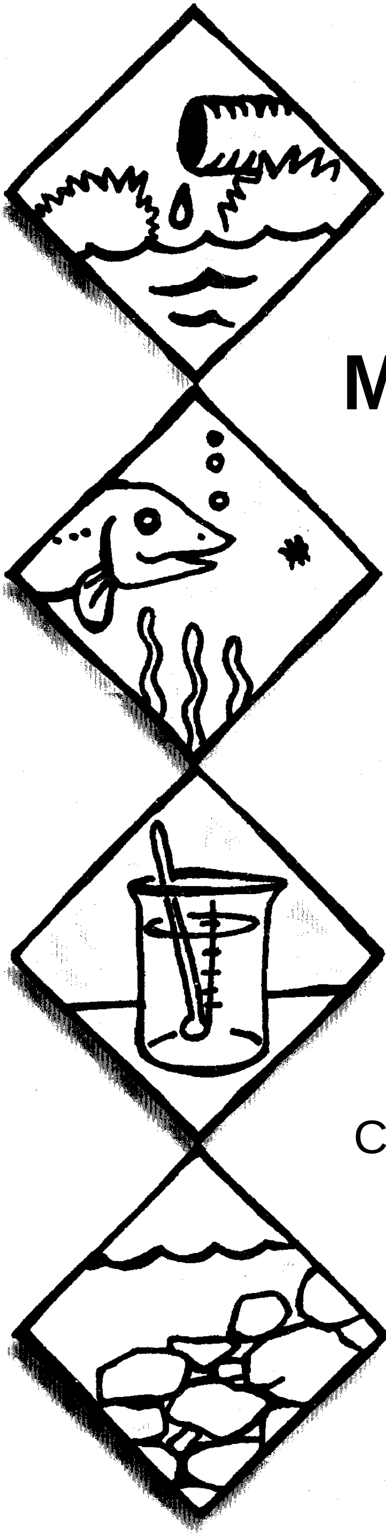


MINE **MONITORING** MANUAL

A Resource for
Community Members

by Sue Moodie

CONTENTS

INTRODUCTION

This manual is designed to help community members monitor the water quality impacts of a mine. It is designed to provide you with information which will help you to determine the main sources of contamination and the level of pollution being generated by the mine. This manual does not describe long term monitoring programs. It is to be used for a "spot check" type of water testing, to detect levels of water contamination at certain sites around the mine that is affecting your community today.

The purpose of an environmental investigation is to find sources of contamination that might be harmful to living beings (people, wildlife, fish and plants), and to determine how to best protect their health and prevent harmful impacts.

Laboratory analysis of water samples can be very expensive. To decrease your costs of analysis while still producing results, this manual approaches environmental investigations in a two tiered manner. First, you can use cheaper field analysis tools to pin point the highest contamination sources on site in a general way (field analysis can give information about some specific contaminants but they are usually measured in a general range rather than a specific number, for example arsenic levels between o.i and 0.5 ppm, this is called "qualitative" and "semi-quantitative"). Second, samples are taken from the "hot spots" to be sent for more accurate and more complete laboratory analysis.

CONCEPTS TO CONSIDER

1. Mine Site Contamination Sources

Exploration and mineral development increase the movement of metals into our environment by exposing rock surfaces (trenching, pit walls), generating tailings and waste rock, as well as stack gases (air pollutants from the smoke stacks of the mill) and effluent (water discharge or run-off from the mine and mill site) from milling processes. Mine site monitoring should consider the impact of a variety of contamination sources and take samples which are representative of all of these. Here are a few examples of the places to take samples:

Trenches- Exploration trenches and diversion ditches expose metals and provide a channel for surface water to carry sediment and contaminants to creeks.

Pit Walls -Fractures in pit walls from blasting and broken rock on benches (the steps in an open pit) can be sources for metal mobilization. The pit waters should be tested, especially if they have contact with surface or ground water flows.

Tailings -Tailings are the finely ground waste product left after the economic metals have been extracted. In addition to metals, they may also contain chemicals used during ore processing (e.g., sodium cyanide, sulphuric acid, diesel oil, and others). They are often deposited in a slurry behind dams to form a tailings impoundment. Tailings ponds may look like a contained lake if the tailings are fully under water, often the tailings are exposed in some parts of the impoundment. Dam structures leak and overflow. Wildlife may drink from the tailings water, and birds may land on the surface of the tailings impoundment and this could affect their health if it is highly contaminated.

Waste Rock - Rock that has been excavated to allow access to ore and piled on site usually with a variety of rock sizes. This exposed rock is often high in metals that aren't of economic value and can be a source of acid generation *(see list of terms)*. Surface water run off and wind erosion can move these metals into the watershed.

Adits - Drainage from underground workings of the mine can ^ occur through surface opening (portals and adits). This water can be high in metal concentrations. In winter, ice can form in adits, water pressure can build behind the ice plug and result in an explosive rupture of the frozen adit.

2. Risk

One method used to discredit concerns you might have about the impact of contaminants is the process of "risk assessment". Often environmental assessments attempt to determine the "risk" associated with certain types and levels of contamination. "Risk" is defined based on hazard (the degree of harm from a particular substance) and exposure (the potential for contact to occur in a way that might result in a harmful effect). Risk assessment assumes that some level of harm is fine and attempts to put a number on what is acceptable.

The risk assessment approach is not always appropriate. Certain contaminants are very hazardous, no matter what the degree of exposure, and the use of these substances should be stopped (e.g., asbestos is banned in many countries). This has been recognized in Europe, where there is a move towards placing bans on the use of a variety of metals in manufacturing (e.g., nickel, cadmium, lead, zinc, and mercury).

In any environmental assessment, it is *those at greatest risk* who should have their concerns regarding harmful impacts *taken seriously* and *proactively dealt with.* Those people at greatest risk may be living downstream from a mining operation, or they may be miners exposed to unsafe levels of metal contamination in the workplace.

3. Metals are Natural

Metals are part of the natural world, so streams in areas high in minerals will often have naturally high levels of metals. However, the harmful impacts of mining on watershed ecosystems (the living beings such as plants, animals, fish and birds in a an area of land where all the water collected through surface water and ground water sources will flow to common streams and lakes) have been known for centuries. In 1556 A.D., Georgius Agricola wrote about the aquatic impacts of mining stating *"when the ores are washed, the water which has been used poisons the brooks and streams, and either destroysfish or drives them away".*

Mineral extraction processes increase the amount of metals entering the environment in a number of ways:

- by exposing rock surfaces to rain, snow, wind, etc. (weathering)
- by grinding and breaking up rock, allowing metals to be blown as dust and carried in surface run-off or leached into ground water
- by pumping water with high metal concentrations from open pits and underground mines (dewatering), or uncontrolled drainage from underground mines (e.g., through adits, portals or seeps)
- if tailings dams leak or overflow
- by increasing acid mine drainage
- metals deposited on stream beds can be brought back into the water due to increases in water flows or changes in the pH, temperature or chemical composition of the stream and moved further downstream (remobilization).

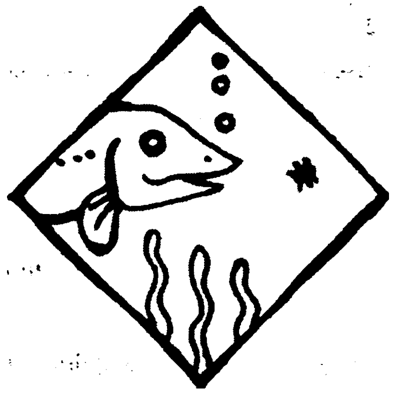
Today, mining is no longer a pick and shovel operation. Mechanisation allows mining to operate on a very large scale. Consequently, the possible damage to aquatic life, human and environmental health is far greater than when metals occur naturally in our environment.

Environmental monitoring aims to determine what high metal levels have come from the mine and should therefore be better contained and treated.

4. Aquatic Impacts

In aquatic systems (streams, rivers, lakes etc), metals which are dissolved in the water will be deposited on the stream bottoms as acid mine drainage flows downstream, creating a slime that can coat streambeds. This coating, which can harden like a cement, may affect streambed habitat for fish and aquatic organisms like benthic macroinvertebrates by fusing gravels together. Benthic macroinvertebrates are bottom-dwelling (benthic) animals without backbones (invertebrates) that are visible with the naked eye (macro), such as the larval stages of many insects. When the spaces between gravels are cemented, fish egg survival is threatened by lack of oxygen, and macroinvertebrate habitat is lost.

Benthic macroinvertebrates and other aquatic organisms that dwell at the bottom of streams and lakes often have the highest concentration of these metals, because they are in frequent contact with the metals that accumulate in sediments. These organisms are eaten by larger organisms and the metals are taken up into the food chain. For example, a large fish which has eaten many small fish and bugs with metals in their bodies, is then eaten by humans and the metals are passed from the first to the last on the food chain. This may result in bioaccumulation, bioconcentration and biomagnification *(see List of Terms).*



PREPARATION FOR FIELD WORK

Useful Information

Be well prepared before going to the site. Learn as much as you can about the mine before planning your investigation. Background information can be found from a variety of sources: interviews with knowledgeable local people, archives, libraries, land survey companies and government offices.

Information that is useful for an investigation includes:

- detailed description and maps of site location
- aerial photographs
- size of site
- geological description of area
- topography
- historical, heritage or archaeological values
- annual rainfall data
- flood potential
- types of surface water (creeks, lakes, marshes, etc.)
- depth of water table
- proximity to drinking water (humans or wildlife)
- uses of adjacent water resources
- fish and wildlife
- land use information
- types of contaminants likely present
- quantity of contaminants
- Environmental Impact Statement (EIS) of the mine

Past Sampling Records

Sampling may have already been conducted at the mine site. But conditions change over time, so the study may no longer be relevant to the current state of the mine. Nevertheless, it is useful to know the results of other studies for comparison.

Check the studies to see how thoroughly they were conducted:

1. What sample locations were chosen? Are all contamination sources represented (air, water, land, and all the structures that might contribute contamination such as the tailings pond, waste rock, effluent pipes etc.)?

2. How many samples were analysed? Were the samples taken properly?

3. What specific metals or contaminants were included in the analyses?

4. Has sampling been conducted for metal content in:

    water

    sediment

    soils

    plants

    fish or wildlife: bone, blood, liver (to give indication of accumulation)

    fish or wildlife: tissue or other portions eaten (for edible portion)

    human: hair, blood, or urine

5. Have metal levels been compared to water quality guidelines or human health standards?

6. Has a dose relationship been established? Is there a pattern : that can be determined about the amount of a contaminant (the dose) and the effect that is witnessed (for example, at 0.5 ppm of copper the fish will avoid the stream). Look, especially, for links between water or sediment metal levels, fish levels and human levels in terms of both accumulation and health effects.

Local Knowledge

Local people will be a wealth of information when attempting to determine the impacts that mining has had on watershed and community health.

Community members should identify priorities for water sampling. Below are suggestions for the type of information that might be useful in discussion with local people to clarify known impacts and key concerns before conducting sampling.

1. Knowledge of area before mining impact:

   personal

   other people known to be familiar with area

   written

   scientific research

2. General impression of changes in the area as a result of mining impacts, which leaves room for discussion of observations that you might not think to ask about.

3. A useful method for determining impacts over time is the establishment of "indicators," which are measurements that reflect the status of larger systems. For example, frogs are sensitive to metals and over time the numbers of frogs will decrease as a result of mine contamination, this is an early warning (an indicator) that other organisms may also become harmed by the metals. Indicators can be used to demonstrate incremental changes that result from mining.

Indicators of mining impact on watershed health:

- presence/absence of known and expected species, abundance (overall #) and diversity (# of kinds of species). Include plants, benthic organisms (stream bottom dwelling organisms), fish (various life stages, spawning, eggs, juveniles, adults), and other aquatic animals such as frogs.
- behaviour: movement, location, general traits, predator prey interactions or competition
- fish and amphibian health: appearance, fat, liver size, spinal curves or deformity, lesions, tumours, cancers, growth, reproduction, disease, death, lifespan
- increased fishing in area due to access roads and mine workers activities
- change in water levels

Indicators of mining impact on wildlife health:

- change in animal populations location-shifts
- behavioural changes
- food availability
- reproduction-numbers, health and survival of new born
- deterioration health and body condition
- disturbed habitat which could lead to changes for wildlife
- human interference such as increased poaching, roads, traffic etc.
- natural fluctuations of populations, species diversity and individual health must be compared to trends noted

Indicators of mining impact on human health:

- food and water source quality and availability
- general physical health
- general mental health
- infant birth weight and mortality rates
- cancer

Equipment List

In the following sections you will find descriptions of how to use the equipment listed below. The following will be useful for your water testing proiect:

- beakers (25Oml and sooml)
- scoops (range of sizes 65ml, 2OOml)
- stainless steel trowel or soil auger
- 5mm screens or sieve
- rinse bottle & deionized water (distilled water)
- conductivity metre and standard solutions
- pH metre and standard solutions
- test strips (pH, metals, cyanide)
- hand held thermometer
- preservatives -sodium hydroxide and 10% HC1
- cooler with lock
- large plastic re-sealable bags (durable)
- sample bottles
- gloves, mask, sturdy boots
- pvc tubing (optional, for siphoning samples out of barrels)
- knife
- notebook
- pencils, marker, grease pencil
- camera and film
- maps
- first aid kit
- axe

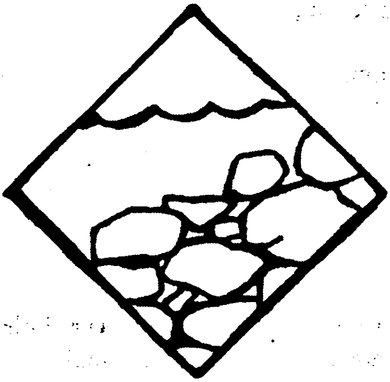
FIELD WORK

Safety

Personal protective equipment must be used appropriately. Gloves must be worn to take samples (rubber gloves for water samples and work gloves for soil). If there is blowing dust, face masks should be used to protect yourself from inhaling dust. Sturdy boots must be worn.

Common sense should govern all your activities. A mine site may have physical hazards such as the possibility that unstable underground workings will break when you walk over them (ground subsidence). Surface debris such as barrels or rusty equipment may also be on the ground around the mine site. Contaminants on site may also include a variety of unknown chemicals used in mineral processing which may be dangerous. Try not to disturb anything on site that may cause contamination, for example do not move barrels because they may be rusty or have leaks.

Keep basic first aid equipment handy.



Field Notes and Labeling

It is important to keep track of information in a systematic way in order to ensure that the results you obtain are useful and repeatable. It is important to be able to accurately describe all the sample locations and procedures so that you can take a follow up sample if it is necessary to do so at a later date. All notes must reference the precise location and date/time of sample, photograph or observation. A code numbering all samples and photographs (for example W1 or P1) must be recorded in the notes and labeled on the sampling container. All parameters measured (temperature, pH etc) must be listed in detail. List any relevant observations to refer to later.

Example of Field Notes:

W1 - Water sample #1 taken from center of creek 50 metres downstream of tailings impoundment on July 5, 2000 at 11:00 am. Conductivity reading was 5OOuS/cm, pH was 5.3 and water tem perature was 7 *degrees* Celsius. **Observations-red** silt covered the stream bottom, there were no plants adjacent to the stream, some erosion and undercutting of the creek banks was noted.

P1 - photograph #*1* was taken at sample location Wl facing up stream towards tailings impoundment (North). Note the erosion lines in the tailings dam and signs of *seepage* on lower west side.

S1 - Soil sample #1 taken at location of W1, 5 meters from west side of stream bank. Dry, coarse texture, 20 cm below surface, light brown colour.

On your sample, provide a label in permanent marker or grease pencil that won't rub off:

W1: Date
Location (eg. Mine site X 50 m below tailings dam)
Initials of who took the sample

A chart of parameters to be tested in all samples, with room for additional notes, can be useful in keeping field data organized.

Sample #	WI	W2	
Location	tailings-W side		
Water Temp	12° C		
Air T	15° C		
pH	3.1		
Conductivity	500us/cm		
Arsenic Strip	5ppm		
Copper Strip	50 ppm		
Colour	clear		
Notes			

List an inventory of waste on site, including number of barrels (note contents if labeled), physical structures, types of dumps, impoundments and waste piles. Note how close they are to surface water.

Field sampling- Initial Reconnaissance

On a first walk through an area, take notes on all observations. Look for:

- signs of stress in vegetation (parasites, leaf discoloured, blotches etc.)
- surface staining and discoloration of soil
- proximity to surface water
- signs of erosion
- instability of dams
- chemical containers (check labels)
- structures- storage tanks, buildings, roads, physical hazards
- oxidizing rock (looks rusty) and coloured deposits on stream-bed
- blowing dust
- take photographs

You can use the clues presented by the mine site to determine priorities for sampling locations.

Field Sampling- Where to sample?

As we stated in the introduction, the purpose of an environmental investigation is to find sources of contamination that might be harmful to living beings (people, wildlife, fish and plants), and to determine how to best protect environmental and human health and prevent harmful impacts. Sampling locations should be chosen based on providing information to achieve this goal.

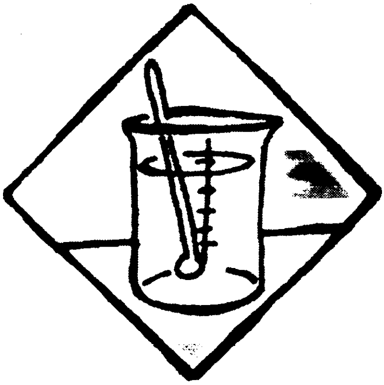
Determining Priorities

To effectively sample in the field, a series of choices must be made to determine priorities for sampling — it is not possible to sample everywhere.

Method A involves dividing the area into a grid and choosing sample locations based on the grid. In most cases, this method is impractical at mine sites because the area is too large and the extensive sampling required would be too expensive.

Method B is a more effective approach to sampling in a monitoring program that is looking for specific types of contamination at specific locations. It targets areas likely to be contaminated and compares results to baseline information. Baseline water quality information (background) is best determined from information gathered before mine exploration and development. If this isn't available, information from upstream or from a comparable stream in the area that has not been impacted by the mine can be used.

Method B is less expensive because even a few well chosen samples can give relevant information. If you use this approach, be sure to take samples from as many different places that have been contaminated as possible. A good cross-section of samples should include waste rock pile, pit wall, tailings impoundment, chemical storage area etc, this is called representative sampling (see descriptions of mine site structures on page 4). **Remember to determine an appropriate background level (baseline) for the area to compare your sample results with.**



Predicting Potential Impact

The more you know about the kinds of contaminants on site and their chemical characteristics, the better you will be able to predict where they will be found and the ways in which they are likely to move. For example, most metals will be carried in acidic water, though a few are carried in basic water (eg. molybdenum and selenium). This knowledge can help you to take fewer samples. Priorities for sampling should based on a prediction of potential for impact. These priorities should also be determined by the key concerns of community members (for example, drinking water source or fish health). The following concepts will help to set a framework for making decisions at a mine site:

Contaminant Characteristics: relative hazard (potential for harm) of contaminants present at the mine site, and their chemical nature that influences how they will react and move.

Exposure Pathways: the route a contaminant may follow to a receptor (e.g. airborne dust which will fall on agricultural land, dissolved in water which will affect fish).

Receptors: living beings or resources that may be exposed to and affected by contamination.

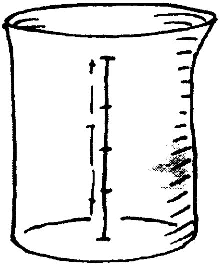
Sampling efforts should be focused on areas with the most harmful contaminant characteristics, and with the greatest chance of the contaminants directly following an exposure pathway to affect a priority receptor.

Taking Samples For On-site Analysis

Samples should be taken and analysed at the mine site to help you find the 'hot spots'. If needed, the samples which are of greatest concern because they show the highest levels of contamination can sent for more accurate laboratory analysis.

Water samples can be taken for on-site analysis in a beaker.

1. Rinse beaker three times with sample water.
2. Fill beaker with sample.
3. Carry out field tests as described in the next sections.
4. The beaker can be re-used and should be washed using a rinse bottle with de-ionized water (distilled water) between samples.



beaker

Soil samples can be analysed on site by preparing a paste solution and using the same on-site sample analysis techniques as for water samples. Paste solutions are prepared as follows:

1. Use a stainless steel metal trowel to pick up soil sample and sift with a 5 mm screen into a clean plastic labeled bag (remember to clean trowel and screen with deionized water before taking next sample).
2. Measure 65 ml of sifted soil sample into beaker and add 100ml of deionized water, stir with stainless steel spatula.
3. Allow to settle approximately 10 minutes before conducting field analysis tests.
4. Carry out field tests as described in the next sections.

Temperature

Using a hand held thermometer, take air temperature of the site before water temperatures. The stream temperatures should be measured when the sample is taken. Industrial discharge can change the temperature of the surface water (thermal pollution). Where possible, measure both upstream and downstream of effluent discharge locations to determine the change.

The temperature of the sample should be taken when it is analysed on-site because the temperature may influence the length of time required for test strip chemistry to give an accurate reading.

1. Fill beaker with water sample or place thermometer directly in the water that will be sampled.
2. Keep checking the thermometer until the thermometer reading stops moving.
3. Read final temperature.

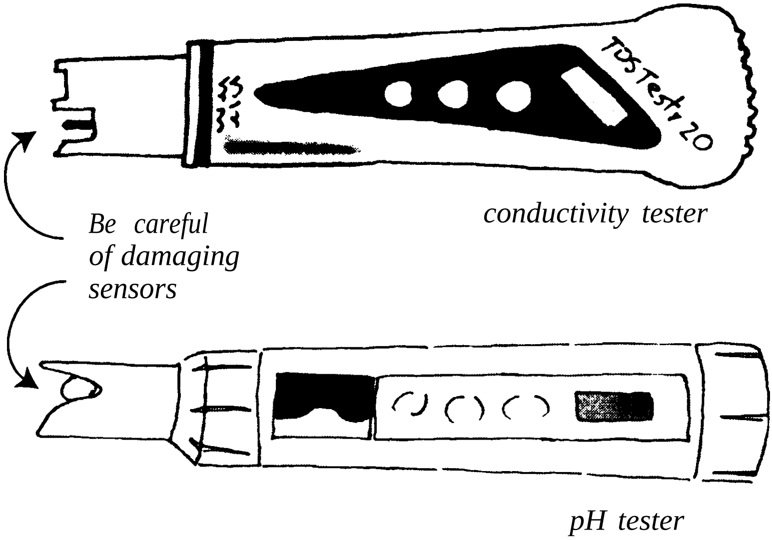
Conductivity and pH

Hand held meters can be used to test conductivity and pH. Always follow the instructions for calibration to set up the meters using standard solutions to ensure that the meters are taking accurate readings. Periodically check the meter readings with the standard solutions to be sure they are still calibrated correctly, re-calibrate if the reading is different than the standard solution.

Be careful to avoid touching the sensors located at the tips of the meters on the soil or beaker bottom —they are fragile and should be treated gently.

The hand held meters are used as follows:

1. Fill beaker with water sample or paste solution
2. Hold meter for required length of time, until the meter reading stops changing.
3. Read final pH and conductivity measurement on meter.

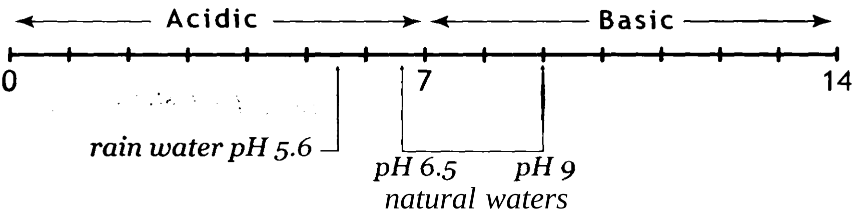


Conductivity

Conductivity measures the ability for water to conduct electricity. This increases with the amount of metals dissolved in water. The higher the conductivity reading, the greater the probability that some metals will be found in high concentrations. Surface water will usually have a conductivity of less than 15OuS/cm (microseconds/ centimeter).

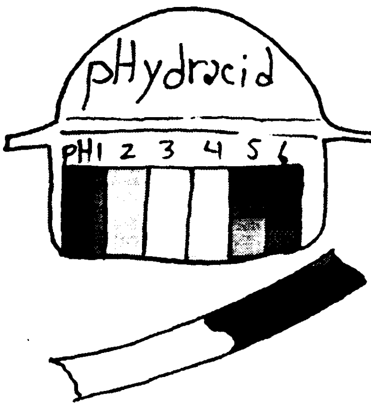
Samples with a conductivity higher than 500 uS/cm should be considered for taking a laboratory sample.

pH is measured on a scale of o to 14, which indicates if the sample is an acid (pH less than 7), a base (pH greater than 7) or neutral (equal to 7). The term "alkaline" is sometimes used interchangeably with the term "base", but this is incorrect, measuring pH does not accurately predict alkalinity. Mining activities can cause water to become too acidic or too basic, and either extreme can become a problem for natural ecosystems because it is harmful to most living organisms. Natural waters generally have a pH range from 6.5 to 9, and rainwater is acidic at 5.6. Most metals move more readily in acidic waters, though some may move in basic water (eg. selenium and molybdenum).



Test strips are also available to measure pH. These are used as follows:

1. Dip test strip in solution.
2. Different test strips require diffe waiting periods, check the instructions to find out how long to wait before checking the colour change.
3. Compare the colour of the test strip to the colour chart on the test strip bottle.



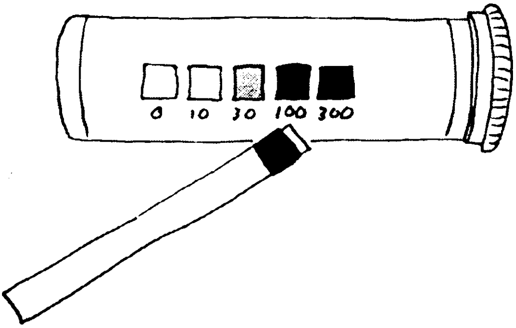
✓ **Samples with pH measured higher or lower than the natural range (6.5-9) should be considered for taking a laboratory sample.**

Metals

Test strips are available for a variety of contaminants. Each strip is specific to one contaminant. These are used by quickly dipping the strip into sample solution. A colour change will occur that can be compared to a colour chart. The colour reflects the range of concentration for that contaminant. The types of test strips used for your field investigation should be chosen based on knowledge of the mine site and the metals that will be of greatest concern at that site. Aside from test strips for metals, there are also test strips available for cyanide, sulphate and nitrate/nitrite.

Metal test strips are used as follows:

1. Dip test strip in solution.
2. Different test strips require different waiting periods, check the instructions to find out how long to wait before checking the colour change.
3. Compare the colour of the test strip to the colour chart on the test strip bottle.



Samples that should be considered for laboratory analysis are those with the highest test strip measurements. If you have high conductivity readings and no registered high metal levels with the test strips, it is likely that there are high levels of metals that have not been tested for with the test strips and these samples may still be a priority for laboratory analysis.

Field Sampling Results

On-site field results are used to determine priorities for taking samples to send for laboratory analysis. Choose the sample locations which best characterize the different types of contaminant sources (tailings dam seepage, runoff from waste rock, effluent pipes, adit drainage (water leaking from inside the mine), pit water etc) and which showed the field measurements of greatest concern. Remember to chose the sampling locations that are most likely to impact drinking water for people or wildlife, or aquatic life downstream.

Parameter	Test Method	Level of Concern
PH	hand held meter or test strip	pH less than 6.5 or pH greater than 9
conductivity	hand held meter	greater than 500 uS/cm
temperature	thermometer	significantly greater than upstream temperature
nitrate/nitrite	test strip	Nitrate greater than 10 mg/L, Nitrite greater than 1 mg/L
cyanide	test strip	any level registered
sulphate	test strip	greater than 300 mg/L
metals	test strip	see "Drawing Conclusions" p. 32

SAMPLING FOR LABORATORY ANALYSIS

Priority sample locations for laboratory analysis are chosen based on the field on-site sampling results and key concerns for exposure to fish, wildlife and people.

Care must be taken to ensure that all tools used for taking samples are cleaned with deionized water between samples and sampling containers are kept sterile until use. Water sample bottles should be rinsed three times with sample water before filling bottle with sample. The chart on the next page describes the containers, minimum and preferred sample sizes, and preservatives required for samples.

All samples must be kept cool, preferably in a locked cooler until shipped. Keep a record of who was involved in taking the samples and shipping. Send samples to be analysed by an accredited laboratory to ensure accurate analysis and proper quality control procedures (in Canada these are CAEAL accredited laboratories).

Sample Size and Preservative

Sample Type	Minimum Size (Recommended)	Preservative (Container)
Soil-metals	100g (400g)	none (plastic bag)
Vegetation-metals	100g (400§)	none (plastic bag)
Sediment-metals	100g (400g)	none (plastic bag)
Water-metals	20ml (500mL)	none*(plastic bottle)
Water-cyanide	20mL (100mL)	sodium hydroxide** (plastic bottle)

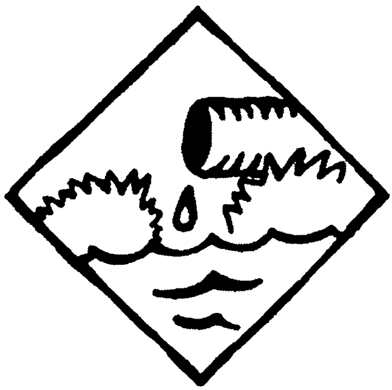
* For legal sampling, the sample should be preserved with 5 mL 20% nitric acid for total metal analysis of a water sample to follow standard sampling procedures. Nitric acid is difficult to ship and must be handled very carefully because it is extremely acidic and can cause chemical burns. However, analysis for total metal content of a water sample can be done accurately without using the preservative, tell the laboratory none was used and they will acidify the whole sample before analysis. Unpreserved samples can also be analyzed for dissolved metal content. The sample can be stored for up to three months and will still be a useful sample.

** Water samples that will be analysed for organic compounds such as cyanide must be preserved with sodium hydroxide and sent to the laboratory as soon as possible. Add 6 pellets of sodium hydroxide. In unpreserved samples, bacteria will degrade the cyanide content and the analysis will not be accurate.

Legal Sampling

All sampling protocols that you follow will be scrutinised if you find sources of contamination that are a cause for concern. As much as possible try to strictly follow standard sampling, preserving, storing, and shipping protocols. In order for sample results to be accurate and best hold up in court, the following must be considered:

- keep sample equipment clean
- preserve, seal and label samples immediately
- record notes carefully, include details of sampling procedures
- keep samples in locked cooler
- maintain control of samples so they cannot be tampered with
- choose a reliable laboratory to analyze samples (in Canada these are CAEAL accredited)



Many metals are essential nutrients (zinc, selenium, copper etc) that can become harmful to health if exposure to these is too high over time. Other metals are toxic to most life forms and will cause some harm to health at very low levels (for example, cadmium, lead and mercury).

Many factors contribute to the overall health impact of metals. The potential toxic effect depends on a combination of the following factors: concentration of contaminant; duration of exposure; how exposure happened (for example, through inhalation, drinking water, food, skin contact); and personal sensitivities resulting from age, gender, state of nutrition, and general health.

Toxicity

Acute toxicity is characterized by severe symptoms developing rapidly. Cause and effect are easier to determine in acutely toxic circumstances because the time lapse is short and symptoms tend to be obvious (for, example, no plants growing or dead fish). Chronic toxicity develops over time or with repeated prolonged exposure and therefore it is more difficult to pin point change as it occurs slowly and many more factors are involved in the health impact (eg. lifestyle and contact with other substances).

Sampling: In response to concerns about human exposure to metals, samples of hair, blood or urine may be analysed for indications that the metals have been taken up into the body. Swabs may be taken of dust in the home and analysed for metal content. Garden soils and harvested plants grown in impacted areas can be tested for metal content. In animals, kidneys and livers often accumulate more metals than muscle tissue. These can be analysed for metal content.

Biological Fate of Metals

When exposed to a metal, there are five possible biological responses within organisms (ie. on fish, animals, people etc.):

1. **Avoidance.** An organism may change its behaviour to avoid continued contact with the metal. For example, very low concentrations of metals may cause fish to avoid certain waters. The avoidance of streams with low metal concentrations may result in the elimination of that species from the watershed. However, this response may not always be possible, and aquatic biota may not be able to leave a stream.
2. **Exclusion.** Organisms have mechanisms in their biological systems which can prevent the uptake of certain metals into the body.
3. **Absorption.** The metal may be taken up locally (ie into skin) and then may be distributed through the body.
4. **Retention.** Once a metal is taken up and retained it can be used nutritionally, stored in breast milk, fat, tissue or bones, or metabolically changed and biotransformed to another compound.
5. **Excretion.** Many compounds are more readily excreted after going through some form of metabolic change.

Harmful impacts from metals occur when an organism is unable to avoid, exclude or excrete the metal. Often this occurs because exposure levels are too high or for too long and the biological system is overloaded.

Relative toxicity of various metals and cyanide, and their effects on health:

Aluminum

AQUATIC: Acutely toxic to fish, forms a gel in gills and suffocates fish. Chronic toxicity for fish affects protective coating of fish scales and increases susceptibility to fungal infections, seen as large red sores.
WILDLIFE: Bird ingestion of aluminum causes small numbers of eggs being laid, defective eggshell formation, poor chick growth and chick lethargy

Antimony

GENERAL: Similar properties to arsenic, but much less toxic. Often associated in ore bodies with gold.
WILDLIFE: Antimony is not an essential element for animals. Antimony is toxic but mobility in food chains is low.
HUMANS: long-term inhalation may cause lung disease; skin, eye, throat irritation; dizziness; headache; nausea, vomiting, diarrhea; stomach cramps; insomnia; and inability to smell properly.

Arsenic

GENERAL: Arsenic can be acutely toxic in low concentrations. Arsenite is more toxic than arsenate. Often associated with ores containing gold, copper and zinc. Arsenic trioxide produced in roasting gold.
AQUATIC: Arsenic is toxic to fish, and invertebrates, aquatic plants and diatoms are not tolerant of arsenic.
WILDLIFE: Bird ingestion of arsenic has lead to reduced appetite and growth, and behavioural abnormalities in chicks.
HUMANS: High doses lead to muscle spasms, nausea, vomiting, abdominal pain, diarrhea, death. Low dose over many years may result in skin, lung, or bladder cancer, peripheral nervous system disorders and dermatitis.

Beryllium

GENERAL: Toxic. Main hazard is inhalation of dust and its salts.
HUMANS: Symptoms (weight loss, weakness, chest pain, cough, eye irritation) may be delayed from 5-10 years. Potential carcinogen and can cause lung disease.

Cadmium

GENERAL: Highly toxic. Often found in ore bodies with silver and zinc.
AQUATIC: Chronic and acute exposure to cadmium causes spinal-column damage in fish.
HUMANS: Known carcinogen. Cadmium accumulates in the liver and kidneys. Chronic exposure can cause renal damage, anemia, osteoporosis and osteomalacia in humans, wildlife and birds.
PLANTS: Lichens can absorb cadmium from air, and plants may accumulate cadmium in roots or leaves.

Chromium

GENERAL: Chromic acids and salts (e.g., chromate) are toxic. Chromium is an essential trace element which can be toxic at higher levels.
PLANTS: Wilting, stunted growth, chlorosis, curled leaves, and stunted root system growth, algae cell walls altered.
HUMANS: Toxic symptoms of chromium include dermatitis, irritated eyes, scouring, dehydration, and skin allergies. Increase in human hypertension, diabetes and death rate has been linked to chromium concentrations in stream sediments Chromium (VI) is more readily absorbed than (III), and these tend to accumulate in the kidneys, bone, spleen, lungs and liver. Chromic acid and chromate are potential carcinogens; may cause liver, kidney damage; irritation of respiratory system; skin irritation.

Cobalt

AQUATIC: Toxic to rainbow trout, carp, char and insect larvae.
HUMANS: Low toxicity for humans. Cobalt is an essential component of vitamin B12. May cause respiratory irritation; breathing difficulty; asthma, dermatitis, weakness and lethargy.

Copper

GENERAL: Often found in ore bodies that contain silver and zinc.
AQUATIC: Toxic to fish, especially young fish, and all aquatic life. Neurological and behavioural avoidance effects in fish.
WILDLIFE: Symptoms include anorexia, depression, abdominal discomfort, jaundice, blood effects, reduced reproduction rates and faulty hoof keratinization, lung, liver, kidney damage, and anemia.
HUMANS: Virtually non-toxic to humans, copper is an essential element. May cause irritation to eyes and nose; dermatitis, anemia, gastric ulcers, renal damage and hemolysis. Greater risk to those with Wilson's disease.
PLANTS: Toxicity apparent in leaves as a very dark green colour, chlorosis, roots may be thick short barbed wire like, tillering decreases. Bioaccumulation in plants.

Cyanide

GENERAL: Very toxic. Can form cyanide gas in acidic water and this vapour is also very toxic.
AQUATIC: Toxic to fish and aquatic life, can inhibit fish reproduction Ammonia, thiocyanates and cyanogen chloride are break down products of cyanide which are toxic to fish
HUMAN: Blocks cells from absorbing oxygen and causes suffocation. Harms the central nervous system, respiratory system, and cardio-vascular system, can cause coma or death.

Iron

GENERAL: Iron is required by all living organisms, deficiency is signalled by anemia
AQUATIC: Toxic to mayflies, stoneflies and caddisflies.
HUMANS: Pure iron - non-toxic to humans. Iron salts may cause irritation eyes, skin, mucous membrane; abdominal pain, diarrhea, vomiting; possible liver damage

Lead
GENERAL: Found in most ore bodies with copper, silver and zinc.
AQUATIC: Toxic to fish.
HUMANS: Toxic. Affects digestive, blood and nervous system. May lead to spinal deformities; kidney dysfunction and hyperactivity in both aquatic organisms and humans. Possible human carcinogen.
PLANTS: Lead is not toxic to most plants, but is accumulated in plants and the health of animals eating these plants may be impacted.

Manganese
GENERAL: Manganese is an essential nutrient.
HUMANS: Inhalation of excessive dust is toxic. Affects nervous system. Symptoms include insomnia, mental confusion; dry throat; cough; chest tightness; breathing difficulty; flu-like fever; low-back pain; vomiting; malaise; fatigue; kidney damage.

Mercury
GENERAL: Toxic vapour or ingestion. Methylmercury (MeHg) is one of the most hazardous environmental pollutants known.
WILDLIFE: Affects nervous system, kidneys, eyes and skin . Birds exposed to MeHg may cause reproductive impairment.
HUMANS: Affects nervous system, kidneys, eyes and skin. Can lead to brain and spinal cord damage; and is a possible human carcinogen.

Molybdenum
GENERAL: An essential nutrient, there is a very narrow range of concentration separating toxicity from deficiency.
WILDLIFE: May cause irritation to eyes, nose, throat; diarrhea; weight loss; breathing difficulties; and liver and kidney damage in animals.

Nickel
GENERAL: Nickel carbonyl - highly toxic.
HUMANS: Nickel is a potential occupational carcinogen, accumulates in kidneys and central nervous system can be severely affected. Nickel carbonyl is carcinogenic.

Selenium
GENERAL: Selenium is an essential element which can also be toxic.
AQUATIC: Selenium increases along aquatic food chains.
WILDLIFE: Emaciation, lameness, deformed hooves and loss of hair are signs of selenium toxicity. Bird ingestion resulted in reduced growth and birth defects, and impacts attributed to food chain accumulation are failure to nest, increased embryo mortality, decreased hatching rate, and chick survival.

Zinc
GENERAL: Toxic. Often found in ore bodies with copper, lead and silver.
AQUATIC: Acutely toxic to aquatic life, causing fish gill damage that ultimately leads to respiratory failure.
HUMANS: May lead to chills, muscle ache, nausea, fever, cough; weakness, headache; blurred vision; low back pain; vomiting; fatigue; breathing difficulty.
PLANTS: Toxicity signs are chlorosis in new leaves and reduced growth.

DRAWING CONCLUSIONS

Laboratory analysis results can be compared to concentration levels defined by regulations in your area. Below is a chart which shows guidelines set by the Canadian Council of the Ministers of the Environment for the Protection of Freshwater Fish and for Drinking Water, as well as the World Health Organization Guidelines for Drinking Water Quality.

The higher the concentration above the levels below, the greater the concern associated with the contaminant and the potential for harmful impacts from the mine. Remember to compare sample results to the background levels for the area to be sure what amount of the contamination has been caused by the mine.

Parameter	CCME Freshwater Aquatic Life (ug/L)	CCME Drinking Water (ug/L)	**CCME** Soil mg/kg	WHO Drinking Water (ug/L)
aluminum	5			
ammonia	1.37			
antimony			20	0.005
arsenic	50	25	5	0.01
barium		1000	200	0.7
beryllium			4	
boron		5000	1	0.5
cadmium	0.2	5	0.5	0.003
chromium (+6)			2.5	0.05
chromium (total)	2		20	
cobalt			10	
copper	2	1000	30	2
cyanide (free)	5		0.25	0.07
cyanide (total)		200	2.5	
iron	300	300		
lead	1	10	25	0.01
mercury	0.1	1	0.1	0.001
molybdenum				0.07
nickel	25		20	0.02
selenium	1	10	1	0.01
silver	0.1			
sulphate		500mg/L		
zinc	30	5000		

List of Terms

To use the sample results effectively, some terms and technical language might be useful. Here are some:

adsorption - process of removing a dissolved ion or molecule from solution through accumulation on a solid surface, influenced by equilibrium factors, surface area

AMD - acid mine drainage is a process which speeds the leaching of metals with the influence of sulfuric acid formed from the oxidation of sulfide ores in the presence of water

bioaccumulation - process of uptake of metals directly into the the tissues of an organism from water or by consumption of food

bioconcentration - net accumulation of a chemical or metal in in the tissues of organisms resulting from a difference between uptake and elimination.

biomagnification - the result of bioaccumulation and bioconcentration in which concentrations of metals increase in the tissue of organisms as they are passed up the food chain.

CAEAL - Canadian Association for Environmental Analytical Laboratories. CAEAL accreditation ensures that the laboratory follows standard procedures for quality control.

ecosystem integrity - refers to level of biological diversity, types and levels of processes (eg. nutrient cycles, energy flow, metabolism, production, predation etc.) and persistence of habitat. .....

PPM - parts per million, describes the concentration of a substance (solute) dissolved in water, ppm is equivalent to miligrams of solute per litre of water (mg/1).

PPB - parts per billion, describes the concentration of a substance (solute) dissolved in water, ppb is equivalent to micrograms of solute per litre of water (ug/1).

stress - a situation in which an anthropogenic factor or stressor acts on a population, community or ecological system with sufficient effect to cause a prolonged disruption of energy flow and pattern of energy storage so as to alter the state and stability characteristics of the affected system with a net loss.

Acute toxicity - is chararcterized by severe symptoms developing rapidly.

Chronic toxicity - develops over time or with repeated prolonged exposure.

ADDITIONAL RESOURCES

EPA. November 1997. ***Volunteer Stream Monitoring: A Methods Manual.*** EPA 841-6-97-003. Phone: (202) 260-7018.

Bertell, Rosalee. March 1994. ***Health 2000, A Guidefor the Community Seeking to Undertake a Health Survey.*** International Institute of Concern for Public Health, Toronto, Ontario, Canada.

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CONTACTS

Shanna Langdon
Project Underground
1916 A Martin Luther King Jr Way
Berkely, CA, 94704
Phone: (510) 705-8981
Fax: (510) 705-8983
Email: shanna@moles.org

Sue Moodie
Yukon Conservation Society
Box 4163, Whitehorse, Yukon, Y1A 3S9
Phone: (867)668-5678
Fax (867) 668-6637
Email: ycsmining@polarcom.com

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