


Fig. 3.6 – Mineral composition of secondary minerals in As concentrate

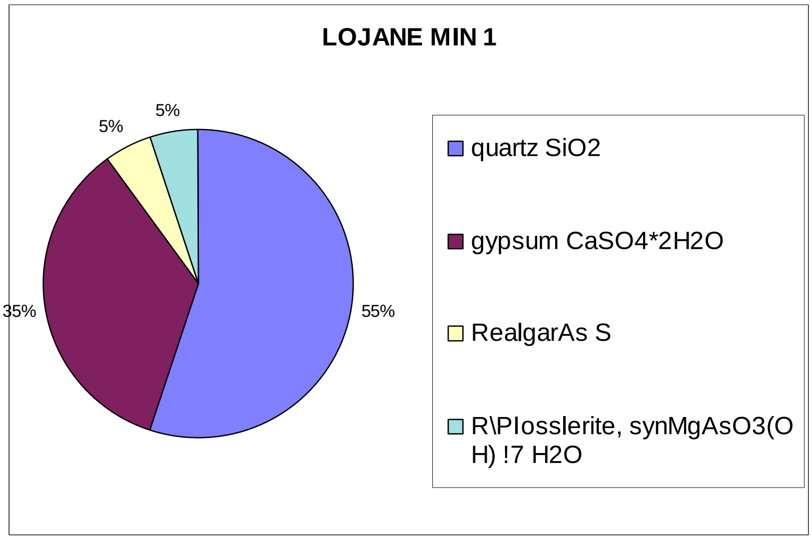


Fig. 3.7 – Mineral composition of secondary minerals from tailings surface

3.2.6 Geomechanic tests

The geomechanic tests have been performed with sample of the tailings only. The parameters measured were:

Bulk density – 903 kg/m^3

Particle density – 2,886 kg/m^3

Angle of discharge – 38.21^o (0.67 rad)

Filtration coefficient k_{10} – 7.0 – 8.8 * 10^{-7}

Grain size distribution – the results are presented in figure 3.6, the tailings are classified as silty sand.

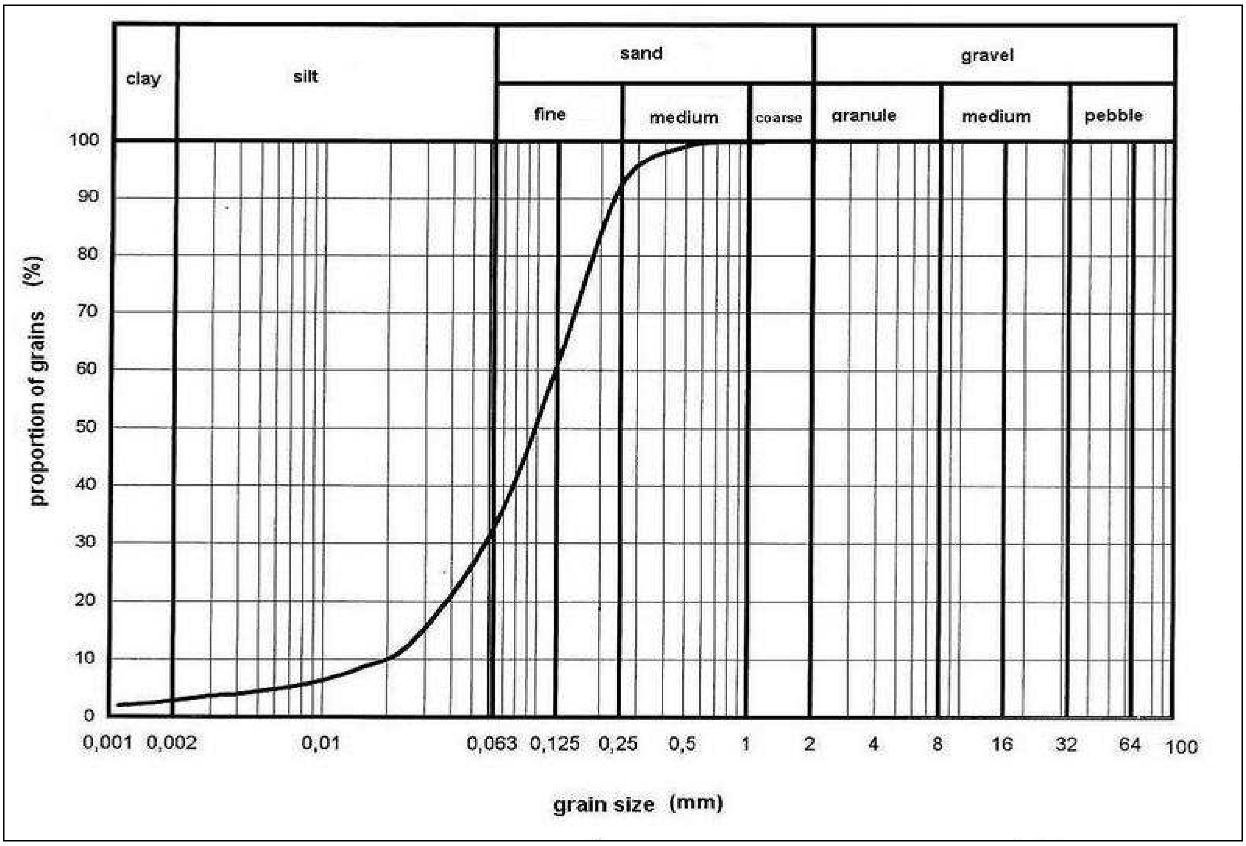


Fig. 3.8 – Grain size distribution - tailings

Compactibility test

The curve for 100% saturation is valid for solid particles density 2,886 kg/m^3.

Maximum dry matter bulk density 1,580 kg/m^3.

Optimum moisture to dry matter 19.0%.

Moisture (%)	14.0	18.1	22.1	26.7
Bulk density of total solids (kg/m^3)	1508	1573	1571	1481

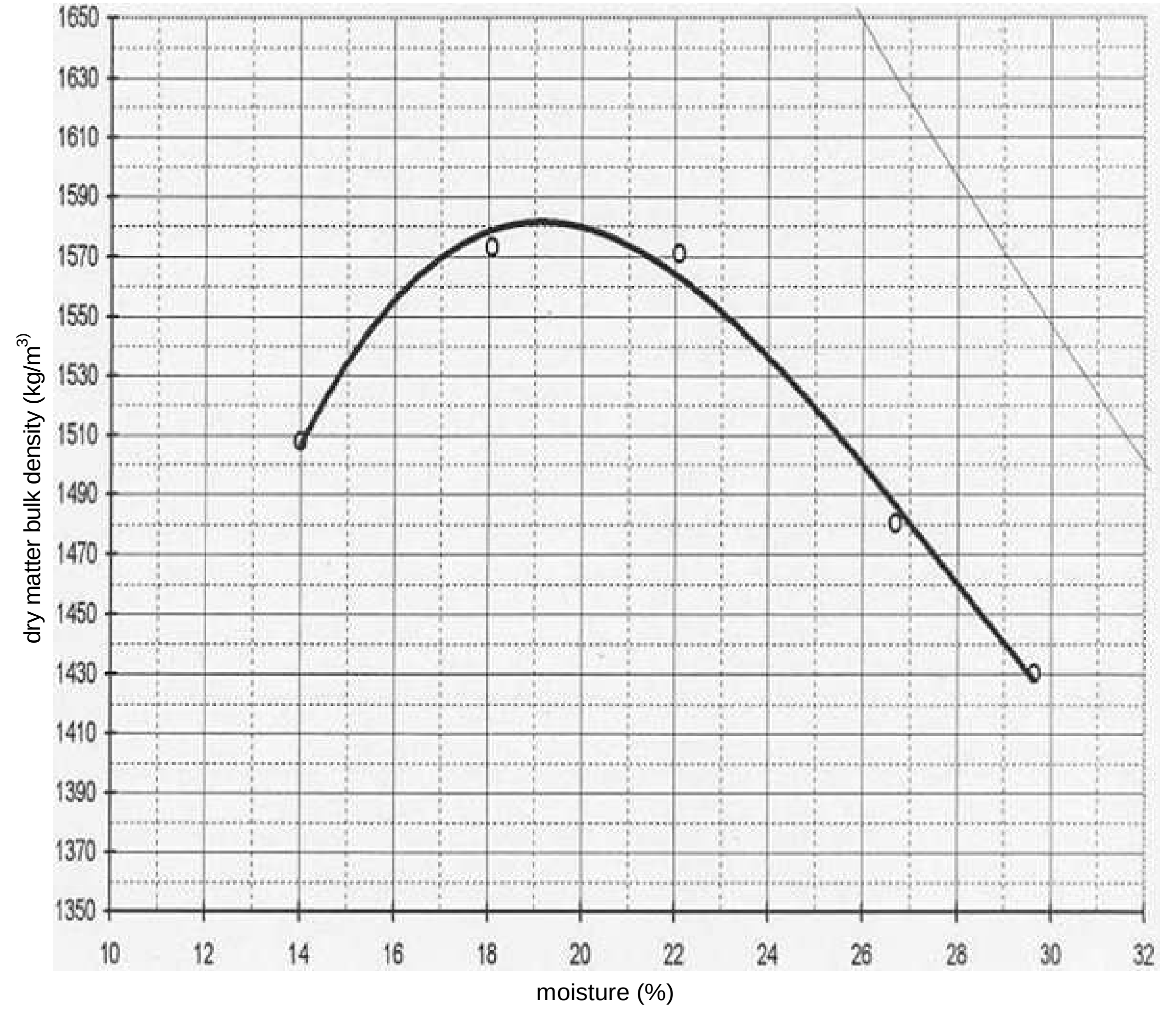


Fig. 3.9 – Compactibility graph

3.2.7 Contaminants identified and waste characterization

3.2.7.1 Contaminants identification

With the aim to identify the contaminants in solid materials (stream sediments, soil, wastes) from the Lojane Mine area, the concentrations of heavy metals and As, Sb were compared to the intervention limits given by Czech legislation (because of lack of similar standards in Macedonian legislation), water samples have been compared with limits given by Macedonian standards – see appendix 4.

The contaminants identified in various mining/ore processing wastes are:

- Mining/ore processing wastes – As, Sb, Ni, likely Tl;
- Stream sediments – As, Sb, Ni;
- Soil – As, Sb, Ni;
- Surface water (Suva River) – As, Cd, Ni;
- Groundwater – As, Cr, Cu, Cd, Zn.

Table 3.8 – Identification of contaminants

Material →			Sample																		Threshold levels	
			Tailings		As concentrate			Stream sediments				Slag	As oxide	Sb conc.	Mixed waste	Waste rock				Topsoil	B	C
Analyte	**Analysis**	**Unit**	**T - 1/1**	**T - 2/1**	**AsC - 1/1**	**AsC - 2/1**	**AsCD - 1**	**SS - 1/1**	**SS - 2/1**	**SS - 3/1**	**SS - 4/1**	**S- 1/1**	**AsO - 1/1**	**SbC - 1/1**	**MW - 1/1**	**WR - 1/1**	**WR - 2/1**	**WR - 3/1**	**WR - 4/1**	**TS-1/1**	**I**	**III**
As	d.m.	%	0.84	0.99	51.1	50.5	22,06	0.41	0.027	0.003	0.005	0.25	69.8	57.7	0.39	0.007	1.3	0.59	<0.001	0.023	0.0065	0.0140
	leachate	mg/l	10.5	11.6	570	773	536	1.43	1,60	<0.05	0.05	2.51	4,203	3,110	<0.05	<0.05	36.1	15.3	<0.05	1.36	0.05	2.5
Cd	d.m.	mg/kg	<5	<5	<15	<15	2	7	<5	<5	<5	<5	<15	<15	17	5	9	<5	<5	<5	10	30
	leachate	mg/l	<0.005	<0.005	<0.005	<0.005	0.019	<0.005	<0.005	<0.005	<0.005	<0.005	<0.05	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.004	0.5
Co	d.m.	mg/kg	66	88	4	5	24	40	51	70	66	40	3	19	5	79	100	67	83	45	50	300
	leachate	mg/l	<0.01	<0.01	0.05	0.08	0.072	0.44	<0.01	<0.01	0.01	<0.01	<0.01	0.05	0.25	<0.01	<0.01	<0.01	<0.01	<0.01	-	-
Cr $_{total}$	d.m.	mg/kg	150	160	37	29	122	370	300	350	290	110	1	19	92	320	320	160	110	150	450	1000
	leachate	mg/l	<0.005	<0.005	0.029	0.032	0.002	<0.005	<0.005	<0.005	0.010	0.006	0.008	<0.005	0.033	<0.005	<0.005	<0.005	<0.005	0.018	0.05	7
Cr^{6+}	d.m.	mg/kg	NA	NA	NA	NA	8	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	12	50
	leachate	mg/l	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-	-
Cu	d.m.	mg/kg	280	41	4	4	27.5	150	24	39	36	17	2	8	330	12	13	15	7	54	500	1500
	leachate	mg/l	<0.02	<0.02	0.04	0.04	0.007	0.03	<0.02	<0.02	<0.02	<0.02	0.03	0.04	2.74	<0.02	<0.02	<0.02	<0.02	0.03	0.2	10
Hg	d.m.	mg/kg	0.12	0.12	0.60	0.48	<3	0.04	0.04	0.05	0.03	0.05	0.11	0.38	0.1		1.18	0.08	0.22	0.26	2.5	20
	leachate	mg/l	<0.01	<0.01	<0.01	<0.01	<0.05	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01		<0.01	<0.01	<0.01	<0.01	0.001	0.2
Ni	d.m.	mg/kg	1200	1500	80	60	3358	330	840	1100	940	660	5	310	90	1600	1900	1300	1400	630	180	500
	leachate	mg/l	0.53	0.58	1.22	1.80	3.71	1.48	0.02	0.02	0.08	0.05	0.02	0.94	2.45	<0.01	0.02	0.01	<0.01	0.09	0.04	4
Pb	d.m.	mg/kg	150	240	19	15	8.8	210	12	10	12	40	<5	25	230	4	8	24	5	42	250	800
	leachate	mg/l	<0.05	<0.05	<0.05	<0.05	0.008	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.05	5
Sb	d.m.	%	0.66	0.68	6.35	6.86	6.19	0.72	0.013	<0.0004	<0.0004	0.2	7.15	17.1	3.21	<0.0004	4.4	0.46	<0.0004	0.026	0.0025	0.0080
	leachate	mg/l	8.36	9.70	3.03	4.41	156	5.50	0.58	<0.07	<0.07	3.24	4.96	11.8	<0.07	<0.05	14.60	4.41	<0.07	0.62	0.006	0.5
Tl	d.m.	mg/kg	30	NA	100	120	198	<5	<5	<5	<5	NA	8	110	190	<5	130	27	<5	NA	-	-
	leachate	mg/l	<0.01	NA	0.3	0.3	0.088	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-
V	d.m.	mg/kg	18	19	2	2	38.8	39	22	19	23	19	2	3	23	9	20	22	3	45	340	550
	leachate	mg/l	<0.01	<0.01	<0.01	<0.01	0.095	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	0.02	-	-
Zn	d.m.	mg/kg	44	44	6	6	49	500	44	41	39	40	3	14	230	40	55	40	37	110	1500	5000
	leachate	mg/l	0.047	0.064	0.26	0.21	0.042	0.53	0.009	0.027	0.019	0.022	0.11	0.13	2.11	<0.005	0.01	0.008	<0.005	0.046	0.4	20

Explanations:

Treshold levels:	B	- when B limit is exceeded further action is needed - i.e. detail investigation
	C ind	- valid for industrial areas, when exceeded remedaition is requested
	I	- waste that does not exceed limit I can be disposed of as inert material
	III	- waste excceding limit I and below limit III may be disposed of as hazardous waste on special landfill

🟨 - values above B limit and below C limit
🟧 - values above C limit
🟪 - extreme values (more then 100 times exceeding the limit given)

🟧 - values exceeding the limit I and below limit III
🟥 - values exceeding the limit III
🟪 - extreme values (more then 100 times exceeding the limit given)

3.2.7.2 Characterization of contaminants identified

As the metals cannot be destroyed, remediation of soil contaminated with metals consists especially of manipulation (e.g. exploiting, increasing, decreasing or maintaining) with the mobility of metal contaminant(s) to produce the treated soil that has an acceptable total or leachable metal content. Metal mobility depends on numerous factors. According to McLean & Bledsoe (1992), metal mobility in soil-waste systems is determined by the type and quantity of soil surfaces present, the concentration of metal of interest, the concentration and type of competing ions and complexing ligands, both organic and inorganic, pH and redox status. Generalization can only serve as rough guides of the expected behavior of metals in such systems. The potential mobility of the metal will change as the soil condition changes.

Cadmium is a bluish-white, soft, ductile metal. Pure Cd compounds are rarely found in nature, although occurrences of greenockite (CdS) and otavite (CdCO3) are known. The main sources of cadmium are sulphide ores of Pb, zinc and copper. Cadmium is recovered as a by-product when these ores are processed. Cd is present in cationic forms under natural environmental conditions. This cationic metal is generally not mobile in the environment and tends to remain relatively close to the point of initial deposition. The capacity of soil to adsorb cationic metals is increased with increasing pH, cation exchange capacity and organic carbon content. Under the neutral to basic conditions typical for most soil, cationic metals are strongly adsorbed on the clay fraction of soil and can be adsorbed by hydrous oxides of iron, aluminum, or manganese present in soil minerals. Cationic metals will precipitate as hydroxides, carbonates or phosphates. In acidic, sandy soil, the cationic metals are more mobile. Under conditions that are atypical for natural soil (e.g., pH <5 or ›9; elevated concentrations of oxidizers or reducers; high concentrations of soluble organic or inorganic complexing or colloidal substances), but may be encountered as a result of waste disposal or remedial processes, the mobility of cadmium can be substantially increased. Also competitive adsorption between various metals has been observed in experiments involving various solids with oxide surfaces (γFeOOH, α-SiO2 and γAl2O3). In several experiments, Cd adsorption was decreased by the addition of Pb or Cu for all three of these solids. The addition of zinc resulted in the greatest decreases of Cd adsorption. Competition for surface sites occurred, when only a few percent of all surface sites were occupied.

Arsenic is a semimetallic element or metalloid that has several allotropic forms. The most stable allotrope is a silver-gray, brittle, crystalline solid that tarnishes in air. Arsenic compounds, mainly As2O3, can be recovered as a by-product of processing complex ores mined mainly for copper, Pb, zinc, gold and silver. Arsenic occurs in a wide variety of mineral forms, including arsenopyrite (FeAsS4), which is the main commercial ore of arsenic worldwide. Arsenic behavior differs considerably from Cd. Arsenic typically exists in anionic form under environmental conditions. In most As-contaminated sites, As appears as As2O3 or as anionic As species leached from As2O3, oxidized to As (V) and then sorbed onto iron-bearing minerals in the soil. Arsenic may be present also in organometallic forms, such as methylarsenic acid (H2AsO3CH3) and dimethylarsenic acid (CH3)2AsO2H), which are active ingredients in many pesticides, as well as the volatile compounds arsine (AsH3) and its methyl derivatives - e.g. dimethylarsine (HAs(CH3)2) and trimethylarsine (As(CH3)3. These As forms illustrate the various oxidation states that As commonly exhibits (-III, 0, III, and V), as well as the resulting complexity of its chemistry in the environment. As (V) is less mobile and less toxic than As (III). As (V) exhibits anionic behavior in the presence of water and hence its aqueous solubility increases with increasing pH; it does not complex or precipitate with other anions. As (V) can form low solubility metal arsenates. Calcium arsenate

(Ca3(AsO4)2) is the most stable metal arsenate in well-oxidized and alkaline environment, but it is unstable in acidic environment. Even under initially oxidizing and alkaline conditions, absorption of CO2 from the air will result in formation of CaCO3 and release of arsenate. In sodic soil, sufficient sodium is available, so that the mobile compound Na3AsO4 can form. The slightly less stable manganese arsenate (Mn2(AsO4)2) forms in both, acidic and alkaline environment, while iron arsenate is stable under acidic soil conditions. In aerobic environment, H3AsO4 predominates at pH < 2 and is replaced by H2AsO4-. HAsO42-, and AsO43- as pH increases to about 2, 7, and 11.5, respectively. Under mildly reducing conditions, H3AsO3 is a predominant species at low pH, but is replaced by H2AsO3-, HAsO32- and AsO33- as pH increases. Under still more reducing conditions and in the presence of sulphide, As2S3 can form. As2S3 is a low-solubility, stable solid. AsS2 and AsS2-are thermodynamically unstable with respect to As2S3. Under extreme reducing conditions, elemental As and volatile arsine (AsH3) can occur. Just as competition between cationic metals affects mobility in soil, competition between anionic species (chromate, arsenate, phosphate, sulphate, etc.) affects anionic fixation processes and may increase mobility.

Antimony can exist in several oxidation states, including -3, 0, +3, and +5. Under natural environmental conditions, antimony exists in the +5 and +3 oxidation states. The +3 oxidation state of antimony is reported to be more toxic than its +5 state. In natural aqueous systems, Sb(V) and Sb(III) are the stable oxidation states under oxidizing and reducing conditions, respectively, based on equilibrium thermodynamic considerations. However, contrary to thermodynamic predictions, Sb(V) and Sb(III) have been found coexisting in natural aqueous systems. For example, Sb(III) has been detected under oxic conditions in different marine water, fresh water, groundwater, and rain. Researchers have suggested that the metastability of Sb(III) under oxic conditions may have resulted from biotic processes and/or a slow rate of Sb(III) oxidation. Antimony(V) has also been detected with Sb(III) in the presence of dissolved sulfide in some anoxic waters. Proposed explanations for this observed metastability of Sb(V) include the transport of Sb(V) on sinking detritus from oxic waters, formation of Sb(V) thiocomplexes, or advection of oxic waters containing high Sb(V) concentrations, all coupled with a slow rate of Sb(V) reduction.

Over 240 antimony-bearing minerals are known. Many of these minerals are sulfides and antimonides, and form in high-sulfide, reducing environments such as hydrothermal ore deposits. Two of the more common antimony-containing minerals found in hydrothermal deposits include stibnite (Sb_2S_3) or kermesite (Sb_2S_2O). Antimony often occurs in minerals in solid solution with arsenic [e.g., guettardite $Pb(Sb,As)_2S_4$] and/or with its other neighboring elements in the periodic table, such as bismuth, tellurium, and lead. Antimony can also exist in minerals in more than one oxidation state, such as cervantite [$Sb^{III}Sb^{V}O_4$] and paradocrasite [$Sb^{III}_2(Sb^{-III},As)_2$]. Antimony, especially under oxic conditions, is very soluble (Rai et al. 1984). The concentrations of antimony in most soil are not likely limited by solubility considerations. Under reducing conditions, antimony concentrations may be limited by the solubility of antimony sulfides, such as stibnite. The availability of thermodynamic data is limited to only a few antimony solids, such as elemental Sb, $Sb(OH)_3$, Sb_2O_3 (valentinite, senarmontite), Sb_2O_4 (cervantite), Sb_2O_5, Sb_4O_6, Sb_2S_3 (stibnite), and a few others.

Very little is known about the adsorption/desorption behavior of Sb(V) or Sb(III). However, the concentrations of antimony in soil and sediments are likely controlled by adsorption reactions. Some general trends can be assumed for the adsorption of antimony. Because adsorption of anions is coupled with a release of OH^- ions, anion adsorption is greatest at low pH where mineral surfaces are positively charged and decreases with increasing pH. On the other hand, the adsorption of cations is coupled with a release of H+ ions. Therefore, cation adsorption is greatest at high pH where mineral surfaces are negatively charged and decreases with decreasing pH. Because dissolved Sb(V) is present primarily as the anionic hydrolytic species Sb(OH)6- over almost the entire pH range, the adsorption of Sb(V) to hydroxide and oxide mineral surfaces should be limited to negligible as pH increases from circumneutral to highly basic pH values. Under these conditions, antimony should be highly mobile in the geochemical environment. However, at acidic pH conditions, the adsorption of Sb(V) may be significant to mineral surfaces.

Nickel is a silvery white metal that takes on a high polish. It belongs to the transition metals, and is hard and ductile. It occurs most usually in combination with sulfur and iron in pentlandite, with sulfur in millerite, with arsenic in the mineral niccolite, and with arsenic and sulfur in nickel glance. Because of its permanence in air and its inertness to oxidation, it is used in coins, for plating iron, brass, etc., for chemical apparatus, and in certain alloys, such as German silver. It is magnetic, and is very frequently accompanied by cobalt, both being found in meteoric iron. It is chiefly valuable for the alloys it forms, especially many superalloys, and particularly stainless steel. The most common oxidation state of nickel is +2, though 0, +1, +3 and +4 Ni complexes are observed. It is also thought that a +6 oxidation state may exist, however, results are inconclusive. The bulk of the nickel mined comes from two types of ore deposits. The first are laterites where the principal ore minerals are nickeliferous limonite: (Fe, Ni)O(OH) and garnierite (a hydrous nickel silicate): $(Ni, Mg)_3Si_2O_5(OH)$. The second are magmatic sulfide deposits where the principal ore mineral is pentlandite: $(Ni, Fe)_9S_8$.

Thallium is a soft, malleable, heavy metal with a bluish-white color. Physical properties of elemental thallium are similar to those of lead. Thallium exists in both – the monovalent (thallous) and the trivalent (thallic) forms. Because the 6s electrons possess only a low tendency to be released or bound covalently, the thallous form is more common and stable and forms numerous stable salts. Thallium (III) is easily reduced to thallium (I) by reducing agents at high temperatures. Below 234oC the metal crystallizes in a hexagonal close-packed form (alpha-thallium), while at 234oC it converts to the β-form, a cubic body-centered lattice. Thallium begins to volatilize at 174oC. When exposed to air and moisture, it is superficially oxidized, forming a coating of thallium (I) oxide (Tl2O). Thallium carbonate (Tl2CO3) is the only heavy metal carbonate that is very soluble in water. In contact with water, thallium (I) hydroxide is formed from the metal. Thallium is very soluble in HNO3 and H2SO4, but only slow dissolution takes place in HCl, because of the low solubility of the halides. It is insoluble in alkali bases. Thallium combines with fluorine, chlorine and bromine at room temperature, and reacts with iodine, sulphur, phosphorus, selenium and tellurium after heating. The metal does not react with molecular hydrogen, nitrogen or carbon. It forms alloys with other metals and readily amalgamates with mercury. Thallium hydroxide, carbonate and sulfate are very soluble in water. With respect to their physical and chemical properties, e.g., poor water solubility, thallium oxide, sulfide and halides show similarities to the corresponding compounds of silver, mercury and lead. In contrast to inorganic thallium compounds, covalent organothallium compounds are only stable in the trivalent form. Thallium (I) is not strongly complexed by humic acids, whereas thallium (III) forms stable complexes of the $(TlX_4)^-$ or $(TlX_6)^{3-}$ type.

3.2.7.3 Waste characterization

Based on the analyses performed, the material/waste present on the site may be characterized:

1. ***Tailings –*** The tailings represent the biggest portion of contaminated material in source zone – about 450,000 tons. With respect to high concentration of As, Ni, and Sb (3,000 – 42,000 ppm of As, 280 – 1,500 ppm of Ni, and 6,600 – 6,800 ppm of Sb) in dry matter exceeding many times any limits, the material should be considered as hazardous. With respect to the grain size distribution – fine-grained material (silty sand) the contaminants can be relatively easily leached from the solid matrix because of large specific surface of the fine particles. The leachates expose very high concentration of As, exceeding the utmost limit (III – see table 3.9) 4 times and in accordance with the Czech legislation such a waste must not be disposed on landfill without pretreatment. The leachate limits for Ni are exceeded 10 times and limits for Sb are exceeded 19 times. In addition, elevated concentration of Tl has been determined in one sample of tailings – 30 mg/kg d.m. – this value exceeds the natural background estimated for the Earth's crust (360 ppb) about 80 times.. This is very significant finding because Tl belongs among toxic metals which bioaccumulates easily in human's tissues and thus Tl would be considered within the frame of further works. A fast action is needed to eliminate the risk posed by the tailings to the environment.
2. ***As concentrate –*** represents also quite a big portion of waste in the contamination source – about 15,000 tons at Rudnicka kolonija and about 5,000 tons at former smelter. Extremely high concentration of As in dry matter – about **51%** and high leachability reaching up to **773 mg/l** (extremely exceeding any limits) pose a high risk to the environment. Very high acidity of the leachate likely results in problems related with ARD – i.e. mobilization and spreading of other heavy metals. In addition, leachates contain elevated concentration of nickel (up to 3358 mg/kg d.m. and up to 3.71 mg/l in leachate), high concentration of antimony (6 – 7% in kg of d.m. and up to 156 mg/l in leachate), and elevated concentration of thallium (up to 120 mg/kg). On the other hand, there is a potential for the re-use of this material which is usually source for production of arsenic oxide. An urgent action is needed to eliminate the risk posed to the environment by this material.
3. ***Waste rock –*** with respect to many scattered dumps of waste rock the sampling performed within the frame of FS - Lot 2 is not representative enough but important indications have been discovered. The waste rock contains relatively high concentration of As (up to 1.3 %) which can be easily leached – the highest concentration of As found in leachate is 36.1 mg/l. This indicates ease release of the As from the waste rock to the environment and thus numerous waste rock dumps pose a significant risk to the environment. In addition, high concentration of Sb both in dry matter (up to 4.4%) and leachate (up to 14.6 mg/l) also pose additional risks. In the waste rock the elevated concentration of Tl were found, too. The exempt represent waste rock pile above the tailings and huge waste rock dump in Suva River valley which is about 1 km above the former mining office (see the values presented in table 3.3).
4. ***As oxide –***this very toxic material has been identified at former smelter. This powdery material contains up to **69.8 %** of arsenic. This material is well soluble – the As concentration in leachate reaches extremely high value **4,203 mg/l**. In addition, high concentrations of Sb were identified and elevated concentrations of Ni and Tl were

found (7.15 – 17.17.1% of Sb, up to 310 ppm of Ni, and 110 ppm of Tl). With respect to the location of the contamination source and properties of the contaminant, **immediate action is needed** to eliminate the risk posed by this highly toxic material.

5. ***Slag –*** with respect to the concentrations of heavy metals, As and Sb in dry matter and in leachate, exceeding threshold levels (see table 3.3), this material also represents hazardous waste. Concerning the location and properties, urgent action is needed to eliminate the risk posed by this material.
6. ***Mixed waste –*** with respect to higher concentrations of As, Cd, Cu, Ni, Sb, Zn and Tl found either in dry matter either in leachates (see table 3.3), this material also represents hazardous waste and poses risk to the environment. With respect to its location and properties, urgent action is needed to eliminate the risk.
7. ***Stream sediments*** – although the stream sediments cannot be considered as waste sensus stricto, they expose properties of hazardous waste – high concentration of As, Ni and Sb in both dry matter and leachate (see table 3.3). The toxic metals can be redissolved in the water and spread the contamination downstream. This risk has to be eliminated, too.
8. ***Topsoil –*** exposes properties of hazardous waste because of high concentrations of heavy metals, although it is hard to distinguish the share of naturally elevated background values and contamination caused by mining activities. This is an example how the topsoil is contaminated and indication of contamination grade in the plume.

3.3 Treatability bench tests

3.3.1 Tests of solid waste treatability

Among prospective techniques for treatment of solid waste disposed of Lojane Mine area, S/S is considered as favorable method. In compliance with the proposal for provision of “Consulting services for preparation of a feasibility study for Lojane Mine, Macedonia” Dekonta carried out laboratory testing of this method.

Stabilization

Stabilization refers to processes that reduce the risk posed by a waste by converting the contaminants into a less soluble, less mobile, and, therefore, less hazardous form without necessarily changing the physical nature of the waste. An example of stabilization as a treatment is the pH adjustment of a sludge which results in making the contaminants in the sludge less mobile.

The effectiveness is dependent on the nature of the material to be treated and the subsequent storage or disposal. Cement based stabilization is often used for many metals to comply with the treatment requirements of the legislative regulations.

Solidification

Solidification refers to processes that encapsulate waste in a monolithic solid of high-structural integrity. Solidification does not necessarily involve a chemical interaction between the waste and the solidifying agents, but involves a physical binding of the waste in the monolith. Contaminant migration is restricted by vastly decreasing the surface area exposed to leaching and/or by isolating the waste within an impervious capsule. Encapsulation may address fine waste particles (i.e. microencapsulation) or large blocks or containers of waste (i.e. macroencapsulation). An example of the solidification involves the use of cement to solidify contaminants into large blocks.

Two methods have been tested:

- solidification/stabilization - with utilization of common construction materials – i.e. cement, lime, quicklime, and various prospective additives, these tests have been performed by Dekonta’s specialists;
- stabilization – innovative method of stabilization of material contaminated with heavy metals has been tested, i.e. phosphate induced metal stabilization, with respect to the hazardous waste characteristic, one sample of the As concentrate (realgar) and one sample of the tailings were sent to UK for testing of stabilization method TRAPPS^{TM} – company SLATER (UK) Limited.

3.3.2 Solidification/stabilization tests

3.3.2.1 Methodology of S/S tests

Initial analyses

Prior the commencement of S/S tests initial analyses were performed - focused on concentration contaminants of interest – i.e. heavy metals and As, Sb in both dry matter and leachate (see tables 3.3 and 3.4). Mineralogical characterization of various materials encountered on the site was performed, too (see chapter 3.2.5.2). In addition, geomechanic tests were also performed (see chapter 3.2.6).

Preparation of mixtures

Composite samples of contaminated material of minimum weight 500 g is mixed with S/S agents (binders and additives) in dry conditions in accordance with the dosing requested. Mixing is performed in the stirring machine Krups 417 (see fig. 3.10) 5 minutes.

Fig. 3.10 – Laboratory stirring machine

After the homogenization, appropriate amount of distilled water is added in order to produce pasty material and the paste is again further mixed 5 minutes. In case that quicklime is used, enough water has to be added to allow the exothermic reaction and material reached the temperature 50 °C at least.

Produced paste is put into form of proper shape (depending on the further tests to be performed with the matured material):

- Leaching tests in accordance wit EPA - pour 100 g of the paste into cylindrical form with length 80 mm and diameter 40 mm, allow 28 days of maturing and then the material have to be crushed below 9.5 mm;

With a help of electric vibrator the air bubbles have to be displaced and the paste must be matured for a period of 28 days at least.

3.3.2.2 Leaching tests

The main criterion for evaluation of S/S successfulness is leachability of the contaminants which simulates leaching of the contaminants into the environment. Several methods for leaching tests are used in order to enable to estimate the long term stability of S/S treated material:

- Leaching test in accordance with the EU and Czech legislation which defines three leachability categories, in compliance with these categories the waste is classified and disposed of in relevant landfills. The utmost limits for particular categories are presented in table 3.9.
- Toxic Characteristic Leaching Procedure (TCLP) – developed by US EPA as quick test for assessment of materials for S/S and subsequent disposal of. For the leaching, acetic acid is used; pH is maintained at level 4.93 or 2.88, extraction time is 18 hours. TCLP is used in many countries but each country defines different number and type of contaminants to be detected. Project relevant limits given by US EPA are listed in table 3.10.

Table 3.9 – Categories of leachability (according to the Czech legislation)

Parameter	**Category of leachability (mg/L)**			
	I	**IIa**	**IIb**	**III**
DOC	50	80	80	100
Phenol index	0.1			
Chlorides	80	1500	1500	2500
Fluorides	1	30	15	50
Sulfates	100	3000	2000	5000
As	0.05	2.5	0.2	2.5
Ba	2	30	10	30
Cd	0.004	0.5	0.1	0.5
Cr total	0.05	7	1	7
Cu	0.2	10	5	10
Hg	0.001	0.2	0.02	0.2
Ni	0.04	4	1	4
Pb	0.05	5	1	5
Sb	0.006	0.5	0.07	0.5
Se	0.01	0.7	0.05	0.7
Zn	0.4	20	5	20
Mo	0.05	3	1	3
DM	400	8000	6000	10000
pH		≥ 6	≥ 6	

Table 3.10 – US EPA limits for TCLP

Contaminant	**TCLP concentration [mg/L]**
As	5
Ba	100
Cd	1
Cr	5
Pb	5
Hg	0,2
Se	1
Ag	5

3.3.2.3 Mixtures prepared for S/S tests

With respect that the target limits for the source zone remediation/cleanup are not specified yet, quite a wide spectrum of prospective binders and additives was tested. This approach enables in later phases of the site rehabilitation to select the proper dosing of binders and additives that will well fit to the site conditions, material characteristic and the cleanup goals.
Table 3.11 depicts 34 mixtures that have been prepared for S/S tests. The wastes tested were tailings and arsenic concentrate. Binders used were Portland cement, quicklime, lime, synthetic gypsum and water glass. Additives tested were fly ash (from power plant fueled with black coal), bentonite, trinatrium phosphate, phosphoric acid, and Fe/Al oxides.

3.3.2.4 Results of solidification/stabilization test

Tailings

The S/S bench tests showed that common binders used in construction works are quite effective in reducing the mobility of contaminants of interest – see table 3.11.

The original leachability of As from tailings was 11.05 mg/L, S/S with Portland cement (samples MAK T-S1, MAK T-S2) and fly ash addition (sample MAK T-S6) has significantly stabilized the tailings, with a reduction of up to 95.5% and 97.6% in leachable As and Sb respectively. This reduction has enabled the material to pass the EU WAC threshold for hazardous waste.

S/S of tailings with quicklime (samples MAK T-S9, MAK T-S10) and addition of fly ash has significantly stabilized the tailings, with a reduction of up to 95.5% and 99 – 99.5% in leachable As and Sb respectively. This reduction has enabled the material to pass the EU WAC threshold for hazardous waste.

S/S of tailings with quicklime (samples MAK T-S11, MAK T-S12) and addition of fly ash has significantly stabilized the tailings, with a reduction of up to 91 – 95.5% and 96.9 – 98.1% in leachable As and Sb respectively. This reduction has enabled the material to pass the EU WAC threshold for hazardous waste.

Leachability of Ni was not a problem, 16 mixture (from 17 mixtures prepared) met the threshold for non-hazardous waste.

As concentrate

No S/S sample met the threshold for hazardous waste landfill (see table 3.11). The best results were obtained again with utilization of Portland cement based mixtures with addition of fly ash although the leachability of As and Sb has increased comparing with the original leachability of untreated samples (11.05 mg/L). The best variants of S/S samples have As leachability in order of hundreds of mg/L and leachability of Sb has been slightly increased too – within the range 7.4 – 25.6 mg/L in comparison with original 9.03 mg/L.

The results of S/S tests indicates that tailings can be effectively treated with the binders and additives tested while the As concentrate could not be cost effective treated with the S/S method.

Table 3.11 – S/S tests – results summary

Sample No.	Dosing of additives (kg of additives in 1kg of mixture, water not included)											Leachability tests - treated waste								Leachability tests - untreated waste EU directive			
	cement	quick lime	lime	synthetic qypsum	fly-ash	water glass	bentonite	trinatrium phosphate	phosphoric acid	Fe/Al oxides	water (ml)	Results EU directive (mg/l)				Results TCLP (mg/l)							
	portland cement, class 350	Lhoist Co, Tman CR	Certovy schody CR	Chvaletice CR	Porici u Trutnova CR	Setuza CR, class 36-38	Obrnice CR	Fosfa CR	Fosfa CR			As	Ni	Sb	Tl	As	Ni	Sb	Tl	As	Ni	Sb	Tl
limit value NHW												0.2	1	0.07									
limit value HW												2.5	4	0.5									
MAK-T-S1	0.6										150	<0.5	<0.1	0.22	<1	3.5	<0.1	4.4	<1	11	0.55	9	<0.01
MAK-T-S2	0.3										150	<0.5	<0.1	0.33	<1	12.3	<0.1	7.2	<1				
MAK-T-S3	0.3					0.1					150	1.4	<0.1	1.0	<1	4.0	<0.1	1.8	<1				
MAK-T-S4	0.1										100	2.3	<0.1	1.6	<1	20.1	6.2	10.9	<1				
MAK-T-S5					0.3						200	1.1	<0.1	2.7	<1	1.0	9.1	15.9	<1				
MAK-T-S6	0.3				0.3						150	<0.5	<0.1	0.28	<1	7.1	0.4	11.0	<1				
MAK-T-S7	0.3				0.3	0.1					150	1.2	<0.1	1	<1	12.0	0.5	6.8	<1				
MAK-T-S8	0.3						0.3				200	1.1	<0.1	0.9	<1	8.6	<0.1	5.8	<1				
MAK-T-S9		0.3									150	<0.5	<0.5	0.09	<1	0.8	<0.1	<0.7	<1				
MAK-T-S10		0.3			0.3						150	<0.5	<0.5	0.05	<1	<0.5	<0.1	<0.7	<1				
MAK-T-S11			0.3								150	1.0	<0.1	0.28	<1	31.5	<0.1	0.9	<1				
MAK-T-S12			0.3		0.3						150	<0.5	<0.1	0.18	<1	0.7	<0.1	<0.7	<1				
MAK-T-S13								0.1			150	201	<0.1	22.0	<1	131	11.0	11.9	<1				
MAK-T-S14									0.1		0	85.5	1.9	4.7	<1	139	14.2	4.7	<1				
MAK-T-S15				0.3							150	4.3	0.3	4.4	<1	2.1	8.4	13.7	<1				
MAK-T-S16				0.3	0.3						150	0.6	<0.1	1.9	<1	1.1	7.2	12.4	<1				
MAK-T-S20						0.1				0.01	0	47.2	<0.1	5.6	<1	4.6	7.3	7.2	<1				
MAK-AsC-S1	0.6										150	275	0.2	25.6	<1	315	<0.1	13.9	<1	671	1	3.7	0.3
MAK-AsC-S2	0.3										150	241	0.1	15.5	<1	388	<0.1	12.3	<1				
MAK-AsC-S3	0.3					0.1					150	374	0.2	7.4	<1	1250	<0.1	17.8	<1				
MAK-AsC-S4	0.1										100	260	0.1	9.5	<1	432	0.2	14.9	<1				
MAK-AsC-S5					0.3						200	505	<0.1	11.8	<1	588	0.4	14.1	<1				
MAK-AsC-S6	0.3				0.3						150	284	<0.1	11.7	<1	1290	<0.1	15.9	<1				
MAK-AsC-S7	0.3				0.3	0.1					150	401	<0.1	7.6	<1	1080	<0.1	17.3	<1				
MAK-AsC-S8	0.3						0.3				200	201	<0.1	13.3	<1	959	<0.1	16.5	<1				
MAK-AsC-S9		0.3									150	1600	0.4	19.9	<1	6830	0.5	1.2	<1				
MAK-AsC-S10		0.3			0.3						150	1510	0.2	10.0	<1	6180	<0.1	2.3	<1				
MAK-AsC-S11			0.3								150	831	<0.1	11.6	<1	1730	<0.1	31.5	<1				
MAK-AsC-S12			0.3		0.3						150	1040	0.2	2.8	<1	3600	<0.1	9.1	<1				
MAK-AsC-S13								0.1			150	692	0.6	1150	<1	798	0.5	891	<1				
MAK-AsC-S14									0.1		0	763	1.0	43.8	<1	858	0.7	68.6	<1				
MAK-AsC-S15				0.3							150	297	0.7	16.3	<1	254	0.5	18.1	<1				
MAK-AsC-S16				0.3	0.3						150	132	0.4	4.8	<1	146	0.4	11.2	<1				
MAK-AsC-S20						0.1				0.01	0	420	0.2	489	<1	438	0.3	312	<1				

Note: The samples highlighted with green color meets the limits for storage in landfill for hazardous waste.

3.3.3 Stabilization tests

Bench scale trial with As, Sb contaminated waste (As concentrate and tailings) were performed by company SLATER (UK) Limited in May 2007 – the method tested was phosphate induced stabilization.

TRAPPS™ is the trade name for a mineral apatite based metal stabilisation product developed by Slater (UK) Limited. The apatite mineral group has been shown on numerous occasions to be highly effective both in sequestering dissolved metals and in transforming soil-bound metals into less soluble phases. The groundwork for this observation lies in a wide body of research across a range of disciplines - phosphate mineralogy and apatite crystal chemistry, the observed accumulation of heavy metals in natural rock apatite deposits, the observed accumulation of heavy metals in fossilized apatite-rich teeth and bone, and remediation studies of apatite/metal systems.

Apatite minerals form naturally and are stable across a wide range of geologic conditions for hundreds of millions of years. Studies of fossilized apatite rich teeth collected from the ocean floor have revealed a greater than 1 million fold accumulation of heavy metals and radionuclides relative to their ambient concentration in seawater. These metal rich apatite fossils have remained stable despite geologic changes including uplift, subsidence, leaching, erosion and earthquakes.

The ultimate driving force for phosphate induced metal stabilisation using apatite minerals is the high stability of metal-substituted apatite crystals. The extremely high stability of apatite family minerals compared to a mineral such as chalk (calcium carbonate) is evident. The increased stability of heavy metal substituted apatites such as chloropyromorphite (lead apatite) relative to the parent hydroxyapatite mineral can also be seen.

Various TRAPPS™ materials were used in the trial. The TRAPPS™ materials differ somewhat in formulation. Dosage rate was also varied within the experiment.

3.3.3.1 Methodology of TRAPPS™ stabilization

Two samples of material form Lojane Mine were provided for the stabilization tests – tailings and As concentrate. Each soil was air dried and then manually crushed to pass through a 2 mm sieve. The sieved samples were used without further processing.

Various TRAPPS™ materials were used in the trial. The TRAPPS™ materials differ somewhat in formulation. Dosage rate was also varied within the experiment.

Each soil was amended with TRAPPS™. Control samples were also set-up. Each soil sample was thoroughly shaken and then stored at room temperature in a sealed bag for 1 week before testing.

A standard 10 : 1 EU WAC 12457 batch leach test was performed on each sample. Soluble metals in each test were analyzed by ICP-MS (sub-contracted Alcontrol Technichem Ltd., UK).

3.3.3.2 Results of TRAPPS™ stabilization trials

Both samples were highly contaminated (see table 3.12) with arsenic (As) and antimony (Sb).

Table 3.12 – Total soil metal concentrations in Lojane Mine samples

Sample	**Total Soil Metal (mg.kg^{-1})**				
	As	**Cu**	**Pb**	**Sb**	**Zn**
Lojane Mine tailings	7,100	23	130	6,500	48
Lojane Mine As concentrate	490,000	<5	25	61,000	<10

The results from the 10 : 1 WAC tests are shown in tables 3.13 and 3.14. Both untreated samples contained an elevated amount of leachable As - at approximately 13 mg.L^{-1} and 560 mg.L^{-1} in the mine tailing and arsenic concentrate respectively. Both untreated samples also contained elevated levels of leachable Sb – at approximately 8 mg.L^{-1} and 3 mg.L^{-1} in the mine tailing and arsenic concentrate respectively. In all cases treatment with either TRAPPS™ significantly reduced the levels of leachable arsenic (up to 99% removal) and antimony (up to 88% removal).

Table 3.13 – EU WAC 10:1 batch test with Lojane Mine tailings

Treatment	**WAC leachable metal (mg.L-1)**		**WAC leachable metal (mg.kg^{-}1)**		**Haz. waste WAC (mg.kg^{-}1)**		**Non – Haz. waste WAC (mg.kg^{-}1)**	
	As	**Sb**	**As**	**Sb**	**As**	**Sb**	**As**	**Sb**
control	13	8.6	130	86	25	5	2	0.7
control	12	8.1	120	81	25	5	2	0.7
TRAPPS A	0.23	1.1	2.3	11	25	5	2	0.7
TRAPPS B	0.39	2.2	3.9	22	25	5	2	0.7

Table 3.14 – EU WAC 10 : 1 batch test with Lojane Mine arsenic concentrate

Treatment	**WAC leachable metal (mg.L-1)**		**WAC leachable metal (mg.kg^{-}1)**		**Haz. waste WAC (mg.kg^{-}1)**		**Non – Haz waste WAC (mg.kg^{-}1)**	
	As	**Sb**	**As**	**Sb**	**As**	**Sb**	**As**	**Sb**
control	560	2.8	5600	28	25	5	2	0.7
TRAPPS A	32	1.7	320	17	25	5	2	0.7
TRAPPS B	16	1.5	160	15	25	5	2	0.7
TRAPPS C	8	4.4	80	44	25	5	2	0.7

3.3.3.3 Conclusions from TRAPPS™ tests

Both samples from Lojane Mine are significantly As and Sb contaminated. Both the *tailings* and the *arsenic concentrate* are currently above the EU WAC hazardous waste threshold for As and Sb. TRAPPS™ has significantly stabilized both materials, with a reduction of up to

99% and 88% in leachable As and Sb respectively. However, this reduction has not enabled the materials to pass the EU WAC threshold in all cases. The mine tailings have been stabilized so as to allow for As to pass the hazardous waste WAC threshold. Antimony has not been stabilized sufficiently to pass the hazardous WAC threshold. Neither As or Sb in the TRAPPS™ treated material passes the WAC for non-hazardous waste.

None of the TRAPPS™ treated materials passes the WAC thresholds for hazardous or non-hazardous waste for the arsenic concentrate.

It is experience that the performance of TRAPPS™ can be improved in a second stage of treatability testing. We would be confident that this is the case with the material from Lojane Mine. From the data produced in this treatability study it is suggested that it appears possible to reduce leachable As and Sb in both materials to below the WAC threshold for hazardous waste. Stabilisation to allow for disposal as non-hazardous waste would appear rather more problematic.

3.3.4 Tests of water treatability

During May 2007 series of laboratory experiments testing effectiveness of three remedial methods (i.e. permeable reactive barriers, coagulation and neutralization) were performed in the DEKONTA laboratory. The aim of these experiments was to evaluate efficacy of the tested methods for decontamination of the Lojane Mine leachate.

3.3.4.1 Principles of tested technologies

Filling for permeable reactive barrier

Permeable reactive barrier (PRB) can provide cost-effective and long-term solutions for many groundwater contamination problems. They are constructed below ground to intercept groundwater flow and to pass it through some chemical and/or biological reactive material. As contaminated groundwater moves through reactive filling, contaminants are treated and transformed into harmless products and/or their by-products. Permeable reactive barriers for heavy metals treatment generally work on principle of chemical reduction on a reactive medium, which is mostly zero-valent iron (ZVI). Previous experiments have shown that ZVI is able to transform As(V+) as well as As(III+) very quickly (within two hours). Further, possibilities to coagulate reduced As ions and/or to form arsenic sulphides from them has been also confirmed.

Coagulation

Coagulation is the destabilization of colloidal particles brought about by the addition of a chemical reagent (called as coagulant). Principle of the coagulation method generally consists in an addition of trivalent aluminium and/or iron ions into treated water. These ions gradually form hydrated oxides and hydroxides, which precipitate from treated water. The formed precipitate adsorbs organic and inorganic substances, then sediments and can be removed from treated water via filtration. The addition of acid coagulants highly decreases water pH, thus it is then necessary to neutralize pH of treated water (ranging from 6 to 7.5).As coagulation agents are generally used aluminium and iron sulphates, partly also iron chloride. Sodium hydroxide is generally used for pH neutralization; in some cases also lime slurry can be applied.

Neutralization

Neutralization is a chemical reaction, according to the Arrhenius theory of acids and bases, in which a water solution of acid is mixed with a water solution of base to form a salt and water.

This reaction is complete only if the resulting solution has neither acidic nor basic properties. Such a solution is called a neutral solution.

Various chemicals are available for industrial neutralization depending upon the application and whether you are neutralizing an acid or base liquid. In most cases, sulphuric acid and sodium hydroxide is used but also calcium or magnesium carbonate can be applied.

3.3.4.2 Methodology of experiments

The laboratory testing was based on series of batch experiments. In these tests zero-valent cast iron with or without sand or sodium sulphate, ferric sulphate or calcium carbonate was added at various rates into a contaminated matrix (250 ml of artificially prepared leaching water). The experimental procedure was then based on a mixing of the leaching water with above-mentioned reagents in a chosen rate. In the case of ZVI models the pH adjustment was also experimentally tested in order to evaluate its eventual effect of pH on iron leaching.

During laboratory tests following model variants have been prepared:

- Permeable reactive barrier model testing:
  - A1) – 10 g of cast iron,
  - A2) – 10 g of cast iron with pH adjustment by hydrochloric acid (HCL),
  - A3) – 10 g of cast iron with pH adjustment by sodium hydroxide (NaOH),
  - B1) – 10 g of cast iron and 10 g of sand,
  - B2) – 10 g of cast iron and 10 g of sand with pH adjustment by hydrochloric acid (HCL),
  - B3) – 10 g of cast iron and 10 g of sand with pH adjustment by sodium hydroxide (NaOH),
  - C1) – 0.6 g of sodium sulphate ($NaSO_4$) and 10 g of cast iron,
  - C2) – 1.2 g of sodium sulphate ($NaSO_4$) and 10 g of cast iron,
  - C3) – 3.6 g of sodium sulphate ($NaSO_4$) and 10 g of cast iron.

All prepared variants were shaken in glass flasks for 24 hrs. During the test pH, temperature, conductivity, oxidation-reduction potential (ORP) were measured and color and other organoleptic characteristics were recorded. After 24 hrs all variants were filtered and samples were taken.

- Coagulation testing:
  - D1) – 0.5 ml of Prefloc (= 40% water solution of ferric sulphate – $Fe_2(SO_4)_3$),
  - D2) – 1 ml of Prefloc,
  - D3) – 2 ml of Prefloc,
  - D4) – 4 ml of Prefloc.

All coagulation variants were prepared in glass beakers and mixed for 5 minutes, after that pH and conductivity were measured. Then sodium hydroxide solution was added to achieve pH 7 to 7.5 and all variants were left to sediment for approx. 1 hr. Before filtration color, precipitate and other organoleptic characteristics were recorded. After filtration samples were taken.

- Neutralization testing:
  - E1) – 0.5 g of calcium carbonate ($CaCO_3$),
  - E2) – 1 g of calcium carbonate ($CaCO_3$),
  - E3) – 2 g of calcium carbonate ($CaCO_3$).

Neutralization variants were also prepared in glass beakers, mixed for 5 minutes and then pH and conductivity were measured. After sedimenting for approx. 1 hr color, precipitate and other organoleptic characteristics were recorded. Then the individual variants were filtrated and samples were taken.

3.3.4.3 Materials and analytical methods

3.3.4.3.1 Materials used

Laboratory tests were performed with leaching water prepared as follows:

- WR1, WR3 and WR4 soil samples taken form the Lojane Mine area were mixed, put in 15 litres of distilled water and left in the laboratory conditions for 48 hrs,
- Due to low As content in such prepared leaching water, the water was artificially contaminated by disodium hydrogen arsenate heptahydrate ($Na_2HAsO_4.7H_2O$) to As content of 10 mg.l^{-1}.

Table.3.15 – Starting parameters of the leaching water prepared

Parameter	Unit	Leaching water*
As Total	mg.l^{-1}	11.0
As(III+)	mg.l^{-1}	0.15
Sb Total	mg.l^{-1}	<0.07
Sb(III+)	mg.l^{-1}	<0.07
Fe Total	mg.l^{-1}	<0.016
Fe(II+)	mg.l^{-1}	0.016
Cr Total	mg.l^{-1}	<0.005
Cr(VI+)	mg.l^{-1}	<0.005
pH	--	8.14
Color	mg Pt.l^{-1}	5.00
Odour at 20℃	--	Fungal
Odour at 60℃	--	Fungal
Cloudiness	ZF	<1
Conductivity	mS.cm^{-1}	13.1
Dissolved Solids	mg.l^{-1}	94.0
Acid Neutralization Capacity 4.5	mmol.l-1	1.429
Chemical Oxygen Demand	mg.l-1	7.5
Ca	mg.l-1	1.17
K	mg.l-1	0.70
Mg	mg.l-1	12.7
Mn	mg.l-1	<0.003
Na	mg.l-1	0.50
NH4+	mg.l-1	0.20
NO2-	mg.l-1	<0.01
NO3-	mg.l-1	0.39
Cl-	mg.l-1	10.6
HCO3-	mg.l-1	37.16
SO42-	mg.l-1	9.56

Chemical agents used in the laboratory tests were common, commercially available reagents – calcium carbonate ($CaCO_3$), disodium hydrogen arsenate heptahydrate ($Na_2HAsO_4.7H_2O$), hydrochloric acid (HCL), sodium sulphate ($NaSO_4$) and sodium hydroxide (NaOH). Prefloc used in coagulation testing contained min. 40% of ferric sulphate ($Fe_2(SO_4)_3$), its density was 1 540 g.cm^{-3} and pH approx. 0. The cast iron used for PRB testing was purchased from the Slezsky kamen company in Jesenik, Czech Republic. The used ZVI material was marked as L2, had a particle size of 0.7 – 1.25 mm with a specific surface area of 0.41 m^2.g^{-1} (see fig. 3.11).

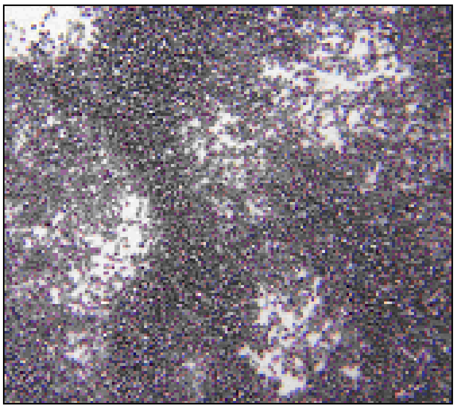


Fig. 3.11 – The cast iron L2 Slezsky kamen

3.3.4.3.2 Analytical methods

Chemical analyses of all leaching water samples were performed in an accredited laboratory of the Research Institute of Inorganic Chemistry in Usti nad Labem, Czech Republic by following methods: SOP 32, SOP 29, CSN EN 99631 and CSN ISO 11083. Measurement of temperature, pH, ORP and conductivity were done by the WTW pH/Cond 304i/SET measuring device equipped with cells of SenTix 41 (temperature, pH), SenTix ORP (ORP) and TetraCon 325 (conductivity).

3.3.4.4 Results and discussion

3.3.4.4.1 Permeable reactive barrier - ZVI

The results achieved during the performed laboratory tests are given in tables below. Tables 3.16 to 3.24 summarise measured process parameters, results of the analyses are presented in the table 3.25.

Table 3.16 – Process parameters – variant A1 (10 g of cast iron)

Parameter → Time ↓	**pH**	**Temperature (℃)**	**Conductivity (mS.cm^{-1})**	**ORP (mV)**	**Color**
Start (leaching water, no ZVI)	8.32	19.0	532	180	Colorless
Time 0 (after mixing with ZVI)	8.37	19.2	218	–389	Light grey
After 1 hrs	8.57	23.5	219	–535	Light brown
After 3 hrs	8.88	24.7	227	–338	Orange-brown
After 5 hrs	8.87	25.1	245	–546	Light orange
After 24 hrs	8.70	25.4	251	–593	Brown-orange

Table 3.17 – Process parameters – variant A2 (10 g of cast iron, pH adjustment by HCL)

Parameter → Time ↓	pH	Temperature (℃)	Conductivity (mS.cm^{-1})	ORP (mV)	Color
Start (leaching water, no ZVI)	8.32	19.0	532	180	Colorless
Time 0 (after mixing with ZVI)	6.48	19.3	300	–346	Light blue
After 1 hrs	6.27	23.6	323	–543	Light blue
After 3 hrs	6.62	24.9	317	–560	Light orange
After 5 hrs	6.95	24.9	314	–653	Orange
After 24 hrs	7.76	25.6	307	–598	Orange

Table 3.18 – Process parameters – variant A3 (10 g of cast iron, pH adjustment by NaOH)

Parameter → Time ↓	pH	Temperature (℃)	Conductivity (mS.cm^{-1})	ORP (mV)	Color
Start (leaching water, no ZVI)	8.32	19.0	532	180	Colorless
Time 0 (after mixing with ZVI)	10.53	19.5	824	–395	Light grey
After 1 hrs	10.23	23.4	545	–589	Light grey
After 3 hrs	10.11	25.4	516	–531	Cloudy, grey
After 5 hrs	10.08	25.8	505	–358	Cloudy, colorless
After 24 hrs	9.95	26.1	472	–548	Colorless

Table 3.19 – Process parameters – variant B1 (10 g of cast iron + 10 g of sand)

Parameter → Time ↓	pH	Temperature (℃)	Conductivity (mS.cm^{-1})	ORP (mV)	Color
Start (leaching water, no ZVI)	8.32	19.0	532	180	Colorless
Time 0 (after mixing with ZVI)	8.35	19.8	244	–532	Light brown
After 1 hrs	8.59	23.6	248	–526	Light brown
After 3 hrs	8.72	24.8	245	–567	Light brown
After 5 hrs	8.76	25.4	244	–601	Brownish
After 24 hrs	9.10	25.8	243	–567	Light brown

Table 3.20 – Process parameters – variant B2 (10 g of cast iron + 10 g of sand, pH adjustment by HCL)

Parameter → Time ↓	pH	Temperature (℃)	Conductivity (mS.cm^{-1})	ORP (mV)	Color
Start (leaching water, no ZVI)	8.32	19.0	532	180	Colorless
Time 0 (after mixing with ZVI)	6.56	20.3	333	–201	Light brown
After 1 hrs	6.63	23.2	362	–538	Light brown
After 3 hrs	7.25	24.8	359	–361	Light brown
After 5 hrs	7.65	25.8	363	–525	Brownish
After 24 hrs	8.05	26.2	370	–560	Light brown

Table 3.21 – Process parameters – variant B3 (10 g of cast iron + 10 g of sand, pH adjustment by NaOH)

Parameter → Time ↓	**pH**	**Temperature (℃)**	**Conductivity ($mS.cm^{-1}$)**	**ORP (mV)**	**Color**
Start (leaching water, no ZVI)	8.32	19.0	532	180	Colorless
Time 0 (after mixing with ZVI)	9.66	20.7	339	–222	Light brown
After 1 hrs	9.49	24.0	325	–570	Light brown
After 3 hrs	9.35	25.4	314	–516	Light brown
After 5 hrs	9.27	26.3	306	–550	Brownish
After 24 hrs	9.31	26.3	283	–562	Light brown

Table 3.22 – Process parameters – variant C1 (10 g of cast iron + 0.6 g of $NaSO_4$)

Parameter → Time ↓	**pH**	**Temperature (℃)**	**Conductivity ($mS.cm^{-1}$)**	**ORP (mV)**	**Color**
Start (leaching water, no ZVI)	8.32	19.0	532	180	Colorless
Time 0 (after mixing with ZVI)	8.19	21.2	3 560	–554	Light grey
After 1 hrs	8.83	25.4	3 570	–575	Yellow-brown
After 3 hrs	9.06	24.5	3 560	–558	Brown-orange
After 5 hrs	9.09	25.3	3 550	–608	Brown-orange
After 24 hrs	9.13	25.7	3 510	–603	Brown-orange

Table 3.23 – Process parameters – variant C2 (10 g of cast iron + 1.2 g of NaSO4)

Parameter → Time ↓	**pH**	**Temperature (℃)**	**Conductivity ($mS.cm^{-1}$)**	**ORP (mV)**	**Color**
Start (leaching water, no ZVI)	8.32	19.0	532	180	Colorless
Time 0 (after mixing with ZVI)	8.10	21.3	6 260	–547	Light grey
After 1 hrs	8.71	25.7	6 290	–569	Light brown
After 3 hrs	8.85	25.1	6 250	–588	Brown-orange
After 5 hrs	8.97	25.7	6 250	–570	Brown-orange
After 24 hrs	9.31	26.1	6 230	–692	Light brown-orange

Table 3.24 – Process parameters – variant of C3 (10 g of cast iron + 3.6 g of $NaSO_4$)

Parameter → Time ↓	**pH**	**Temperature (℃)**	**Conductivity ($mS.cm^{-1}$)**	**ORP (mV)**	**Color**
Start (leaching water, no ZVI)	8.32	19.0	532	180	Colorless
Time 0 (after mixing with ZVI)	8.01	21.7	16 060	–574	Light grey
After 1 hrs	8.66	24.2	16 050	–602	Light brown
After 3 hrs	9.08	25.1	16 150	–605	Brown-orange
After 5 hrs	9.17	25.9	16 040	–692	Brown-orange
After 24 hrs	9.24	26.5	15 950	–685	Brown-orange

The parameters measured, summarised in the tables above, show a little difference among the tested model variants. In the most of them very fast reduction of the ORP potential was observed just after mixing with ZVI, soil and sodium sulphate; pH and temperature slightly increased during reaction. Some difference was observed in the variants with pH adjustment. In the basic variants (A3 and B3) pH went slightly down during reaction. In the acid variants (A2 and B2) conductivity decrease was lower that in variants without pH adjustment and in basic variants.

In the variants with sodium sulphate (C1 to C3) high increase of conductivity was measured due to added sulphate and conductivity decrease was minimal during reaction.

Observation of the organoleptic characteristics showed formation of precipitate only in the A3 variant (10 g of cast iron, pH adjustment by NaOH). This observation leads to the assumption that most of As content was adsorbed onto ZVI surface and did not come out from leaching water as a visible precipitate of arsenic hydroxide ($As(OH)_3$), arsenic sulphide (As_2S_3) or tetra-arsenic tetra-sulphide (As_4S_4).

Table 3.25 below summarises results of As, Fe and SO_4^{2-} analyses in the all model variants.

Table 3.25 – As, Fe and SO_4^{2-} contents in the ZVI model variants

Parameter → Variant ↓	**As Total [mg.l^{-1}]**	**As Total [%]**	**As (III+) [mg.l^{-1}]**	**As(III+) [%]**	**Fe Total [mg.l^{-1}]**	**SO_4^{2-} [g.l^{-1}]**
Start (leaching water, no ZVI)	11.00	100.00	0.15	100.00	0.016	9.56
A1 (10 g ZVI)	0.04	0.36	<0.01	6.67	<0.05	ND
A2 (10 g ZVI + HCL)	<0.01	0.09	<0.01	6.67	<0.05	ND
A3 (10 g ZVI + NaOH)	5.26	47.82	0.06	40.00	<0.05	ND
B1 (10 g ZVI + 10 g soil)	0.20	1.82	<0.01	6.67	<0.05	ND
B2 (10 g ZVI + 10 g soil + HCL)	0.04	0.36	0.01	6.67	<0.05	ND
B3 (10 g ZVI + 10 g soil + NaOH)	1.02	9.27	0.01	6.67	<0.05	ND
C1 (10 g ZVI + 0.6 g $NaSO_4$)	0.05	0.45	0.03	20.00	<0.05	1.78
C2 (10 g ZVI + 1.2 g $NaSO_4$)	0.11	1.00	0.01	6.67	<0.05	3.42
C3 (10 g ZVI + 3.6 g $NaSO_4$)	0.15	1.36	0.03	20.00	0.06	10.40

ND = not determined

The obtained analytical results confirmed high efficiency of used cast iron for arsenic removal. The similar results were achieved with 10 g of ZVI (A1 variant) and with the mixture of 10 + 10 g of ZVI and soil (B1 model). The adjustment of the pH by HCL had no effect on efficacy of As removal but the addition of NaOH had negative impact on it. The worst results were obtained for the A3 variant (10 g ZVI + NaOH). Nevertheless in the both cases, the pH adjustment had no effect on the used ZVI and leaching of iron from this material.

The models with sodium sulphate showed high removal of arsenic as well. Slight effect of added sulphates on iron and sulphate contents in the leaching water was observed in the C3 variant (10 g ZVI + 3.6 g $NaSO_4$).

Concentrations of total and trivalent As in the PRB-ZVI variants are depicted in figures 3.12 and 3.13.

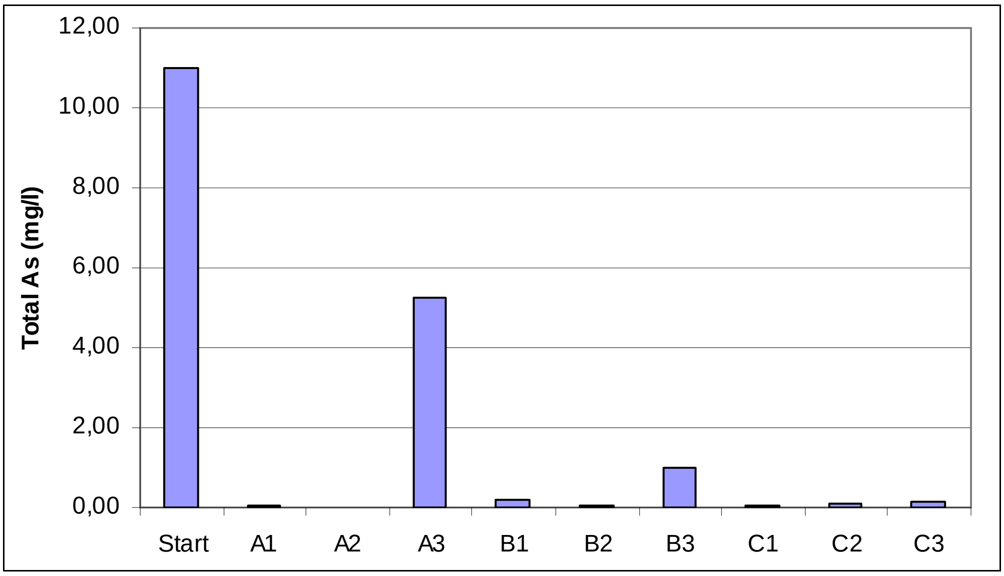


Fig. 3.12 – PRB-ZVI – total As concentrations in variants tested

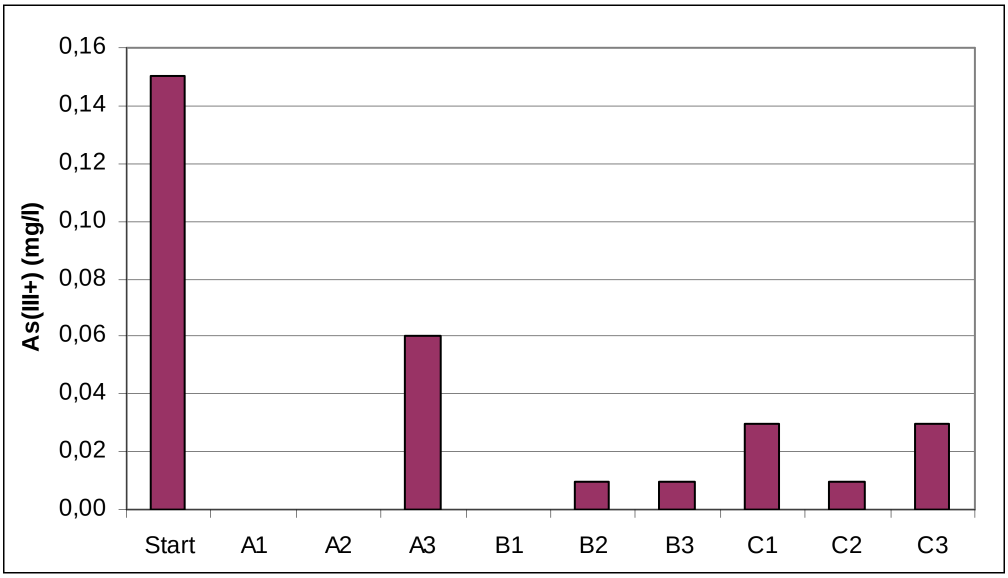


Fig. 3.13 – PRB-ZVI – As (III+) concentrations in variants tested

Economic consideration of the permeable reactive barrier technology:

Economic evaluation of the tested PRB technology cannot be given at the moment because only basic screening batch tests were performed. Generally, it is believed that this technology option could be economically advantageous for Lojane Mine leachate treatment. The reason for such an assumption is the price of the Slezsky kamen L2 cast iron (approx. 0.5 EUR per 1 kg) and results of the previously performed experiments in batch and also in column settings that confirmed high and stable reactivity of this material within long period of time.

3.3.4.4.2 Coagulation technology

The results achieved within the performed laboratory tests are depicted in tables below. Table 3.26 summarises measured process parameters, overall results of the analyses are given in the table 3.27.

Table 3.26 – Process parameters – D1 to D4 variants (various amount of Prefloc = 40% water solution of $Fe_2(SO_4)_3$)

Parameter → **Variant ↓**	**pH**	**Conductivity ($mS.cm^{-1}$)**	**Color**
Start (leaching water, no Prefloc)	8.32	532	Colourless
D1 (0.5 ml Prefloc)	2.68	1 605	Orange-brown, 1 cm precipitate
D2 (1.0 ml Prefloc)	2.45	2 460	Orange-brown, 1.5 cm precipitate
D3 (2.0 ml Prefloc)	2.21	3 870	Orange-brown, 2 cm precipitate
D4 (4.0 ml Prefloc)	2.02	6 390	Orange-brown, 3 cm precipitate

The measured parameters summarised in the table above show dependence of pH, conductivity and also quantity of precipitate formation on added amount of Prefloc. Thus the higher added volume of Prefloc, the higher decrease of pH, increase of conductivity and degree of precipitation can be observed.

Table 3.27 below gives the results of performed chemical analyses.

Table 3.27 – As, Fe and SO42- contents in the coagulation model variants

Parameter → **Variant ↓**	**As Total [$mg.l^{-1}$]**	**As Total [%]**	**As (III+) [$mg.l^{-1}$]**	**As(III+) [%]**	**Fe Total [$mg.l^{-1}$]**	**SO_4^{2-} [$g.l^{-1}$]**
Start (leaching water, no Prefloc)	11.00	100.00	0.15	100.00	0.016	9.56
D1 (0.5 ml Prefloc)	0.21	1.91	<0.01	6.67	<0.05	1.02
D2 (1.0 ml Prefloc)	<0.01	0.09	<0.01	6.67	<0.05	1.94
D3 (2.0 ml Prefloc)	<0.01	0.09	<0.01	6.67	<0.05	3.66
D4 (4.0 ml Prefloc)	<0.01	0.09	<0.01	6.67	<0.05	7.17

The analytical results, summarised in the above table, confirm high efficacy of the coagulation method for arsenic removal. The similar results were achieved for all variants. The addition of ferric sulphate had no effect on iron content but slightly affected content of remaining sulphates in leaching water.

Figures 3.14 and 3.15 below depict concentrations of both total and trivalent As in the coagulation model variants.

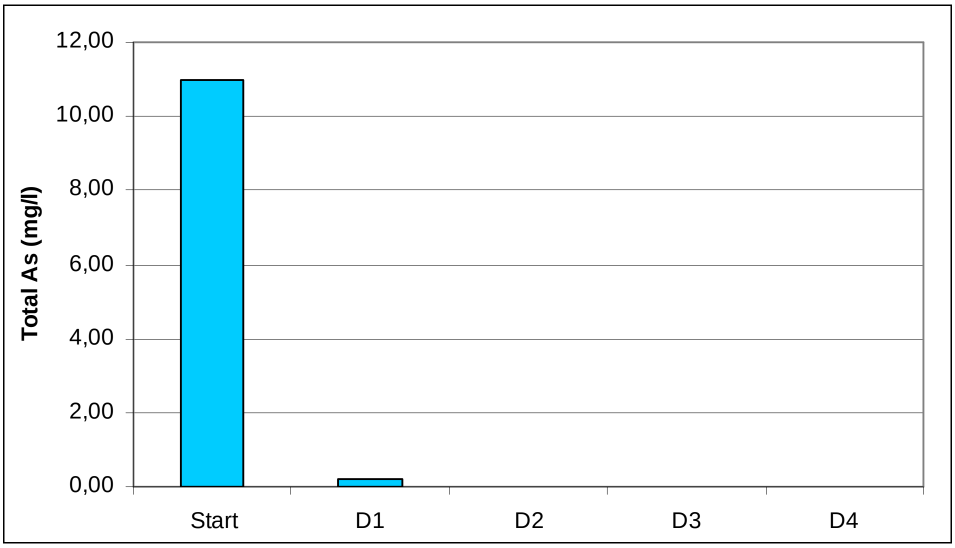


Fig. 3.14 – Coagulation – total As concentration in the model variants tested

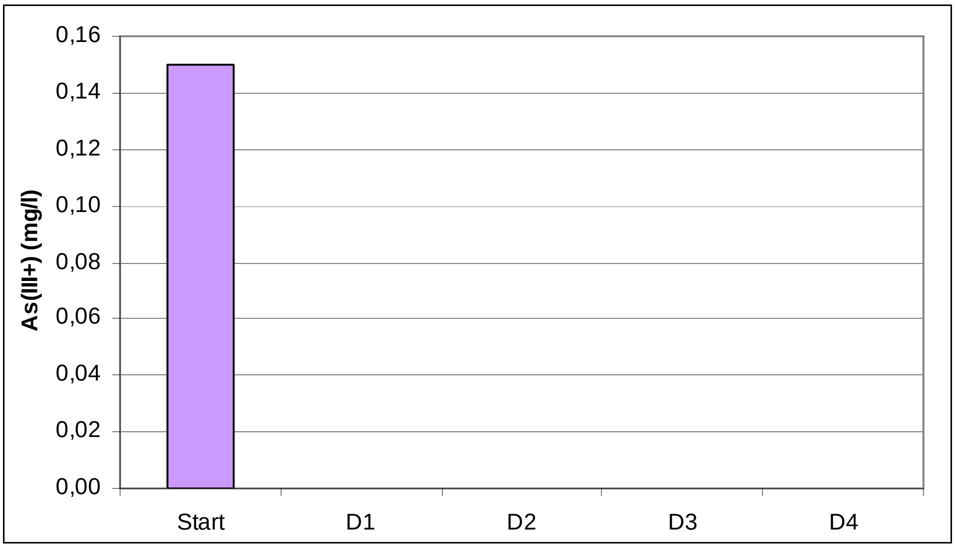


Fig. 3.15 – Coagulation – As (III+) concentration in the model variants tested

Economic consideration of the coagulation technology:

As in the previous case, economic evaluation of the coagulation method cannot be given at the moment because only basic screening batch experiments were performed. But as with the PRB technology, it is also believe in this case that the coagulation method could be economically advantageous for treatment of the Lojane Mine leachate. The assumption is based on low price of Prefloc (approx. 0.18 EUR per 1 kg), its very low consumption during reaction and high removal efficiency achieved in the performed batch tests.

3.3.4.4.3 Neutralization technology

The results of the neutralization laboratory tests are summarised in tables below. Table 3.28 provides measured process parameters, analytical results are summarised in the table 3.29.

Table 3.28 – Process parameters – E1 to E3 variants (various amount of $CaCO_3$*)*

Parameter → Variant ↓	pH	Conductivity (mS.cm^{-1})	Color
Start (leaching water, no calcium carbonate)	8.32	532	Colourless
E1 (0.5 g $CaCO_3$)	8.34	237	Cloudy, white, low precipitate
E2 (1.0 g $CaCO_3$)	8.53	232	White, precipitate
E3 (2.0 g $CaCO_3$)	8.64	223	White, precipitate

The results of measured parameters, given in the table above, show just slight difference among the prepared model variants. The application of calcium carbonate had minimal effect on pH of the leaching water. Precipitate of arsenic was also very low.

Table 3.29 below summarises results of chemical analyses of As and HCO_3^- contents.

Table 3.29 – As and HCO_3^- *contents in the neutralization model variants*

Parameter → Variant ↓	As Total [mg.l^{-1}]	As Total [%]	As (III+) [mg.l^{-1}]	As(III+) [%]	HCO_3^- [mg.l^{-1}]
Start (leaching water, no calcium carbonate)	11.00	100.00	0.15	100.00	37.16
E1 (0.5 g $CaCO_3$)	9.90	90.00	0.13	86.67	133.57
E2 (1.0 g $CaCO_3$)	9.50	86.36	0.12	80.00	135.64
E3 (2.0 g $CaCO_3$)	11.30	102.73	0.11	73.33	135.09

The analytical results summarized in the table above show very low efficiency of this technology for arsenic removal. The addition of calcium carbonate had high effect on carbonate ions content in leaching water. Figures 3.16 and 3.17 below depict concentrations of both - total and trivalent As in the neutralization model variants.

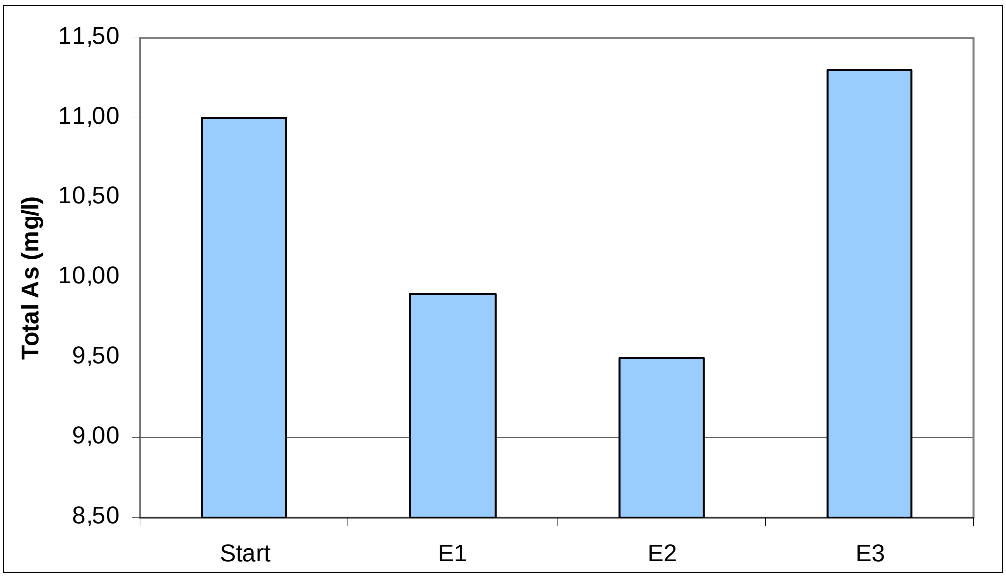


Fig. 3.16 – Neutralization – total As concentration in tested variants

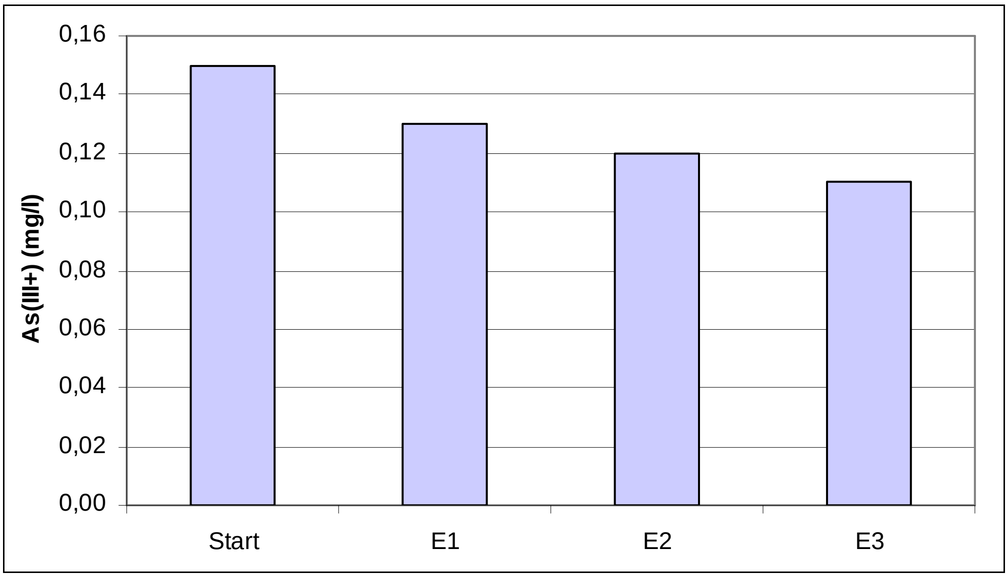


Fig. 3.17 – Neutralization – As (III+) concentration in tested variants

Economic consideration of the neutralization technology:

Economic consideration of this method is not given because of its low efficacy achieved during this model batch testing.

3.3.4.5 Conclusions of water treatability bench tests

Results of the performed laboratory tests confirmed that the permeable reactive barrier technology (with zero-valent iron) and the coagulation method (with ferric sulphate) are very effective for removal of arsenic (total as well as trivalent) from the prepared Lojane Mine leaching water. The achieved average reduction was in both cases higher than 90 %. The last tested technology – neutralization – showed very low efficiency for arsenic removal (<15 %).

Although the obtained positive results of permeable reactive barrier and coagulation technologies for As removal from the Lojane Mine leaching water, it is necessary to further verify this experimental data by additional tests (as far as possible in pilot-scale and/or in column settings). The testing should be also performed on real leachate taken from the Lojane Mine (not on the leaching water artificially prepared in the laboratory). The overall aim of these tests would be to finally evaluate efficacy of the two chosen methods as well as to assess their economical feasibility.

3.4 Preliminary human health risk assessment

This chapter provides the human health risk assessment, based on soil and groundwater measurements at the locality of Lojane mine. It also stems from the information in the Baseline Study funded by UNDP-Macedonia and performed by the University “Ss. Cyril and Methodius” Skopje in 2006 and the site investigation conducted by Dekonta, a.s. in 2007.

3.4.1 Brief site description

The site of interest was a mining area for long time in history. Ore occurrences in the area consist mainly of antimony and arsenic deposits. Mineral occurrences of chromium are also present. Primary sources of dissolved pollutants from metal mining operations include underground mine works, overburden and waste rock piles in Suva River valley, tailings pile and arsenic concentrate storage pond near the former processing plant. Dissolved pollutants at the mine site are primarily metals such as As, Sb, Ni, Mn, Cr, Co, Cu, Cd, Pb, Fe, Zn etc., but may include sulfates, nitrates, and radio nuclides. These contaminants, once dissolved, migrate from mining operations to local ground, surface water and sediments. Contamination of surface water may also occur as contaminated soil or waste materials are eroded and washed into water bodies. The results obtained from the examinations indicated extremely elevated concentrations of arsenic in Suva River flow (occasionally used for irrigation) as well as extremely elevated concentrations of arsenic and nickel in sediments and soil surrounding the river’s watershed. Elevated concentrations of arsenic and aluminum in groundwater as well as elevated concentration of arsenic, nickel, chromium, cadmium and cobalt exceeding Macedonian as well as European quality criteria for drinking water and soil were identified in local wells and within the Mine colony. Gradual environmental pollution is also caused by fugitive dust emissions from dry excavation materials.

Based on soil and groundwater contamination measurements during the Baseline Study preparation in 2006 and screening investigations by Dekonta in 2007 the following major hot spots of contamination were identified:

- Deposits of dry tailings from ore flotation in front of the former processing plant in the Mine colony. The tailings pile covers a surface of app. 18,000 m^2, and contains app. 450,000 tons of fine sized material with an average concentration of arsenic and antimony up to 1-2 %. Next to the pile there is a concentrate storage pond (stone structure with estimated volume of app. 5,000 m^3) containing app. 15,000 tons of >50% arsenic concentrate (As_4S_4). The piles are located app. 100 m from an elementary school built in Mine colony and app. 1,000 m and 900 m from residential buildings of Vaksince and Lojane villages, respectively.
- 5,000 tons of arsenic concentrate stored at an open storage yard of ore smelting-frying facility located nearby Tabanovce international railway station and app. 250 m from residential buildings of Tabanovce village. There are also app. 2,500 barrels (almost disintegrated) filled with As_2O_3 and some unknown substances stored near the facility.
- Three waste rock dumps (up to 50,000 tons each) and mined ore stockpile containing 5,000 tons of high grade antimony and chromium ore located on both sides of Suva River valley. There are also ruins of mine office/service buildings scattered on the area of approximately 3,000 m^2

All of these hot spots are left completely unprotected, prone to the mechanical disintegration, wind and water erosion and as such present a significant source of contamination.

The presented health risk assessment is based on chemical analysis of soil samples taken from the vicinity of tailings pile (Mine colony area), grassland in the vicinity of tailings pile, roasting facility area near Tabanovce railway station and aerial deposits collected at schoolyard in the Mine colony. Investigation of environmental contamination was conducted primarily during preparation of the Baseline Study in 2006 and also during Dekonta’s site investigation in 2007. Results obtained indicate elevation of heavy metals and metalloids (As, Sb, Ni, Mn, Cr, Cd, Co, Cu, Pb, Zn and Fe) in almost all soils sampled. Particularly concentrations of arsenic, antimony, nickel and manganese are extremely elevated in soils near the sources of pollution, while their concentrations decrease with increasing distance from the sources. Analyses of soil samples from "clean" area near Vaksince village suggest high natural background of elements investigated. The total land area with extreme pollution is estimated to be approximately 50 hectares.

Samples of groundwater were taken from wells located in the Mine colony, Vaksince and Tabanovce villages (the well's depth range from 12 m to over 80 m). Again, samples from areas presumed "clean" indicated relatively high background pollution of groundwater by metals such as arsenic, antimony and chromium caused by the local geological bedrock (most of the wells are drilled in serpentines).

In addition, the investigated area is burdened with a number of other environmental problems, which among others there are generally poor hygiene, low quality of drinking water and absence of satisfactory wastewater treatment.

None of the settlements is connected to water supply system. Drinking water is supplied from local small and individual springs, which are without sanitary control. Many of schools, including the biggest with 1000 pupils, have no drinking water. Only four in ten schools in the region have normal water supply, and only three have toilets.

In all mountain settlements fecal wastewater from households is usually drained through the septic holes and open channels direct into watercourses, into soil, to open roads, yards etc. All available chemical analyses of ground water used for drinking show high bacteriological pollution. As a result epidemics (e.g. hepatitis) were frequently registered. Water quality is further endangered by uncontrolled use of agrochemicals onto arable land.

An appropriate system for communal solid waste disposal in mountain settlements also does not exist. Solid waste is usually disposed in valleys, river flows, near the roads and presents serious problem to the quality of living. In Lojane municipal waste (and probably also hazardous waste from the private health organizations in villages) is disposed directly onto the tailings pile.

Main economic activity within the subjected region is agricultural production (app. 95 % of active population is involved) with predominance of cereals and vegetable for own needs and for the green markets in Kumanovo and Skopje. Pasturage and stockbreeding for home needs is also important for living. Fields and pastures occupy significant area in the close vicinity of the Mine colony. For irrigation of arable land, local water sources such as water from Suva River are used.

3.4.2 Hazard identification

3.4.2.1 Identification of contaminants of primary interest

As a result of mining and ore manufacturing the primary contaminants in the area of mine and its surroundings are represented by numerous heavy and toxic metals. Based on the data from preliminary investigation phase environmental pollution by As, Sb, Cr, Cd, Cu, Ni, Pb, Zn, Mn and Fe was identified, from which As, Sb, Ni and Mn are present in the highest concentrations. Following text describes toxicological profiles of these particular metals that are also a subject of further human health risk assessment. The description is based on data search in ATSDR (Agency for Toxic Substances and Disease Registry) and US EPA IRIS (Integrated Risk Information System) and RBC (Risk Based Concentration) databases and on information published in the Baseline Study by UNDP-Macedonia and University “Ss. Cyril and Methodius”-Skopje in 2006.

Toxicological Profile of Antimony

Antimony (Sb) is a naturally occurring metal, generally found as sulphides or oxides, that is used in various manufacturing processes (e.g. in various solders and other alloys), in electronics, paints and flame proofing.

Exposure to antimony and antimony-containing compounds (antimonials) may be via inhalation, oral and dermal routes. Antimony is sparingly absorbed following ingestion or inhalation, the extent of its absorption in organism is a function of compound solubility (US EPA IRIS, 1998). Trivalent antimony is more readily absorbed than pentavalent forms. Antimony is transported in the blood, it is not metabolized but it can bind to macromolecules and react covalently with sulfhydryl and phosphate groups. Excretion of antimony is primarily via the urine and feces (ATSDR, 1990).

Antimony poisoning is very similar to effects of arsenic. In small doses, antimony causes headache, dizziness and depression. Oral exposure of humans and animals to high doses of antimony or antimonials may cause gastrointestinal disorders (vomiting, diarrhea), respiratory difficulties, and death at extremely high doses (ATSDR, 1990). Subchronic and chronic oral exposure may affect hematologic parameters. Reproductive dysfunction has been demonstrated in rats exposed to antimony trioxide. Eye irritation due to exposure to several antimony oxides has been also reported.

Acute occupational exposure may cause gastrointestinal disorders, while long term occupational exposure has resulted in electro cardiac disorders, respiratory disorders, and possibility of increased mortality. Occupational exposure of women to metallic antimony and several antimonials has reportedly caused alterations in the menstrual cycle and an increased incidence of spontaneous abortions.

Antimony and its compounds are not classified as human carcinogens. Although carcinogenicity of antimony trioxide and antimony trisulphide is discussed, no data on cancer potency to perform cancer risk assessments currently do exist.

The US EPA (RBC Tables 2007) has determined following exposure limits (reference doses RfD) for oral subchronic and chronic exposure to antimony and inhalation exposure of antimony trioxide:

RfD_{oral}	0.4	μg/kg-day
$RfD_{inhalation}$	0.057	μg/kg-day

World Health Organization (WHO, 2006) set a drinking water guideline for antimony of 0.02 mg/L.

Toxicological Profile of Arsenic

Arsenic (As) is a brittle, gray metal that tarnishes in air. It is a natural component of the earth’s crust and occurs mostly in a form of sulfides in small amounts in rock, soil, water and underwater sediments. Natural background concentrations of arsenic in waters vary around tens of µg/L. Its main economic source is the mineral arsenopyrite and the most important compounds of arsenic are white arsenic trioxide (As_2O_3), yellow arsenic sulfide (As_2S_3) and red realgar (As_4S_4). Arsenic is used mainly to preserve wood and as to control insects and weeds.

Arsenic is chemically similar to phosphorus and such it partly substitute for phosphorus in numerous biochemical reactions and acts as their inhibitor. Arsenic has a tendency of accumulation in sediments and in biological food chains. Toxicity and absorption efficiency of arsenic compounds in organism depend on the solubility in water. Elemental arsenic is not soluble in water and as such it is not poisonous, however it is metabolized to toxic substances. Arsenic trisulfide is sparingly soluble and non-toxic, whereas all other arsenic compounds toxicity potential. Inorganic compounds with the trivalent form of arsenic have app. 5 to 20 higher toxicity potential than compounds with As (V). Organic compounds of arsenic are generally less toxic that the inorganic ones.

Distribution of arsenic within the body is affected by route, through which exposure occurs. Given sufficient time for equilibration, arsenic generally tends to be evenly distributed amongst tissues within the body. The primary pathway of elimination of inorganic arsenic is excretion via the urine.

Inhalation exposures to inorganic arsenic dusts in the workplace have been reported to cause irritation of the airways, laryngitis and bronchitis; cases of very high exposures have been reported to result in perforation of the nasal septum (ATSDR, 1993). However, respiratory effects have not been noted at exposure levels that range between 0.1 and 1.0 mg/m^3 (ATSDR, 1993). Several studies have indicated that inhalation exposures to inorganic arsenic can lead to a number of neurological effects in humans (e.g. loss of reflexes and muscle weakness).

Ingestion of inorganic arsenic can lead to hematological effects and serious damage of the cardiovascular system (ATSDR, 1993). Both acute and long-term exposures can result in myocardial depolarization and cardiac arrhythmias. Long-term exposures to low levels of arsenic can also result in damage to the vascular system, characterized by a progressive loss of circulation in the hands and feet (ATSDR, 1993). Acute effects of oral arsenic exposure include vomiting, nausea, diarrhea, gastrointestinal hemorrhage and death. Two reports indicate that doses ranging between 1 and 22 mg As/kg body weight per day have resulted in death. Similar effects are often seen with long-term exposures to lower doses of arsenic (ATSDR, 1993). Oral exposures to relatively low levels of inorganic arsenic have been reported to cause several toxic effects in the liver including, elevated levels of hepatic liver (ATSDR, 1993). Chronic exposures to lower levels of arsenic, ranging between 0.019 and 0.5 mg/kg-day, may lead to adverse neurological effects that are typically characterized by a peripheral neuropathy similar to that seen with inhalation exposures.

Numerous studies have shown that dermal effects are common in humans exposed to inorganic arsenic levels that range between 0.01 and 0.1 mg As/kg-day. Skin changes including hyperkeratosis and hyper/hypo-pigmentation results also from ingestion of inorganic arsenic.

There is sufficient convincing epidemiological evidence indicating the cancer potential of arsenic to humans (e.g. Health Canada (1996) classified inorganic arsenic compounds as Group I - carcinogenic to humans). Inhalation exposure to inorganic arsenic can increase the risk of developing lung cancer, whereas the risk of developing skin cancer increases after ingestion of inorganic arsenic.

The US EPA (RBC Tables 2007) has determined following exposure limits (reference doses RfD) for oral and inhalation sub-chronic and chronic exposure to arsenic:

RfD_{oral}	0.3	μg/kg-day
$RfD_{inhalation}$	0.2	μg/kg-day

Note: reference dose for inhalation exposure was derived from tolerable concentration in air TCA for arsenic of 0,001 mg/m^3 (RIVM, 2000)

In respect to carcinogenic potency of inorganic arsenic and its compounds after oral and inhalation exposure US EPA set up following cancer slopes factors:

CSF_{oral}	1.5	1/(mg/kg-day)
$CSF_{inhalation}$	15.1	1/(mg/kg-day)

World Health Organization (WHO, 2006) set a drinking water guideline for arsenic of 0.01 mg/L.

Toxicological Profile of Nickel

Pure nickel (Ni) is a hard, silvery-white metal, which is often used for alloys (e.g. in jewelry or stainless steel production), nickel plating, ceramics, batteries, and for catalysts production. Nickel is present in cigarette smoke as a very toxic nickel tetracarbonyl.

An important issue relating to nickel toxicity is its speciation (metallic form, salt, oxide, etc.) and related solubility. The solubility (in water) of different nickel compounds ranges from the highly soluble nickel salts (nickel chloride - 642 g/L, nickel sulphate 293 g/L) down to the insoluble nickel oxide (1.1 mg/L) and the sparingly soluble nickel subsulphide (517 mg/L) (ATSDR, 1997). Some of the more insoluble nickel compounds (e.g. nickel subsulphide) may have higher solubility in biological fluids

Following inhalation exposure, nickel may deposit in the respiratory system depending on the size of the particle inhaled. In case of oral exposure of humans nickel sulphate was found to be up to 40 times more bioavailable if administered in water than in food. Quantitative absorption data for unspecified forms of soluble nickel range between 1 – 27 % after ingestion. Most of ingested nickel is excreted via feces, urine but also through hair, sweat, milk and skin. Nickel compounds tend to accumulate in lungs, thyroid and adrenal glands, kidney, heart and liver.

Nickel containing compounds such as nickel oxide, nickel subsulphide and nickel sulfate induce respiratory lesions in rats and mice. The only data available for chronic nickel inhalation exposure for humans is limited to occupational data. Lung effects, including chronic bronchitis, reduced lung function, and lung cancer, as well as nasal effects, including rhinitis, nasal sinusitis, nasal mucosal injury and sinus cancer, have been observed in workers who breathed high levels of nickel while working in nickel refineries or nickel processing plants. Nickel platers exposed to nickel sulfate and welders exposed to nickel oxides have been linked with asthma. Workers that were chronically exposed to nickel oxide or metallic nickel at concentrations greater than 0.04 mg/m^3 had a greater incidence of death from respiratory disease (ATSDR, 1997).

Acute poisoning results in damage of gastrointestinal tract, cardiovascular system, kidneys and central nervous system. Long-term exposure to high doses of nickel lead to weight loss, heart and liver disorders and skin inflammation. Nickel is suspected to negatively affect kidneys, immunity system and fetus and children development; it also may affect endocrine function regulating prolactin levels.

In case of dermal contact nickel salts induce skin dermatitis called „nickel itch“. Moreover, approximately 6 – 10 % of population suffers from allergic reactions to nickel resulting in erythematic and eczematous dermatitis. Nickel dust is irritating to the eyes, nose and throat.

Evidence for the carcinogenic effects of nickel metal and other compounds is relatively weak or inconclusive, but insoluble dusts of nickel oxides, and soluble aerosols of nickel sulfate, nitrate, and chloride, have been implicated as potential carcinogens.

Nickel is capable of bioaccumulation in plants. It has significant toxic effects towards aquatic organisms, therefore its limits in water supply rivers are often more rigorous than quality criteria for drinking water.

The US EPA (RBC Tables 2007) has determined following exposure limits (reference doses RfD) for oral and inhalation sub-chronic and chronic exposure to nickel:

RfD_{oral}	20	μg/kg-day
$RfD_{inhalation}$	0.0143	μg/kg-day

Note: reference dose for inhalation exposure was derived from tolerable concentration in air TCA for nickel subsulfide of 5.10^{-5} mg/m^3 (RIVM, 2000)

The carcinogenic potency of nickel under inhalation exposure can be described by a risk specific concentration (RSC) of 2.1×10^{-5} mg/m^3 (US EPA 1987), which equals to cancer slope factor $CSF_{inhalation}$ of 1.68 1/(mg/kg-day). There is a lack of data concerning nickel’s cancer potential after oral administration.

World Health Organization (WHO, 2006) set a drinking water guideline for nickel of 0.07 mg/L.

Toxicological Profile of Manganese

Manganese is a naturally occurring element (often in combination with iron), although it is not naturally found in the metallic form. The free element is a grey-white metal essential to iron and steel production by virtue of its sulfur-fixing, deoxidizing, and alloying properties. Its salts are also widely used in chemistry, glass industry, paint production, electrolytic processes and medicine. Manganese is Manganese (II) ions function as cofactors for a number of enzymes and the element is thus a required trace mineral for all known living organisms.

Solubility of manganese compounds in water ranges from poorly soluble (manganese dioxide, manganese tetroxide, manganese carbonate, and manganese sulfide) to soluble (manganese sulfate, manganese chloride, manganese nitrate, permanganate ion).

Most exposure to manganese and its compounds will be associated with drinking water and consuming foods containing manganese. Exposure to manganese and its compounds may also occur during mining and processing of the ore and manganese smelting. Manganese can be inhaled or ingested. Absorption of inorganic manganese through the skin appears to be negligible. However, with organo-manganese compounds there can be significant absorption through the skin.

Manganese naturally occurring concentrations are hardly toxic and also relatively large doses can be tolerated without serious adverse effects. Occupational exposure to manganese can be substantial. In its acute form, manganese poisoning has an effect characteristic of other heavy metals, leading to “metal fume fever” if dust or fume is inhaled in sufficient quantity. Chronic exposure to manganese can express itself in two major ways, namely bronchitis/pneumonitis after inhalation of manganese dust, and “manganism”. Manganism disease arises from damage to the central nervous system (CNS), usually begins with psychological symptoms followed by neurological symptoms such as muscular weakness, speech disturbances, impaired motor skills and headaches, as well as symptoms resembling those of Parkinson's disease (tremors, stiffness, motor dysfunction). Signs of adverse effects may occur at manganese concentrations ranging from 2 to 5 mg/m^3 in air.

Exposure to high levels of manganese in air and dust may lead to an increased incidence of pneumonia and impotence (in case of men). Manganese posses a particular risk for children due to its propensity to bind to CH-7 receptors.

There is no evidence of carcinogenic effects of manganese and its compounds to humans.

The US EPA (RBC Tables 2007) has determined following exposure limits (reference doses RfD) for oral and inhalation sub-chronic and chronic exposure to manganese:

RfD_{oral}	20	μg/kg-day
$RfD_{inhalation}$	0.0143	μg/kg-day

World Health Organization (WHO, 2006) set a drinking water guideline for nickel of 0.4 mg/L.

3.4.2.2 Toxicity assessment

The purpose of the toxicity assessment is to weigh available evidence regarding the potential for particular contaminants to cause adverse effects in exposed individuals and to provide, where possible, an estimate of the relationship between the extent of exposure to a contaminant and the increased likelihood and/or severity of adverse effects. Toxicity assessment of investigated contaminants stems from their toxicological profiles stated above.

Non-carcinogenic health effects: Non-carcinogenic chemicals require a threshold level to be reached before adverse biological effects are evident. Criteria used to evaluate non-carcinogenic effects include both the reference dose (RfD) or reference concentration (RfC). An RfD is an estimate of the dose of a chemical (mg/kg-day) for the human population, including sensitive subpopulations, that is likely to be without an appreciable risk of deleterious effects during a lifetime. The RfC is the concentration of a chemical in air that can be inhaled daily during a lifetime without risk of deleterious effects.

Carcinogenic health effects: Chemicals that are termed carcinogens are treated as if they have no threshold for biological response. It is assumed, therefore, that any dose of a carcinogen, no matter how small, presents some cancer risk. To identify the health risks posed by these compounds, slope factors (SF) or unit risk (UR) values derived from epidemiological or animal studies are used to estimate the cancer potency in humans exposed to carcinogenic substances at low doses and the subsequent risk of cancer. Slope factors (or potency) generally represent an upper-bound estimate of the probability of developing cancer per unit dose of a chemical over a lifetime (mg/kg/day)$^{-1}$. Similarly, URs represent an upper-bound estimate of the risk of developing cancer per unit concentration (mg/m^3 or mg/l) of a chemical over a lifetime.

3.4.2.3 Identification of exposure scenarios

Exposure scenarios describe the major risk receptors on site and all available contacts to contaminants through the contaminated media. Based on environmental presence of heavy metals and in respect to human activity in the area, children visiting elementary school in the Mine colony and citizens of neighboring villages (Lojane, Vaksince and Tabanovce) were identified as the two current and future groups of **potential risk receptors**.

Schoolchildren – The elementary school in the Mine colony is located app. 100 m from the former processing facility, dry tailings pile and arsenic concentrate storage pond, therefore a significant risk of immediate exposure of schoolchildren to the fugitive dust and contaminated soil during their outdoor activities at the schoolyard, playgrounds and in the area of school in the Mine colony does exist. There is no information on the exact number of pupils currently studying at the school however, rough estimate range between 200 and 300 children. It is assumed that schoolchildren might be exposed during the whole period of their elementary studies, i.e. 10 years.

Citizens of neighboring villages – It is expected that citizens (adults and children) of Lojane, Vaksince and Tabanovce villages might be exposed to contaminants in groundwater from local wells they use as a source of potable water as much as to fugitive dust from dry excavation materials and contaminated soil during their outdoor and agricultural activities in the areas surrounding their villages and in area of the Mine colony, eventually in area of the roasting facility near Tabanovce railway station. According to general methodology of US EPA of residential health risk assessment exposure duration was set to 24 years for adults. This conservative exposure scenario include also potential exposure of employees of the storage yards located nearby the former processing facility in the Mine colony and near former roasting facility near Tabanovce railway station. Unfortunately any information on the number of employees or frequency of their presence on sites is missing.

In terms of exposure scenarios deduction the following **key exposure pathways** are assumed:

1) Exposure of children and adults to contaminated soil and dust

Certainly the most important environmental issue on abandoned Lojane mine site is the soil contamination by numerous toxic metals. Soil is polluted by local watercourses (e.g. Suva River) running from the former mining area but primarily by down wind deposition of fine particles of dust from dry tailings pile, arsenic concentrate ponds, rock dumps, abandoned mine facilities in the valley of Suva River and ruined mineral processing facilities of old Lojane mine as well as by fine particles of contaminated sediments that accumulated in watersheds over decades throughout the area.

Although deposition of fugitive dust from above mentioned sources at any distance may have been at a relatively low concentration, the long period of deposition (i.e., from decades) and the persistency of metals have significantly contaminated communal surfaces, local roads, commercial and living areas as much as nearby agricultural lands and grasslands.

Intensive fugitive dust emissions (dust clouds) are reported especially from very fine grained dry tailings piles and arsenic concentrate storage ponds located in the Mining Colony between villages Vaksince and Lojane. These structures are completely unprotected and very prone to wind erosion and therefore endangering nearby local school as much as wider surrounding area of neighboring villages. The similar problem occurs at the old roasting facility nearby the Tabanovce train station, which is situated in the vicinity of Čivluk and Tabanovce villages.

High level of dustiness in the subjected area is intensified by dry Mediterranean climate, agricultural land preparation and traffic and is most frequently reported as the main environmental problem in the region.

In respect to the exposure to contaminated soil and dust particles two exposure scenarios were assumed:

- Exposure of schoolchildren through inadvertent ingestion of soil/dust, dermal contact with soil/dust particles and inhalation of fugitive dust during outdoor activities at the schoolyard, playgrounds and in the area of school in the Mine colony.
- Exposure of citizens of Lojane, Vaksince and Tabanovce villages through inadvertent ingestion of soil/dust, dermal contact with soil/dust particles and inhalation of fugitive dust during occasional outdoor and agricultural activities in the area of mine and its surroundings. Exposure to metals (As, Sb, Ni and Mn) polluting mostly the soil in the areas investigated was assessed separately for adults and children. For simplification, potential health risks to children (citizens) are assumed to be equivalent to risks connected with exposure of schoolchildren in the Mine colony.

2) Exposure through consumption of groundwater

Elevated concentrations of arsenic and aluminum were observed in water from wells in the Mine colony, Lojane, Vaksince and Tabanovce villages. These concentrations exceed both Macedonian and Czech limits for potable water and most of them also C value of ground water quality criteria issued by the Czech Ministry of Environment 1996 for the purpose of the assessment of remediation action pertinence. Elevated concentrations of chromium and cadmium were also detected in the wells investigated.

At two locations, extremely high concentrations (up to 2.73 mg/l) of arsenic were detected. These locations are natural spring below the tailings and positive pressure well nearby tailings pile (Bilnet Komerce well). In both cases, due to positive pressure ground water is coming up to the surface and wash the tailings before exiting to the ground, thus collecting huge amount of contaminants. Water from the spring creates a stream flowing through the field and entering Suva River. Special concern for risk posed by this contaminated water, present a fact that a school is located nearby and the schoolchildren could easily come in contact with it - during the site visit it was observed that a part of the natural spring below the tailings is lead into a tap and consumed by children passing by.

In terms of the exposure scenario consumption of ground water from local wells in Lojane (including water sources of the school located in Mine colony), Vaksince and Tabanovce villages is assumed. Exposure to metals (As, Sb, Ni) polluting mostly the ground water was assessed separately for adults and children. Health risk assessment of children in the locality of Lojane village includes also potential exposure of schoolchildren due to consumption of groundwater at school located in the Mine colony.

3) Other relevant exposure pathways

Another exposure pathway (not assessed) of potential concern presents intake of heavy metals through consumption of agricultural crops, meet and diary products from cattle grown in contaminated environment. According to site visit and the Baseline Study (2006) wide area surrounding the Mine colony is intensively used as an agricultural land (almost 95 % of active population is involved in agricultural production). Soil samples taken from grassland in the vicinity of tailings pile in the mine colony indicate an elevated burden of arable land by heavy metals contamination. Moreover, according to available information arable soils are occasionally irrigated by water from local watercourses such as Suva River – heavily polluted by heavy metals. Since number of toxic metals present on the investigated area tends to bioaccumulation in plants and subsequently in tissues of higher organisms a serious risk of biological food chains pollution does exist. Consumption agricultural crops, meet or diary products from farm animals exposed to the contaminated waters, plants and surface soil (farm animals are kept in open) may cause an additional intake of hazardous chemicals. Because of lack of fundamental information this exposure pathway was not assessed.

3.4.3 Quantification of exposure

According to US EPA definition, exposure is defined as the contact of an organism with a chemical or physical agent. Exposure assessment is thus the determination or estimation (qualitative or quantitative) of the magnitude, frequency, duration, and route of that potential contact.

This section describes the methodology for calculating chemical-specific intakes for the receptors and exposure pathway selected for quantitative evaluation. Reliable estimates of exposure point concentrations in soil and groundwater are required to calculate the magnitude of exposure for receptor groups identified in the previous section. Values of variables used in exposure models stem from the Methodological Guidance of the Czech Ministry of Environment issued as a guideline for health risk assessment of contaminated sites. This methodology corresponds to US EPA's up-to-date guidelines on health risk assessment). All evaluations are calculated for the reasonable maximum exposure (RME) exposure. Equations are used for estimating the Average Daily Dose (ADD) for non-carcinogenic effects of chemicals (arsenic, antimony, nickel and manganese) and the Lifetime Average Daily Dose (LADD) for carcinogenic effects of chemicals (arsenic and nickel).

In respect to US EPA's methodology the exposure through inadvertent soil ingestion and dermal exposure through skin contact with contaminated soil and dust particles are generally assessed and evaluated together. Therefore values of average daily dose (ADD) and lifetime average daily dose (LADD) resulting from these two exposure pathways are summarized in this study.

In respect to the limited availability of thorough site-specific data and information on the particular population behavior and activities, general exposure parameters describing a residential exposure in RME (reasonable maximum exposure) setting ware applied. The selected exposure models parameters used for calculation of exposure doses from particular exposure pathway are presented in the following tables 3.30 – 3.33.

Table 3.30 – Exposure model and default set of parameters used for calculation of exposure from inadvertent ingestion of soil and dust particles (for children and adults)

INADVERTENT SOIL AND DUST INGESTION

Equation:

$$\text{Intake}(mg/kg/day) = \frac{\text{Cs} \times \text{IR}_\text{S} \times \text{ET} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}}$$

Variable values:

Cs: *Concentration of chemical in soil (mg/kg dw)*

Site-specific measured value

Cs = site-specific (arithmetic mean of measured values)

IRs: *Soil ingestion rate (mg/day)*

Age, sex and activity based values; for RME:

IRs (children) = 200 mg/day

IRs (adults) = 100 mg/day

EF: *Exposure frequency (days/year)*

Dependent on frequency of exposure-related activities

EF = 274 day/year

ED: *Exposure duration (years)*

Dependent on population migration and duration of performing exposure-related activities; for RME:

ED (children) = 10 years

ED (adults) = 24 years

BW: *Body weight (kg)*

Used for children, youths or adult

BW = 70 kg (adult, average)

BW = 15 kg (child 1-6 years old, average)

AT: *Averaging time (days)*

Period of exposure for carcinogenic effects

AT = 25,550 days (70 years)

Period of exposure for non-carcinogenic effects

AT = ED

Table 3.31 – Exposure model and default set of parameters used for calculation of dermal exposure from a skin contact with soil and dust particles (for children and adults)

DERMAL CONTACT WITH SOIL/DUST PARTICLES

Equation:

$$\text{Intake}(mg/kg/day) = \frac{\text{Cs} \times \text{SA} \times \text{AF} \times \text{ABS} \times \text{ET} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}}$$

Variable values:

Cs: *Concentration of chemical in soil (mg/kg dw)*
Site-specific measured value
Cs = site-specific (arithmetic mean of measured values)

SA: *Skin surface area exposed (cm^2/day)*
Age, sex and clothes based values; for RME:
SA (children) = 0,28 cm^2/day
SA (adults) = 0,57 cm^2/day

AF: *Skin-soil adherence factor (m^2/day)*
Age and activity based values; for RME:
AF (children) = 0,2 mg/cm^2
AF (adults) = 0,07 mg/cm^2

ABS: Dermal absorption factor *(-)*
Chemical specific
ABS (arsenic) = 0,03
ABS (nickel) = 0,01
ABS (inorganic compounds generally) = 0,001

EF: *Exposure frequency (days/year)*
Dependent on frequency of exposure-related activities
EF = 274 day/year

ED: *Exposure duration (years)*
Dependent on population migration and duration of performing exposure-related activities; for RME:
ED(children) = 10 years
ED (adults) = 24 years

BW: *Body weight (kg)*
Used for children, youths or adult
BW = 70 kg (adult, average)
BW = 15 kg (child 1-6 years old, average)

AT: *Averaging time (days)*
Period of exposure for carcinogenic effects
AT = 25,550 days (70 years)
Period of exposure for non-carcinogenic effects
AT = ED

Table 3.32 – Exposure model and default set of parameters used for calculation of exposure through fugitive dust inhalation (for children and adults)

INHALATION OF FUGITIVE DUST

Equation:

$$\text{Intake}(mg/kg/day)=\frac{\text{Cs}\times\text{IR}\times\text{PEF}\times\text{ET}\times\text{EF}\times\text{ED}}{\text{BW}\times\text{AT}}$$

Variable values:

Cs: *Concentration of chemical in soil (mg/kg dw)*
Site-specific measured value
Cs = site-specific (arithmetic mean of measured values)

IR: *Inhalation rate (m^3/day)*
Age, sex and activity based values; for RME:
IR (children) = 7,6 m^3/day
IR (adults) = 20 m^3/day

PEF: *Particulate emission factor (mg/m^3)*
Climate, land cover and activity dependent; for RME:
PEF (elevated dustiness) = 1 mg/m^3

EF: *Exposure frequency (days/year)*
Dependent on frequency of exposure-related activities
EF = 350 day/year
ED: *Exposure duration (years)*
Dependent on population migration and duration of performing exposure-related activities; for RME:
ED(children) = 10 years
ED (adults) = 24 years

BW: *Body weight (kg)*
Used for children, youths or adult
BW = 70 kg (adult, average)
BW = 15 kg (child 1-6 years old, average)

AT: *Averaging time (days)*
Period of exposure for carcinogenic effects
AT = 25,550 days (70 years)
Period of exposure for non-carcinogenic effects
AT = ED

Table 3.33 – Exposure model and default set of parameters used for calculation of exposure from consumption of groundwater (for children and adults)

CONSUMPTION OF GROUNDWATER

Equation:

$$\text{Intake}(mg/kg/day) = \frac{C_W \times IR_W \times ET \times EF \times ED}{BW \times AT}$$

Variable values:

Cw: *Concentration of chemical in groundwater (mg/L)*
Site-specific measured value
Cw = site-specific (arithmetic mean of measured values)

IRw: *Grounwater consumption rate (L/day)*
Age and sex based values; for RME:
IRw (children) = 1 L/day
IRw (adults) = 2 L/day

EF: *Exposure frequency (days/year)*
Dependent on frequency of exposure-related activities
EF = 350 day/year

ED: *Exposure duration (years)*
Dependent on population migration and duration of performing exposure-related activities; for RME:
ED(children) = 10 years
ED (adults) = 24 years

BW: *Body weight (kg)*
Used for children, youths or adult
BW = 70 kg (adult, average)
BW = 15 kg (child 1-6 years old, average)

AT: *Averaging time (days)*
Period of exposure for carcinogenic effects
AT = 25,550 days (70 years)
Period of exposure for non-carcinogenic effects
AT = ED

3.4.4 Risk characterization

In this section the toxicity and exposure assessment are summarized and integrated into quantitative and qualitative expressions of risk. This section characterizes the potential non-carcinogenic and carcinogenic risk for the exposure scenarios on the investigated site. It also highlights the primary contributors to risk estimates such as exposure pathways, and exposure media. The potential health effects are characterized separately for non-carcinogenic and carcinogenic endpoints. Arsenic and nickel are determined as a carcinogenic contaminants and antimony and manganese as non-carcinogens, therefore an evaluation of both carcinogenic and non-carcinogenic adverse effects on human health follows.

The magnitude of health risk is characterized by comparing calculated average exposure dose or risk levels (derived from the ADDs and LADDs presented above) to maximum "acceptable" doses or risks. The potential non-carcinogenic health risks are determined using the hazard index approach that defines the relative hazard based on the ratio of the estimated ADD to the acceptable intake level (*i.e.*, the Reference Dose RfD). The potential carcinogenic health risks are determined by multiplying the LADD by an appropriate cancer slope factor (CSF) and determining whether the calculated incremental lifetime cancer risk (ILCR) exceeds acceptable risk level.

The methodologies used to determine potential non-carcinogenic and carcinogenic health effects are presented below. The potential human health risks posed by environmental contamination in area of the Mine colony and surrounding villages are examined in terms of the groundwater consumption, inadvertent ingestion and dermal exposure as well as inhalation exposure to carcinogenic and non-carcinogenic contaminants found in groundwater, soil and dust.

Non-carcinogenic Risk Characterization

It is important to recognize how the benchmark values for both potential cancer and non-cancer risks are derived and used in order to maintain an appreciation for their utility in the risk assessment process. Non-carcinogenic properties are addressed using hazard index (HI) approach. Simply stated, HI is derived by dividing the estimated average daily dose (i.e., ADDs) of a non-carcinogen by its reference dose (RfD).

$$HI = \frac{ADD}{RfD}$$

where:

HI = Hazard Index;

ADD = the average daily dose in mg/kg-day

RfD = Reference Dose in mg/kg-day

RfD is defined as the maximum daily dose of a substance to which one can be exposed for a lifetime without the potential occurrence of non-carcinogenic effects. It is generally derived by establishing the dose that results in no effect for the most sensitive endpoint in the most sensitive species tested.

According to US EPA, hazard index scores at or below 1 are considered *de minimis* regulatory risks and such exposures can be reasonably assumed not to pose a health concern. In addition, HI scores of 1 or greater are an indication of concern but are not necessarily an indication of a serious health risk since both the ADD and RfD represent conservative values. HI greater than

1 suggests the need for a more rigorous evaluation of the exposure estimates and toxicity values to assess whether there may be a true health concern.

If more than one contaminant and exposure pathway is to be assessed, the individual HI of particular contaminants could be summarized across various pathways in a given exposure scenario to form a total hazard index (HI_T). Since it is unlikely that all contaminants would act on the same target organs in an additive fashion, this characterization of non-cancer risks is highly conservative. Therefore, generally HI_T lower and/or equal to the value 1 means level of non-carcinogenic risk, which is acceptable, and no mitigation measure is required. It is quite clear that exceeding of it has the opposite meaning.

Carcinogenic Risk Characterization

The theoretical incremental lifetime cancer risk (ILCR) associated with exposure to contaminants with carcinogenic effects is calculated by multiplying the conservatively estimated lifetime average daily dose (LADD) by a cancer slope factor (CSF).

$$ILCR = LADD \times CSF$$

The cancer slope factor is derived by extrapolating the results of a high dose study to the low dose range that occurs in most environmental exposures. The dose-response model used to establish this slope factor is among the most conservative available to risk assessors, and a further "safety" factor is used by incorporating a statistical upper bound of the most likely slope factor estimate of this model. The risk estimates derived are thus highly conservative estimates of the potential cancer risk from the exposure(s) under evaluation. The term "increased cancer risk of $1\text{x}10^{-6}$" is the estimated probability that 1 additional cancer will occur in a population of one million individuals exposed to the average daily dose (LADD) of a carcinogen over their lifetime (assuming seventy years of continuous exposure at the estimated dose).

For risk assessment and regulatory purposes, cancer risks of less than $1\text{x}10^{-6}$ are considered *de minimis* and no further action is deemed necessary. Cancer risks that fall in the range of $1\text{x}10^{-6}$ to $1\text{x}10^{-4}$ require regulatory scrutiny, but generally are considered acceptable. Cancer risks exceeding value of $1\text{x}10^{-4}$ require immediate remedial measures.

The following tables 3.34 – 3.37 present results of quantitative health risk assessment conducted in respect to non-carcinogenic as well as carcinogenic effects of selected metals with the highest potential adverse impact. According to defined exposure scenarios, exposure is evaluated separately for schoolchildren exposed to elevated concentrations of metals present in the surface soil, fugitive dust and groundwater in the area of school and its vicinity in the Mine colony. Likewise, exposure of adults to contaminated environmental media is assessed in respect to the three selected location – tailings pile area (Mine colony), roasting facility area near Tabanovce railway station and grassland in the area of Mine colony representing an agricultural land.

The following abbreviations are used:

RfDo/RfDi	reference dose for oral/ inhalation exposure pathway
CSFo/CSFi	cancer slope factor for oral/inhalation exposure pathway
CSF	cancer slope factor for inhalation exposure pathway
ADD_O/ADD_i	average daily dose from oral/inhalation exposure pathway (in case of this assessment ADD_O represents the average intake from soil ingestion summarized with intake from dermal contact with soil)

HI(o)/HI(i)	hazard index resulting from oral/inhalation exposure (in case of this assessment HI(o) results from soil ingestion and dermal contact with soil and dust)
HI	total hazard index across investigated exposure pathways related to the same contaminant
LADDo	lifetime average daily dose from oral/inhalation exposure pathway (in case of this assessment LADDo represents the average intake from soil ingestion summarized with intake from dermal contact with soil)
ILCR	incremental lifetime cancer risk

Exposure of children and adults to contaminated soil and dust

Table 3.34 – Exposure of children to selected metals in soil (non-cancer chronic effects)

LOCATION	**Metal**	**Csoil** [mg/kg]	**RfDo** [mg/kg/d]	**RfDi** [mg/kg/d]	**ADDo** [mg/kg/d]	**ADDi** [mg/kg/d]	**HI(o)**	**HI(i)**	**HI**
Schoolyard (Mine colony)	As	384.2	3.0E-04	2.0E-04	4.17E-03	1.10E-04	13.90	0.55	14.44
	Sb	131.0	4.0E-04	5.7E-05	1.31E-03	3.74E-05	3.28	0.66	3.93
	Ni	330.3	2.0E-02	1.4E-05	9.92E-04	9.42E-05	0.05	6.59	6.64
	Mn	1053.7	2.0E-02	1.4E-05	3.16E-03	3.01E-04	0.16	21.02	21.18

Table 3.35 – Exposure of adults to selected metals in soil (non-cancer chronic effects)

LOCATION	**Metal**	**Csoil** [mg/kg]	**RfDo** [mg/kg/d]	**RfDi** [mg/kg/d]	**ADDo** [mg/kg/d]	**ADDi** [mg/kg/d]	**HI(o)**	**HI(i)**	**HI**
Grassland (Mine colony)	As	23	3.0E-04	2.0E-04	2.8E-05	3.7E-06	0.09	0.02	0.11
	Sb	26	4.0E-04	5.7E-05	2.8E-05	4.2E-06	0.07	0.07	0.14
	Ni	630	2.0E-02	1.4E-05	2.3E-04	1.0E-04	0.01	7.09	7.10
Roasting facility area (Tabanovce)	As	504	3.0E-04	2.0E-04	6.1E-04	8.1E-05	2.02	0.41	2.42
	Sb	18	4.0E-04	5.7E-05	1.9E-05	2.8E-06	0.05	0.05	0.10
	Ni	129	2.0E-02	1.4E-05	4.7E-05	2.1E-05	0.00	1.45	1.46
	Mn	615	2.0E-02	1.4E-05	2.2E-04	9.9E-05	0.01	6.91	6.93
Tailings pile area (Mine colony)	As	761	3.0E-04	2.0E-04	9.1E-04	1.2E-04	3.05	0.61	3.66
	Sb	23	4.0E-04	5.7E-05	2.5E-05	3.7E-06	0.06	0.06	0.13
	Ni	567	2.0E-02	1.4E-05	2.1E-04	9.1E-05	0.01	6.38	6.39
	Mn	838	2.0E-02	1.4E-05	3.1E-04	1.3E-04	0.02	9.43	9.45

Table 3.36 – Exposure of children to arsenic and nickel from soil and dust (carcinogenic effects)

LOCATION	**Metal**	**Csoil** [mg/kg]	**CSFo** 1/[mg/kg/d]	**CSFi** 1/[mg/kg/d]	**LADDo** [mg/kg/d]	**LADDi** [mg/kg/d]	**ILCR(o)**	**ILCR(i)**	**ILCR**
Schoolyard (Mine colony)	As	384.2	1.5	15.1	8.2E-04	2.4E-04	1.2E-03	3.6E-03	4.8E-03
	Ni	330.3	-	1.68	-	2.3E-05	-	3.8E-05	3.8E-05

Table 3.37 – Exposure of adults to arsenic and nickel from soil and dust (carcinogenic effects)

LOCATION	Metal	Csoil [mg/kg]	LADDo [mg/kg/d]	LADDi [mg/kg/d]	ILCR(o)	ILCR(i)	ILCR
Grassland (Mine colony)	As	23	9.5E-06	3.7E-06	1.4E-05	5.6E-05	7.0E-05
	Ni	630	-	3.5E-05	-	5.8E-05	5.8E-05
Roasting facility area (Tabanovce railway st.)	As	504.1	2.2E-05	8.1E-05	3.3E-05	1.2E-03	1.3E-03
	Ni	129.2	-	7.1E-06	-	1.2E-05	1.2E-05
Tailings pile area (Mine colony)	As	761.1	3.1E-04	1.2E-04	4.7E-04	1.9E-03	2.3E-03
	Ni	567.1	-	3.1E-05	-	5.3E-05	5.3E-05

Note: Carcinogenic slope factors for oral and inhalation administration are equal to the table ZZ

The results in the tables 3.34 – 3.37 indicate elevated health risk both to children and adults from non-carcinogenic exposure to As, Ni, Sb and Mn present in soil and dust at all investigated locations. There is particularly serious health risk towards schoolchildren as a result of their outdoor activities at the schoolyard located in vicinity of tailings pile in the Mine colony. In this case hazard index values of arsenic and antimony exceeds 13 (for arsenic) and 3 (for antimony) due to ingestion and dermal contact with soil, and 21 (for manganese) and 14 (for arsenic) as the result of dust and soil particles inhalation.

For adults, the most serious non-carcinogenic health threat in the whole area comes from the inhalation of contaminated fugitive dust and soil particles. This way of exposure results in HI(nickel) = 7.1 at the grassland area, HI(manganese) = 6.9 at the roasting facility area, HI(nickel) = 6.4 and HI(manganese) = 9.45 in the vicinity of tailings pile.

Outcomes of the assessment of exposure to arsenic and nickel contaminated soil and dust particles presented in table 3.36 indicate significant increase of carcinogenic risk to schoolchildren, particularly due to ingestion and inhalation of soil/dust particles containing arsenic. When the inhalation exposure to nickel-polluted fugitive dust is assumed incremental lifetime cancer risk (ILCR) falls into the range of $1x10^{-6}$ to $1x10^{-4}$ of acceptable cancer risk incidence. However, in case of arsenic the estimated exposure results in a cancer risk significantly exceeding this tolerance and ILCR comes up to $4.8x10^{-3}$ (with approximately equal contribution from the both exposure pathways).

For adults, there is a similar trend of cancer risk estimates. Again, exposure to arsenic pose more severe risks than intake of nickel except grassland near the Mine colony where the ILCR values of the both metals are more or less similar and fall into the range of acceptable cancer risk. Adults' exposure in the tailings pile area and the area of roasting facility near Tabanovce railway station leads to ILCR exceeding value of $1x10^{-3}$ for arsenic and falls between $1x10^{-5}$ to $6x10^{-5}$ for nickel.

Exposure of children and adults through the consumption of groundwater

Table 3.38 – Exposure of children to selected metals in groundwater (non-carcinogenic chronic effects)

Location	Metal	Cwater [mg/L]	RfDo [mg/kg/d]	ADD [mg/kg/d]	HI
Wells in Lojane	As	0,184	3,0E-04	9,21E-03	30,69
	Sb	0,008	4,0E-04	3,75E-04	0,94
	Ni	0,017	2,0E-02	2,53E-04	0,01
Wells in Vaksince	As	0,109	3,0E-04	5,45E-03	18,18
	Sb	0,008	4,0E-04	4,00E-04	1,00
	Ni	0,704	2,0E-02	1,06E-02	0,53
Wells in Tabanovce	As	0,059	3,0E-04	2,95E-03	9,84
	Sb	0,009	4,0E-04	4,60E-04	1,15
	Ni	0,552	2,0E-02	8,29E-03	0,41

Table 3.39 – Exposure of adults to selected metals in groundwater (non-carcinogenic chronic effects)

Location	Metal	Cwater [mg/L]	RfDo [mg/kg/d]	ADD [mg/kg/d]	HI
Wells in Lojane	As	0,184	3,0E-04	3,95E-03	13,15
	Sb	0,008	4,0E-04	1,61E-04	0,40
	Ni	0,017	2,0E-02	1,08E-04	0,01
Wells in Vaksince	As	0,109	3,0E-04	2,34E-03	7,79
	Sb	0,008	4,0E-04	1,72E-04	0,43
	Ni	0,704	2,0E-02	4,53E-03	0,23
Wells in Tabanovce	As	0,059	3,0E-04	1,27E-03	4,22
	Sb	0,009	4,0E-04	1,97E-04	0,49
	Ni	0,552	2,0E-02	3,55E-03	0,18

Table 3.40 – Exposure of children to arsenic in groundwater (carcinogenic effects)

Location	Cwater [mg/L]	CSFo 1/[mg/kg/d]	LADD [mg/kg/d]	ILCR
Wells in Lojane	0,184	1,5	1,32E-03	1,97E-03
Wells in Vaksince	0,109	1,5	7,79E-04	1,17E-03
Wells in Tabanovce	0,059	1,5	4,22E-04	6,33E-04

Table 3.41 – Exposure of adults to arsenic in groundwater (carcinogenic effects)

Location	Cwater [mg/L]	CSFo 1/[mg/kg/d]	LADD [mg/kg/d]	ILCR
Wells in Lojane	0,184	1,5	1,35E-03	2,03E-03
Wells in Vaksince	0,109	1,5	8,02E-04	1,20E-03
Wells in Tabanovce	0,059	1,5	4,34E-04	6,51E-04

The results in tables 3.38 – 3.41 indicate elevated health risk both to children and adults from consumption of groundwater in the area caused exclusively by the presence of high arsenic pollution. This trend is significant in all the three villages, especially in Lojane where the exposure dose of arsenic is app. 30-times higher than the relevant oral reference dose for children and app. 13-times higher for adults. Serious situation occurs also in Vaksince village where hazard indexes for children and adults equal to 18 and 8, respectively. Consumption of groundwater in Tabanovce village results in a hazard index of 10 for children and 4 for adults.

Exposure of children to the extremely high concentrations of arsenic found in the natural spring below the tailings located in the Mine colony was not included in the calculation. However, under the selected scenario, consumption of groundwater from this source would result in an exposure dose of arsenic far exceeding the relevant oral reference dose (HI = 455).

Based on the results of assessment of carcinogenic risk from arsenic-polluted groundwater consumption presented in tables 3.40 and 3.41 the incremental lifetime cancer risk (ILCR) for exposed child and adult populations significantly exceed value of $1x10^{-4}$, which is defined as the acceptable risk of cancer incidence. Again, the highest risk of cancer incidence was identified in Lojane and Vaksince villages where it even exceeds a value of $1x10^{-3}$.

3.4.5 Conclusion of the preliminary risk assessment

Outcomes of this preliminary health risks assessment indicate that the Lojane mine site’s soil and groundwater contamination by heavy and toxic metals exceeding both Macedonian and European quality criteria for drinking water and soil leads to immediate health risk to schoolchildren studying in the area of the Mine colony as well as to the citizens of neighboring villages Lojane, Vaksince and Tabanovce.

Generally the elevated environmental contamination and subsequently increased health risks were identified particularly close to the sources of contamination, i.e. in the area of the Mine colony and Lojane village. Magnitude of the contamination/risks decrease with increasing distance from contamination source, however health risks identified in villages Vaksince and Tabanovce also do exceed generally acceptable values.

Based on the defined exposure scenarios and the results of risk assessment calculation, the major exposure pathways contributing the most to the overall carcinogenic and non-carcinogenic health risks on the investigated site are inhalation of fugitive dust and consumption of groundwater. In case of children’s exposure, inadvertent ingestion of soil and dust particle is also of concern. As it is presented in tables 3.34 – 3.41 exposure to number of heavy and toxic metals (also with developmental and carcinogenic effects) present on site may lead to non-carcinogenic and carcinogenic health risks far exceeding the generally accepted limits.

It is clear that wind erosion especially at the tailings pile and arsenic concentrate depots significantly contributes to the elevated dustiness in the area and pose respiratory hazards to exposed population, especially to schoolchildren since the elementary school in the Mine colony is located within only 100 m from the source of the contamination. Therefore there is a necessity of stabilization of the dry tailings and arsenic concentrate ponds at the Mine colony and Tabanovce roasting facility area in order to protect their further dispersion to the environment.

Another ominous health risks originate from consumption of groundwater from local wells polluted by elevated amount of arsenic, antimony and nickel. Obviously, the use of the ground water from the Mine colony as well as from wells in Lojane, Vaksince and Tabanovce villages for drinking could seriously affect exposed human population especially in a long-term.

Heavy and toxic metals contaminating soil and surface waters occasionally used for irrigation provides a serious long-term source of persistent pollutants also in respect to pollution of arable land, contamination of agriculture crops and subsequent accumulation in biological food chains.

These preliminary health risks assessments of the Lojane mine site are based on rough exposure estimates and limited input data. However, its outcomes clearly indicate the immediate health risk to people studying and living in the vicinity of such an extremely polluted area. The preliminary health risk assessment offers outcomes providing first warning on the seriousness of potential health impacts of rigorous environmental contamination on the investigated Lojane mine site and the importance of remediate, emergency and regulatory actions. However, for the detailed description of health risk to people living in the area additional thorough investigation is required.

3.5 Description of applicable cleanup methods

This chapter provides a brief description of available treatment technologies for cleanup of soil, solid waste and water contaminated with heavy metals (including metalloids As, Sb). Treatment technologies are those technologies that either change the composition of the contaminant to form other compounds that are less dangerous to human health or the environment, or limit contaminants mobility by physical or chemical means.

The overview depicts conventional and innovative/emerging methods. Conventional methods are those having a successful track record in mine site cleanup, or technologies that are considered standard practice for mine site management. Such approaches have been widely applied to remediation of mining and mineral processing sites, as well as other waste management units.

Innovative/Emerging Technologies - two types of technologies are included in this category. Innovative technologies include processes or techniques for which cost or performance data is incomplete and the technology has not yet been widely applied. An innovative technology may require additional field scale testing before it is considered proven and ready for commercialization and routine application at mine sites. Emerging technologies typically are even earlier in the development process. While they are potentially applicable at mine sites, additional laboratory or pilot-scale testing to document effectiveness is highly recommended.

3.5.1 Conventional cleanup methods

Chemical treatment

In chemical treatment, reagents are used to destroy or chemically modify organic and inorganic contaminants, converting hazardous constituents into less environmentally damaging forms. Typically, chemical treatment is used as part of a treatment train, either as a pretreatment technique to enhance the efficiency of subsequent processes or in post-treatment of an effluent. One of the common uses of chemical treatment at mining and mineral processing sites is the use of lime to neutralize ARD and to precipitate the metals.

The cost of chemical treatment ranges from low to high depending on the site conditions, including the chemicals that are used and the nature of the products that are produced by the chemical treatment – e.g. if the sludge that precipitates after the addition of lime is disposed of as a solid waste, the additional cost of disposal would bring the cost into the high range. In many cases the operating and maintenance costs will be significant over the life of the remediation.

Stabilization

Stabilization refers to processes that reduce the risk posed by a waste by converting the contaminants into a less soluble, less mobile, and, therefore, less hazardous form without necessarily changing the physical nature of the waste. An example of stabilization as a treatment is the pH adjustment of a sludge which results in making the contaminants in the sludge less mobile.

The cost of stabilization will be in the medium to high range depending on treatment required for stabilization ($ 72 – 348). The effectiveness is dependent on the nature of the material to be treated and the subsequent storage or disposal. Cement based stabilization is often used for many metals to comply with the treatment requirements of the legislative regulations.

Solidification

Solidification refers to processes that encapsulate waste in a monolithic solid of high-structural integrity. Solidification does not necessarily involve a chemical interaction between the waste and the solidifying agents, but involves a physical binding of the waste in the monolith. Contaminant migration is restricted by vastly decreasing the surface area exposed to leaching and/or by isolating the waste within an impervious capsule. Encapsulation may address fine waste particles (i.e. microencapsulation) or large blocks or containers of waste (i.e. macroencapsulation). There is, however, inherent risk that the stabilized solidified waste matrix will break down over the time, potentially releasing harmful constituents into the environment. An example of the solidification involves the use of cement to solidify contaminants into large blocks.

The cost of solidification ranges from medium to high depending on the steps required to encapsulate the waste ($ 72 – 348). A simple encapsulation into a large concrete block would be an example of the medium end of the cost range. The effectiveness is dependent on the potential of the solid to break down over the time.

Pyrometallurgical Technologies

Pyrometallurgy is used here as a broad term encompassing elevated temperature techniques for extraction and processing of metals for use or disposal. High-temperature processing increases the rate of reaction and often makes the reaction equilibrium more favorable, lowering the required reactor volume per unit output. Some processes that clearly involve both metal extraction and recovery include roasting, retorting, or smelting. While these processes typically produce a metal-bearing waste slag, metal is also recovered for reuse. A second class of pyrometallurgical technologies is a combination of high temperature extraction and immobilization. These processes use thermal means to cause volatile metals to separate from the soil and report to the fly ash, but the metal in the fly ash is then immobilized, instead of recovered, and there is no metal recovered for reuse. A third class of technologies are those that are primarily incinerators for mixed organic-inorganic wastes, but which have the capability of processing wastes containing the metals of interest by either capturing volatile metals in the exhaust gases or immobilizing the nonvolatile metals in the bottom ash or slag.

Thermal desorption

This technique refers to the treatment alternatives that use heat to remediate contaminated soils, sediments, and sludge. Thermal desorption is used to separate a contaminant from the containing media. The off-gas from desorption unit usually must be further treated.

Temperatures utilized for the thermal desorption of metals is high enough that other contaminants, such as volatile organic compounds, may actually undergo thermal destruction. Thermal desorption is not commonly used at mining and mineral processing sites since the common contaminants at such sites – metals, are not easily volatilized (heated to their gas phase).

The cost of thermal desorption is in the range of medium to high and the effectiveness at most sites is poor since there may be only a limited quantity of chemicals in the soils that can be easily volatilized.

Thermal destruction

Thermal destruction is a treatment alternative that uses heat to remediate contaminated soils, sediments, and sludge. This method typically uses higher temperatures to actually decompose the contaminants, potentially with no hazardous contaminant residues requiring further management. Thermal destruction is not commonly used at mining and mineral processing sites since the process does not destroy metals – typical and common contaminants at mine sites.

The costs are in range of medium to high and the effectiveness is limited to those materials that can be destroyed.

Soil washing

The ex-situ process of soil washing employs chemical and physical extraction and separation techniques to remove a broad range of organic, inorganic and radioactive contaminants from soils. The process begins with excavation of the contaminated soil, mechanical screening to remove various oversize materials, separation to generate coarse and fine-grained fractions, and treatment of those fractions. Surficial contaminants are removed through abrasive scouring and scrubbing action using a washwater that may be augmented by surfactants and/or other agents. The soil is then separated from the spent washing liquid, which carries some of the contaminants. The recovered soils consist of a coarse fraction, sands and gravels, a fine fraction, silts and clays, and an organic humic fraction, any or all of which may be contaminated. The washed soil fraction may be suitable for re-depositing on site or other beneficial uses. The fines usually carry the bulk of the contaminants and generally require further treatment using another remediation process, such as thermal destruction, thermal desorption, or bioremediation.

The costs of soil washing range from medium to high, however, the costs are impacted by the soil excavation and by the controlled method of recovering the liquid. The effectiveness is determined by the ability of the washing liquid to remove the contaminants.

Soil flushing

Soil flushing is in-situ variant of the soil washing – it uses water, enhanced water, or gaseous mixtures to accelerate the mobilization of contaminants from a contaminated soil for recovery and treatment. The process principle is in acceleration of one or more of the same geochemical dissolution reactions – e.g. adsorbtion/desorbtion, acid/base reactions, that alter contaminant concentration in ground – water system. In addition, soil flushing accelerates a number of subsurface contaminant transport mechanisms, including advection and molecular diffusion that are found in conventional groundwater pumping. The fluids used for soil flushing can be applied or drawn from groundwater and can be introduced to the soil through surface flooding or sprinklers, subsurface leach fields, and other means. When the contaminants have been flushed, the contaminated fluids may be removed by either natural seepage or a groundwater recovery system. Depending upon the contaminants and the fluids used, the soil may be left in place after the soil flushing is completed.

The costs of soil flushing ranges from medium to high depending on the means of applying the flushing fluid and the method of their recovery ($ 72 – 348). The effectiveness of soil flushing is dependent on the characteristic of the soil and the fluid used for flushing. If the fluid can mobilize the contaminants and be recovered, the technology can be effective. There often is a problem, however, with either mobilizing the contaminants or recovering the fluid that limits the effectiveness. In contrast, another concern is that contaminants may be highly mobilized with subsequent possibility of contaminating groundwater.

Solvent extraction
Solvent extraction is an ex-situ separation and concentration process in which a non-aqueous liquid reagent is used to remove contaminants from waste, soils, sediments, sludge, or water. The process is based on well-documented chemical equilibrium separation techniques utilized in many industries, including the mining and mineral processing industry. In the mine site remediation, one type of solvent extraction technology – leaching is used extensively, primarily because of the application of accepted mining and beneficiation technologies to the remediation field.

The cost of solvent extraction is in the range of low to high depending on site characteristics, which include – the media necessary for contaminants extraction, the system for recovery of contaminated solution, the process to remove the process to remove the contaminants from the solution, and the handling and disposal of the spent waste or soil. The effectiveness is good if the contaminants can be extracted by the liquid reagent.

Vapor extraction
This is an in-situ technology that uses vacuum technology and subsurface retrieval systems to remove contaminants in their gas phase. Vacuum extraction of vapors from contaminated soil and subsurface strata has been successfully employed to remove volatile compounds from permeable soils. This technology cannot be utilized for removal of heavy metals from soils.

3.5.2 Collection, diversion and containment methods

Collection, diversion, and containment technologies are used at sites where treatment technologies cannot control the contaminants to an acceptable level. These engineering controls include technologies that contain or capture the contaminants to reduce or minimize releases.

Landfill disposal
Landfills are waste management units, typically dug into the earth, but including above ground units that are not exposed on the sides (i.e. not freestanding waste piles), that accept waste for permanent placement and disposal. While landfilling is a conventional disposal technology, it has had its share of recent innovations. Landfilling may be lined to contain leachate, drained with a leachate collection system, and capped.

The cost of landfills can range from medium to high at mining and mineral processing sites depending on the site conditions that impact the design, including low permeability cover, low permeability liner, leachate collection, and leachate treatment. The operation and maintenance costs of leachate treatment or cap maintenance can be significant. The effectiveness of the landfill depends on the design. A landfill that can isolate the waste is effective. Should the cap or liner be breached, however, the effectiveness will be greatly diminished. On-site landfills should be designed to meet site specific cleanup goals and address applicable regulatory considerations.

Cutoff walls

Cutoff walls are structures used to prevent the flow of groundwater from either leaving an area, in the case of contaminated groundwater, or entering a contaminated area, in the case of clean groundwater.

> *Slurry walls* – are basically trenches refilled with a material (e.g. bentonite slurry) that combines low permeability and high adsorption characteristics to impede the passage of groundwater and associated contaminants.
>
> The cost of slurry walls is in the medium range, with depth being the factor on the cost due to equipment limitation. The effectiveness depends on the ability of the wall to get a seal on the bottom – i.e. by contact with an impermeable soil or rock layer, to keep the groundwater from flowing under the slurry wall. Similarly, effectiveness is affected by construction of the slurry wall with no gaps or other point for by-pass.
>
> *Cement walls* – are similar to the slurry walls, except that instead of low permeability clay-type slurry, cement based slurry is used. Construction may be by trench and fill as with the slurry walls. Alternatively, construction may utilize a larger excavation in which forms are constructed to pour a concrete wall after which the excavated area around the wall is backfilled. The backfill may be with a high permeability material used to capture and channel the groundwater flow.
>
> The cost is greater than the slurry walls especially if the wall is formed in place, with a cost range of medium to high. This increased cost however may buy an increase in effectiveness.
>
> *Sheet piling* – is a technology that is often used to install a cutoff wall. Sheet piling has been used in the past to funnel groundwater to a treatment cell for treatment and is regularly used as temporary cutoff wall during the remediation period.
>
> The cost of the sheet piling is in the medium to high range, with the high range utilizing a better mechanism to seal the joints between the sheets. The effectiveness of sheet piling is similar to the slurry wall, however there is a greater potential of the wall to have leaks at the joints.

Pumping groundwater

A pump-and-treat process for addressing groundwater contamination is a combination of an extraction technology (pumping) and a subsequent treatment technology. The treatment, which can vary by contaminant, could be any of the other technologies discussed. The pump-and-treat technology has been the preferred method of remediating contaminated groundwater.

The adsorption of As(III) versus As(V) is impacted very differently by source water pH. The adsorption of As(V) decreases with increasing pH values in the 3 to 10 range because, as the pH increases, the surface charge of the media becomes less positive and there is less attraction to the negatively charged As(V) species of $H_2AsO_4^-$ and $HAsO_4^{2-}$. The As(V) species of $H_2AsO_4^-$ dominates at a pH value between 2.0 and 7.0, and $HAsO_4^{2-}$ dominates at a pH value between 7.0 and 11.0. On the other hand, As(III) adsorption is shown to increase with an increase in pH value with a maximum adsorption at pH 9.0. This is likely because the uncharged species, H_3AsO_3, predominates for As(III) in the pH range of natural waters, and at pH 9.0, the $H_2AsO_3^-$ form occurs, thus increasing the affinity for the positively-charged iron solid surface. The range of effective adsorption of both As(III) and As(V) overlaps within the pH range of 6.0 to 7.5, with more As(V) adsorbed at a low value pH and more As(III) adsorbed at a high pH value (Jain and Loeppert, 2000). The optimal pH range for arsenic removal is specific to each media type.

- ***Competing Anions.*** The adsorption of arsenic is influenced by the presence of other competing anions in source water such as fluoride, bicarbonate, sulfate, silica, and phosphate. Anions compete directly for available binding sites on the surface of the media and also can alter the electrostatic charge at the media surface. This competition has the potential to reduce the overall effectiveness of arsenic removal from source water. In order for a competing ion to have an effect, it must be present in sufficient concentration and/or have a stronger affinity for adsorption onto the media than arsenic.

- ***Media-Specific Characteristics.*** Each media has unique characteristics related to its arsenic adsorption capacity and the kinetics or rate at which arsenic is adsorbed onto the media. These factors play a role in its overall cost-effectiveness for technology selection and are related to the chemical composition of the media, its mesh size and surface area, its pore structure, and other physicochemical properties (such as zero point charge [ZPC]) that impact adsorption processes.

- ***Ion Exchange Technology***. Ion exchange is a fixed-bed process that involves exchanging ions from solution onto a resin. For arsenic removal, an anion resin in the chloride form is used to remove As(V). Anion exchange resins also remove other anions such as sulfate, nitrate, and uranium. Because As(III) occurs in water below pH 9 with no ionic charge, As(III) is not removed by the anion exchange process. When the resin eventually becomes saturated with arsenate and other anions such as nitrate and sulfate, the resin must be regenerated. In the regeneration step, a sodium chloride brine solution is passed through the spent resin where the adsorbed arsenate and other anions are replaced with chloride ions. Because of high concentrations of arsenic in the spent brine, it likely will be classified as a hazardous waste. The advantages of the anion exchange technology for arsenic removal is simplicity of operation, long resin life, ease of regeneration, and lack of impact of pH on the exchange capacity.

  The efficiency of the ion exchange process for arsenic removal is strongly affected by competing ions, such as sulfate, nitrate, and TDS. In general, the ion exchange process is not economically attractive if source water contains high levels of TDS (>500 mg/L) and sulfate (>250 mg/L). Sulfate is more preferred by the ion exchange resin than arsenate (i.e., $H_2AsO_4^-$).

- ***Coagulation/Filtration and Iron Removal Technologies***. Iron removal processes can be used to remove arsenic from drinking water supplies. Iron removal processes involve the oxidation of soluble iron and As(III), adsorption and/or co-precipitation of As(V) onto iron hydroxides, and filtration. The actual capacity to remove arsenic during iron removal processes depends on a number of factors, including the amount of arsenic present, arsenic speciation, pH, amount and form of iron present, and existence of competing ions, such as phosphate, silicate, and natural organic matter (EPA, 2004a). The main advantage of the process is that it uses the natural iron to remove arsenic. Thus, sites with high iron concentrations requiring an iron removal process can use one process to remove both iron and arsenic.

The cost of the pumping portion can range from medium to high, including, but not limited to, the number and spacing of wells, the volume to be pumped, and the depth to groundwater. The long-term effectiveness of this method is limited for certain contaminants, especially some metals in certain soil types. Consideration must be given to such factors as desorption rates and chemical properties of the contaminants themselves.

Capping

Capping is typically used to cover a contaminated area of waste unit to prevent precipitation from infiltrating an area, to prevent contaminated material from leaving the area and to prevent human or animal contact with the contaminated materials. An example of preventing releases is growing of vegetation on tailings to prevent fugitive dust from blowing off and being transported downwind. Capping could include: surface armoring, soil/clay cover, soil enhancement to encourage growth, geosynthetic or asphaltic cover system, polymeric/chemical surface sealers, revegetation, concrete and synthetic covers.

The cost of caps can range from low (e.g., planting grasses) to high (e.g., synthetic caps) depending on the cap selected ($54/ton). The cap may or may not be effective in achieving multiple performance objectives, for example; a cap designed to minimize erosion, however, may not be an effective cap to minimize infiltration and vice versa.

Detention/Sedimentation

Detention/sedimentation controls are used to control erosion and sediment laden runoff. “Treatment” generally consists of simply slowing the water flow and reducing the associated turbulence to allow solids to settle out. Settling may be allowed at natural rates; in other cases flocculants may be added to increase the settling rate. The settled sediments may be removed and disposed; if the sediment is contaminated then treatment may be required.

The cost of detention and sedimentation is generally in the range of low to medium, depending on the operation and maintenance costs to remove the settled solids. The detention/sedimentation basins can be effective if they can be designed to allow the proper amount of settling time; however, in some cases the solids settle at a very slow rate and a portion of the solids leave the settling basin.

Settling Basins

Settling basins may be used to contain surface waters so that contaminated sediments suspended in the water column can be treated, settled, and managed appropriately. Dissolved contaminants and/or acid waters may be contained as well to allow for treatment or natural degradation (e.g., contained cyanide will degrade naturally). As the impoundment fills with the solids that have settled out, solids must be removed and disposed of in order for the impoundment to continue working effectively.

The cost of operating settling basins is in the low to medium range, depending on the construction of the impoundment and dam. For example, a lined impoundment will cost more than an unlined impoundment. The operation and maintenance costs of the settling basin could be significant over the life of the basin to remove and dispose of any settled solids. Properly designed settling basins can be effective in removing suspended solids from surface waters.

Interceptor Trenches

Interceptor trenches are trenches that have been filled with a permeable material, such as gravel, that will collect the ground water flow and redirect it for either *in-situ* or *ex-situ* treatment. Interceptor trenches are often used to collect and treat groundwater (permeable reactive barriers) and/or prevent it from leaving a containment area, such as a landfill. The initial cost of interceptor trenches is low to moderate depending on the availability of materials. However, the operating and maintenance cost can be significant if the liquid flowing through the trench precipitates material that will plug the trench, thus minimizing the permeability and requiring the permeable material to be cleaned or replaced. Interceptor trenches are effective at capturing ground water flow if the permeability of the media in the trench is greater than the native material.

Erosion Controls

Erosion controls are those engineering controls used to eliminate or minimize the erosion of contaminated soils by either air or precipitation (i.e., stormwater or snow melt). Erosion controls include:

> **Capping or covers** (as discussed above), particularly in the form of revegetation, polymer/chemical surface sealers, armoring and soil enhancements. The caps or covers for erosion control, in general, are lower than the costs of caps to limit infiltration.
>
> The cost range of the erosion control caps is low to medium. The O&M costs of the cap could be significant, particularly if the cap or cover can be easily damaged. For example, if revegetation is selected, then the O&M costs will include revegetating areas where the vegetation does not grow, or is damaged by factors which could include natural conditions such as drought or insect invasion. The effectiveness of the caps or covers to prevent erosion is dependent on site conditions; however the caps or covers should generally prevent the erosion of soils by either water or air.
>
> **Wind breaks** are used to minimize the erosion of soils and dusts by the wind and can include planting of trees and other vegetation to reduce the wind velocity, and/or the installation of fences.
>
> The cost of wind breaks is generally in the low to medium range. The effectiveness of wind breaks is dependent on the prevailing wind. In general, wind breaks are not as effective at eliminating airborne dust as the caps or covers.
>
> **Diversions** (as discussed below) are used to control surface water around areas that have a high probability of erosion. An example of this would be construction of a diversion ditch to capture runoff which prevents the flow from reaching a steep slope, where it could cause erosion.

Diversions

Diversions are engineering controls that are used to divert ground water or surface water from infiltrating waste units or areas of contamination, thereby preventing the media from being contaminated and pollutants from leaching and migrating. Two types of diversions are run-on controls and capping:

> **Run-on controls** prevent surface water from entering waste units or areas of contamination and becoming contaminated. For example, surface waters may be diverted to avoid contact with stockpiled waste rock. This would prevent the water from becoming acidified. Examples of run-on controls would include retaining walls, gabion dams, check dams (both permanent and temporary), and diversion ditches.
>
> The costs of run-on controls are low to medium depending on the method used for the diversion. The use of run-on controls to divert surface water away from areas of contamination is effective in reducing the quantity of water that requires treatment.
>
> **Capping** is the placement of synthetic liners or impervious earthen materials (typically clay) to prevent precipitation from infiltrating waste materials or severely contaminated areas and leaching contaminants into the ground water. This allows water to be captured and diverted elsewhere.
>
> The cost and effectiveness of caps are discussed above.

Stream Channel Erosion Controls are used to minimize the mobilization and transport of contaminated sediments by streams within the site. At many mining and mineral processing sites, historic transport of contaminated sediment into the stream has occurred. Many sites have areas where these sediments have been deposited along stream shores and beds. Stream channel erosion controls can be used to minimize the remobilization and transport of these sediments, often during periods of high flows. Technologies to control stream channel erosion often include both erosion controls and diversions such as channelization or lining of stream channels, diversion dams and channels (construction of diversion dams and or channels to reduce flow to contaminated areas and ground water recharge areas, to reduce water velocity, trap sediment and divert clean water), riprap, and gabions.

The cost of these controls can range from low (e.g., revegetation of stream banks) to high (e.g., diversion to an engineered channel) depending on the site conditions. Some of the technologies may be temporary until other remediations are completed. The O&M cost to the erosion controls could be significant, especially with damage from flood events.

3.5.3 Reuse, recycle, reclaim

Sale of Useable Materials

Sale of materials that can be utilized by other is another management approach that may be employed. The useable materials could include: finished product in the unlikely case that any remains on site; supplies of materials that remained unused at the site; feedstock, ore or concentrate that remains on site; demolition debris for reprocessing; and/or waste materials for reprocessing. The cost from this technology may be either low or positive. In evaluating the cost of selling useable materials, the cost should be compared to the cost of disposal to ensure that the cost of selling the material minus any money received is actually less than the cost of disposal. Recycling or reusing these materials is an effective means of eliminating contaminants, although there generally are limited materials that should be sold.

Remining/Reprocessing

Remining is the process of taking mine “waste” material and running it through a process to recover valuable constituents. Remining typically utilizes the same mining and beneficiation processes to extract metal contaminants from tailings or other waste materials. For example, tailings may be reprocessed to recover metals that remain, by any or all of the following methods: gravity separation (if there is a difference in the specific gravity of the desired mineral and the rest of the tailings), flotation, or leaching.

The cost of remining/reprocessing may range from profitable to high depending on the cost of the remining/reprocessing minus the value paid for the metals or other materials. The “new tailings” can be placed in an engineered containment facility which generally is more desirable than the existing facility, thereby minimizing the potential of releases to the environment. The “clean tailings” may also have other beneficial uses, depending on the characteristics of the tailings. The effectiveness of the remining and reprocessing can vary significantly depending on the site. In general, however, it is very effective for the portion of the waste that is reprocessed.

3.5.4 Innovative cleanup methods

The following treatment technologies are considered to be innovative/emerging technologies. The discussion is intended to provide examples; innovative and emerging technologies are continually evolving

Bioremediation

For the purpose of this discussion, refers to the use of micro biota to degrade hazardous organic and inorganic materials to innocuous materials. Certain bacteria and fungi are able to utilize, as sources of carbon and energy, some natural organic compounds (e.g., petroleum hydrocarbons, phenols, cresols, acetone, cellulose wastes) converting these and other naturally occurring compounds to byproducts (e.g., carbon dioxide, methane, water, microbial biomass) that are usually less complex than the parent material. At metal contaminated sites, such as mining and mineral processing sites, the addition of biological nutrients has been demonstrated to stimulate natural microorganisms to operate a natural process for biological attenuation and stabilization of heavy metals.

The cost of bioremediation is in the range of medium to high; as the technology evolves the cost may decrease.

> **Phytoremediation** is the use of plants and trees to extract stabilize or detoxify contaminants in soil and water. The phytoremediation process generally describes several ways in which plants are used to remediate or stabilize contaminants at a site. Plants can break down organic pollutants or stabilize metal contaminants by acting as filters or traps. The three ways that phytoremediation works are: phytoextraction, rhizofiltration, and phytodegradation.
>
> **Phytoextraction**, also termed phytoaccumulation, refers to the uptake of metal contaminants by plant roots into stems and leaves. Plants that absorb large amounts of metals are selected and planted at a site based on the type of metals present and other site conditions that will impact the growth. The plants are harvested and either incinerated or composted to recycle the metals.
>
> The cost of phytoextraction is in the low to medium range depending on site conditions and the costs of disposal of the harvested plant material. The operating and maintenance costs may be significant if the plants need to be harvested for many years. The effectiveness of phytoextraction has been good for some metals where there are shallow, low levels of contamination; the technology is, however, considered innovative for most metals.
>
> **Rhizofiltration** is used to remove metal contamination in water. The roots of certain plants take up the contaminated water along with the contaminants. After the roots have become saturated with metals, they are harvested and disposed.
>
> The cost of rhizofiltration is in the low to medium range depending on site conditions and the cost of disposal of the harvested plant material. The operating and maintenance costs may be significant if the plants need to be harvested for many years. The effectiveness of rhizofiltration is not yet determined as the technology is considered innovative.
>
> **Phytodegradation** is a process in which plants are able to degrade organic pollutants. Phytodegradation is not currently used for inorganic contaminants.

Vitrification

Vitrification is a solidification process employing heat to melt and convert waste materials into glass or other crystalline products. Waste materials, such as heavy metals and radionuclides, are actually incorporated into the relatively strong, durable glass structure that is somewhat resistant to leaching. The high temperature also destroys any organic constituents with byproducts treated in an off-gas treatment system that generally must accompany vitrification.

The cost of vitrification is very high and has not been commonly used at mining and mineral processing sites ($ 480 – 1044). The effectiveness of the vitrification is dependent on the material that is treated. If a glass like product can be made, the ability to isolate the waste is very effective.

Electrokinetics

Electrokinetics is a new emerging method which uses low intensity direct current applied to anode and cathode inserted into contaminated soil and/or water. Direct current initiates electroosmosis and ion migration to the appropriate electrode. Method can be used in fine-grained geologic materials. The disadvantage of this method is that contaminated soil to be treated need to be saturated with water. This method has not been commercially used yet.

The cost estimation is < $ 120/ton.

3.6 Case studies

Case Study No. One – Arsenical Pesticide Manufacturing Site

Waste materials from the manufacture of sulfuric acid and lead arsenate were disposed of at this site. Subsequent disposal of animal by-products and hides caused reducing conditions which mobilized the arsenic resulting in arsenic(3+) and organic (methylated) arsenic in groundwater. The contaminated groundwater is confined to the outwash deposits of a buried valley aquifer and discharges to a surface water pond. Even though elevated concentrations of arsenic enter the pond from the groundwater (490 µg/L) and pore water concentrations in the pond sediments are high (1,700 µg/L), concentrations of arsenic in water discharging from the pond are very low (<5 – 12.2 µg/L). EM studies of the pond sediments indicated that the arsenic had been removed by adsorption to natural iron-containing minerals (e.g., biotite). The adsorption capacity of the sediments was measured to be 3,350 mg As/Kg of sediment.

Case Study No. Two – Wood Treating Site

At this site, wood was treated with zinc meta-arsenite ($ZnAs_2O_4$) and resulted in contaminated soil. Batch leaching studies were performed to determine the mobility of the arsenic in the soil. Results indicated “reverse” isotherms with lower adsorbed concentrations in the soil at higher water concentrations. EM studies of the soil revealed arsenic-containing (e.g., 0.5 percent) iron oxyhydroxide solid phases. In addition, small particles of arsenic oxide (63 percent arsenic) were identified. Overall, the arsenic is present as arsenic oxide, in solid-solution with iron oxyhydroxide and adsorbed to iron containing minerals. The “reverse” isotherms are caused by dissolution of arsenic phases followed by adsorption onto the iron-containing minerals.

Case Study No. Three – Smelter Site

During the smelting of mineral concentrates to produce lead, zinc and other metals, a variety of waste materials were produced including calcine and bag house dust. These wastes and the associated contaminated soil contained large concentrations of arsenic (up to 20,900 mg/kg). One alternative to treat the contaminated soil and solid waste was through solidification/stabilization (S/S) techniques. EM analyses were used to identify the form of the arsenic in the original waste materials and contaminated soil and in the treated materials from the S/S processes. The evaluations were used to determine the type and quantity of S/S agent to use and to determine the effectiveness of the treatment process. The calcine waste contained arsenic in the form of arsenopyrite, scorodite and arsenic-bearing oxyhydroxides. Due to the potential instability of scorodite at elevated pH values (caused by the cement S/S agent), ferrous sulfate was added to the mixture. The iron (2+) assisted in removing any arsenic leached from the solidified waste by coprecipitation with iron oxyhydroxides. EM studies indicated this process was effective with abundant iron oxyhydroxides present with up to 0.7 percent arsenic in the solidified materials.

Case Study No. Four – Pharmaceutical Superfund Site

Site Background

- ROD selected remedy included excavation, on-site solidification/stabilization, and off site disposal at a RCRA Subtitle C landfill
- Submitted Explanation of Significant Difference (ESD) to amend Record of Decision (ROD) for off-site solidification/stabilization
- Treatability study tested a total of 88 mixture designs. The effectiveness of a wide range of binding agents and pre-treatment additives were compared for a single waste type (K084).

Treatability study objective was to verify feasibility of S/S and identify cost-effective fixation formulation:

Binders	Other Pre-Treatment Additives
Portland Cement (I, II, V)	Potassium permanganate (oxidation)
Class F Fly Ash	Hydrogen peroxide (oxidation)
Cement Kiln Dust	Calcium hypochlorite (oxidation)
Lime Kiln Dust	Potassium persulfate (oxidation)
Sodium Silicate	Sodium persulfate (oxidation)
HWT-25, Organophyllic Clay	Calcium chloride (precipitation)
	Ferric chloride (precipitation)
PH Control Additives	Ferric sulfate (precipitation)
Sulfuric acid	Ferrous sulfate (precipitation)
Phosphoric acid	Magnesium oxide (adsorbent)
Buffer solution	Activated carbon (adsorbent)

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Binders	Other Pre-Treatment Additives
Portland Cement (I, II, V)	Potassium permanganate (oxidation)
Class F Fly Ash	Hydrogen peroxide (oxidation)
Cement Kiln Dust	Calcium hypochlorite (oxidation)
Lime Kiln Dust	Potassium persulfate (oxidation)
Sodium Silicate	Sodium persulfate (oxidation)
HWT-25, Organophyllic Clay	Calcium chloride (precipitation)

PH Control Additives

Sulfuric acid

Phosphoric acid

Buffer solution

Ferric chloride (precipitation)

Ferric sulfate (precipitation)

Ferrous sulfate (precipitation)

Magnesium oxide (adsorbent)

Activated carbon (adsorbent)

Treatability Test Results:

- The optimized treatability study mix formula was as follows:
    - Potassium persulfate 0.15 g/g
    - Ferric sulfate 1.0 g/g
    - Type I Portland cement 0.5 g/g
- Initial arsenic TCLP results = 6,900 mg/L versus post-treatment TCLP = 0.67 to 1.9 mg/L after a 4-hour cure time
- Full-scale system used a similar formulation with the substitution of sodium persulfate for oxidation
- Full-scale system TCLP results = 1.24 to 3.44 mg/L for a 4-hour cure time

The full-scale system experienced several challenges that were not anticipated based on the bench-scale studies including excessive heat production during mixing

- Total cost for off-site S/S treatment and disposal was $910/ton. Cost for S/S treatment alone was approximately $780 per ton
- K101 and K102 wastes contained a high enough organic content that incineration was determined to be the appropriate treatment method. The incineration costs were approximately $2,000 per ton

3.7 Costs of cleanup technologies

Estimated cost ranges for the basic operation of the technologies described are depicted in fig.3.18. Information has been compiled from EPA electronic databases. The cost estimates does not include pre-treatment, site preparation, regulatory compliance costs, costs of additional treatment of process residuals (e.g. stabilization of incinerator ash), or profit. Because of site specific conditions, the actual cost of utilization of a remedial technology may be different than these estimates. The data may serve for order-of-magnitude cost evaluation.

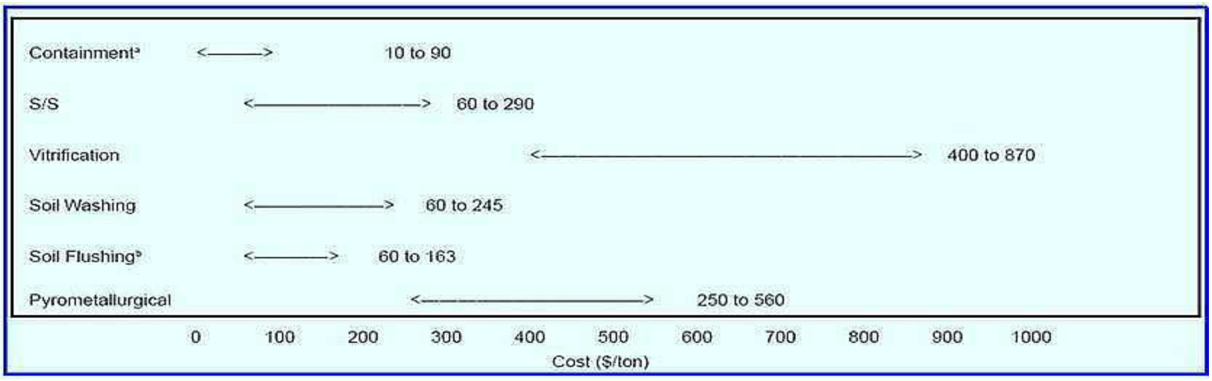


Fig. 3.18 – Metals remediation technologies – cost range

Remediation technologies matrix, presented in table 3.42, provides orientationaly information on the cleanup methods, their cost and advantages/disadvantages.

Table 3.42 – Remediation technologies matrix

Technology	Type	Media	Cost	Effectiveness	Comments
Bioremediation	I/E	S	M - H	Innovative technology	
Capping	C	S, sludge, waste	L - H	Effective	
Capping (erosion)	C	S, SW, A	L - M	Depends on site conditions, generally effective	O&M costs could be significant if the cap is damaged
Cement walls	C	GW	M - H	Effective	
Chemical treatment	C	SW, GW	M - H	Effective	O&M costs may be significant
Detention/sedimentation	C	SW	L - M	Effective	
Interceptor trenches	C	GW	L - H	Effective in capturing GW if the permeability is greater than native material	Significant O&M costs if the GW materials precipitate and reduce the permeabilty, requiring the media to be replaced or cleaned
Landfill disposal of	C	S, soils, waste	M - H	Effective as the cap or liner are not breached	May have significant O&M costs to maintain cap or treat leachate
Phytoremediation Phytoextraction	I/E	S	L - M	Has been successful for some metals	May be considered innovative
Pump and treat	C	GW	M - H	Depends on site conditions and contaminant characteristic	
Remining/reprocessing	I/E	S, wastes	L - H	If all the material can be removed, this is a very effective technology; only a limited amount of material may be available for remining	Depends on the characteristic of the material to be reworked. Recovering salable metal may offset remediation costs. The time could be significant and may not be acceptable.
Rhizofiltration	C	SW, GW	L - M	Innovative technology	
Sale of useable materials	C	feedstocks, wastes	L	Good	Limited to those materials that there is market for.
Settling basins	C	SW	L - H	Effective in removing suspended solids	May have significant O&M costs over the life of the dam
Sheet piling	C	GW	M - H	Effective	May have leaks in the wall
Slurry walls	C	GW	M - H	Effective	May have leaks in the wall
Soil flushing	C	S	M - H	Site conditions affect fluid's ability to mobilize contaminants	May be a concern with contamination of GW
Soil washing	C	S	M - H	Site conditions affect fluid's ability to mobilize contaminants	
Solidification	C	S, sludge, wastes	M - H	Depends on the ability of the solid to break down over time.	
Solvent extraction	C	S, sludge, wastes	L - H	Depends on the solutions ability to extract contaminants	
Stabilization	C	S, sludge, wastes	M - H	Depends on the nature of material to be treated	
Thermal destruction	C	S, sludge, wastes	M - H	Poor for metals	Not common at mining sites
Thermal desorption	C	S	M - H	Depends on site characteristic and contaminants	Not common at mining sites
Vapor extraction	C	S	M - H	Depends on site characteristic and vapor phase contaminants	Not common at mining sites
Vitrification	I/E	S, solid waste	VH	Effective	Not common at mining sites
Electrokinetics	I/E	S, GW, SW	M - H		No commercial use

3.8 Selection of applicable closure/remediation methods

3.8.1 Criteria used for method selection

Multi-criteria screening of selected applicable closure/remediation options has been performed using the following criteria:

- Overall protection of human health and the environment;
- Regulatory compliance;
- Effectiveness and performance;
- Long term maintenance issues;
- Reductions in toxicity, mobility, and/or volume of contaminants;
- Implementability;
- Cost.

The above mentioned criteria have been used for screening of applicable method for contamination source zones management only (i.e. short term risk reduction) – for the long term site remediation measures insufficient data are available definitely.

3.8.2 Data gaps and uncertainties

With respect that very limited financial funds were available for the Baseline study data gaps still exist – especially lack of information on detail hydrogeology of the area of interest, delineation of contamination source zones in both vertical and lateral extent, and delineation of contamination plumes, cleanup goals.

Site hydrogeology

No information available on the aquifer (s) in the contamination source zones – related to the aquifer rock environment, thickness, groundwater table depth. Understanding the characteristics of source zones is critical to effectively conducting both site characterization and remediation. The nature of the hydrogeologic environment, the composition and release of the chemical contaminants, and subsequent transport and transformation processes in the subsurface combine to determine how contaminants are distributed within source zones. Five hydrogeologic settings are broadly representative of the common conditions of concern:

- Type I granular media with low heterogeneity and moderate to high permeability
- Type II granular media with low heterogeneity and low permeability
- Type III granular media with moderate to high heterogeneity
- Type IV fractured media with low matrix porosity
- Type V fractured media with high matrix porosity

These settings differ in their permeability, heterogeneity, and porosity — parameters that control how contaminants are stored and released from source zones under natural and engineered conditions. For example, fractured media sites characterized by high matrix porosity (Type V) tend to store contaminants in stagnant aqueous zones and sorbed to aquifer solids. Reverse diffusion of contaminants from these areas can sustain elevated contaminant concentrations in groundwater for long periods of time. The scale of the representative hydrogeologic settings is in the range of a few meters, whereas the size of an entire source zone can be on the order of tens or hundreds of meters. Source zones can occur within a single hydrogeologic setting (e.g., a sand deposit) or can include multiple hydrogeologic settings (e.g., alluvium overlying fractured crystalline rock). In addition to determining the overall subsurface distribution of contamination, the existing hydrogeologic setting limits the types of tools that can be used to characterize the source zone and the technologies that might achieve reductions in source mass.

Delineation of contamination source zones

With respect to the fact that mining/ore processing wastes are insecurely dumped in the roaster area as well as in the tailings dump area, it is expected that the rock environment beneath the wastes and close vicinity are heavily contaminated too. For the final design of proper corrective measures it is necessary to delineate the contamination source zones and to define the distribution of contaminants of interest.

Delineation of contamination plumes

Contamination plumes in soil and groundwater are not delineated too, for the long term remediation and environment protection measures the contamination plumes have to be identified. For source zones, contaminant plumes develop downgradient of the source material in cases where the contaminants are soluble in water and are resistant to natural biodegradation. In general, groundwater plumes tend to have larger spatial extents and to be more continuous in nature in comparison to contaminant mass distributions within source zones. Over time, attenuation processes in the plume can result in a contaminant mixture with a very different composition than the original release materials. It should be noted that sorption or diffusion of contaminants *from the plume* onto aquifer solids (and subsequent reverse diffusion) is common in many hydrogeologic settings.

Cleanup objectives

Remedial objectives should be laid out *before* deciding to attempt source remediation and selecting a particular technology. Remedies are often implemented in the absence of clearly stated objectives, which are necessary to ensure that all stakeholders understand the basis of subsequent remediation decisions. Failure to state objectives in advance virtually guarantees stakeholder dissatisfaction and can lead to expensive and fruitless “mission creep”. This step is as important as accurately characterizing source zones at the site.

A clear distinction between functional and absolute objectives is needed to evaluate options. If a given objective is merely a means by which an absolute objective is to be obtained (i.e., it is a functional objective), this should be made clear to all stakeholders. This is particularly important when there are alternative methods under consideration to achieve the absolute objectives, and when it is known or is likely that different stakeholders have a different willingness to substitute objectives for one another.

Each objective should result in a metric; that is, a quantity that can be measured at the particular site in order to evaluate achievement of the objective. Objectives that lack metrics should be further specified in terms of subsidiary functional objectives that do have metrics. Furthermore, although decisions depend upon both technical and nontechnical factors, once a decision has been made, the focus should be on the technical metric to determine if remediation is successful.

Without filling the data gaps the final design of corrective measures might result in ineffective project.

Potential re-use of arsenic concentrate and remining of reusable mining/ore processing wastes would be considered too. So far, the Farmakom MB Zajaca Company present holder of mining concession for Lojane area (www.farmakommb.com) carries out the site investigation and thus the future options have to be discussed and agreed with the concessionaire prior the final design of corrective measures.

3.8.3 Selection of applicable methods for short term risk reduction

3.8.3.1 Screening

For the selection of cleanup remediation methods it is necessary to consider that contaminants of interest (i.e. As, Sb – metalloids, and Ni, (Tl) – heavy metals) cannot be destroyed, the aim of remediation/cleanup is to immobilize/isolate the contaminants and thus avoid their further migration and eliminate their bioavailability. Local conditions for applicability of the treatment technologies should be considered too.

The chemical nature of arsenic compounds makes them difficult to treat effectively. Arsenic is a semi-metallic element and is labile, readily changing chemical form in the environment (and in waste treatment processes). Arsenic mobility is affected by environmental conditions including acid-base equilibria and overall pH; oxidation-reduction potential and electron activity; the presence of complexing cations and anions (such as sulfides, calcium, and iron); and adsorption/ desorption reactions. Arsenic can be readily precipitated from aqueous waste (including As-generated waste and groundwater) if the form of the arsenic and other waste characteristics are considered. Oxidation of arsenic to its less soluble As^{+5} state can increase the effectiveness of precipitation. Ion exchange, carbon adsorption, and membrane filtration are also used. The treatment methods used are chemical precipitation (31% of the aqueous waste), other aqueous organic treatment (8%), and incineration of solids or liquids (13%).

Since recycling of arsenic-containing materials is technically challenging and cost prohibitive, there is a great demand for the development of effective treatment technologies for the safe disposal of arsenic-contaminated hazardous wastes. The industrial use of arsenic has been curtailed in recent times; however, historic operations have led to significant contamination at some industrial sites where arsenic compounds were previously used. Current uses of arsenic are more limited and include the use of chromated copper arsenate for wood-preserving operations and the use of gallium arsenide in the development of semiconductor material for the electronics industry. In addition, mining operations often involve the smelting of ores with high arsenic concentrations

Discussion of aspects of particular treatment techniques:

Landfill disposal of – not applicable in Macedonia, so far there is no landfill for hazardous waste in the country.

Soil washing – not feasible – high investment cost, huge volume of waste to be excavated and treated, the waste to be treated is fine grained – the contaminants are adsorbed onto the fine fraction, which would have been further treated/landfilled, necessity of treatment/liquidation of washing liquids.

Soil flushing - is in-situ variant of the soil washing –the process principle is in acceleration of one or more of the same geochemical dissolution reactions – e.g. adsorbtion/desorbtion, acid/base reactions, that alter contaminant concentration in ground – water system. In addition, soil flushing accelerates a number of subsurface contaminant transport mechanisms, including advection and molecular diffusion that are found in conventional groundwater pumping. This method is not also feasible – very low permeability of the material to be treated and the contamination could be spread.

Solidification/stabilization – the disadvantage is the huge volume of waste to be treated, might be used for tailings treatment (see the bench test results), necessity of capping construction. Some wastes on the site (As oxide and As concentrate) are not treatable with reasonable costs (see the results of bench test).

Phytoremediation – not feasible for the site conditions – uptake possible only up to the depth of root penetration, limited to the growing season, requires proper biomass disposal/treatment, litter from plants could be a problem, long lasting process.

Capping – eliminates the infiltration of precipitation and runoff, the contaminants are isolated from the surrounding environment, low cost.

Remining/reprocessing – the most feasible method which allows to remove and re-use significant quantity of the contaminants; if the As concentrate and Sb concentrate would be remined and transported of site for reprocessing, about 60 % of As which is in wastes at tailings dump and former roaster) would be removed from the site (total amount of As in both the contamination source zones is about 12,000 t!, As and Sb concentrates contains about 7,000 t of As).

The results of applicable methods screening are summarized in table 3.43 below.

Table 3.43 – Screening of applicable cleanup methods

Method **Criteria**	Capping	Landfill disposal of	Phyto-remediation	Remining, reprocessing	Soil flushing	Soil washing	Solidification/ stabilization	Vitrification
Overall protection of human health and the environment	2	2	3	2	3	2	2	2
Regulatory compliance	1	1	2	1	2	1	1	1
Effectiveness and performance	1	1	3	1	3	2	2	2
Long term maintenance issues	2	2	3	1	2	2	2	2
Reductions in toxicity, mobility, and/or volume of contaminants	1	1	4	2	3	2	3	1
Implementability	1	5	4	1	3	3	1	4
Cost	1	5	2	1	2	3	3	5
Score	**9**	**17**	**21**	**9**	**18**	**15**	**14**	**17**

Classification	1	2	3	4	5
	excellent	very good	good	acceptable	unacceptable

Apparently, the most feasible method is remining, but this method cannot be applied on all the spectrum of mining/ore processing wastes on the site because of low content of re-usable compounds (Sb mainly). The advantage of this method is also the fact that the cost of remining will be covered by the Concessionaire as well as the closure measures.

The second feasible method is capping which can effectively stop the contaminants migration either in the form of fugitive dust, or as sediments spread by runoff water and/or via groundwater. Very important advantage of this method is fact that no waste, requesting further treatment/disposal of, is generated.

3.8.3.2 Variants proposed for short term risk reduction

With respect to the screening results, local conditions, urgency of remedial action and current situation these variants for short term risk reduction are proposed:

- ***Variant 1 – Remining and capping*** – this variant would be adopted in such a case that the Concessionaire will complete successfully the site exploration and will commence the remining in sensible time period.
- ***Variant 2 – Capping*** only – this variant is proposed for that case that the Concessionaire will find the remining economically non feasible or the launch of remining will be planned unacceptably late.

Zero variant (no action) is not considered because of unacceptable risk posed to the human health and to the environment (see preliminary Risk Assessment).

3.9 Proposal on remedial/corrective measures to be adopted

3.9.1 Approach

Proposal on corrective measures takes into the account:

- Site specific conditions – i.e. site history, contaminants of interest, waste character, geological settings, several contamination sources, unacceptable risk posed;
- Data gaps – delineation of contaminated soil, limited information on groundwater contamination, no information on vertical distribution of the contaminants, lack of data on site hydrogeology;
- Funding - for large remediation projects, funding may not be available all at one time but in increments, it may therefore be appropriate to plan the implementation of remediation in increments - the challenge is to divide the project into increments that can stand alone from environmental and engineering feasibility perspectives should the next funding increment be delayed or unavailable.
- Risk based approach - based upon comparison of risk levels and costs to eliminate it the Highest Acceptable Risk should be evaluated, the public and relevant Authorities should achieve consensus what is the highest socially acceptable risk.
- Screening of applicable methods

With respect to the site conditions, governing the operational sequence of remedial works to be carried out, and financial possibilities, we propose to perform the site closure/remediation in two phases broken down into partial stages:

Phase 1 – Short term risk reduction

- **Advance works** – complementary site investigation aimed to fill the data gaps, installation of monitoring system;
- **Emergency measures –** focused on elimination of immediate risk posed by insecurely dumped hazardous waste at former roaster and tailings dump – i.e. elimination of fugitive dust release and direct contact with the hazwaste;
- **Conceptual site model and final design –** focused on elaboration of conceptual site model, which is the one of the primary planning tools used in systematic project planning, it organizes the information known about the site and helps to identify additional information that needs to be obtained; Risk assessment and preparation of the finale deign of closure/remediation ;
- **Project implementation** – focused on execution of the final corrective measures;

Phase 2 – Post-closure measures - focused on post monitoring.

Phase 3 – Groundwater remediation – focused on remediation of contaminated water in contamination source zones at the tailings dump and at former roaster in case that the recommended complementary detail investigations and RA will determine the necessity of remedial action.

Phase 4 – Remediation in Suva River valley - focused on complementary investigation, Risk Assessment, remediation.

Phase 5 – Remediation of wider area-agricultural land - focused on complementary site investigation, Risk Assessment, and potential remediation if requested by RA.

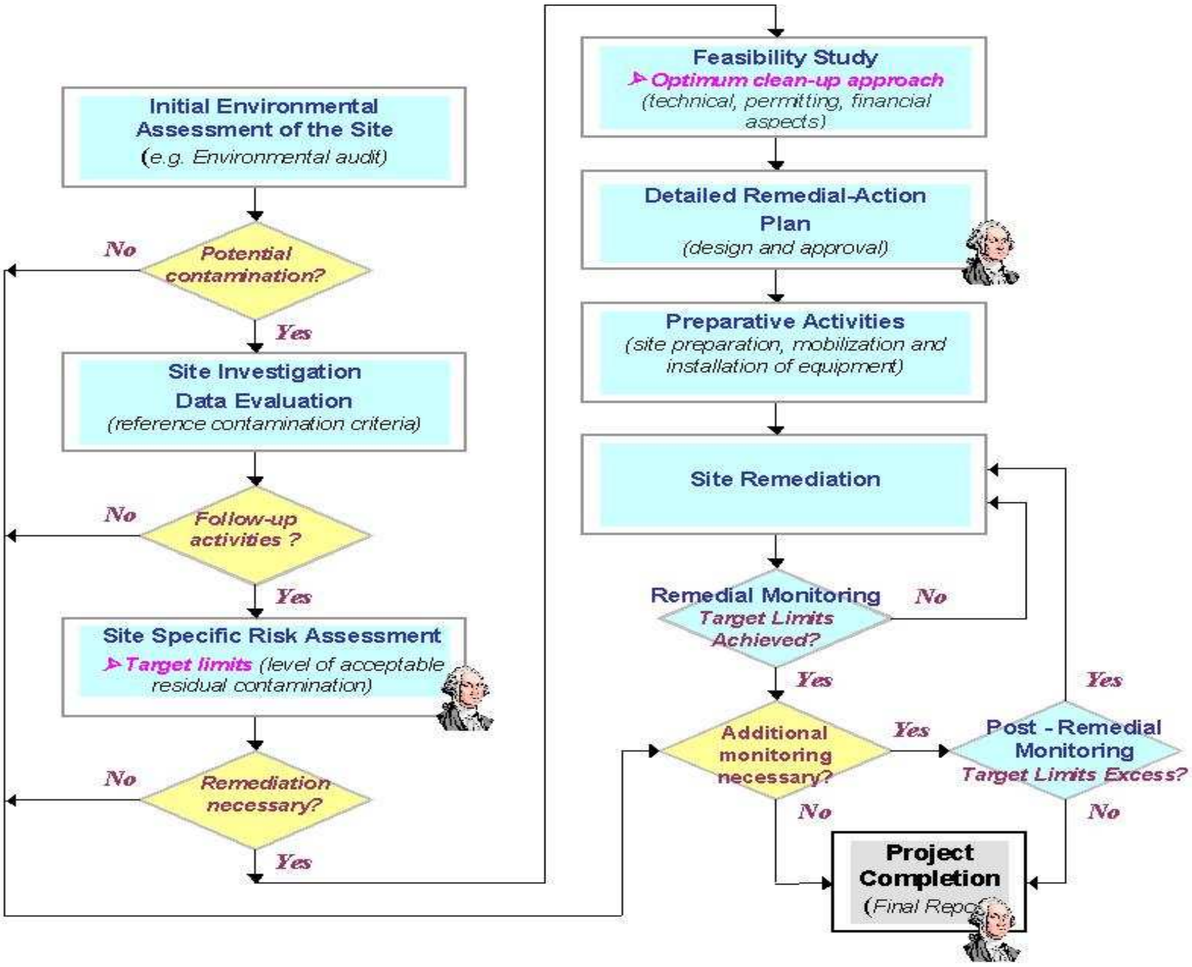


Fig. 3.19 – General approach to remediation of environmental burdens

3.9.2 Short term risk reduction measures recommended

3.9.2.1 Phase 1 – Short term risk reduction

This chapter provides general description of the measures to be adopted in both the variants proposed – there are only dispensable methodological differences – those are depicted in the chapter 3.9.3.

The assumed goal of the short term risk reduction is to eliminate further spreading of contamination – i.e. to eliminate the fugitive dust release, to eliminate percolation of precipitated water, elimination of transport of contaminated sediments, and elimination of ARD. Short term risk reduction measures are focused on two main contamination source zones – roaster area and tailings dump.

With respect to the goals defined for the short term risk reduction at the main contamination sources identified and with respect to the necessity to fill in the data gaps, the works to be carried out within the frame of Phase 1 would consist of these particular stages:

1. ***Advance works*** – aimed to fill the existing data gaps and eliminate uncertainties, monitoring system would be installed within this phase too. During the advance work stage completion, the detail site plan has to be elaborate too – in scale 1 : 2,500. The complementary site investigation is definitely necessary for the conceptual site model development – design of corrective measures without detail knowledge of site conditions would likely result in project failure. It is recommended to carry out the monitoring

system installation and complementary site investigation simultaneously in order to minimize the costs. Monitoring system would consist of installation of monitoring wells at roaster area and at the tailings dump. Complementary site investigation would be focused on delineation of mining/processing waste, identification of contaminants distribution (lateral and vertical), and quantification of waste to be excavated and transported to the tailings dump for the final disposal of, characterization of the site hydrogeologic conditions, investigation of groundwater contamination. Monitoring system would be installed – enabling monitoring of the ambient air quality and groundwater quality. The monitoring system has be installed prior commencement of remediation works – in order to enable to record the initial site conditions and efficacy evaluation of closure/remediation measures adopted. Based on the complementary site investigation the final design of Phase 1 should be prepared. Post closure measures proposed consist of post monitoring of the ambient air quality and groundwater quality. Scope of work anticipated:

- ***Site surveying –*** geodetic work, focused on elaboration of site plan, satellite image purchased within the FS completion can be utilized in order to reduce the scope of work and cost.
- ***Complementary site investigation*** – hydrogeolocigal investigation, investigation of soil contamination (lateral and vertical), at both the main contamination sources – tailings dump area and former roaster area. It is recommended to drill several boreholes at the contamination source zones in order to identify the vertical distribution of contaminants of interest as well as to characterize the rock environment and identify the contamination in groundwater; shallow drillings of small diameter (depth about 3 m, diameter 50 mm) are proposed in order to evaluate the extension (lateral and vertical) of contaminated soil in the close vicinity of the dumped waste at roaster area and at the tailings dump, based on this investigation the volume of contaminated soil to be excavated and transported onto the tailings dump for final disposal of will be quantified.

  The proposed wells will be drilled (with core recovery) to the aquifer bottom with the aim to evaluate extent of groundwater contamination with As, Sb and HM. Soil samples and groundwater samples will be collected to analyse the considered contaminants concentration. Additional samples will be collected to ensure all data needed for final corrective measures design. Newly developed monitoring wells will be developed in such a way that enables their utilization in the future – i.e. in the groundwater clean-up process for monitoring. Mobile drilling rig will be used, the wells will be drilled with diameter 160 mm without drilling fluids, PVC casing of diameter 120 mm will be installed, screen will depend on the groundwater level. The core recovered from the unsaturated zone will be sampled after core extraction in regular intervals (each 1 m). Samples will be stored in glass containers with tight caps. The wells will be air-lifted to remove fine drill cuttings, and standard groundwater sampling procedure will be applied (low stress pumping).
- ***Monitoring system installation and monitoring*** – it is anticipated that the boreholes drilled within the frame of complementary site investigation will be developed as monitoring wells; five monitoring wells is proposed at the tailings dump and four monitoring wells are proposed at former smelter. Anticipated depth of the monitoring wells is about 20m in the tailings dump area and 25 m in the roaster area. Situation of the monitoring wells proposed is depicted in figures 3.29 and 3.30 (see chapter 3.11). Prior commencement of the site cleanup/remediation, two automatic stations for

monitoring of the ambient air quality should be installed in order to monitor the air quality prior work commencement, during the site cleanup as well as post monitoring after the action completion. The surface water quality would be also monitored – for the purpose of occupational health and safety as well as for the RA update. One monitoring station is proposed to be located at the school building in Rudnicka kolonija and the second one would be located at the roaster area. The influence of the work proposed on the quality of surface water should be monitored too. Details on the monitoring proposed are summarized in chapter 3.11.

- ***Laboratory works*** – within the frame of complementary site investigation and monitoring samples of soil, groundwater and fugitive dust will be collected and analyzed in order to determine concentration of contaminants of interest and other heavy metals.

2. ***Emergency Measures at Lojane Mine*** -.the emergency measures are proposed in order to reduce the fugitive dust release and further spreading of the contamination. The waste insecurely dumped at former smelter pose unacceptable risk for the humans and the environment – fine grained material (As concentrate, As oxide) serve as source of fugitive dust release, high leachability of contaminants makes them bioavailable, unprotected well in the smelter area enables direct infiltration of contaminants into the groundwater, close proximity of Lojanska and Tabanovska Rivers makes them very vulnerable and those rivers can easily spread the contamination, the smelter area lays within the agricultural lands in flats and in case of flooding the contaminants would be flushed away and large area of agricultural land would be affected. As concentrate dumped at the tailings dump poses also high risk to the human's health and the environment – fugitive dust release, potential ARD and spreading the contamination by runoff and percolating precipitation. The most feasible method applicable for the risk reduction is capping of the mining/ore beneficiation and processing waste at the tailings dump, therefore the waste located at former roaster would be transported to the tailings prior construction of the final cover system. The work planned within the frame of Emergency Measures consists of several tasks:
   - ***Mobilization*** – mobilization of machinery, preparation of the site – connection to the electric power supply, construction of cleaning facility for the machinery, installation of mobile office and dressing room for the workers, installation of tank for fresh water.
   - ***Separation and collection of various waste dumped at former smelter*** – various wastes placed on the site will be separated.
   - ***Pre-treatment of As oxide waste*** – with respect to toxic properties of the As trioxide it will be packed in 1 m^3 plastic bags in fabric pack ("big bags").
   - ***Transport of waste to the tailings dump area*** – ore processing waste will be transported to the tailings dump for the final disposal; in order to minimize costs and reduce transport distance, the road on the basement of former narrow railroad connecting the flotation plant with roaster will be used.
   - ***Temporary cover of As concentrate pond at tailings dump*** – in case that the Concessionaire will attempt to the remining of specified waste (most likely the As concentrate and likely the As oxides with high concentration of Sb) temporary cover of As concentrate pond will be developed with the aim to stop the fugitive dust release.

- ***Temporary cover of pre-treated As oxide transported to the tailings dump*** – the temporary cover protecting the pre-treated As trioxide will be developed in order to protect the big bags against puncture**..**

3. Conceptual site model and final design – based on the information collected during the previous stages the final design of site closure will be elaborated. The work to be completed within the frame of this stage would consist of these tasks:

- ***Real estate*** – the acquisition of real estate, easements, and rights-of-way for project construction and operation need to be completed before a construction contract is advertised; these acquisitions may include land for pretreatment, treatment, and disposal operations; easements for an area to mobilize equipment; or a right-of-way for construction equipment and material transportation.
- ***Design of closure measures*** – conceptual site model and detailed design of the remedial alternative and preparation of plans and specifications for construction; by the completion of this step, virtually every aspect of the construction and operation of the remedial alternative should be designed and thoroughly reviewed to ensure the technical accuracy and engineering feasibility of the alternative, including QA/QC, HASP and EIA – elaboration of EIA reflecting the work procedures of the detailed design.
- ***Permits*** - applicable permits and certifications for project construction and operation should be obtained before a construction contract is advertised.
- ***Contracting*** - contracting mechanisms and regulations are organization-specific and are beyond the scope of this proposal; parts of the remediation project, or the entire effort, may be contracted; the most common contracting approach for remediation construction is to advertise the entire remediation project as a single contract for a turn-key operation - in this case, a prime contractor would be responsible for obtaining the necessary subcontractors with the specialized equipment or experience required.

4. Project implementation – based on the final design of closure/remediation measures, the project will be implemented. The anticipated tasks are:

- Mobilization – preparation of the site for the work planned:
  - building site development – parking for vehicles and machinery, storage areas, office, base for the workers, decontamination facility for the machinery, connection to electric power supply,
  - cleanup and improvement of access roads – removal of municipal waste from the access roads and their improvement where necessary to enable access for machinery,
  - deforestation – to enable access to the area to be covered with capping system and to areas with anticipated highly contaminated soil, some areas have to be deforested – the foot of tailings dump and its surface, close vicinity of the As concentrate pond, and the roaster area.
- Site clean – up:
  - collection of municipal waste and various debris from the roaster area and tailings dump and its close vicinity,
  - transport of collected waste to the tailings dump.
- Excavation of contaminated soil from the tailings dump vicinity

  - excavation of contaminated soil and transport onto the tailings dump,
  - backfilling of the excavations with inert material,
  - road reconstruction.

- Diversion ditches construction – to prevent entering the runoff water and spreading the contamination via water erosion;
- Pulling down the ore beneficiation plant ruins:
  - pulling down the ruins and crushing the debris;
  - liquidation of the leaking well installed within the tailings dump;
  - scraping the waste rock from the slope above flotation plant to the tailings;
  - spreading the debris from crushed ruins onto the tailings surface (western part)
- Reshaping of the tailings dump body – the eastern slope adjacent to the road from Vaksince to Lojane will be adapted to the slope rate approx. 1 : 2 and the slope will be disrupted with horizontal berm of minimum width 4 m (with transverse dip 2 – 3 % from the slope), this berm will run along the entire adapted slope (see figures 3.19 and 3.20). The excavated material will be evenly spread on the upper part of the tailings body. On the upper area the crushed debris from demolished objects will be also placed. Reshaping is necessary in order to:
  - optimize the total area to be covered,
  - optimize the slopes (length, dip) prior cap construction,
  - minimize wind and water erosion,
  - eliminate ponding,
  - maximize runoff.
- Capping construction:
  - base layer construction – will be constructed after reshaping completion, this layer will line up the compacted tailings surface and will separate the waste from liner, at the same time this layer will serve as dustproof measure until the work completion. For construction of this base layer the waste rock dumped at tailings and in Suva River valley will be used. Surface of this layer will be smoothened with thin layer of compacted clayey soil.

    next layer will consist of geosynthetic liner (bentonite mat) creating the impermeable insulation of the waste. This material has sandwich construction – consisting of two geotextile layers, between them is bounded layer of activated sodium bentonite. The upper geotextile layer is from woven polypropylene with high strength, the lower layer consists of mechanically resistant non-woven geotextile. Both the geotextile layers are connected with quilting (see fig.3.20). Based on large tests performed with these type of liner, the filtration coefficient has been determined – $k_f = 1.10^{-12}$ m/s. the big advantage of this material is its high ductibility – ranging between 60 – 130 % in longitudinally, and 50 – 100 % transversally. Further advantages of this liner are: the liner can be installed independently on the weather conditions, no tests are needed during the installation (like compaction tests in case of clay liner), easy application, faster construction, longevity, costs reduction (no excavation, transport, compaction, as in case of mineral liner), lower impact on the environment during construction.

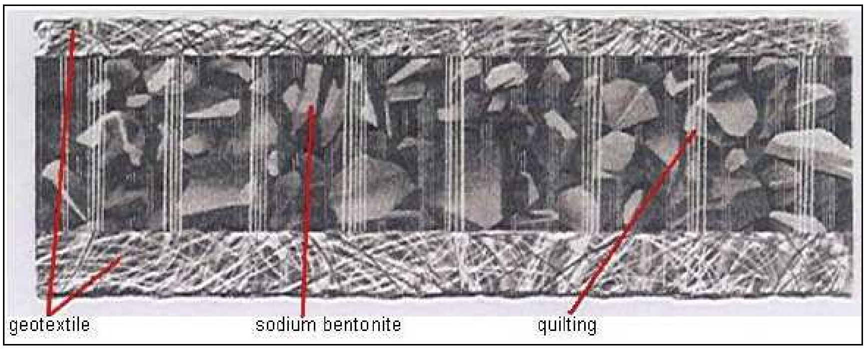
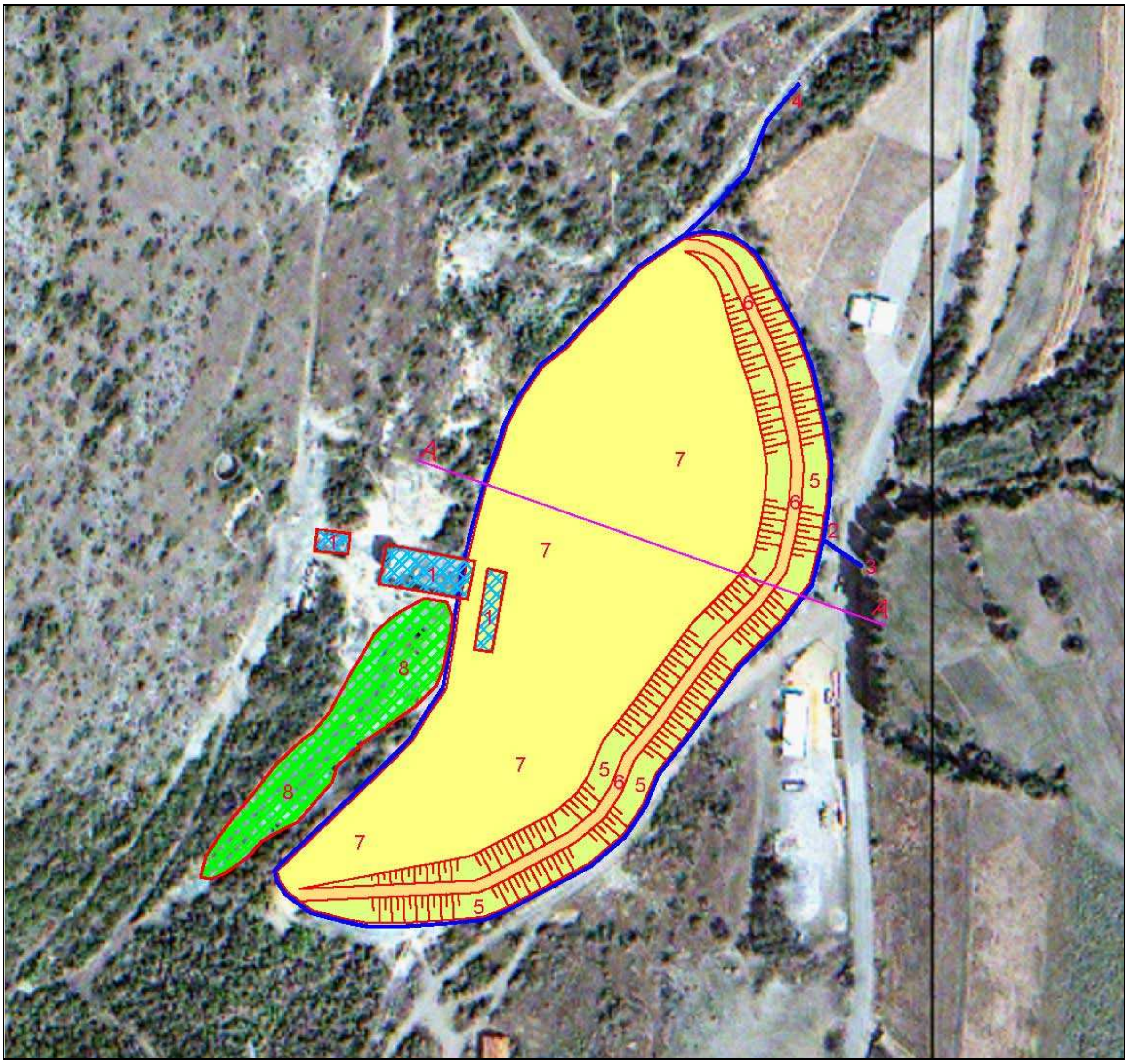


Fig. 3.20 – Bentonite mat - cross section

  - After completion of the geosynthetic liner cap, drainage layer of minimum thickness 20 cm has to be constructed. This layer serves also as protection of the liner – biota barrier. This drainage layer will be constructed from the waste rock deposited in Suva River valley – a dump of waste rock with good properties has to be selected (to avoid ARD). This layer will drain the infiltrated precipitation.
  - The final phase consists of covering the entire surface with layer of cultivable soil, thickness of this layer is proposed 30 cm, which allows the seeding with indigenous vegetation.

- Surveying – final shape of the capped area will be performed in order to allow its future monitoring (subsidence);
- Operational monitoring of air quality, groundwater quality and runoff water quality;
- QA/QC – quality assurance and quality control measures,
- Engineering, project management, and evaluation and reporting.



Legend:

1 – ruins of the ore beneficiation plant

2 – spring below the tailings dump

3 – culvert aqueduct

4 – perimeter ditch

5 - reshaped slope of the tailings dump

6 – horizontal berm

7 – leveled surface of the final cover

8 – waste rock pile

Fig. 3.21 – Area to be capped

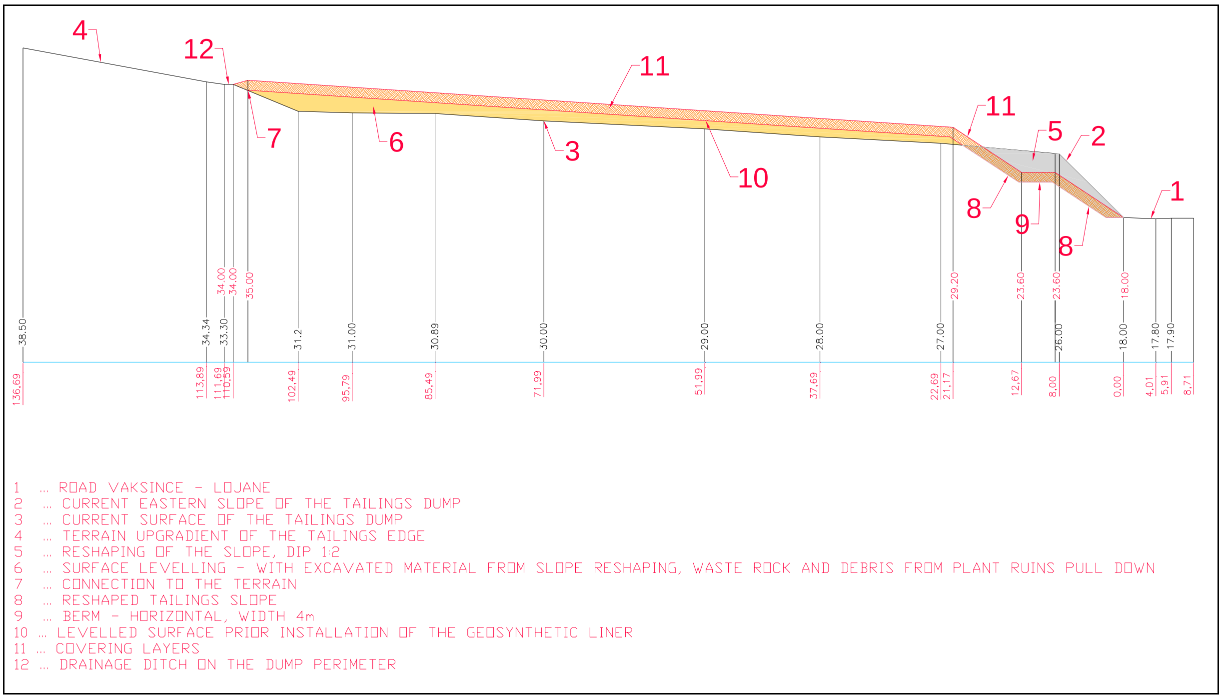


Fig. 3.22 – Cross section through capped tailings body

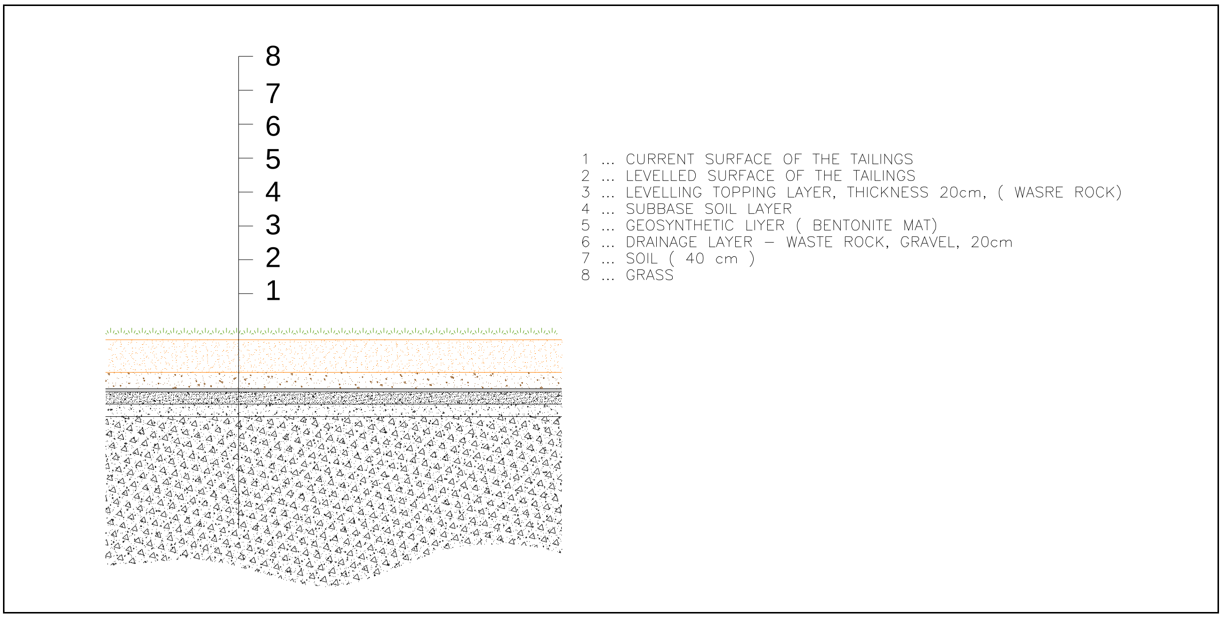


Fig. 3.23 – Profile of proposed capping

3.9.2.2 Phase 2 – Post-closure measures

With respect to remedial methods proposed, the post closure measures are undemanding, this works would consist of long term monitoring – 30 years monitoring is proposed. In order to evaluate positive effect of dust release reduction the air quality monitoring is proposed for the period of 5 years. In order to check the performance of capping the long term groundwater monitoring is necessary – minimum twice per year for the period 30 years. During the post monitoring capping inspections – regular visual and surveying observations are necessary to check the vegetative cover as well as the integrity of soil cover (erosion, subsidence). Maintenance – i.e. removal of deep rooting plants, repair of soil cover in case of water erosion and/or significant subsidence (e.g. ponding).

3.9.3 Scope of work recommended for the short term risk reduction measures

3.9.3.1 Scope of work – Variant 1 – Remining and capping

The scope of work proposed for the Variant 1 – Remining and capping slightly differs from the general work method proposed in chapter 3.9.2.1. The main difference is given by different volume of ore processing waste to be removed from the roaster area and transported to final disposal on the tailings dump (see table 3.44) below. It is anticipated that about 5,000 t of waste (As concentrate and As trioxide with high concentration of Sb) might be removed and transported to off site reprocessing and re-use. In case of remining of the As concentrate at the tailings dump, this storage pond would be only temporarily capped with HDPE liner covered with protective thin layer of soil in order to eliminate the fugitive dust release until the final cap construction. The area to be capped has to be reduced – because of remining of As concentrate.

Table 3.44 – Scope of work – Variant 1

Task / item	***Unit***	***Number of units***
Phase 1 - Short term risk reduction		
Advance works		
Surveying		
purchase of cadaster maps 1 : 2,500	sheet	6
detail site map construction 1 : 2,500 (tailings dump and close vicinity)	ha	4
Complementary site investigation		
shallow probes drilling (av. depth 3 m, Ø 50 mm)	m	60
soil samples collection	sample	90
drilling core documentation	m	60
laboratory analyses of soil - dry matter	sample	90
laboratory analyses of soil - leachate	sample	25
QA/QC	LS	1
HASP	LS	1
transport (personnel, samples)	LS	1
evaluation and reporting	LS	1
management	LS	1
Monitoring system installation and initial monitoring		
Groundwater monitoring system installation and monitoring		
monitoring wells installation (20 m deep, PVC casing Ø120 mm)	well	9
groundwater samples collection (low flow method)	sample	27
soil samples collection	sample	45
collection of water samples from Lojane River and Tabanovska River	sample	10
drilling core documentation	m	180
laboratory analyses of soil - dry matter	sample	45
laboratory analyses of soil - leachate	sample	11
laboratory analyses of groundwater samples	sample	27
laboratory analyses of surface water	sample	10
QA/QC	LS	1
HASP	LS	1
transport (personnel, samples)	LS	1
evaluation and reporting	LS	1
management	LS	1
Installation of ambient air quality monitoring system and initial monitoring		
purchase of monitoring station	piece	2
installation of monitoring station	piece	2
operation and maintenance of the monitoring stations	month	2
controll of monitoring stations and samples collection	LS	1
laboratory analyses	sample	12
Engineering and management of advance works		
engineering	month	2
evaluation and reporting	month	2
project management	month	2

Table 3.44 cont.

Task / item	*Unit*	*Number of units*
Phase 1 - Short term risk reduction		
Emergency measures		
Mobilization		
site development	LS	1
liquidation of unprotected well at former roaster	LS	1
liquidation of the well in the tailings area	LS	1
Mining and ore processing waste separation, collection and transport		
waste separation and collection	t	6000
pre-treatment of waste	m^3	200
waste loading onto trucks	t	1500
waste transport to the tailings dump	t	1500
Temporary cover at tailings dump		
temporary cover of the waste transported from smelter area	m^2	1600
temporary cover of the As pond	m^2	2400
HASP		
personal protective equipment	LS	1
health and safety training of the crew	LS	1
mitigation of fugitive dust release and cross contamination during site clean-up	month	2
warning signs installation	LS	1
mobile office rental	month	2
mobile dressing room rental	month	2
fresh water supply	m^3	200
electric power supply	kWh	2000
mobile toilet rental (including cleaning)	month	2
site guard	month	2
Demobilization		
reconstruction of cart-road through the site	m^2	600
dismantling of the site equipment	LS	1
of site transport of the equipment	LS	1
Engineering and management of emergency measures		
transport (personnel)	LS	1
evaluation and reporting	LS	1
site manager	month	2
project manager	month	2
Conceptual site model and final design		
real estate	LS	1
design of closure measures (including RA, EIA)	LS	1
permits	LS	1
contracting	LS	1

Table 3.44 cont.

Task / item	***Unit***	***Number of units***
Phase 1 - Short term risk reduction		
Project implementation		
Mobilization		
site development	LS	1
clean-up and access roads improvement	m^2	10000
deforestation	m^2	4000
Site clean-up		
collection of municipal waste and various debris	LS	1
transport of collected municipal waste and debris onto the tailings dump	LS	1
Excavation of contaminated soil		
excavation of contaminated soil from the tailings dump vicinity and roaster area	m^3	6000
transport of contaminated soil onto the tailings	m^3	6000
backfilling the excavations with clean soil (inert material)	m^3	6000
Pulling down the ruins		
pulling down the ruins at former roaster and tailings dump area	m^3	500
crushing the debris from ruins and the debris on the site	m^3	600
Capping construction - roaster area		
diversion ditches construction	m	1000
capping construction	m^2	9000
Capping construction - tailings dump		
diversion ditches construction	m	1000
capping construction	m^2	17000
Surveying		
operational surveying	month	5
QA/QC surveying	LS	1
Operational monitoring - samples collection		
air quality monitoring	month	6
groundwater monitoring	month	6
surface water quality monitoring	month	6
Laboratory analyses		
analyses of soil and fugitive dust	sample	54
analyses of water	sample	84
QA/QC analyses	LS	1
HASP		
personal protective equipment	LS	1
health and safety training of the crew	LS	1
mitigation of fugitive dust release and cross contamination during site clean-up	month	6
warning signs installation	LS	1
mobile office rental	month	6
mobile dressing room rental	month	6
fresh water supply	m^3	600
electric power supply	kWh	5000
mobile toilet rental (including cleaning)	month	6
site guard	month	6
Closure measures		
reconstruction of cart-road through the site	m^2	2000
final surveying of the area capped	ha	2
revegetation of the site vicinity	m^2	4000
Demobilization		
dismantling of the site equipment	LS	1
of site transport	LS	1
Engineering and project implementation management		
engiennering	month	6
evaluation and reporting	month	6
project management	month	6

3.9.3.2 Scope of work – Variant 2 – Capping

Comparing with the Variant 1, this variant differs in volume of ore processing waste to be excavated and transported from former roaster area to the tailings dump, and area to be capped – see the scope of work summarized in table 3.45.

Table 3.45 – Scope of work – Variant 2

Task / item	***Unit***	***Number of units***
Phase 1 - Short term risk reduction		
Advance works		
Surveying		
purchase of cadaster maps 1 : 2,500	sheet	6
detail site map construction 1 : 2,500 (tailings dump and close vicinity)	ha	4
Complementary site investigation		
shallow probes drilling (av. depth 3 m, Ø 50 mm)	m	60
soil samples collection	sample	90
drilling core documentation	m	60
laboratory analyses of soil - dry matter	sample	90
laboratory analyses of soil - leachate	sample	25
QA/QC	LS	1
HASP	LS	1
transport (personnel, samples)	LS	1
evaluation and reporting	LS	1
management	LS	1
Monitoring system installation and initial monitoring		
Groundwater monitoring system installation and monitoring		
monitoring wells installation (20 m deep, PVC casing Ø120 mm)	well	9
groundwater samples collection (low flow method)	sample	27
soil samples collection	sample	45
collection of water samples from Lojane River and Tabanovska River	sample	10
drilling core documentation	m	180
laboratory analyses of soil - dry matter	sample	45
laboratory analyses of soil - leachate	sample	11
laboratory analyses of groundwater samples	sample	27
laboratory analyses of surface water	sample	10
QA/QC	LS	1
HASP	LS	1
transport (personnel, samples)	LS	1
evaluation and reporting	LS	1
management	LS	1
Installation of ambient air quality monitoring system and initial monitoring		
purchase of monitoring station	piece	2
installation of monitoring station	piece	2
operation and maintenance of the monitoring stations	month	2
controll of monitoring stations and samples collection	LS	1
laboratory analyses	sample	12
Engineering and management of advance works		
engineering	month	2
evaluation and reporting	month	2
project management	month	2

Table 3.45 cont.

Task / item	***Unit***	***Number of units***
Phase 1 - Short term risk reduction		
Emergency measures		
Mobilization		
site development	LS	1
liquidation of unprotected well at former roaster	LS	1
liquidation of the well in the tailings area	LS	1
Mining and ore processing waste separation, collection and transport		
waste separation and collection	t	6000
pre-treatment of waste	m^3	200
waste loading onto trucks	t	6000
waste transport to the tailings dump	t	6000
Temporary cover at tailings dump		
temporary cover of the waste transported from smelter area	m^2	1600
temporary cover of the As pond	m^2	2400
HASP		
personal protective equipment	LS	1
health and safety training of the crew	LS	1
mitigation of fugitive dust release and cross contamination during site clean-up	month	2
warning signs installation	LS	1
mobile office rental	month	2
mobile dressing room rental	month	2
fresh water supply	m^3	200
electric power supply	kWh	2000
mobile toilet rental (including cleaning)	month	2
site guard	month	2
Demobilization		
reconstruction of cart-road through the site	m^2	600
dismantling of the site equipment	LS	1
of site transport of the equipment	LS	1
Engineering and management of emergency measures		
transport (personnel)	LS	1
evaluation and reporting	LS	1
site manager	month	2
project manager	month	2
Conceptual site model and final design		
real estate	LS	1
design of closure measures (including RA, EIA)	LS	1
permits	LS	1
contracting	LS	1

Table 3.45 cont.

Task / item	***Unit***	***Number of units***
Phase 1 - Short term risk reduction		
Project implementation		
Mobilization		
site development	LS	1
clean-up and access roads improvement	m^2	10000
deforestation	m^2	4000
Site clean-up		
collection of municipal waste and various debris	LS	1
transport of collected municipal waste and debris onto the tailings dump	LS	1
Excavation of contaminated soil		
excavation of contaminated soil from the tailings dump vicinity and roaster area	m^3	6000
transport of contaminated soil onto the tailings	m^3	6000
backfilling the excavations with clean soil (inert material)	m^3	6000
Pulling down the ruins		
pulling down the ruins at former roaster and tailings dump area	m^3	500
crushing the debris from ruins and the debris on the site	m^3	600
Capping construction - roaster area		
diversion ditches construction	m	1000
capping construction	m^2	9000
Capping construction - tailings dump		
diversion ditches construction	m	1000
capping construction	m^2	20000
Surveying		
operational surveying	month	5
QA/QC surveying	LS	1
Operational monitoring - samples collection		
air quality monitoring	month	6
groundwater monitoring	month	6
surface water quality monitoring	month	6
Laboratory analyses		
analyses of soil and fugitive dust	sample	54
analyses of water	sample	84
QA/QC analyses	LS	1
HASP		
personal protective equipment	LS	1
health and safety training of the crew	LS	1
mitigation of fugitive dust release and cross contamination during site clean-up	month	6
warning signs installation	LS	1
mobile office rental	month	6
mobile dressing room rental	month	6
fresh water supply	m^3	600
electric power supply	kWh	5000
mobile toilet rental (including cleaning)	month	6
site guard	month	6
Closure measures		
reconstruction of cart-road through the site	m^2	2000
final surveying of the area capped	ha	2
revegetation of the site vicinity	m^2	4000
Demobilization		
dismantling of the site equipment	LS	1
of site transport	LS	1
Engineering and project implementation management		
engiennering	month	6
evaluation and reporting	month	6
project management	month	6

3.9.4 Long term remedial measures

3.9.4.1 Phase 3 – Groundwater remediation

With respect to the waste character insecurely dumped at former roaster and tailings dump and considering the duration of this improper state we assume that groundwater in the both contamination source zones is contaminated with As, Sb and Ni. The groundwater contamination is also indicated by some groundwater samples collected and analyzed during the Baseline Study. That is why the groundwater remediation is also proposed although no data on the site hydrogeology and groundwater contamination are available so far – Risk Assessment and likely design of groundwater remediation would be completed within the frame of Phase 1 after completion of complementary site investigation.

The method for groundwater remediation would comply with the screening criteria (see chapter 3.8.1) – the method of permeable reactive barriers fully complies with these criteria. This method is easily constructible, cost effective, efficient (with ZVI filling – see chapter 3.3.4.4), with no operation cost and with high longevity.

For the PRB projects ZVI was the most commonly used reactive media. As groundwater reacts with ZVI, pH increases, Eh decreases, and the concentration of dissolved hydrogen increases. These basic chemical changes promote a variety of processes that impact contaminant concentrations. Increases in pH favor the precipitation of carbonates of calcium and iron as well as insoluble metal hydroxides. Decreases in Eh drive reduction of metals and metalloids with multiple oxidation states (e.g. As, Sb, Tl). Finally, an increase in the partial pressure of hydrogen in subsurface systems supports the activity of various chemotrophic organisms that use hydrogen as an energy source, especially sulfate-reducing bacteria and iron-reducing bacteria. Arsenate [As (V)] ions bind tightly to the iron fillings, causing the ZVI to be oxidized to ferrous iron (see chapter 3.3.4.4.1), aerobically or anaerobically in the presence of water, as shown by the following reactions:

(anaerobic) $Fe^0 + 2H_2O \bullet \bullet Fe^{+2} + H_2 + 2OH^-$

(aerobic) $2Fe^0 + 2H_2O + O_2 \bullet \bullet 2Fe^{+2} + 4OH^-$

The process results in a positively charged iron surface that sorbs the arsenate species by electrostatic interactions. In systems where dissolved sulfate is reduced to sulfide by sulfate-reducing bacteria, arsenic may be removed by the precipitation of insoluble arsenic sulfide (As_2S_3) or co-precipitated with iron sulfides (FeS). PRBs can be constructed by excavating a trench of the appropriate width and backfilling it with a reactive medium – e.g. mixture of sand/gravel (depending on the water conductivity of the aquifer) and ZVI.

Commercial PRBs are built in two basic configurations: the funnel-and-gate and the continuous wall. The funnel-and-gate uses impermeable walls, for example, sheet pilings or slurry walls, as a “funnel” to direct the contaminant plume to a “gate(s)” containing the reactive media, while the continuous wall transects the flow path of the plume with reactive media.

This technology can treat both organic and inorganic contaminants. Organic contaminants are broken down into less toxic elements and compounds, such as carbon dioxide and water. Inorganic contaminants are converted to species that are less toxic or less mobile.

Inorganic contaminants that can be treated by PRBs include, but are not limited to, chromium (Cr), nickel (Ni), lead (Pb), uranium (U), technetium (Tc), iron (Fe), manganese (Mn), selenium (Se), cobalt (Co), copper (Cu), cadmium (Cd), zinc (Zn), arsenic (As).

The characteristics that these elements have in common are that they can undergo redox reactions and can form solid precipitates with common groundwater constituents, such as carbonate, sulfide and hydroxide. Some common sources of these contaminants are mine tailings, septic systems, and battery recycling/disposal facilities.

PRBs are designed to treat groundwater in situ. This technology is not applicable to other contaminated media such as soil, debris, or industrial wastes.

PRBs are commercially available and are being used to treat groundwater containing arsenic at a full scale.

PRBs are a passive treatment technology, designed to function for a long time with little or no energy input. They produce less waste than active remediation (for example, extraction systems like pump and treat), as the contaminants are immobilized or altered in the subsurface. PRBs can treat groundwater with multiple contaminants and can be effective over a range of concentrations. PRBs require no aboveground equipment, except monitoring devices, allowing return of the property to economic use during remediations. PRBs are best applied to shallow, unconfined aquifer systems in unconsolidated deposits, as long as the reactive material is more conductive than the aquifer.

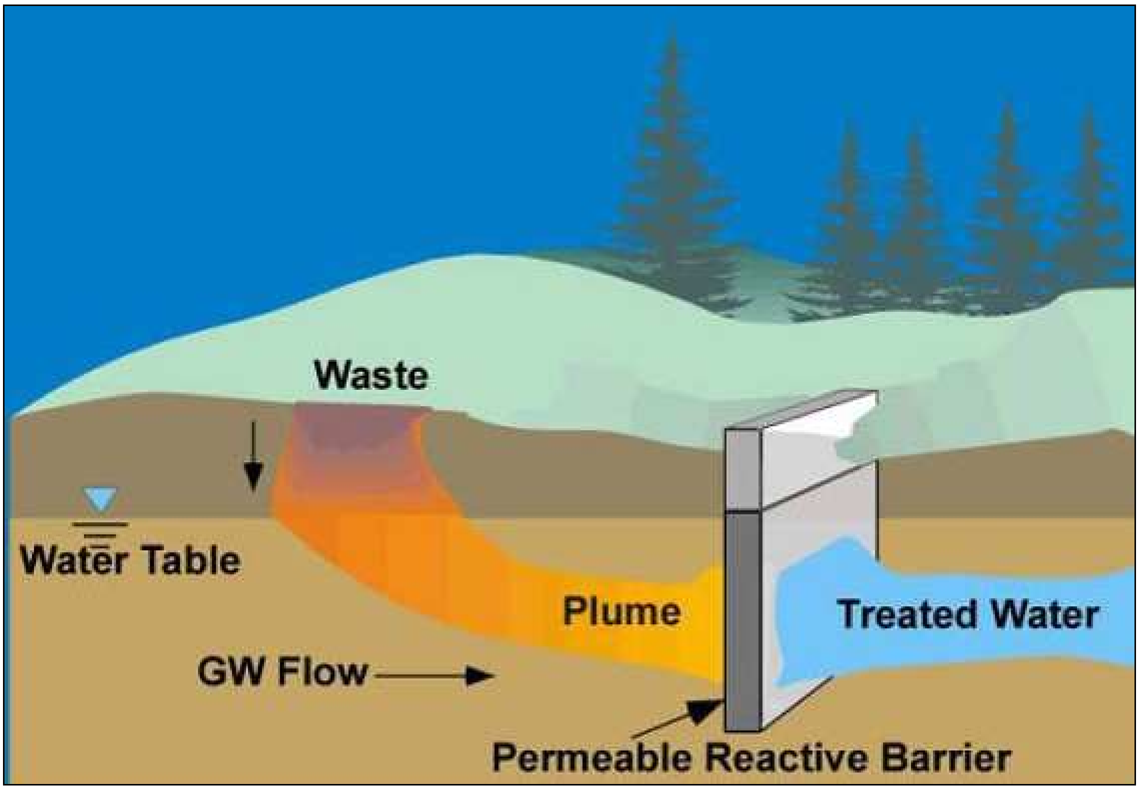
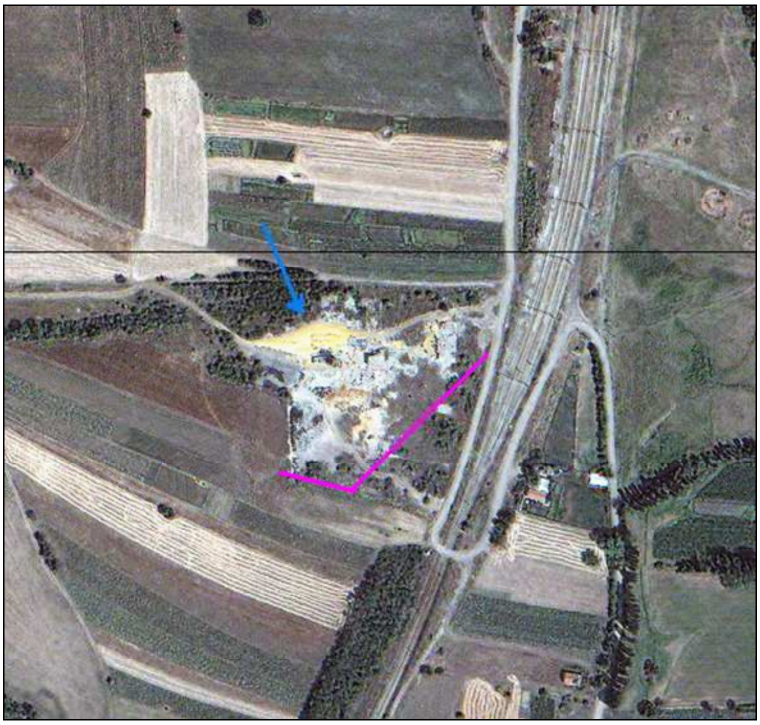


Fig. 3.24 – PRB scheme

PRBs rely on the natural movement of groundwater; therefore, aquifers with low hydraulic conductivity can require relatively long periods of time to be remediated. In addition, PRBs do not remediate the entire plume, but only the portion of the plume that has passed through the PRB.

Figures 3.25 and 3.26 depict the preliminary proposal on location of PRBs at both the contamination source zones.



→ expected groundwater flow; / proposed PRB

Fig. 3.25 – Proposed location of PRB at former roaster

/ proposed PRB

Fig. 3.26 – Proposed location of PRB at tailings dump

3.9.4.2 Phase 4 – Remediation in Suva River valley

Suva River valley represents specific contamination source:

- contaminated media – surface water, likely groundwater, stream sediments, waste rock;
- contamination sources - man made – resulting from ore extraction activities (mainly sulphide ores), and natural – given by geological setting – i.e. naturally elevated concentrations of contaminants in the rock environment.

For the long term remedial activities in the Suva River valley risk based approach is to be adopted - the risk assessment is an essential step for consequential step of environmental decision in the frame of risk management. Often these two steps are undertaken in parallel.

The objectives of the risk assessment include:

- determination of risk resulting from residual contamination;
- assessment of target limits of decontamination;
- further steps of remedial action optimizing.

Action Plan for the area of Suva River valley

1. Detail investigation in order to characterize:
    - natural background level of contaminants identified;
    - contamination level and delineation of contaminated area(s);
    - geochemical patterns;
    - hydrology and hydrogeology;
2. Risk Assessment in order to:
    - determine of possible migration pathways and exposition scenarios;
    - calculate of determinable expositions;
    - determination of risks resulting thereof;
    - propose limits in frames of risk control;
    - propose monitoring plan.
3. Decision

   Based upon comparison of risk levels and costs to eliminate it the Highest Acceptable Risk will be evaluated. The public and relevant Authorities should achieve consensus what is the highest socially acceptable risk.
4. Action
    a) acceptable risk found – monitoring;
    b) unacceptable risk found – risk reduction/remedial measures, monitoring. Accent to be put on simple and robust methods demanding low installation, operational, and maintenance costs – in situ passive treatment methods.

Based on the data acquired during the Baseline Study and Feasibility Study completion these contaminated media can be expected:

a) Stream sediments – partially reflecting the naturally high background of HM and As, Sb and partially contaminated by mining activities – i.e. release of contaminants from waste rock and their sorption onto the fine fraction of the stream sediments.

b) Surface water – partially reflecting naturally elevated background of the contaminants and partially reflecting the consequences of mining activities – i.e. leaching of the contaminants from waste rock dumped in the valley and desorption from contaminated stream sediments.

c) Groundwater – in this area we consider only the shallow aquifer in the Quaternary sediments in the valley (alluvial and delluvial sediments) – its contamination is caused by infiltration of contaminated surface water and dissolution of ore minerals (especially As is soluble in variety of pH and redox conditions – see chapter 3.2.7.2)

d) Soil – this medium is not considered- elevated values represent the naturally elevated background of contaminants resulting from the geochemical aureole of mineralized rock environment.

With respect to the waste characteristic (table 3.8), geological settings and contaminated media the preliminary proposal on remedial activities (in case that unacceptable risk will be identified by RA) consists of:

- Stream sediments – run-on control measures, preventing surface water from entering waste rock dumps – by retaining walls, excavation and off site transport – some portion of waste rock – mainly that containing sulfidic As-Sb (i.e. ARD producing) ores can be excavated and used for base layer construction during the remediation (capping construction) of the tailings dump – see chapter 3.9.2.1. ARD non-producing waste rock can be re-used in construction of further corrective measures – see below. To minimize the mobilization and transport of contaminated sediments by streams within the site and off site stream channel erosion control is recommended too. In order to slowdown the stream velocity rip-raps are recommended and dams to trap sediments.

- Surface water – due to the environmental condition in the area, Suva River has very low flow rate during prevailing part of year, elevated flow rate is anticipated during the snow melt period and in case of extraordinary precipitation. Thus the surface water can be treated by simple measures – small retention ponds can be developed diverting the water stream into reactive cells filled with mixture of pea gravel and ZVI (surface equivalent of PRB).
- Groundwater – pH and oxidation-reduction potential adjustment and/or adsorption – PRBs (with ZVI filling) constructed across the valley.

The scope of work of action plan proposed for the area of Suva River valley is presented in table 3.46. Corrective measures proposed for the case of remedial action necessity are depicted in figure 3.27 further.

Table 3.46 – Scope of work proposed – area of the Suva River valley

Task / item	***Unit***	***Number of units***
Phase 4 - LONG TERM REMEDIATION - SUVA RIVER VALLEY (including post monitoring)		
Detail site investigation		
monitoring wells installation	well	5
shallow probes drilling	m	150
soil samples collection	sample	165
groundwater samples collection	sample	10
surface water samples collection	sample	48
laboratory work	LS	1
surveying	LS	1
engineering	LS	1
evaluation and reporting	LS	1
management of the site investigation	LS	1
Risk Assessment	***LS***	***1***
Implementation project + EIA	***LS***	***1***
Project implementation - remedial action	***LS***	***1***
Phase 4 - Post monitoring	***year***	***30***

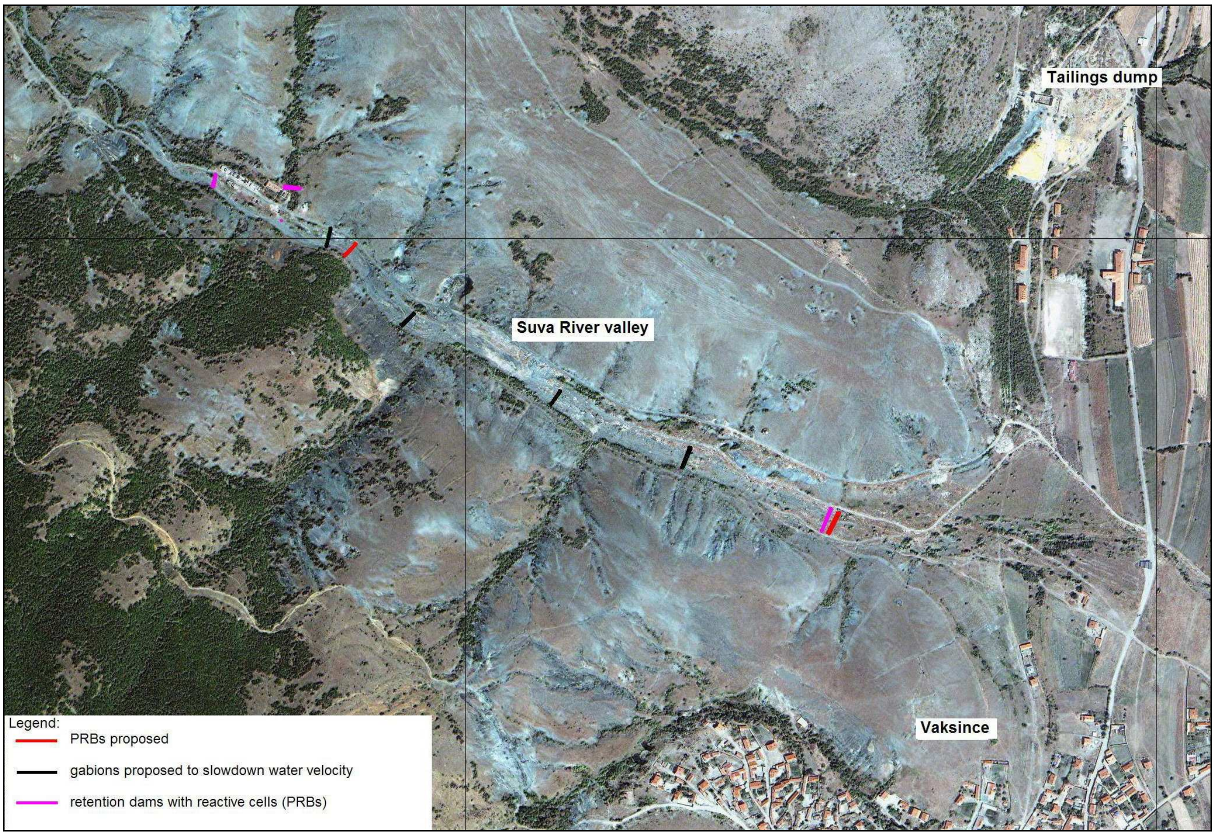


Fig. 3.27 – Anticipated corrective measures in Suva River valley

3.9.4.3 Phase 5 – Remediation in wider area – agricultural land

Similar situation as in the Suva River valley – again, risk based approach is to be adopted:

1. Detailed site investigation (including food chain):
    - natural background level of contaminants identified;
    - contamination level and delineation of contaminated area(s);
    - geochemical patterns;
    - hydrology and hydrogeology;
    - uptake of contaminants by crops and

The area proposed for the detailed complementary site investigation is depicted in fig. 3.28 further. The area which might be affected by contamination is quite a large – about 4.5 km^2 and is located between former roaster, tailings dump, Vaksince and highway Kumanovo – Tabanovce – Belgrade. This area is expected to be contaminated due to:

- long term fugitive dust emissions,
- irrigation with contaminated water,
- spillage during transport of ore concentrates from ore beneficiation plant to the roasting facility,
- transport of contaminated sediments.

2. Risk assessment in order to:
    - determine possible migration pathways and exposition scenarios;
    - calculate the determinable expositions;
    - determine the risks resulting thereof;
    - propose limits in frames of risk control;
    - propose monitoring plan.
3. Decision

   Based upon comparison of risk levels and costs to eliminate it the Highest Acceptable Risk will be evaluated. The public and relevant Authorities should achieve consensus what is the highest socially acceptable risk.
4. Action
    - acceptable risk found – no corrective measures, monitoring;
    - unacceptable risk found – remedial action, monitoring.

Prospective measures

Measures should respect that contaminated media is agricultural soil (strong socio-economic aspect).

Options:

1. To cultivate crops exposing minimal uptake and accumulation of contaminants – this might request some compensation to the farmers in case of reduction of their profit.
2. Application of innovative method within the frame of immobilization methods – PIMS, through simple soil mixing PIMS stabilizes metals using a natural and benign

phosphate additive (apatite) that chemically binds soluble metals into stable, insoluble minerals, once the metals are removed from the soil solution and sequestered in the new apatite phase (within minutes), the metals are stable, i.e. with significantly reduced mobility and bioavailability for geologically long time periods.

Table 3.47 – Scope of work proposed – wider area

Phase 5 - LONG TERM REMEDIATION - WIDER AREA (including post monitoring)		
Detail site investigation		
drilling and monitoring wells installation	well	10
shallow probes drilling	m	250
soil samples collection	sample	280
groundwater samples collection	sample	48
laboratory work	LS	1
special works - EM, XRD	LS	1
surveying	LS	1
evaluation and reporting	LS	1
management of the site investigation	LS	1
Risk assessment	***LS***	***1***
Implementation project + EIA	***LS***	***1***
Project implementation - remedial action	***LS***	***1***
Phase 5 - Post monitoring	***year***	***3***

Fig. 3.28 – Anticipated area for detail investigation – wider area – agricultural land

3.9.5 Timing of the corrective measures proposed

The timing proposed reflects the fact that the Concessionaire performs the exploration in the area of interest. Proposed timing and succession of works proposed is based on these assumptions:

- the exploration works focused on evaluation of potential re-use of some mining/ore processing wastes will not be completed prior the end of the year 2007;
- a period of a few months will be necessary in order to allow the relevant Macedonian Authorities and stakeholders to study the proposals on corrective measures and to make decision on the future steps to be taken in the Lojane Mine area;
- further negotiations with the Concessionaire will be needed in order to avoid works that might block the future re-use of mining/ore processing wastes;
- a time period will be needed for permitting process and approvals of corrective measures;
- it will be also necessary to mobilize financial funds for covering the remedial cost.

With respect to the above written we expect that the remedial action at Lojane Mine will not be commenced earlier then in January 2008. All the phases proposed (except post monitoring) might be completed by the end of the year 2010 – see table 3.48 further.

Table 3.48 – Proposed timing and succession of corrective measures in Lojane Mine area

Phase / task	2008				2009				2010				2011 - 2020	2021 - 2030	2031 - 2040
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4			
Phase 1 - Short term risk reduction	----	----	----	----											
Advance works	--														
Emergency measures	--	-													
Conceptual model and final design		--													
Project implementation			----	----											
Phase 2 - Post closure measures															
Ambient air quality monitoring					-		-		-		-		- - - - - - - - - -	- - - - - - - - - -	- - - - - - - -
Groundwater monitoring					-		-		-		-		- - - - - - - - - -	- - - - - - - - - -	- - - - - - - -
Inspections of capping					-		-		-		-		- - - - - - - - - -	- - - - - - - - - -	- - - - - - - -
Capping maintenance					-		-		-		-		- - - - - - - - - -	- - - - - - - - - -	- - - - - - - -
Phase 3 - Groundwater remediation					----	----									
Groundwater remediation in the tailings dump area					---										
Groundwater remediation in the roaster area						---									
Phase 4 - Long term remediation - Suva River valley					----	----	----	----	-		-		- - - - - - - - - -	- - - - - - - - - -	- - - - - - - -
Detail site investigation					--										
Risk Assessment						--									
Implementation project + EIA						--									
Project implementation - remedial action							----	----							
Phase 4 - Post monitoring									-		-		- - - - - - - - - -	- - - - - - - - - -	- - - - - - - -
Phase 5 - Long term remediation - wider area (agricultural land)							----	----	----	----	----	----	- - -		
Detail site investigation							---								
Risk assessment								---							
Implementation project + EIA									---						
Project implementation - remedial action										----	----				
Phase 5 - Post monitoring												-	- - -		

Note: The succession of the measures proposed might be affected by lack of financial funds – that is why the works proposed are split into relatively small independent increment that can be completed gradually in technically feasible manner in accordance with financial increments.

3.9.6 Estimated cost of the corrective measures proposed

3.9.6.1 Cost estimation

The cost of closure/remediation measures in the Lojane Mine area are divided into two parts – estimation of cost for the short term risk reduction measures, i.e. cost of Phase 1, and estimation of cost for the long term remediation measures, i.e. cost for the Phases 2 - 5.

The cost estimation of both the variants for short term risk reduction is based on detail search for the costs of construction works, drilling works, materials, energy and manpower in Macedonia. The cost estimates are based on the price level of the year 2007.

Detail cost overview is presented in priced bill of quantities – see tables 3.49 and 3.50 for Variant 1 and Variant 2 respectively. All the cost estimations do not include VAT.

Table 3.49 – Priced bill of quantities – Variant 1

Task / item	***Unit***	***Number of units***	***Unit costs (US $)***	***Total (US $)***
Phase 1 - Short term risk reduction (including contingency)				**1,177,378**
Advance works				**155,259**
Surveying				***2,308***
purchase of cadaster maps 1 : 2,500	sheet	6	74.0	444
detail site map construction 1 : 2,500 (tailings dump and close vicinity)	ha	4	466.0	1,864
Complementary site investigation				***19,379***
shallow probes drilling (av. depth 3 m, Ø 50 mm)	m	60	27.0	1,620
soil samples collection	sample	90	4.0	359
drilling core documentation	m	60	6.7	399
laboratory analyses of soil - dry matter	sample	90	73.2	6,585
laboratory analyses of soil - leachate	sample	25	213.0	5,325
QA/QC	LS	1	1,191.0	1,191
HASP	LS	1	600.0	600
transport (personnel, samples)	LS	1	800.0	800
evaluation and reporting	LS	1	1,000.0	1,000
management	LS	1	1,500.0	1,500
Monitoring system installation and initial monitoring				***125,172***
Groundwater monitoring system installation and monitoring				*37,577*
monitoring wells installation (20 m deep, PVC casing Ø120 mm)	well	9	2,000.0	18,000
groundwater samples collection (low flow method)	sample	27	66.5	1,796
soil samples collection	sample	45	4.0	180
collection of water samples from Lojane River and Tabanovska River	sample	10	13.3	133
drilling core documentation	m	180	6.7	1,197
laboratory analyses of soil - dry matter	sample	45	73.2	3,292
laboratory analyses of soil - leachate	sample	11	212.8	2,394
laboratory analyses of groundwater samples	sample	27	126.4	3,412
laboratory analyses of surface water	sample	10	126.4	1,264
QA/QC	LS	1	218.2	218
HASP	LS	1	600.0	600
transport (personnel, samples)	LS	1	1,100.0	1,100
evaluation and reporting	LS	1	1,330.2	1,330
management	LS	1	2,660.5	2,660
Installation of ambient air quality monitoring system and initial monitoring				*87,595*
purchase of monitoring station	piece	2	39,907.0	79,814
installation of monitoring station	piece	2	2,660.5	5,321
operation and maintenance of the monitoring stations	month	2	250.0	500
controll of monitoring stations and samples collection	LS	1	1,000.0	1,000
laboratory analyses	sample	12	80.0	960
Engineering and management of advance works				***8,400***
engineering	month	2	1,200.0	2,400
evaluation and reporting	month	2	500.0	1,000
project management	month	2	2,500.0	5,000

Table 3.49 cont.

Task / item	***Unit***	***Number of units***	***Unit costs (US $)***	***Total (US $)***
Phase 1 - Short term risk reduction (including contingency)				**1,177,378**
Emergency measures				**50,879**
Mobilization				***5,060***
site development	LS	1	1,995	1,995
liquidation of unprotected well at former roaster	LS	1	1,064	1,064
liquidation of the well in the tailings area	LS	1	2,000	2,000
Mining and ore processing waste separation, collection and transport				***11,373***
waste separation and collection	t	6000	0.4	2,394
pre-treatment of waste	m^3	200	8.0	1,596
waste loading onto trucks	t	1500	2.0	2,993
waste transport to the tailings dump	t	1500	2.9	4,390
Temporary cover at tailings dump				***7,981***
temporary cover of the waste transported from smelter area	m^2	1600	2.0	3,193
temporary cover of the As pond	m^2	2400	2.0	4,789
HASP				***12,675***
personal protective equipment	LS	1	1,330.2	1,330
health and safety training of the crew	LS	1	698.4	698
mitigation of fugitive dust release and cross contamination during site clean-up	month	2	2,035.3	4,071
warning signs installation	LS	1	399.1	399
mobile office rental	month	2	798.1	1,596
mobile dressing room rental	month	2	1,000.0	2,000
fresh water supply	m^3	200	6.7	1,330
electric power supply	kWh	2000	0.1	186
mobile toilet rental (including cleaning)	month	2	200.0	400
site guard	month	2	332.0	664
Demobilization				***4,390***
reconstruction of cart-road through the site	m^2	600	4.0	2,394
dismantling of the site equipment	LS	1	1,330	1,330
of site transport of the equipment	LS	1	665	665
Engineering and management of emergency measures				***9,400***
transport (personnel)	LS	1	1,000.0	1,000
evaluation and reporting	LS	1	1,000.0	1,000
site manager	month	2	1,200.0	2,400
project manager	month	2	2,500.0	5,000
Conceptual site model and final design				**63,000**
real estate	LS	1	1,000.0	1,000
design of closure measures (including RA, EIA)	LS	1	60,000.0	60,000
permits	LS	1	1,000.0	1,000
contracting	LS	1	1,000.0	1,000

Table 3.49 cont.

Task / item	***Unit***	***Number of units***	***Unit costs (US $)***	***Total (US $)***
Phase 1 - Short term risk reduction (including contingency)				**1,177,378**
Project implementation				**801,206**
Mobilization				***17,700***
site development	LS	1	2,500.0	2,500
clean-up and access roads improvement	m^2	10000	1.0	10,000
deforestation	m^2	4000	1.3	5,200
Site clean-up				***10,000***
collection of municipal waste and various debris	LS	1	5,000.0	5,000
transport of collected municipal waste and debris onto the tailings dump	LS	1	5,000.0	5,000
Excavation of contaminated soil				***37,200***
excavation of contaminated soil from the tailings dump vicinity and roaster area	m^3	6000	1.5	9,000
transport of contaminated soil onto the tailings	m^3	6000	2.2	13,200
backfilling the excavations with clean soil (inert material)	m^3	6000	2.5	15,000
Pulling down the ruins				***115,400***
pulling down the ruins at former roaster and tailings dump area	m^3	500	160.0	80,000
crushing the debris from ruins and the debris on the site	m^3	600	59.0	35,400
Capping construction - roaster area				***181,500***
diversion ditches construction	m	1000	1.5	1,500
capping construction	m^2	9000	20.0	180,000
Capping construction - tailings dump				***341,500***
diversion ditches construction	m	1000	1.5	1,500
capping construction	m^2	17000	20.0	340,000
Surveying				***11,000***
operational surveying	month	5	2,000.0	10,000
QA/QC surveying	LS	1	1,000.0	1,000
Operational monitoring - samples collection				***2,580***
air quality monitoring	month	6	200.0	1,200
groundwater monitoring	month	6	100.0	600
surface water quality monitoring	month	6	130.0	780
Laboratory analyses				***16,023***
analyses of soil and fugitive dust	sample	54	73.2	3,951
analyses of water	sample	84	126.4	10,615
QA/QC analyses	LS	1	1,456.6	1,457
HASP				***29,303***
personal protective equipment	LS	1	2,500.0	2,500
health and safety training of the crew	LS	1	750.0	750
mitigation of fugitive dust release and cross contamination during site clean-up	month	6	1,000.0	6,000
warning signs installation	LS	1	1,200.0	1,200
mobile office rental	month	6	800.0	4,800
mobile dressing room rental	month	6	1,100.0	6,600
fresh water supply	m^3	600	6.7	3,991
electric power supply	kWh	5000	0.1	466
mobile toilet rental (including cleaning)	month	6	199.5	1,197
site guard	month	6	300.0	1,800
Closure measures				***9,000***
reconstruction of cart-road through the site	m^2	2000	3.0	6,000
final surveying of the area capped	ha	2	500.0	1,000
revegetation of the site vicinity	m^2	4000	0.5	2,000
Demobilization				***4,800***
dismantling of the site equipment	LS	1	2,500.0	2,500
of site transport	LS	1	2,300.0	2,300
Engineering and project implementation management				***25,200***
engiennering	month	6	1,200.0	7,200
evaluation and reporting	month	6	500.0	3,000
project management	month	6	2,500.0	15,000
Contingency	%	10	10,703.4	**107,034**

Detail priced bill of quantities for short term risk reduction – Variant 2 – Capping is presented in table 3.50.

Table 3.50 – Priced bill of quantities - Variant 2

Task / item	***Unit***	***Number of units***	***Unit costs (US $)***	***Total (US $)***
Phase 1 - Short term risk reduction (including contingency)				**1,268,622**
Advance works				**155,259**
Surveying				***2,308***
purchase of cadaster maps 1 : 2,500	sheet	6	74.0	444
detail site map construction 1 : 2,500 (tailings dump and close vicinity)	ha	4	466.0	1,864
Complementary site investigation				***19,379***
shallow probes drilling (av. depth 3 m, Ø 50 mm)	m	60	27.0	1,620
soil samples collection	sample	90	4.0	359
drilling core documentation	m	60	6.7	399
laboratory analyses of soil - dry matter	sample	90	73.2	6,585
laboratory analyses of soil - leachate	sample	25	213.0	5,325
QA/QC	LS	1	1,191.0	1,191
HASP	LS	1	600.0	600
transport (personnel, samples)	LS	1	800.0	800
evaluation and reporting	LS	1	1,000.0	1,000
management	LS	1	1,500.0	1,500
Monitoring system installation and initial monitoring				***125,172***
Groundwater monitoring system installation and monitoring				*37,577*
monitoring wells installation (20 m deep, PVC casing Ø120 mm)	well	9	2,000.0	18,000
groundwater samples collection (low flow method)	sample	27	66.5	1,796
soil samples collection	sample	45	4.0	180
collection of water samples from Lojane River and Tabanovska River	sample	10	13.3	133
drilling core documentation	m	180	6.7	1,197
laboratory analyses of soil - dry matter	sample	45	73.2	3,292
laboratory analyses of soil - leachate	sample	11	212.8	2,394
laboratory analyses of groundwater samples	sample	27	126.4	3,412
laboratory analyses of surface water	sample	10	126.4	1,264
QA/QC	LS	1	218.2	218
HASP	LS	1	600.0	600
transport (personnel, samples)	LS	1	1,100.0	1,100
evaluation and reporting	LS	1	1,330.2	1,330
management	LS	1	2,660.5	2,660
Installation of ambient air quality monitoring system and initial monitoring				*87,595*
purchase of monitoring station	piece	2	39,907.0	79,814
installation of monitoring station	piece	2	2,660.5	5,321
operation and maintenance of the monitoring stations	month	2	250.0	500
controll of monitoring stations and samples collection	LS	1	1,000.0	1,000
laboratory analyses	sample	12	80.0	960
Engineering and management of advance works				**8,400**
engineering	month	2	1,200.0	2,400
evaluation and reporting	month	2	500.0	1,000
project management	month	2	2,500.0	5,000

Table 3.50 cont.

Task / item	***Unit***	***Number of units***	***Unit costs (US $)***	***Total (US $)***
Phase 1 - Short term risk reduction (including contingency)				**1,268,622**
Emergency measures				**73,828**
Mobilization				***5,060***
site development	LS	1	1,995	1,995
liquidation of unprotected well at former roaster	LS	1	1,064	1,064
liquidation of the well in the tailings area	LS	1	2,000	2,000
Mining and ore processing waste separation, collection and transport				***33,522***
waste separation and collection	t	6000	0.4	2,394
pre-treatment of waste	m^3	200	8.0	1,596
waste loading onto trucks	t	6000	2.0	11,972
waste transport to the tailings dump	t	6000	2.9	17,559
Temporary cover at tailings dump				***7,981***
temporary cover of the waste transported from smelter area	m^2	1600	2.0	3,193
temporary cover of the As pond	m^2	2400	2.0	4,789
HASP				***12,675***
personal protective equipment	LS	1	1,330.2	1,330
health and safety training of the crew	LS	1	698.4	698
mitigation of fugitive dust release and cross contamination during site clean-up	month	2	2,035.3	4,071
warning signs installation	LS	1	399.1	399
mobile office rental	month	2	798.1	1,596
mobile dressing room rental	month	2	1,000.0	2,000
fresh water supply	m^3	200	6.7	1,330
electric power supply	kWh	2000	0.1	186
mobile toilet rental (including cleaning)	month	2	199.5	399
site guard	month	2	332.6	665
Demobilization				***4,390***
reconstruction of cart-road through the site	m^2	600	4.0	2,394
dismantling of the site equipment	LS	1	1,330	1,330
of site transport of the equipment	LS	1	665	665
Engineering and management of emergency measures				***10,200***
transport (personnel)	LS	1	1,800.0	1,800
evaluation and reporting	LS	1	1,000.0	1,000
site manager	month	2	1,200.0	2,400
project manager	month	2	2,500.0	5,000
Conceptual site model and final design				**63,000**
real estate	LS	1	1,000.0	1,000
design of closure measures (including RA, EIA)	LS	1	60,000.0	60,000
permits	LS	1	1,000.0	1,000
contracting	LS	1	1,000.0	1,000

Table 3.50 cont.

Task / item	Unit	Number of units	Unit costs (US $)	Total (US $)
Phase 1 - Short term risk reduction (including contingency)				**1,268,622**
Project implementation				**861,206**
Mobilization				***17,700***
site development	LS	1	2,500.0	2,500
clean-up and access roads improvement	m^2	10000	1.0	10,000
deforestation	m^2	4000	1.3	5,200
Site clean-up				***10,000***
collection of municipal waste and various debris	LS	1	5,000.0	5,000
transport of collected municipal waste and debris onto the tailings dump	LS	1	5,000.0	5,000
Excavation of contaminated soil				***37,200***
excavation of contaminated soil from the tailings dump vicinity and roaster area	m^3	6000	1.5	9,000
transport of contaminated soil onto the tailings	m^3	6000	2.2	13,200
backfilling the excavations with clean soil (inert material)	m^3	6000	2.5	15,000
Pulling down the ruins				***115,400***
pulling down the ruins at former roaster and tailings dump area	m^3	500	160.0	80,000
crushing the debris from ruins and the debris on the site	m^3	600	59.0	35,400
Capping construction - roaster area				***181,500***
diversion ditches construction	m	1000	1.5	1,500
capping construction	m^2	9000	20.0	180,000
Capping construction - tailings dump				***401,500***
diversion ditches construction	m	1000	1.5	1,500
capping construction	m^2	20000	20.0	400,000
Surveying				***11,000***
operational surveying	month	5	2,000.0	10,000
QA/QC surveying	LS	1	1,000.0	1,000
Operational monitoring - samples collection				***2,580***
air quality monitoring	month	6	200.0	1,200
groundwater monitoring	month	6	100.0	600
surface water quality monitoring	month	6	130.0	780
Laboratory analyses				***16,023***
analyses of soil and fugitive dust	sample	54	73.2	3,951
analyses of water	sample	84	126.4	10,615
QA/QC analyses	LS	1	1,456.6	1,457
HASP				***29,303***
personal protective equipment	LS	1	2,500.0	2,500
health and safety training of the crew	LS	1	750.0	750
mitigation of fugitive dust release and cross contamination during site clean-up	month	6	1,000.0	6,000
warning signs installation	LS	1	1,200.0	1,200
mobile office rental	month	6	800.0	4,800
mobile dressing room rental	month	6	1,100.0	6,600
fresh water supply	m^3	600	6.7	3,991
electric power supply	kWh	5000	0.1	466
mobile toilet rental (including cleaning)	month	6	199.5	1,197
site guard	month	6	300.0	1,800
Closure measures				***9,000***
reconstruction of cart-road through the site	m^2	2000	3.0	6,000
final surveying of the area capped	ha	2	500.0	1,000
revegetation of the site vicinity	m^2	4000	0.5	2,000
Demobilization				***4,800***
dismantling of the site equipment	LS	1	2,500.0	2,500
of site transport	LS	1	2,300.0	2,300
Engineering and project implementation management				***25,200***
engiennering	month	6	1,200.0	7,200
evaluation and reporting	month	6	500.0	3,000
project management	month	6	2,500.0	15,000
Contingency	%	10	11,532.9	**115,329**

Comparison of differences between the two variants of short term risk reduction is presented in table 3.51 below.

Table 3.51 – Financial comparison of Variant 1 and Variant 2

Task	Variant 1	Variant 2
Advance works	155,259	155,259
Emergency measures	50,879	73,828
Conceptual model and final design	63,000	63,000
Project implementation	801,206	861,206
Contingency	107,034	115,329
TOTAL Phase 1	**1,177,378**	**1,268,622**

Estimated costs of the post-closure measures (Phase 2) are presented in table 3.52 below.

Table 3.52 – Estimated costs for post-closure measures

Task / item	*Unit*	*Number of units*	*Unit costs (US $)*	*Total (US $)*
Phase 2 - POST- CLOSURE MEASURES				**208,450**
Ambient air quality monitoring				***11,200***
operational cost (including sampling and maintenace)	year	5	1500	7,500
analyses	year	5	740	3,700
Groundwater monitoring				***110,250***
sampling	year	30	1200	36,000
analyses	year	30	2275	68,250
wells maintenance	year	30	200	6,000
Inspections of capping				***21,000***
visual inspection	year	30	200	6,000
surveying (subsidence)	year	30	500	15,000
Capping maintenance				***21,000***
removal of deep rooting plants	year	30	200	6,000
cover repair	year	30	500	15,000
Management of post-closure measures				***45,000***
reporting	year	30	500	15,000
management	year	30	1000	30,000

Estimated cost of the Phase 3 – long term corrective measures, focused on the expected remediation of groundwater at both the contamination sources, is presented in subsequent table 3.53.

Table 3.53 – Estimated costs of groundwater remediation at contamination sources

Task / item	*Unit*	*Number of units*	*Unit costs (US $)*	*Total (US $)*
Phase 3 - Groundwater remediation				**575,000**
Groundwater remediation in the tailings dump area				***350,000***
installation of permeable reactive barrier (filling with ZVI)	LS	1	300,000	300,000
engineering	LS	1	30,000	30,000
evaluation and reporting	LS	1	5,000	5,000
management	LS	1	15,000	15,000
Groundwater remediation in the roaster area				***225,000***
installation of permeable reactive barrier (filling with ZVI)	LS	1	190,000	190,000
engineering	LS	1	20,000	20,000
evaluation and reporting	LS	1	4,000	4,000
management	LS	1	11,000	11,000

Note: Monitoring costs are not calculated - it is included in post-closure measures

Cost estimation for the Phase 4 – long term remediation activities in the area of Suva River valley is presented in table 3.54 further.

Table 3.54 – Cost estimation – Phase 4 – remediation of Suva River valley

Task / item	***Unit***	***Number of units***	***Unit costs (US $)***	***Total (US $)***
Phase 4 - LONG TERM REMEDIATION - SUVA RIVER VALLEY (including post monitoring)				**648,705**
Detail site investigation				***68,705***
monitoring wells installation	well	5	1,800.0	9,000
shallow probes drilling	m	150	34.0	5,100
soil samples collection	sample	165	4.0	660
groundwater samples collection	sample	10	66.5	665
surface water samples collection	sample	48	13.3	638
laboratory work	LS	1	32,241.6	32,242
surveying	LS	1	3,200.0	3,200
engineering	LS	1	7,200.0	7,200
evaluation and reporting	LS	1	2,500.0	2,500
management of the site investigation	LS	1	7,500.0	7,500
Risk Assessment	***LS***	***1***	***15,000.0***	***15,000***
Implementation project + EIA	***LS***	***1***	***15,000.0***	***15,000***
Project implementation - remedial action	***LS***	***1***	***400,000.0***	***400,000***
Phase 4 - Post monitoring	***year***	***30***	***5,000.0***	***150,000***

Finally, the cost estimation for the Phase 5 – remediation of wider area (agricultural land) is presented in table 3.55.

Table 3.55 – Cost estimation – Phase 5 – remediation of wider area

Phase 5 - LONG TERM REMEDIATION - WIDER AREA (including post monitoring)				**932,313**
Detail site investigation				***131,313***
drilling and monitoring wells installation	well	10	2,000.0	20,000
shallow probes drilling	m	250	34.0	8,500
soil samples collection	sample	280	4.0	1,120
groundwater samples collection	sample	48	66.5	3,193
laboratory work	LS	1	65,000.0	65,000
special works - EM, XRD	LS	1	15,000.0	15,000
surveying	LS	1	8,000.0	8,000
evaluation and reporting	LS	1	3,000.0	3,000
management of the site investigation	LS	1	7,500.0	7,500
Risk assessment	***LS***	***1***	***15,000.0***	***15,000***
Implementation project + EIA	***LS***	***1***	***15,000.0***	***15,000***
Project implementation - remedial action	***LS***	***1***	***750,000.0***	***750,000***
Phase 5 - Post monitoring	***year***	***3***	***7,000.0***	***21,000***

To conclude, the cost of short term risk reduction measures could vary in the range 1,070,344 – 1,153, 293 US $ without contingency. Because of data gaps and uncertainties it is recommended to include 10% contingency – thus the anticipated costs of short term risk reduction measures (Phase 1) will reach 1,177,378 – 1,268,622 US $ for the Variant 1 and 2 respectively.

The post-closure measures has been calculated for the period of 30 years, due to the remediation method proposed, the costs of post-closure measures are low – 208,450 US $.

With respect to the data lack the costs of long term remediation measures can be estimated roughly only - 575,000; 648,705; 932,313 US $ for the Phases 1, 2, and 3 respectively.

The total costs for remedial action in Lojane Mine are can vary in the range 1,385,828 – 1,477,072 US $ in case that only Phases 1 and 2 will be completed. In case that the necessity of further remediation (Phases 3 – 5) will be requested the remedial costs might reach up to 3,633,090 US $. These costs include also the long term (30 years) post monitoring.

3.9.6.2 Anticipated cashflow

The discounted cashflow expected is based on the assumption that sufficient financial funds will be available and the work will be carried out in proposed order and without delay.

The cashflow is presented in tables 3.56, 3.57 and 3.58, 3.59 for the Variant 1 and 2 respectively.

Table 3.56 – Estimated annual costs – Variant 1

Phase / task	2008				2009				2010				2011	2012	2013	2014-2019	2020-2024	2025-2029	2030-2034	2035-2039	2040
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4									
Phase 1 - Short term risk reduction	**1,177,378**																				
Advance works	155,259																				
Emergency measures	16,960	33,919																			
Conceptual model and final design		63,000																			
Project implementation			400,603	400,603																	
Contingency		35,678	35,678	35,678																	
Phase 2 - Post closure measures					**8,815**				**8,815**				**8,815**	**8,815**	**8,815**	**32,875**	**32,875**	**32,875**	**32,875**	**32,875**	
Ambient air quality monitoring					1,120		1,120		1,120		1,120		2,240	2,240	2,240						
Groundwater monitoring					1,838		1,838		1,838		1,838		3,675	3,675	3,675	18,375	18,375	18,375	18,375	18,375	
Inspections of capping					350		350		350		350		700	700	700	3,500	3,500	3,500	3,500	3,500	
Capping maintenance					350		350		350		350		700	700	700	3,500	3,500	3,500	3,500	3,500	
Management of post-closure measures					750		750		750		750		1,500	1,500	1,500	7,500	7,500	7,500	7,500	7,500	
Phase 3 - Groundwater remediation					**575,000**																
Groundwater remediation in the tailings dump area					350,000																
Groundwater remediation in the roaster area						225,000															
Phase 4 - Long term remediation - Suva River valley					**498,705**				**5,000**				**5,000**	**5,000**	**5,000**	**25,000**	**25,000**	**25,000**	**25,000**	**25,000**	**5,000**
Detail site investigation					68,705																
Risk Assessment					7,500	7,500															
Implementation project + EIA						15,000															
Project implementation - remedial action							200,000	200,000													
Phase 4 - Post monitoring									2,500		2,500		5,000	5,000	5,000	25,000	25,000	25,000	25,000	25,000	5,000
Phase 5 - Long term remediation - wider area (agricultural land)					**146,313**				**768,500**				**7,000**	**7,000**	**3,500**						
Detail site investigation							131,313														
Risk assessment								15,000													
Implementation project + EIA									15,000												
Project implementation - remedial action										375,000	375,000										
Phase 5 - Post monitoring												3,500	7,000	7,000	3,500						

Table 3.57 – Discounted cashflow Variant 1

Period	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**perpetuity**
Cash flow	$1,177,378	$1,228,833	$782,315	$20,815	$20,815	$17,315	$294,375

Discounted cash flow	
Discount rate	10%
DCF I. Period 2008-2013	$2,710,588
DCF II.Period 2014-	$209,207
Total discounted cash flow	**$2,919,795**

Table 3.58 – Estimated annual costs – Variant 2

Phase / task	2008				2009				2010				2011	2012	2013	2014-2019	2020-2024	2025-2029	2030-2034	2035-2039	2040
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4									
Phase 1 - Short term risk reduction	**1,268,622**																				
Advance works	155,259																				
Emergency measures	24,609	49,218																			
Conceptual model and final design		63,000																			
Project implementation			430,603	430,603																	
Contingency		38,443	38,443	38,443																	
Phase 2 - Post closure measures					**8,815**				**8,815**				**8,815**	**8,815**	**8,815**	**32,875**	**32,875**	**32,875**	**32,875**	**32,875**	
Ambient air quality monitoring					1,120		1,120		1,120		1,120		2,240	2,240	2,240						
Groundwater monitoring					1,838		1,838		1,838		1,838		3,675	3,675	3,675	18,375	18,375	18,375	18,375	18,375	
Inspections of capping					350		350		350		350		700	700	700	3,500	3,500	3,500	3,500	3,500	
Capping maintenance					350		350		350		350		700	700	700	3,500	3,500	3,500	3,500	3,500	
Management of post-closure measures					750		750		750		750		1,500	1,500	1,500	7,500	7,500	7,500	7,500	7,500	
Phase 3 - Groundwater remediation					**575,000**																
Groundwater remediation in the tailings dump area					350,000																
Groundwater remediation in the roaster area						225,000															
Phase 4 - Long term remediation - Suva River valley					**498,705**				**5,000**				**5,000**	**5,000**	**5,000**	**25,000**	**25,000**	**25,000**	**25,000**	**25,000**	**5,000**
Detail site investigation					68,705																
Risk Assessment					7,500	7,500															
Implementation project + EIA						15,000															
Project implementation - remedial action							200,000	200,000													
Phase 4 - Post monitoring									2,500		2,500		5,000	5,000	5,000	25,000	25,000	25,000	25,000	25,000	5,000
Phase 5 - Long term remediation - wider area (agricultural land)					**146,313**				**768,500**				**7,000**	**7,000**	**3,500**						
Detail site investigation							131,313														
Risk assessment								15,000													
Implementation project + EIA									15,000												
Project implementation - remedial action										375,000	375,000										
Phase 5 - Post monitoring												3,500	7,000	7,000	3,500						

Table 3.59 – Discounted cashflow Variant 2

Period	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**perpetuity**
Cash flow	$1,268,622	$1,228,833	$782,315	$20,815	$20,815	$17,315	$294,375

Discounted cash flow	
Discount rate	10%
DCF I. Period 2008-2013	$2,793,537
DCF II.Period 2014-	$209,207
Total discounted cash flow	**$3,002,744**

3.10 Recommendations for the development of Emergency Response Plan

3.10.1 Purpose of the Emergency Response Plan

Industry facilities that store, manufacture, transport, recycle or handle dangerous goods, hazardous wastes, or hazardous chemicals should prepare a response (contingency) plan to respond to emergencies involving the accidental release of these substances into the environment. Such facilities can include, but not limited to: waste landfills, recycling (plastics, tires, paint, pesticide, batteries) facilities, chemical and petroleum bulk storage or transportation facilities. Industrial sectors that response planning apply include mining, forestry, manufacturing, retail, and oil and gas.

Response plans should identify potential hazards, develop systems for preventing accidents, provide appropriate mechanisms for minimizing risk, loss and damage resulting from such incidents (*i.e.* reduce exposures to communities), and provide an incident management structure to guide response activities.

Terms used:

Accident means an unexpected event that result in loss or injury to a person and/or damage to property or the environment.

Dangerous Goods include explosives, compressed and liquefied gases, flammable and combustible materials, oxidizing materials and organic peroxides, poisonous and infectious substances, radioactive materials, corrosives, and miscellaneous dangerous goods.

Emergency means an accidental situation involving the release or imminent release of dangerous goods or other substances that could result in serious adverse effects on the health and/or safety of persons or the environment. An emergency may be the result of man-caused or natural occurrences such as, but not limited to, process upsets, uncontrolled reactions, fires, explosions, threats, structural failures, tornados, earthquakes, floods, and storms.

Emergency Response Plan means a detailed program of action to control and/or minimize the effects of emergency requiring prompt corrective measures beyond normal procedures to protect human life, minimize injury, to optimize loss control, and to reduce the exposure of physical assets and the environment from an accident.

Hazard means an event with a potential for human injury, damage to property, damage to the environment, or some combination thereof

Risk means the chance of a specific undesired event occurring within a specified period or in specified circumstances. It may be either a frequency or a probability of a specific undesired event taking place.

Risk Analysis means the identification of undesired events that lead to the materialization of a hazard, the analysis of the mechanisms by which these undesired events could occur and, usually, the estimation of the extent, magnitude, and likelihood of any harmful effects.

Risk Assessment means the quantitative evaluation of the likelihood of undesired events and the likelihood of harm or damage being caused by them, together with the value judgments made concerning the significance of the results.

Risk Frequency means the number of occurrences per unit of time.

Risk Management means the program that embraces all administrative and operational programs that are designed to reduce the risk of emergencies involving acutely hazardous materials. Such programs include, but are not limited to, ensuring the design safety of new and existing equipment, standard operating procedures, preventive maintenance, operator training, accident investigation procedures, risk assessment for unit operations, emergency planning, and internal and external procedures to ensure that these programs are being executed as planned.

Spill means an unauthorized release or discharge of a dangerous good into the environment.

Policy statement

A company should have a policy statement reflecting its commitment to emergency prevention and preparedness. The statement is usually signed by a senior official such as the Chief Executive Officer or the company president. A policy statement should include:

- management's commitment to safeguard the health and safety of the employees and the public and to protect the environment.
- a statement of the company's priorities in the event of a spill. Generally priority is in the order of the immediate safety of employees at the site and the members of the surrounding community, followed by protection of the environment.
- a clear indication of the first-line supervisor's authority for emergency action and expenditure.
- a statement of authority regarding who will deal with public and media inquiries.
- a statement concerning the company's plan to monitor compliance with this policy.
- the effective date of the plan.
- a schedule for review and for testing/exercising of the plan.

Purpose and Scope

The purpose of formulating a response plan is to develop a state of readiness which will allow for a prompt and orderly response to an emergency. This section of a response plan should state the intent and scope of the plan. Response plans should be structured around four major objectives:

- understanding the type and extent of a potential emergency (risk/exposures);
- establishing a high order of preparedness (equipment, personnel) commensurate with the risk;
- ensuring an orderly and timely decision-making and response process (notification, standard operating procedures), and
- providing an incident management organization with clear missions and lines of authority (Incident Command System, field supervision, unified command).

Prevention is by far the most effective way of reducing or eliminating the potential for a spill, as well as impact mitigation to reduce community and environmental impacts should a spill occur. Development of spill prevention measures (e.g. product loss control) and mitigation measures (buffer-zones, dangerous goods transportation corridors, land-use plans) are separate endeavors to a response plan. These approaches are beyond the scope of these guidelines and are not addressed.

The terms of reference for the plan should include such items as:

- whether the plan is for an individual operation or a part of an industry cooperative in a given area;
- the geographic and physical location(s) covered by the plan;

- types of emissions or spills which the plan is designed to address including spills to land, water and air. This should include all dangerous goods and hazardous chemicals being handled along transportation routes and at the particular plant for which the plan is being developed.
- a list of any other organizations or groups having responsibility under the plan.

Finally, the response plan must be compatible and integrated with the disaster, fire and/or emergency response plans of local, provincial, and state agencies/authorities.

Pre-Emergency Planning

Hazard Identification

The first step is to identify potential hazards. This section of a response plan should identify all potential on-site and off-site hazards of the operation, and the type of damage that may result. This requires information on toxicological, physical, and chemical properties of the substances being handled. The potential impact on downwind air quality or downstream water quality from an accidental release and danger to human and animal health should be clearly identified. A mitigation plan can be developed to passively reduce exposures to the community or the environment should a spill occur (e.g. buffer-zones, fencing, dykes/barriers, transportation corridors). Man-made perils such as fire, explosion, transportation accidents, pipeline breaks or equipment failure should be considered in addition to the natural perils such as floods, earthquakes or landslides.

Risk Analysis

The second step of the process is to determine the risk of an incident associated with each hazard. The basic procedure in a risk analysis is as follows:

- identify potential failures or accidents (including frequency);
- calculate the quantity of material that may be released in each failure, estimate the probability of such occurrences, and
- evaluate the consequences of such occurrences based on scenarios such as most probable and worst case events.

This combination of consequences and probability will allow the hazards to be ranked in a logical fashion to indicate the zones of important risk. Criteria should then be established by which the quantified level of risk may be considered acceptable to all parties concerned.

To reduce or eliminate risk, consideration should also be given to spill prevention and spill mitigation in conjunction with the preparation of a response plan. For this purpose, workers involved in operating the plant, equipment or systems should be encouraged to provide information concerning weaknesses in systems or operating procedures, "near misses," and potential problems they have observed, along with recommended measures for prevention/mitigation of such occurrences.

3.10.2 Recommended Emergency Response Plan

The proposed structure/template of ERP is presented further, this template can be modified for variety of site conditions as well as variety of activities.

Emergency Response Plan

For

Insert Project Name/Identification

Prepared by

Name:

Appointment:

Date of issue:

And further the Contents Page:

Table of Records

- 1) Emergency Plan Revision
- 2) Emergency Exercise Conducted

Schedule of Clearance[+]

Note: [+] **Schedule of Clearance** refers to the issuing of License & permit by relevant regulatory agencies

1 Main Plan

- 1 Situation
- 1.1 Introduction
- 1.2 Area of Operation
  - 1.2.1 Location of Installation and its main access road
  - 1.2.2 General Description of site area (including Neighboring buildings and installations)
  - 1.2.3 Description of Process Areas (including summary of the processes and operations carried out)
  - 1.2.4 Location, storage and quantities of Hazmat in facility map.
  - 1.2.5 Layout of installation
- 1.3 Hazard and Risk Assessment
  - 1.3.1 Main Areas where hazards present on site
  - 1.3.2 Inventory list of Hazardous Substance handled, stored at the facility
  - 1.3.3 Descriptions of all Possible Scenario(s)

2 Aim

3 Execution

- 3.1 Concept of Operations
- 3.2 Emergency Actions by installation
- 3.2.1 Procedure to notify relevant agencies/authorities, police, etc.
  - 3.2.1.1 Office Hours and after office hours

3.2.1.2 Details of workers population during day and night

3.2.2 Evacuation Procedure

3.3 Grouping and Tasks

3.4 Coordinating Instructions

3.4.1 Key Personnel Emergency Contact Numbers

3.4.2 Factory listing of Neighboring Companies

3.4.3 Sector Boundaries

3.4.4 Reporting / Alerting relevant agencies/authorities, police, etc.

3.4.5 Control Points

3.4.6 Safety and Others

3.4.6.1 Emergency Shutdown Procedures

3.4.6.2 Containment of Hazardous Substances

3.4.6.2.1 Containment Procedure

3.4.6.2.2 List of containment equipment

3.4.6.3 Monitoring of Release Hazardous Substances

3.4.6.3.1 Monitoring Procedure

3.4.6.3.2 List of monitoring equipment

3.4.6.4 Fire fighting and rescue

3.4.7.4.1 Fire fighting and Rescue Procedure

3.4.7.4.2 List of fire fighting and rescue equipment

3.4.6.5 Clean up Operations

3.4.7.5.1 Clean up Procedure

3.4.7.5.2 List of clean up equipment available

3.4.7.5.3 Contact List of clean up contractors

4 Service Support

4.1 Equipment

4.1.1 Fire Protection Facilities

4.1.1.1 Detection System

4.1.1.2 Extinguishment System

4.1.1.3 Other Extinguishing agents available

4.1.2 Containment equipment

4.1.3 Other Protection and General Equipment

4.1.4 Safety and First Aid Equipment

4.2 Manpower

4.2.1 In-house Emergency Response Team

5 Command and Signal

5.1 Command

5.1.1 Incident Organization Chart

5.1.2 Location and Component of Command Centre

5.2 Signal

5.2.1 Communication Flowchart

Further pages of the ERP would contain data on ERP revisions and records on emergency exercise conducted – e.g.

Table of Records of Emergency Plan Revision

S/N	Plan Version	Date of Exercise*	Date of Approval	Name and Appointment of Approving Officer	Signature of Approving Officer	Remarks

Note:

Date of Exercise – Date where the newly drafted / revised emergency plan been validated the plan. Emergency Plan should only be endorsed and approved after it has been exercised and validated with relevant agencies/authorities.

Table of Records of Emergency Exercise Conducted

S/N	Date of Exercise	Comments	Appointment of Conducting Officer	Signature of Conducting Officer

Note: Emergency exercise shall be conducted in frequency given by relevant regulations

Further, the general description of the content of particular chapter of the ERP is provided:

1 SITUATION

1.1 Introduction

State the ownership and management of the installation. Write up of the nature of business, products and method of the installation's activities and the various agencies involved in the operation such as supplying raw material, etc. (If any other companies are used in the process, state down the company).

1.2 Area of Operations

1.2.1 Location of Installation and its main access road

State the address of the Installation. State all the possible entrances to the installation from the main access roads (Indicate the entrances on the site plan, surrounding lands should be included in the site plan.)

1.2.2 General Description of the surroundings and neighboring premises of the installation

Identify and describe the neighboring occupancies (such as highly populated residential or environmental sensitive areas) surrounding the installation.

1.2.3 Layout of installation

To provide a brief description of the layout of the site such as the location of the admin block, process plants, tank farm, storage warehouse etc with the aid of a schematic site map.

1.2.4 Location, storage and quantities of Hazardous products, chemicals and gases

Detailed description of the location, quantity stored and the storage conditions of hazmat such as storage temperature, pressure etc at site. Location of the Hazmat must be indicated on the site plan(s) clearly.

1.2.5 Description of Process Areas (including summary of the Process and operations carried out)

A brief summary of the processes, operations and other activities such as hot works carried out within the process areas. State the duration of the each processes and operations (24 hours daily, only normal office works). Provide a summary table of all process at various location of the installation.

1.3 Hazard and Risk Assessment

1.3.1 Main Areas where hazards present on site

State the main areas of hazards (flammable, toxic, etc) and the Safety / Emergency Control Measures that are in place to handle the hazards. The MSDS of each hazmat that could be found at site must be included in the ERP.

Eg. Releases from XXXX Handling

(1) Hazards

The two principal potential hazards following a release of XXXXX are evaporation of the volatile liquid leading to the formation of a flammable vapor cloud in the atmosphere, and radiation from an ignited pool fire. Ignition of the cloud might also lead to a vapor cloud explosion.

If XXXXX were spilled onto open, flat ground, it would spread out to form a shallow pool. If the releases were not stopped, the pool would continue to spread until it reached an equilibrium size where the spill rate was equal to the evaporation rate (for unignited releases) or burning rate (for ignited releases).

(2) Emergency Control Measures

XXXXX vapor is normally1.5 times heavier than air and the vapor produced as XXXXX vaporizes from the liquid at its normal boiling point is even heavier. Therefore, it will tend to spread along the ground assisted by the visible fog of condensed water vapor created. Ignitable mixtures extend beyond the visible area. Such escape can be controlled by water spray. Water should be applied to fire-exposed tanks and cool surrounding risks. Eliminate all sources of ignition and the flow of gas should be stopped, if possible.

(3) Safety Control Measures:
a. XXXXX gas leak detectors are installed to detect gas leaks.
b. Automatic water spray system with heat detectors is installed to activate and drench the tanks when the temperature is high.
c. Daily monitoring by shift personnel for leakage.

1.3.2 Descriptions of ALL possible scenarios

Identify and describe all the possible scenario(s), including the worst case scenarios that could happen. State briefly all the assumptions, risk studies methodology adopted and mitigation measures identified in these scenarios. Tabulate and draw all the possible hazard zones, consequence distances and safety distances necessary for each scenario involved on the site plan.

2 AIM

The aim of this emergency response plan is to detail the various preventive measures and operational actions that need to be undertaken by the company to contain any hazmat leaks, spill and control or extinguish any fire in the event of a emergency situations that occur within the installation so to prevent and reduce injury to personnel and minimize property damage and loss.

3 EXECUTION

3.1 Concept of Operations

The emergency operation to be conducted in phases is as follows:

Phase	Action
I	Company personnel to carry out initial response and alert relevant agencies/authorities
II	Relevant agencies/authorities predetermined turnout response to the scene for mitigation, Containment, security cordoning, evacuation and rescue activities.
III	To conduct major operations for containment and minimise risks with other related agencies.
IV	To cleanup / decontaminate and resume normal operations.

3.2 Emergency Actions by installation

Detail description of the emergency actions to be carried out by Company Emergency Response Team (CERT) as follows.

3.2.1 Procedure to notify relevant agencies/authorities and police

3.2.1.1 Notification procedure during office hour and after office hour

Standard Operating Procedures (SOP) to be adopted to notify relevant agencies/authorities and police in the event of an emergency discovered during and after office hours.

Eg: During office hour, any occurrence of incident resulting in an emergency alarm, the shift supervisor on duty will activate in house emergency response procedure. The site incident commander (SIC) will be notified and he will inform relevant agencies/authorities by telephone after initial assessment of the situation. The SIC will be the liaison officer with relevant authorities representative in charge. He will provide information and necessary assistance to the relevant authorities' representative in charge.

3.2.1.2 Workers population during day and night

State the working population of during day and night including Sundays and public holidays.

3.2.2 Procedure for emergency evacuation

The purpose of this section is to ensure a safe and orderly emergency evacuation of each area or the entire plant. If required, the plan should also include procedures for the notification and evacuation of the surrounding community. The planning for communities is done as a joint effort with local government and industry. The following elements must be considered when developing evacuation plans:

- need for an alarm system capable of defining different areas and/or degrees of evacuation.
- maps showing both the primary and alternate evacuation routes.
- designation of primary as well as alternate off-site assembly areas.
- designation of employees responsible for checking the evacuation area and for taking personnel counts at the assembly area to ensure that the area has been safely evacuated.
- designation of emergency escape equipment.
- providing dispersion estimates for worst and most likely gas/vapour releases to better define the affected areas.
- procedures to increase the degree/extent of areas to be evacuated if the emergency situation escalates.

Evacuation decisions require knowledge by local authorities of the projected path of an air-borne chemical cloud, atmospheric dispersion rate, and ground level concentrations. The ability to warn residents on a rapid and reliable basis is also required. Use of appropriate and agreed on warning systems such as sirens, emergency broadcast systems, mobile public address systems and/or house-by-house contacts should be specified in the plan.

3.3 Grouping and Tasks

State the role and responsibilities of various group (Site main controller, site incident controller, emergency response team, security personnel, key personnel) in Annex.

3.4 Coordinating Instructions

3.4.1 Key Personnel Emergency Contact Numbers

The key personnel to be notified must be contactable during office hour and after office hour (Contact No. must include both the contact numbers during office hour and after office hour, e.g. individual Handphone / Pager or Home contact no.).

3.2 Emergency Actions by installation

Detail description of the emergency actions to be carried out by Company Emergency Response Team (CERT) as follows.

3.4.2 Contacts of Neighboring Companies

To provide the contact number of the neighboring companies within 500m radius, whereby in the event of the incident escalating beyond the boundaries of the installation, the company will have to inform its neighbors.

3.4.3 Sector Boundaries

To identify the various sectors of operations so as to determine the potential hazard zones and evacuation zones.

Note:
The incident site will be sectorized into HOT, WARM and COLD zone during emergency. The definitions of the various zones can be as follows:
Hot Zone – This is the area around the incident that required all personnel entering to be fully protected by means of Breathing Apparatus sets and proper protective clothing and to be decontaminated upon leaving the zone.
Warm Zone – This is the area directly outside Hot Zone. All personnel in this zone should be equipped with Breathing Apparatus and if situation requires, done the mask for full protection against toxic hazard gas,
Cold Zone – This is non-hazard zone outside the Warm Zone.

3.4.4 Reporting / Alerting

Detail the procedures and method of activation of relevant agencies/authorities and upon arrival of representative of relevant agencies/authorities in charge.

For Example:

(1) For activation of relevant agencies/authorities:
The message to be used to activate relevant agencies/authorities and police during emergency shall include the following information:
(a) Location of the incidents.
(b) Type of incident.
(c) Chemical involved.
(d) Leakage with or without fire.
(e) Chemical company name and contact number.
(f) Casualties involved.

(2) Upon arrival of representative of relevant agencies/authorities in charge Site incident commander will marry up with that representative in charge, brief him on the incident and the actions that the ERT had done prior to his arrival and provide him all necessary information (such as location map, etc) and necessary communication equipment.

3.4.5 Control Points

Explain the purpose of each control point (Reporting Point, Evacuation Assembly Area, First Aid Point, etc). Indicate the location of all control points on the layout map.

3.4.6 Safety and Others

Details of other safety measures adopted by company to minimize the risks involved during an emergency.

3.4.6.1 Emergency Procedures

3.4.6.1.1 Emergency Shutdown Procedure

To describe briefly the emergency shutdown procedures for various process and equipment, during an emergency such as the gas leakage, loss of containment storage tank etc. Attach details of shutdown procedure of various process and equipment as Annex.

3.4.6.1.2 Evacuation Procedure

General description of how evacuation will be conducted. Attach the company’s emergency evacuation plan as an Annex.

3.4.6.2 Containment of Hazardous Substances

3.4.6.2.1 Containment Procedure

To describe briefly of the containment procedures in-place for hazmat spill, leak and vapor release. Attach full plan as an Annex.

3.4.6.2.2 List of containment equipment

Tabulate the information (type, quantity and function) of the containment equipment or facilities that are available in the company.

3.4.6.3 Monitoring of Release Hazardous Substances

3.4.6.3.1 Monitoring Procedure

Describe how monitoring activities will be carried by the company. Attach monitoring plan as an Annex.

3.4.6.3.2 List of monitoring equipment

Tabulate the information (type, quantity, general functions / capabilities and location) of the monitoring equipment (portable gas detectors, pH meters, organic vapor monitor, etc) that are available in the company.

3.4.6.4 Fire Fighting and Rescue

3.4.6.4.1 Fire fighting and Rescue Procedures

Descriptions of the fire fighting and rescue procedures that will be carry out by the installation to mitigate the incident. Attach full details of the fire fighting and rescue procedure / plan in an Annex.

3.4.6.4.2 List of fire fighting and rescue equipment

Tabulate the information (type, quantity, general functions / capabilities and location) of the fire fighting and rescue equipment (fire hydrant, tug boat, fixed monitor, fire hoses, fire nozzles, portable pump, foam carrier, foam tender, fire engine, etc) that are available in the installation.

3.4.6.5 Clean up Operations

3.4.6.5.1 Clean up Procedure

Descriptions of the cleanup procedures that will be carried out by the company at the recovery stage. Attach full details of containment procedure / plan in an Annex.

3.4.6.5.2 List of clean up equipment

Tabulate the information (Type, quantity, general functions / capabilities and location) of the clean up equipment (boom, absorbent, overpack drums, etc) that are available in the installation.

3.4.6.5.3 List of clean up contractors

Tabulate the information (Name, Address, Contact Person and Contact No, type of the clean up actions take will be done) the cleanup contractors used by the installation.

4 SERVICE SUPPORT

4.1 Equipment

4.1.1 Fire Protection Facilities

4.1.1.1 Detection System

Description of the detection system such as smoke, fire fighting monitoring and gas detection, leakage detection system, wind vane/wind sock etc available in installation. Indicate the location of detection system on the site installation map.

4.1.1.2 Extinguishment System

Description of the extinguishing system (such as fire-water extinguishing, sprinkler system, drencher system for fuel oil tanks, hydrant, fire extinguishers carbon dioxide and foam system) available in installation. Indicate the location and quantities (if any) of the various extinguishment system on the site map.

4.1.2 Extinguishing Agent

Tabulate the information of the extinguishing agents (type – foam concentrate stock, chemical powder, brand name, package, location and quantities) used.

4.1.3 Containment equipment (leak control, spill control, absorbents, etc)

Tabulate the information (name, quantity and location) of the containment equipment used.

4.1.4 Other Protection and General Equipment

Tabulate the information (name, quantity and location) of other protection and general equipment used in the installation.

4.1.5 Safety and First Aid Equipment

Tabulate the information (type, capacity, quantity and location) of the safety and first aid equipment such as breathing apparatus, resuscitators, stretcher, blanket, first aid box, etc.

4.2 Manpower

4.2.1 In-house Emergency Response Team

Show the organization structure of the in-house emergency response team. Describe the roles, responsibilities and functions of the in-house company emergency response team (CERT).

5 COMMAND AND SIGNAL

5.1 Command

5.1.1 Incident Organization Chart

Show the incident organization chart. Describe the roles and responsibilities of the key personnel in the incident organization chart.

5.1.2 Location and Component of Command Centre

Indicate the location of the command centre on the installation map Indicate the location of site incident controller, site main controller, etc.

5.2 Signal

5.2.1 Communication Flowchart

Communication flowchart showing details on the linkage between Site Main controller, site incident controller, in-house emergency response team commander and representative of relevant agencies/authorities in charge. State also means of communication (walkie-talkie, etc) between each party.

3.11 Recommendations for the development of Monitoring Plan

This Monitoring Plan proposed is aimed to address the monitoring needs of short term risk reduction and post-closure measures. With respect to the site specific conditions and reflecting the data gaps it is proposed to monitor air quality, groundwater quality and surface water quality.

The purpose of monitoring is to:

1. establish a baseline prior closure/remediation action commencement,
2. monitor the impact on the environment during closure/remediation activities, and
3. monitor the environment after the closure/remediation completion to verify the efficacy of measures adopted.

In order to enable assessment of the corrective measures efficiency it is necessary to carry out the initial monitoring prior commencement of remediation/cleanup action, during the initial monitoring, some data gaps and uncertainties can be eliminated – data on hydrogeology, groundwater contamination and vertical distribution of contaminants in the unsaturated zone can be acquired.

To control the environmental impact of the remediation/cleanup measures adopted, it is necessary to carry out remediation/cleanup monitoring.

In order to evaluate the efficacy of corrective measures adopted and to control the performance of technology applied for the contamination sources remediation/cleanup, it is necessary to carry out long term post-closure monitoring.

Thus the monitoring can be split into three phases:

- ***initial monitoring*** - in fact this phase can be carried out within the frame of complementary site investigation;
- ***remediation monitoring*** – can be carried on the monitoring objects developed in the Phase 1, if necessary, additional monitoring objects can be used for monitoring – e.g. private wells;
- ***post-closure monitoring*** – it is not necessary to monitor all the wells installed during previous phases, the data gaps related to the hydrogeology and groundwater contamination would be eliminated and thus the number of monitoring objects can be reduced.

3.11.1 Initial monitoring

The initial monitoring has to be performed during the early stage of Phase 1 – i.e. during the emergency measures, with respect to the works proposed and their succession the scope of monitoring should be in minimum as:

Air quality monitoring – continuous monitoring of weather parameters like wind direction, wind velocity, ambient air temperature, precipitation, concentration of dust particles, monthly collection of fugitive dust particles and laboratory analyzes focused on assaying the concentration of As, Sb, Ni, (Tl).

Groundwater monitoring – on the monthly basis, all wells installed including the wells up gradient have to be monitored, groundwater samples are to be collected by the method low rate pumping. Proposed locations of monitoring wells to be installed are depicted in figures 3.29 and 3.30 for the roaster area and tailings dump area respectively. The samples should be analyzed for As, Sb, Ni, Tl as main contaminants identified and additionally for Pb, Zn, Cr, Cd, and Co.

Surface water monitoring – the monitoring of surface water quality is proposed for Lojanska and Tabanovska Rivers that might be affected by activities at the roaster area. Surface water samples should be collected up gradient the roaster area in both the streams, downgradient but above the confluence of both the streams and the last sampling point should be on Tabanovska River downgradient of the confluence with Lojanska River. The sampling frequency should be monthly. The scope of analyses to be performed is the same as for groundwater – i.e. As, Sb, Ni, Tl as main contaminants identified and additionally for Pb, Zn, Cr, Cd, and Co.

3.11.2 Remediation monitoring

During the project implementation the monitoring of particular environmental media has to be carried out in order to ensure that the work performed has not adverse impact. It is proposed to perform the sampling of media that might be potentially affected with the remediation/cleanup works on the basis of monthly performed sampling campaign, air quality, groundwater quality and surface water quality will be monitored in the points of monitoring system developed within the advance works stage (fig. 3.29 and 3.30). The samples collected should be assayed in order to determine concentration of contaminants identified during the FS (i.e. As, Sb, Ni, Tl) at least; and potentially further HM in dependence on results of complementary site investigation and RA updated.

Fig. 3.29 – Proposed locations of monitoring points at roaster area

Fig. 3.30 - Proposed locations of monitoring points at tailings dump

3.11.3 Post-closure monitoring

The post-closure monitoring represents an important part in the entire site remediation/cleanup process, that is why it was set aside as Phase 2. The post-closure monitoring is aimed to enable assess the efficacy of corrective measures adopted, and, mainly to monitor the performance of treatment technology adopted – i.e. whether the contaminants, isolated from the environment by capping, remain immobilized within the capped area.

Within the frame of post monitoring, it is proposed to monitor the quality of ambient air and groundwater in both the contamination sources. Monitoring of the air quality (fugitive dust release) is proposed for the period of five years which is enough to assess the reduction of the dust release after completion of cleanup at both the contamination sources. Samples of fugitive dust should be collected twice per year – once in dry period and one sample during the wet period.

The groundwater quality should be monitored for the period of 30 years with frequency twice per year – once within the period of high precipitation and once during the dry period – the best timing for groundwater monitoring should be proposed on the basis of evaluation of complementary site investigation and initial monitoring. On the basis of experience acquired during the project implementation, the number of wells to be monitored might be reduced. Contaminant to be analyzed – As, Sb, Ni, Tl at least, likely also Pb, Zn, Cr, Co, Cd.

3.12 Workshop organization

3.12.1 Presentation of Feasibility Study

Workshop has been organized in the UNDP Macedonia office in Skopje on July 11 with the aim to inform the relevant Authorities and stakeholders on the FS findings and recommendations. The results of Baseline Study have been presented by the project manager Mr. Dejan Mirakovski. A comprehensive characterization of the area of interest has been presented.

The findings and recommendations for the future measures to be adopted as identified within the frame of the Feasibility Study completion have been presented by project manager Jan Vana. Waste characterization, description of applicable methods, screening results, evaluation of bench tests performed and proposal on the corrective measures, including preliminary cost estimation, have been presented.

After presentation the participants presented their queries and various issues have been discussed.

List of the workshop participants is presented in table 3.60.

Table 3.60 – List of workshop participants

Name	Institution	E_Mail	Phone Nr.	Mobile Nr.
Ana K. Maznevska	MoEPP	a.karanfilova@moepp.gov.mk	3066930 ext 145	070 359 484
Dije Arifi	Municipality of Lipkovo	dijearifi@hotmail.com	031 463180	070 820 141
Xhemail Memeti	Municipality of Lipkovo	m_likova@	031 463180	070 602 710
Jan Vanek	Dekonta	vanek@dekonta.cz	00420 235 522 252	00420 602 274 558
Robert Raschman	Dekonta	raschman@dekonta.cz	00420 235 522 252	00420 606 751 936
Jan Vana	Dekonta	vana@dekonta.cz	00420 235 522 252	00420 602 337 513
Dejan Mirakovski	Faculty of Mining & Geology	mirakovski@yahoo.com		070 376004
Lendita Dika	MoEPP	l.dika@moepp.gov.mk	3066930 ext 145	
Anita Kodzoman	UNDP CO Macedonia	anita.kodzoman@undp.org	3249560	
Radka Konderlova	UNDP Bratislava	radka.konderlova@undp.org	// 421 2 59337248	
Nadica Andonovska	Farmakom MB - Zajaca	farmakommb@mt.net.mk nandonovska@gmail.com	3239594	075 481 984
Stojan Andonovski	Farmakom MB - Zajaca	farmakommb@mt.net.mk	3239594	075 445 591
Samir Memedov	UNDP CO Macedonia	samir.memedov@undp.org	3249562	

3.12.2 Workshop feedback

All the stakeholders expressed their desire for urgent management of the problems related to the insecurely dumped waste in the Lojane Mine area. Representatives of MOEPP informed the participants about the limited financial funds. That is why the final proposal presented in this study has been modified – in order to split the corrective measures proposed into particular stages/tasks that can stand alone from environmental and engineering feasibility perspectives should the next funding increment be delayed or unavailable.

Representatives of Lipkovo Municipality discussed the remediation/site closure presented in LEAP – consisting of “capping” the waste with polymer compound – this method is not applicable for Lojane Mine, it is used on municipal waste landfills, storage areas of fine grained material (coal, fly ash, etc.) to prevent the fugitive dust release. Durability of this solution is about 3 – 6 months only.

4 Conclusions and recommendations

The Feasibility Study represents a first step within the targeted program of the Environment and Security Initiative (UNDP, UNEP, OSCE and NATO), “Reducing Environment and Security Risks from Mining in South-Eastern Europe” to decrease trans-boundary environmental and safety risk posed by sub-standard mining and mineral processing operations in the past, as well as to reduce the significant risk associated with non-operational, abandoned site where large quantities of physically and chemically unstable and poorly contained mine wastes are stored.

The Baseline Study presents all data collected during the LOT 1 activities for preparation of Feasibility Study for Lojane Mine.

In general data present provide a solid base for planning of response actions including proper rehabilitation measures. These measures should comprise pollution mitigation techniques, cleanup measures and site access and usage limitations.

Site characteristic

The abandoned Lojane Mine Site and associated processing facilities are located north of city of Kumanovo, on the territory of Lipkovo municipality. Lipkovo municipality is located on the northern part of Republic of Macedonia with area of about 270 km^2. The total mine site area is about 10 km^2.

According the climatic-vegetation parameters and basic elements regime the Lipkovo area is classified as a continental submediterranean region.

The area under investigations consists of a complex of Precambrian rocks, of Paleozoic metamorphic rocks and magmatites, a complex of Mesozoic sediments and magmatites, a complex of Tertiary sediments and volcanics as well as Quaternary layers and volcanics. In terms of the geology the area belongs to the Vardar zone, only a small part (in the northeast) being part of the Serbo-Macedonian massif. Considering the geological conditions, the rocks in the area, in terms of their hydrogeology can be classified as: hydro geological collectors of fracture-karts porosity with marble layers, hydro geological collectors of intergranular porosity with alluvial layers, hydro geological insulators with deluvial occurrences, relative hydro geological insulators with schists, diabases, granodiorites and serpentinites.

The area of the consideration is part of the Lojanska and Lipkovska Rivers river basins that flow into the Tabanovska which joins the Pcinja. There are two water reservoirs on the Lipkovska River called Lipkovo and Glaznja.

The area belongs to continental submediterranean climatic zone of the country. Oak forests are most widely spread in this area. Grass and forest vegetation prevail in the area of Lojane compared with the other part of the Kumanovo region with predominance of forest species.

A typical represents of vertebral fauna are Ponto Mediterranean and Syrian arboreal elements, like worm water snake (Typhlops Vermicularis), cat snake (Typhlops Fallax), Balkan snake (Coluber Gemonesis), Balkan green frog (Pelobates yuriasly balcanicus), Eripaseiy concolor, Mustela Nivalis and others. Also varies birds could be found in the area.

There are no urban settlements on the territory of the Municipality, with 21 rural settlements which have population of various demographic dynamics and structure. The central settlement of the Municipality is the village of Lipkovo towards which other rural settlements incline. The closer urban settlement in the area is city of Kumanovo with population of around 120.000. According to the 1994 census total 22.861 inhabitants are recorded.

Lipkovo municipality is one of poorly developed regions and there are no industrial objects on its territory. Main economic activity is agriculture and 95 % of active population is involved in it. There is area of 22,599 ha for agriculture, from which 8,256 ha or 36.5 % is cultivable soil which is irrigated by Lipkovo hydro system. Pastures has an area of 4,375 ha or 19.3 %, and forests are the most spread on area of 9,968 ha or 44.2 %.

Urbanization in municipality is on low level.

Current negative economic conditions, as much as ecological problems present in the municipality, have adversely affected economical development. In that regard, there are ideas for local management and state institutions to make more efforts for correct economic development of the region.

In the study area there are no cultural and archaeological sites that are of historic interest within the zone of visual influence of the abandoned mine site.

Total quantity of material excavated during the period when mine was active (1923- 1979) is estimated to amount of app. 1,300,000 tons, so the annual production capacity was between 25,000 to 30,000 tons per annum, thus classifying the operation as relatively small (in today terms very small). Total quantity of wastes generated by extraction operations (waste rocks) are estimated to app. 90,000 tons. In the Suva River valley 3 main waste rock dumps and mined ore stockpiles are located. Considering the beneficiation facilities, remains found on place clearly indicate that flotation process was used.

The ore excavated was transported in processing plant by narrow rail line to the processing plan where ore was reduced in size by the crushing and/or grinding circuit. Antimony and arsenic minerals where concentrated by flotation process. The wastes generated by this process, known as tailings, were disposed in dry form on the pile created just in front of the plant. The tailings pile covers a surface of app. 17,400 m^2, and contains app 450,000 tons of tailings. A concentrate storage pond (stone structure with surface app. 2,400 m^2 and estimated volume of app. 5,000 m^3) built near the plant contains app. 15,000 tons 50% arsenic concentrate (realgar, As_4S_4) with admixture of antimonite (Sb_2S_3) concentrate. At the end concentrates where transported to the roasting plant, used to oxidize ore concentrates for smelting. The facility ruins and storage yard covers surface app. 17,000 m^2.

Impacts identified

Results obtained indicate extremely elevated concentrations of As only in Suva River flow, while in Lojanska and Tabanovska Rivers, although increased concentrations of As are detected, the values are significantly lower.

Extremely elevated As concentrations in Suva River waters have certainly detrimental effect on aquatic life/biota in this waters. Additionally these waters are occasionally used for irrigation, thus polluting the plants/food produced, as much as the soil irrigated.

In huge majority of the ground water samples taken, the waters quality is satisfactory and only slightly increased (up to 5 times) concentrations of As are determined. This data indicate the thesis that there is no direct connection between contaminated surface waters and groundwater, posed by preliminary hydrogeolocigal survey. It is obvious that increased concentrations of As are results of high natural background of this element, and all wells drilled in serpentine are naturally contaminated. Even in the wells from the zones considered to be none affected with former mining activates, similar concentrations are detected. At only two locations, extremely high concentrations of As are detected in the groundwater. These locations are spring below the tailings and positive pressure well nearby tailings pile (Bilnet Komerce well). In both cases, groundwater due to positive pressure coming to the surface likely washes the tailings before exiting to the surface, thus collecting huge amount of contaminants. Water from the spring creates a stream flow through the field and enters the Suva River.

Samples of Suva River sediments, shows highly elevated concentrations of As. In addition, elevated concentrations of other metals are detected like extreme values for Ni and occasionally Cd. Although elevated concentrations of contaminants are detected in sediments of Lojanska and Tabanovska Rivers, the values are again much lower.

The highest risk associated with the sediments is posed by the fact that sediment contamination provides long-term source of pollutants through potential re-dissolution in the water column, acting as persistent source of chemicals to human and aquatic life.

Although quantitative data concerning fugitive dust emission are not available, considering the chemical composition of the dust and assumed intensity of the fugitive emissions, it is more than certain that this fugitive emissions present significant respiratory hazard for humans exposed. Especially since elementary school and residential objects are located within the radius of only 100 m apart the tailings dump and As concentrate pond.

In addition, fugitive dust emissions significantly contribute to contamination of areas downwind as dust particles settle out of the air suspension. Although deposition may have been at a relatively low concentrations, the long period of deposition have significantly contaminate communal surfaces, commercial and living areas, as much as nearby agricultural lands, and water courses.

Results obtained show elevation of contaminants concentration in almost all soils sampled. Concentrations of the contaminants like arsenic, chromium nickel and manganese are extremely elevated in soils near the sources of pollution, while their concentration decrease as the distance is increased, and although elevated concentration of some toxic metals are found in soil sample at larger distances, they have much lower values. The most important mechanism of soils pollution is down wind deposition of contaminants (aero sedimentation), while contamination of soils with waters is less intensive and limited in area.

Soil pollution, especially with higher elevation of these contaminants could pose a serious risk to humans exposed.

Special concern is posed by the fact that contaminated soils can serve as a persistent long term pollution source even if no new contamination is entrained. This could cause long term contamination of all products grown in the soil, especially those which can bioaccumulate the contaminants. In this way through entering the food chain, soil contamination could have much wider area of influence, since these soils are used for production of vegetables sold in green markets in Kumanovo and Skopje.

The Feasibility study presents the results of on site and laboratory activities completed as well as results of archives internet databases search, treatment methods description and results of treatability bench tests. Proposal on further short term risk reduction measures and long term remediation and site rehabilitation measures is provided including cost estimation, discounted cashflow and timing expected.

Site reconnaissance – the important findings are:

- the area of interest is heavily littered with municipal waste and construction debris and their separation, collection, treatment and disposal of must be taken into account in further steps;

- there are several sources of contamination within the area considered disregarding the ubiquitous municipal waste and various debris:
    - waste rock dumped in the valley of Suva River,
    - waste rock dumped on Masguri ridge and its slopes – possible ARD directed by the valley on northeastern slope of Masguri to the tailings,
    - tailings and As concentrate at Rudnicka kolonija,
    - spring below the tailings at Rudnicka kolonija,
    - and As oxide, As concentrate, slag and other hazardous material freely dumped at former roasting facility.
- Suva River appears to be a permanent watercourse and thus a solution for treatment of its water prior entering into an aquifer and/or joining other watercourse has to be found and mitigation measures are to be taken in order to minimize transport of contaminated stream sediments;
- the valley, beginning on the South slope of Maja padine hill and entering the flats at Rudnicka kolonija, poses a risk – the runoff water flows around the foot of the As pond and tailings and thus it can spread the contamination.

Waste characterization – prevailing portion of the wastes at Lojane Mine is classified as hazardous due to high concentrations of contaminants identified (As, Sb, Ni, and Tl potentially) as well as due to their high leachability (except some waste rocks).

Risk Assessment - Based on the data collected within the frame of Baseline Study completion and complementary data acquired within the frame of Feasibility Study preliminary human health Risk Assessment has been carried out. This RA indicates unacceptable risks posed by the mining/ore processing wastes insecurely dumped in both the contamination source zones – i.e. the tailings dump at Rudnicka kolonija and the area of former roasting facility at Tabanovce.

Description of treatment technologies – description of treatment methods for soil, water and waste contaminated with heavy metals and As, Sb is provided, including overview of unit costs for applicable methods.

The Feasibility Study also presents recommendations for the development of ***Emergency response Plan*** and recommendations for the development of ***Monitoring Plan.***

Proposal on short term risk reduction measures **-** On the basis of the investigation of local conditions (economic, legal) and screening of applicable methods the proposal on mitigation/corrective short term risk reduction measures is provided. The method proposed is excavation and off site transport of mining/ore processing waste from the area of former roasting facility, the waste would be transported to the tailings dump at Rudnicka kolonija and subsequently all the waste will be capped with engineered capping system consisting of geosynthetic liner covered with cultivable soil, the surface will be recultivated by seeding the indigenous shallow rooting flora. This proposal can be modified dependently on the results of site exploration currently performed by the Concessionaire, which may result in remining and off site transport of reusable part of ore/processing waste (likely the As concentrate and As oxides with high content of Sb).

Proposal on long term remediation measures is provided in general terms because of data gaps and uncertainties identified. It is recommended to follow up the risk based approach - based upon comparison of risk levels and costs to eliminate it the Highest Acceptable Risk should be evaluated, the public and relevant Authorities should achieve consensus what is the highest socially acceptable risk.

Reflecting the financial demandingness of the site remediation/rehabilitation it is recommended to split the works proposed into five phases that are further broken down into partial stages/tasks that can stand alone from environmental and engineering feasibility perspectives should the next funding increment be delayed or unavailable.

Cost of the remedial measures depends on several factors – the volume of remined/reused of waste (if any), implementation of long tem remediation measures.

The project scoping, succession and costs are depicted in the table below.

Table 3.61 – Overview of project phases proposed and cost estimated

Phase 1 - Short term risk reduction	Variant 1	Variant 2
Advance works	155,259	155,259
Emergency measures	50,879	73,828
Conceptual model and final design	63,000	63,000
Project implementation	801,206	861,206
Contingency	107,034	115,329
TOTAL Phase 1	**1,177,378**	**1,268,622**
Phase 2 - Post closure measures		
Ambient air quality monitoring	11,200	11,200
Groundwater monitoring	110,250	110,250
Inspections of capping	21,000	21,000
Capping maintenance	21,000	21,000
Management of post-closure measures	45,000	45,000
TOTAL Phase 2	**208,450**	**208,450**
Phase 3 - Groundwater remediation		
Groundwater remediation in the tailings dump area	350,000	350,000
Groundwater remediation in the roaster area	225,000	225,000
TOTAL Phase 3	**575,000**	**575,000**
Phase 4 - Long term remediation - Suva River valley		
Detail site investigation	68,705	68,705
Risk Assessment	15,000	15,000
Implementation project + EIA	15,000	15,000
Project implementation - remedial action	400,000	400,000
Phase 4 - Post monitoring	150,000	150,000
TOTAL Phase 4	**648,705**	**648,705**
Phase 5 - Long term remediation - wider area		
Detail site investigation	131,313	131,313
Risk assessment	15,000	15,000
Implementation project + EIA	15,000	15,000
Project implementation - remedial action	750,000	750,000
Phase 5 - Post monitoring	21,000	21,000
TOTAL Phase 5	**932,313**	**932,313**
GRAND TOTAL (Phases 1 - 5)	**3,541,846**	**3,633,090**

Discounted costs are estimated at total amount $ **2,919,795** and $ **3,002,744** for Variant 1 and 2 respectively.

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