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APPENDIX A - TECHNICAL SUMMARY NOTES:

Guideline Document For Monitoring Acid Mine Drainage

MEND Project 4.5.4

**This work was done on behalf of MEND and sponsored by
the Ontario Ministry of Northern Development and Mines and
the Canada Centre for Mineral and Energy Technology (CANMET)
through the CANADA/Northern Ontario Development Agreement (NODA)**

October 1997

APPENDIX A:
TECHNICAL SUMMARY NOTES:

GUIDELINE DOCUMENT FOR
MONITORING ACID MINE DRAINAGE

Prepared For:

Mine Environment Neutral Drainage (MEND) Program

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PROJECT S.185
Contract 23440-5-1176/01-SQ

OCTOBER 1997

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1.0 INTRODUCTION

This section describes a wide range of potential monitoring categories and summarizes the available sampling, monitoring or analytical techniques (elemental content, water quality, gas sampling, etc.) In most instances the following headings are used, though due to the diverse nature of these techniques the headings are not always universally applicable.

Application: Explanation of the information obtained from each sampling category and what it is used for.

Background: Where the information is used, and what other sampling work may be carried out in conjunction with this category;

Methods: Describes the more common methods, along with a brief description of the methods;

Limitations / Advantages: Outlines the limitations and advantages of the different methods.

Recommendations: Whenever possible recommendations are provided for the methods.

Cost: General cost estimates are provided when they are not too site-specific to determine. They are provided on a cost per analysis, per sample, per hole, etc.

References: Recommended sources for additional information.

The information is based in part on the following monitoring/sampling manuals, which are the first sources to consult if more detailed information is required:

- MEND Report 4.5.1-2 (1994), *Handbook for Waste Rock Sampling Techniques,* which is a summary of available waste rock sampling techniques, with recommendations;

- MEND Report 4.5.1- 1 (1994), *Review of Waste Rock Sampling Techniques,* which is a more comprehensive document that contains detailed descriptions of available waste rock sampling techniques;

- MEND Report *4.1.1* (1989), *Field Sampling Manual for Reactive Sulphide Tailings.* In this report, an approach is developed to assist in selecting appropriate methodologies for the sampling of tailings solids, liquids, and pore gas. The selection process is based on initial reference to classification index charts and a flowchart which are categorized on the basis of: phase; sample position relative to the water level; equipment power requirements; degree of required isolation from sources of contamination; and degree of disturbance to the sample during its collection. Equipment details provided in the report include technical descriptions, sketches where appropriate, listings of advantages and disadvantages, and the suitability of the equipment for use in collecting samples for microbiological and geochemical analyses.

- National Uranium Tailings Program (1985), *Uranium Tailings Sampling Manual,* which describes sampling procedures applicable to any TMF.

2.0 AMD ASSESSMENT TEST PROCEDURES FOR SOLIDS

2.1 Static Tests

Application: To determine the net potential acidity that could result from oxidation of the sulphides to acid (AP - acid potential) versus the neutralization potential (NP) provided by buffering minerals contained in the waste rock or tailings (e.g. acid-base accounting). Required for characterization of AMD potential.

Background: Static samples are usually taken as part of a program which would also involve selection of samples for chemical and mineralogical testing.

Methods:

a) Protocol developed by B.C. Research (Duncan and Bruynesteyn 1979) for determination of oxidizable sulphur and carbonate.

b) Modified version of Duncan and Bruynesteyn 1979 test presented in B.C. AMD Task Force, Draft Acid Rock Drainage Technical Guide (SRK, Norecol and Gormely 1990) which involves differentiation between oxidized (i.e. sulphate), leachate and non-leachable sulphur.

c) Method developed by Sobek et al. (1978) involving addition of excess hydrochloric acid followed by titration with sodium hydroxide to pH 7.

d) U.S. EPA method and various modifications to U.S. EPA method.

The first three methods are in common use. Many practitioners are investigating or using modifications to these standard procedures, and several other procedures exist, as listed in Table III: 1.2- 1.

Limitations /Advantages: No static test is a true indicator of whether samples would produce acidity. Furthermore contaminated leachates can be produced without the production of acid. There is some concern that NP estimates may vary with test procedure. Therefore, some quality assurance using an alternative procedure for determination of NP is warranted. The advantages and disadvantages are summarized in Table III: 1.2-l of the main text.

Recommendations: All of the above. For simplicity and speed, Item c) is preferred.

Cost: Average cost is $75-1 00/sample.

References:

See Ch:III: 1.2.1 and Table III: 1.2-l of main text.

2.2 Dynamic Tests

Dynamic tests involve the time dependent study of acid generation. These tests are designed so that the variables indicating sulphide oxidation (dissolved iron concentration, sulphate concentration, pH) can be routinely monitored. Generally dynamic experiments are short-term laboratory procedures lasting no more than a few months.

Application: Investigative monitoring used to determine the rate and extent of acid generation from waste rock. This information is essential for prediction and modelling purposes.

Background: Dynamic tests are not performed routinely or in large numbers. A limited number of samples may be selected for dynamic testing based on the results of static and chemical tests.

Methods:

The most common method is the stationary column, followed by the humidity cell, and field lysimeter . Less commonly used are stirred reactor studies and soxhlet extraction tests.

A **stationary column test** involves placing rock or tailings into a column, and adding water to the top of the column following a predetermined test schedule. The water infiltrates through the test column and the **leachate** is collected from the bottom. Chemical analyses are conducted on the original sample, each leachate sample and in some cases on the solid sample upon completion of the test. **Lysimeters are the** field equivalent of column tests but operate on a larger scale and for longer time periods.

A **humidity cell** consists of a chamber designed to mimic the effect of weathering on the test material. The chamber allows control of air temperature, and humidity, with leachate collected via a drain in the bottom of the chamber. The cell is usually operated on a standard 7 day cycle, consisting of 3 days of dry air flow, followed by 3 days humid air flow and ending with the addition of a measured amount of distilled water which is drained after a specified holding time has passed. This **leachate** is then analysed. A complete humidity cell test generally runs for 6 to 50 cycles.

Stirred Reactor studies are completed with pulverized rock powder suspensions, which are fluidized by continuous stirring. The simplest and most common of these are shake flask studies. These involve placing a number of flasks containing rock powder and an extractant solution on rotary shakers. Over the length of the experiment water samples are periodically collected for analyses.

Soxhlet Extraction involves the placing the pulverized rock sample in the thimble of the soxhlet extraction apparatus. A reservoir is filled with water or a weak organic or inorganic acid solution. The solution in the reservoir is heated and vaporized and passed through a condenser. The condensate drips onto the sample, percolating through and draining back into the reservoir. The leachate is analysed after 64 to 192 hours.

A basic summary of the objectives for each of these methods is provided below (From BC AMD 1989).

Objective	Test Procedure			
	Column / Lysimeters	Humidity Cell	Stirred Reactor	Soxhlet Extraction
Selection or confirmation of disposal options				
Determination of overall water quality impacts				
Determination of effect of flushing rates				
Determination of influence of bacteria				
Confirm potential to generate acid under test conditions				
Determination of rate and variability in rate of acid generation				

Limitations /Advantages: ***No*** dynamic laboratory tests can represent field conditions; therefore the tests should be interpreted with caution. Field lysimeter tests are very expensive to build and monitor and therefore are not routinely used. An ASTM standard is currently being developed for humidity cells. This standard, when released, will make it easier to interpret and compare test results. The advantages and disadvantages are summarized in Table III: 1.2-2 of the main text.

Recommendations: For new sites, columns and if possible field lysimeters are recommended. For existing sites, on-site monitoring takes the place of dynamic tests. Samples that are not crushed and that include larger, more representative particle sizes are preferred. For samples with large particle sizes, column tests are preferred. Quality control (duplicates, triplicates) are important to assess the variability and reproducibility of the dynamic test program. The major issue with most dynamic tests is that the short test duration relative to the actual process in the field. Nominal test programs are conducted for 10 weeks while practice has shown it can take much longer periods (e.g. 1 year) for sample to become acidic and/or produce contaminated leachates.

Cost: Costs for column tests are approximately $5,000/test, including sample analysis. Duplicate tests, which are preferred, would double cost to $10,000. Costs for field lysimeter tests are: $50,000 plus for design and set-up; and $30,000 to $50,000/year for operating.

References:

See ChIII: 1.2.2 and Table III: 1.2-2
BC AMD 1989
Duncan and Bruynesteyn 1979
Halbert et al. 1983
Scharer and Nicholson 1991
BC AMD 1990
Finkelman and Giffin 1986
MEND 1.16.1c 1991
Sobek et al. 1978

3.0 AMD MODELLING PARAMETERS

3.1 Gas Sampling

Application: Gas sampling is used to evaluate oxygen availability or concentrations as a function of depth within waste rock dumps or tailings for use in modelling, and to monitor products of acid production (e.g. CO_2). Oxygen sampling is also used for monitoring the effectiveness of covers. For the majority of projects oxygen is the most commonly sampled gas.

Oxidation of sulphide minerals contained within tailings is controlled by the flux of oxygen across the surface of the tailings. Consumption of oxygen within the tailings creates a vertical oxygen gradient unsaturated portion of the tailings, which can be measured in the through the use of gas sampling ports at various depths. For modelling, the flux can be calculated from this gradient and other physical parameters such as grain size, diffusion coefficients, moisture content, etc.

Background: Gas sampling ports are often installed in boreholes in conjunction with temperature thermistors. Temperature at gas sampling location is measured when gas is sampled. Gas sampling ports may also be used for air permeability tests.

Methods of Sampling: Gas is usually sampled from tubes installed at different depths in borehole. Sampling devices include portable peristaltic pumps or hand bulbs. Samples are analysed with the use of on-line gas meters, or sampling into container for future analysis (e.g. Tedlar bags). A new method called the Oxygen Consumption Method can be used to directly measure oxygen flux into a tailings area without having to measure oxygen gradients, and other parameters such as grain size diffusion coefficients, moisture content, etc. This method is described below under the New and Emerging Techniques subheading.

Limitations /Advantages: Most carbon dioxide meters cannot measure values greater than 2-3% by volume. If concentrations exceed this, the gas must be collected and analysed by gas chromatography or infrared spectrometer. Below 0 C, sample lines may freeze on-line gas meters.

Recommendations: Analyse gas from ports using on-line meters, if possible. The Oxygen Consumption Method described below should be considered as an alternative.

Cost: Drilling and installation of gas ports costs approximately $1,000 to $2,000/hole (depending on depth and number of ports). Drilling costs approximately $70-$100/metre, and may also be used for temperature measurements, waste rock sampling, installation of piezometers, etc. Instrumentation costs $15-$20/metre. Costs for an on-line gas analyser range from $1,000 to $3,500. Labour time estimates to sample a hole range from 10 to

30 minutes (depending on depth and number of ports). Reusable syringes ($30 to $50 each) are used to collect samples for gas chromatography ($50 to $80/sample).

New and Emerging Techniques: An alternative to using oxygen sampling at various depths to obtain oxygen flux has recently been developed by Nicholson and Williams (1995) as a MEND research project conducted on INCO's Copper Cliff tailings. The technique is referred to as the Oxygen Consumption Method.

In this method, a closed chamber is driven into the tailings surface and the decrease in oxygen with time in the closed chamber above the tailings surface is measured. A plot of normalized oxygen concentration in the closed chamber allows the immediate calculation of the flux of oxygen across the tailings surface.

This is a rapid real-time technique for evaluating the rate of oxidation at TMFs, without the need for other parameters such as grain size, diffusion coefficients, etc . In one day, multiple samples can be taken that will characterize oxidation at different locations across a TMF.

This technique is also being applied experimentally to waste rock. *An in-situ* application is not possible in waste rock because the open ended chamber used for tailings cannot be sealed when used on a waste rock dump. Instead waste rock is taken from a pile and placed in a sealed chamber in the lab, where the decrease in oxygen with time is measured.

References:

Nicholson and Williams 1995
Nolan, Davis and Associates Ltd. 1993

3.2 Oxygen Diffusion

Application: The rate of oxygen diffusion is often the rate-limiting step for acid generation in waste rock piles and especially in tailings. Hence, oxygen diffusion rates are an important modelling parameter for predicting acid generation. Oxygen diffusion measurements are also required for investigations of covers designed to provide an oxygen barrier.

Background: Oxygen diffusion is measured in the lab, or estimated empirically using known physical parameters.

Methods: Use of non-reactive gas (nitrogen, carbon dioxide, argon, etc.) in gas permeation (column diffusion) studies, and dynamic measurements of oxygen diffusion in a column test are the methods most commonly used to assess oxygen diffusion.

Limitations / Advantages: Controlled conditions are required for accurate measurements; however, accurately representing the heterogeneity of waste rock dumps with these laboratory experiments is difficult. Samples of different areas of the dump should be analysed in column studies.

Recommendations: No preferred method. Laboratory estimates should be compared to oxygen profiles measured in the field.

Cost: Laboratory program to assess diffusion into waste rock or cover materials is approximately $5,000/sample.

References:

Domenico and Schwartz 1990	Freeze and Cherry 1979
Hvorslev 195 1	Weeks 1978

3.3 Infiltration Estimates

Application: Water infiltration estimates are used in predictive modelling. They are combined with flow monitoring and meteorological data to complete water balance estimates.

Methods: Infiltration estimates may be based on meteorological data (monthly precipitation, temperature and evapotranspiration, etc.). Infiltration can also be measured directly correlating lysimeter data with site precipitation data. Predictive models such as HELP can also be used to estimate infiltration. Often more than one of these methods is used.

Limitations / Advantages: Lysimeters (TSN 14.2.2) have the advantage of providing direct measurements; however, they are limited by problems associated with high internal variability (for waste rock piles), and seasonal variations in infiltration rates. to counter this year round monitoring with multiple lysimeters is required. Predictive infiltration models have the advantages of speed and lower overall cost.

Recommendations: No preferred method. Use of more than one method will improve confidence in estimates. Uncertainty in infiltration estimates may translate to uncertainty in model predictions of contaminant loadings.

Cost: Lysimeters cost approximately $1,000 to install per lysimeter. Costs for HELP model are approximately $2,000.

References:

Schroeder et al. 1989

3.4 Permeability Measurements

3.4.1 Water Permeability (Hydraulic Conductivity in Saturated Zone)

Application: To evaluate permeability (hydraulic conductivity) of waste rock piles, tailings, and soil and bedrock surrounding AMD sources. Water permeability is rarely required when assessing waste dumps, as they are usually unsaturated, but is required for TMFs as typically all or some fraction of the tailings is saturated. Water permeability measurements of underlying and surrounding soil/rock may also be required.

Background: Hydraulic conductivity can be measured in the field using piezometers installed in boreholes. These boreholes are often also used for other purposes such as waste rock/tailings sampling, gas monitoring, temperature monitoring and air permeability tests. Laboratory permeability estimates may be obtained using grain size correlation procedures, permeameters or triaxial tests.

Methods: Hydraulic conductivity may be measured in the field with single-well response test (slug test), or with a pumping test using a network of observation wells. Laboratory testing of samples can be conducted using a permeameter test. Permeameters measure the rate at which water percolates through the sample material. Several tests are run with each sample and an average determined. Empirical methods of estimating hydraulic conductivity based on grain size distribution are used for approximate estimates.

Limitations/Advantages:

TYPE	ADVANTAGES	DISADVANTAGES
In Situ		
Single Well Response Test	Allows rapid determination of hydraulic conductivity in porewater sampling piezometers. Allows numerous tests to assess spatial variability.	Zone of influence for each test is small Determines only horizontal hydraulic conductivity Quality of the test is dependent on the quality of the piezometer installation.
Pumping Test	Most accurate means of determining hydraulic conductivity and storability Allows determination of bulk. hydraulic conductivity and storability.	Requires a large diameter pumping well and observation piezometers. Tests are generally long-term and costly. Requires special monitoring configuration to determine vertical conductivity.
Field Permeameter	Field permeameters provide data within minutes and are easy to use.	Field permeaters require relatively permeable material and accuracy is limited. Requires relatively undisturbed sample to mimic in situ packing density.
Laboratory		
Grain-size Correlation	Determined using solid samples and empirical relationships, hence does not require expensive monitoring wells.	Only provides extremely rough estimates. Subject to interpretation therefore requires a great deal of experience. Generally only applicable to sandy materials.
Permeameter	Results from properly built and operated permeameters can be quite accurate. Disturbed core samples may be used to determine vertical hydraulic conductivity.	Generally restricted to large engineering firms or academic institutions due to sophistication and technical experience required. Ability to represent in situ conditions is highly dependent on re-establishing in situ packing density of the sample. Generally restricted to relatively permeable materials.
Triaxial Test	Similar to lab permeameter but primarily used for low permeable silty tailings.	Same as permeater with the exception of the ability to analyse silty tailings.

Recommendations: *In situ* slug tests are recommended if monitoring wells are available. Laboratory permeameter or triaxial experiments may be used if monitoring wells are not available. Grain size correlation should only be used for preliminary assessments to aid in directing future permeability investigations.

Cost: Cost for slug test is approximately $100/hour, or on average $200/borehole, although this will vary widely with the permeability of the material being tested. Costs for laboratory determinations will include field sampling time and laboratory expenses.

3.4.2 Permeability to Air

Application: Evaluation of air permeability of a waste rock pile is required for predictive modelling if oxygen travels by convection. Permeability measurements are primarily applicable to waste rock, as bulk permeability of tailings is typically several orders of magnitude lower than in a waste rock pile. In tailings oxygen transport primarily occurs through diffusion.

Background: The most common objective is to evaluate oxygen availability as a function of depth. Carbon dioxide may also be measured as an indicator of acid generation as it is released as a by-product of acid neutralization by carbonate rocks. Gas sampling is usually completed to Gas sampling ports are used to evaluate air permeability.

Methods: Air pumping tests, air injection tests and estimates from measuring natural barometric gradients are all used but all are fairly experimental. Temperature (at surface and/or within pile) and porosity are also needed to calculate permeabilities.

Limitations /Advantages: The risk of test failure is high for air pumping tests, especially for coarse dump materials. Air injection tests are not recommended as they can modify gas composition and temperature in pile and introduce oxygen, which is not desirable. Measuring natural barometric changes is difficult as changes are unpredictable and if permeability is high the method may not work. Unpredictable weather changes can be compensated for by using pressure transducer and automatic recorder.

Recommendations: Estimates from measuring natural barometric gradients are recommended, otherwise a good estimate of air permeability is required.

Cost: Can be less than $1,000 per test if suitable boreholes with gas sampling ports are already installed.

3.5 Porosity

Application: Porosity influences infiltration rates of water and oxygen both into and through potential or actual acid generating sources. It is an important component for predictive modelling techniques.

Methods: Porosity can be calculated using bulk mass density and particle mass density. A standard procedure for estimating aggregate porosity involves the calculation of rock relative density established by a water displacement test. Both these methods are commonly used. Calculation of overall bulk porosity of a waste rock dump can also be done when the volume of the dump, and the mass and density of waste rock in the dump are known.

Limitations / Advantages: These measurements are conducted on a relatively small, disturbed sample, and then assumed to apply to entire pile. This assumption is more applicable to tailings than waste rock, although both will vary spatially.

Recommendations: Use the first method for tailings, and the second method for waste rock, unless the dump volume, and mass/density of waste rock is available. Estimates from the various methods can be used as a check.

Cost: Costs are approximately $100 for the second method and $200 for the first method.

References:

ASTM 1991c
ASTM 1988c

3.6 Temperature Measurements

Application: Investigative monitoring. Temperature recordings inside waste rock dumps or tailings management facilities are important to evaluate several processes: reaction rates, diffusion and convection, control of bacterial growth, oxygen solubility in water, water movement in the vapour phase and general monitoring of dump evolution.

Background: Elevated temperatures inside rock piles and similar structures can indicate areas of rapid acid generation. Most chemical and biological reaction rates and the solubility of many metal species are significantly influenced by temperature. Foe example, at temperatures < 4 C oxidation rates are negligible. Meteorological measurements such as air temperature, precipitation, wind velocity, atmospheric pressure, and snow cover are usually taken when internal temperature is taken (See TSN 10.0).

Locations: Temperature is usually measured within boreholes using a thermistor. Less useful are temperature measurements at surface and at seepage collection points. Infrared thermometry (airborne or hand-held) is used experimentally or in research.

Limitations /Advantages: Measurements at surface and at seepage collection points are not as useful as internal temperatures, because readings are affected by ambient conditions. Temperature can vary a great deal within a rock pile.

Recommendations: Temperature measurements from within boreholes are useful for investigative monitoring of rock piles known to be acid generating. They are primarily of value for AMD modelling purposes.

Cost: Thermistors are usually installed in boreholes drilled for a combination of purposes such as rock sampling, installation of piezometers, gas ports, etc. The cost of installing instrumentation is typically $500-$2,000/hole. Thermistors are read at a rate of 7-15 per hour, and each hole may have 10-20 thermistors. Cost for measurements may be reduced by combining with gas monitoring costs. Automatic data logger capital cost is $2,000 to $3,000 plus per borehole and is more expensive than manual readings unless readings are required frequently (this is site-specific and also depends on sampling frequency).

References:

Lefebvre et al. 1994
MEND 1.14.2g 1994

3.7 Bacterial Monitoring

Application: The rate of sulphide oxidation and acid generation is enhanced in some environments by bacterial activities, primarily *those* of *Thiobacillus ferroxidans*. Sampling can be completed to confirm the presence and oxidative activity of bacteria in the waste rock pile for predictive purposes and to determine whether the application of bactericidal agents would be beneficial.

Background: Bacterial sampling can be completed in conjunction with drilling, trenching or seepage sampling. It is primarily used for advanced predictive modelling or research investigations.

Methods: A number of options are available for sampling bacterial populations. Moist rock samples can be collected from the surface or interior of rock piles using drilling or trenching procedures. These samples are placed in a sterile nutrient solution for culturing and analysis. Sampling devices filled with a sulphide substrate and referred to as "bacteria traps" may also be used. Seepage waters may also be cultured and analysed for bacterial composition and density.

Limitations /Advantages: The collection and culturing of bacteria associated with moist rock samples and seepage is the most common and simplest procedure. Solid samples are usually collected when drilling and trenching is completed for other monitoring purposes. Bacteria traps require placement, a colonization period and recovery, making them time consuming and more costly. They can however, be used to obtain information on rates of colonization, oxidation and additional research related information.

Recommendations: Biological sampling is classified as investigative monitoring or used for research purposes. Culturing from solid samples or seepage waters is the simplest and least expensive procedure. Research objectives will determine whether bacteria traps are required.

Cost: The cost to collect solid samples for culturing will depend on the collection method (drilling or trenching) but is usually not a factor as this sampling is most often combined with other sampling requirements. Additional expenses will depend on the objectives of the investigation. Confirmation of the presence of bacteria is inexpensive, however, costs will increase if species composition and experiments are required.

References:

Lafleur et al. 1993
MEND 1.14.2a 1994
MEND 1.14.2b 1994
Ragusa and Madgwick 1993

4.0 BIOLOGICAL MONITORING

4.1 Aquatic Macrophyte Community Sampling/Surveying

Application: The term aquatic macrophyte refers to the macroscopic forms of aquatic vegetation, which includes aquatic flowering plants, aquatic mosses, liverworts, ferns, and the larger freshwater algae (i.e. *Chara*). Aquatic macrophytes can be sensitive to changes in the environment such as pH, temperature, water level, metal loadings, and salinity. Therefore, changes in the aquatic macrophyte community composition or biomass can be used to assess potential environmental impacts.

Methods: Macrophyte surveys can range from simple qualitative mapping of the area1 spread of the dominant macrophyte groups to quantitative surveys of community composition and biomass.

Qualitative macrophyte mapping is usually completed during the environmental characterization phase. This involves reviewing historical reports, maps, charts, and aerial photographs of the study area to determine access routes, potential plant community distribution, and habitat characteristics that may influence plant distribution.

A field survey is completed with the objective of documenting the area1 distribution of the dominant macrophyte species and the completion of a species list. The spatial extent of macrophyte beds can be approximated by locating the margins on a map or more accurately determined by employing standard mapping techniques such as the baseline method or the base point-stadia rod-alidade method (Raschke 1984, Wetzel and Likens 1990). Determination of the dominant macrophyte species can be completed using underwater viewing boxes or divers. Voucher specimens should be collected.

Quantitative macrophyte community composition and biomass studies are most often completed using line-transect and quadrat methods. Monitoring for potential shifts in macrophyte community composition with exposure to AMD requires the establishment of permanent study plots at exposed and reference(s) sites. Reference and exposure study plots should have similar physical and chemical characteristics. The basic procedures for permanent line-transect macrophyte studies involving both littoral and shoreline transects are outlined below. Consult the accompanying references for additional information.

Littoral transects serve to document the diversity and density of aquatic macrophyte species in the littoral zone at each station. The number of transects within a plot, sampling intensity along a transect, and quadrat size will need to be determined on a study specific basis.

- Select plot location(s) based on plume exposure and the presence of large permanent macrophyte beds.
- Establish a number of transects parallel to the shoreline within the bed.

- Permanently mark the on-shore starting point for the transect. This should be located above the high water mark. Record distance from this point to the water-line.
- Data should be collected at the selected intervals using a quadrat frame.
- In each quadrat, data collection includes water depth, plant species present, percent cover of each species, the number of stems or plants (by species), and substrate type. Digitising video tape or photographs of the quadrats allows for greater accuracy in area1 measurements.

Shoreline transects serve to document the diversity and density of macrophyte species along the shoreline of each permanent sampling station.

- A quadrat frame is placed at the first linear lake transect such that half of the quadrat is on permanent shoreline vegetation, and the other half extends into the water body.
- Data collection within the quadrat includes water depth (for lake-ward portion), plant species present, percent cover of each species, the number of stems or plants (by species), and substrate type.
- Relocate the quadrat a selected distance interval towards the second perpendicular transect. This process should be continued until 15 quadrats of 1 m^2 have been completed.

Macrophyte biomass investigations most commonly involve above-ground harvest procedures, due to the difficulties in determining root biomass. Peak standing crop investigations are competed at the time of apparent maximum standing crop. Standard procedures usually involve clipping all of the above-ground plant material within a number of randomly located quadrat frames. The biomass within each quadrat is determined on a wet weight basis, by spinning off water and weighing sample, or more commonly by drying the plant material to a constant weigh in drying ovens.

The data should be evaluated for changing patterns of species and functional composition, as well as abundance and biomass. Changes in community structure should be determined using a number of biological diversity indices and multivariate statistical techniques to identify changing patterns in community composition.

Remote sensing involving aerial photography and satellite imagery can be used to locate areas of aquatic macrophyte growth within the study area. Densities of emergent and sub-emergent stands of aquatic macrophytes can be quantified using remote sensing technologies, however, the technology is restricted in its ability to identify species within mixed stands of vegetation. The primary use of remote sensing is to provide a historical record of the aquatic macrophyte spatial distribution within the study area (APHA 1992). As technology advances, these methodologies will be incorporated more often into monitoring programs.

Limitations/Advantages: Qualitative macrophyte mapping and the use of remote sensing techniques are limited to detecting gross changes to macrophyte spatial distribution with limited capability to assess impacts relating to shifts in species composition. Permanent quantitative sampling plots accompanied by suitable reference plots allows for the identification of changes in species composition related to long-term chronic exposure to mining related influences. These study plots also have the advantage of being non-destructive, and therefore truly repeatable through time. Biomass above-ground harvest investigations are destructive sampling programs and are thus not truly repeatable through time.

Recommendations: Qualitative macrophyte mapping should be completed as a part of the environmental characterization of a study site. Macrophyte mapping should also be used as part of the fisheries habitat classification. Quantitative permanent macrophyte community composition plots should be established when macrophyte beds identified as important fish rearing or spawning habitat have been identified as being at risk due to the mining activities.

References

APHA. 1992 Kerekes et al. 1984
Gauch 1982 Whittaker 1978

4.2 Benthic Macroinvertebrate Sampling/Surveying

Application: Diagnostic and/or investigative monitoring for the evaluation of biological effects within the receiving environment. Community species composition changes are used to detect shifts in community/population responses to water and sediment quality.

Background: Benthic invertebrate species composition is monitored to determine the response of a biological component to contaminant loading due to AMD impacts. Samples are compared with baseline and reference station species compositions. Should be sampled in conjunction with sediment chemical characterization and sediment toxicity assessments.

Methods: Standard benthic macroinvertebrate sampling equipment and methods should be used to collect **quantitative** samples. Benthic macroinvertebrate samplers may be subdivided into depositional samplers, erosional samplers and artificial substrates:

1. **Depositional samplers:** In depositional habitat, such as lake bottoms or slow moving areas of streams, the recommended sampler is of the grab type. Two of the most commonly used grabs are the ponar grab sampler and the Ekman grab sampler. When first attempting to use either of these grabs, it is important to familiarize yourself with the functioning of the equipment and know its limitations.

Most grabs are heavy sampling devices that require a hand or powered winch and cable from a boat. Grabs must be lowered slowly for proper deployment, so that pressure waves do not disturb the surface sediments. Upon placement on the bottom, the samplers weight allows for penetration into the sediment. When the cable slackens, the grab will close thus trapping the sediment and benthic invertebrates within the sampler. Other samplers, such as the Ekman grab, require a messenger to be sent down to contact a trigger mechanism which will close the jaws around the sediment. The sampler is retrieved and the collected material is washed through a 250 micron sieve to remove silt and other fine particles. This field washed sample may now be stored in a sample container. Any subsampling should be performed in the laboratory during the identification process.

Limitations /Advantages: The ponar grab is appropriate for sampling coarse and hard substrates, whereas the Ekman grab is most suitable for soft sediments. The weight of the ponar grab allows its use in areas with moderate current and deep waters. The Ekman grab is light weight and therefore should not be used in deep waters or under adverse weather conditions. Both grab samplers can be affected by rocks and other debris which may prevent proper closure of jaws or closing mechanism. Care should be taken to ensure that sample loss did not occur during retrieval.

Recommendations: Which sampler to use is dependent on the physical conditions of the sampling waterbody and substrate as outlined in Table IV: 3.4-4.

Costs: The cost for these types of depositional samplers ranges from $400.00 to $600.00. The majority of cost for a benthic invertebrate survey will accrue from time required to obtain samples, sort invertebrates and identify species. It should be noted that additional expenses for multivariate analysis of data and professional interpretation of results will also be required.

2. Erosional samplers: Benthic macroinvertebrate sampling in erosional zones , such as riffles in rivers, is best conducted with stream-net samplers. Two commercially available, and most commonly used samplers are the Surber sampler and cylinder (e.g., Hess or Neill) samplers.

When using stream-net samplers, proper technique is very important. The user is required to approach the sampling area from downstream. This is to prevent disturbance of the area prior to sampling. Once the stream-net sampler has been placed in the appropriate location, (mouth of the sampler pointing upstream and net flowing downstream), the user stands behind the sampler, and washes organisms from the cobble and sediments within the sampling area (Surber frame or area encased by cylinder samplers) into the net. The sampler is lifted out of the water and organisms are rinsed into the collection container at the end of the capture net.

One of the main problems associated with sampling natural systems is the heterogenous nature of the bottom sediments. Sampling heterogenous areas can result in high variance within a sampling station, therefore, reducing the ability to detect significant differences between sampling stations. Standardizing sampling substratum in terms of depth, cobble size, sediment composition, and current velocity will help reduce the variance within a sampling station. If standardization between sites is not possible, then other physical and chemical characteristics should be recorded at each site. These measurements will provide information for future assessment of environmental influences on the benthic invertebrate communities at the different sites.

Limitations /Advantages: Both samplers are limited by the depth and velocity of the waterbody to be sampled. The user must be able to kneel or stand within the stream while operating the sampler. Both samplers define a sampling area and allow for an accurate qualitative collection of macroinvertebrates. Due to the enclosed structure of the Hess type sampler, replicated samples can have less operator error then the Surber. For additional information see Table IV:4.2- 1.

Recommendations: Cylinder samplers are recommended over the Surber sampler as the enclosed cylinder minimizes sample losses. If historical information has been collected using a Surber sampler then continued sampling with this device would be required for historical comparisons.

Costs: A Surber sampler is typically constructed of a stainless steel frame with 0.35 mm Nitex nylon mesh. The cost is approximately $200.00. Cylinder samplers are often constructed from stainless steel with Nitex nylon mesh. They range in price from approximately $300.00 to $600.00.

3. **Artificial substrates**: The incorporation of artificial substrates into monitoring programs have been used to alleviate some of the difficulties associated with sampling natural substrates. Artificial substrates are used more frequently in lotic environments then lentic systems and are typically situated above the natural substrate.

Two types of artificial substrates have been utilized: 1) Representative artificial substrates, consisting of wire baskets filled with natural materials from the substratum; and 2) standardized artificial substrates, which are constructed of man-made materials (i.e., ceramic tiles) of equal size, shape, and texture.

Limitations / Advantages: Artificial substrates provide a consistent habitat between samples (i.e., within and between sampling stations) thereby minimizing the effect of this potential confounding factor. A major disadvantage of artificial substrates is the potential for selective colonization of only a few taxa that inhabit the natural environment. It is necessary to place artificial substrates into the sampling stations as early as possible to allow for more organisms to compete for and colonize the substrates (i.e., representative of the natural community composition). An additional limitation is the need to purchase several per sampling stations, even if variance is reduced, within station replication is still required.

Recommendations: Artificial substrates should only be used when the natural in-situ community cannot be sampled (e.g., large boulders or deep cobble). Using the standardized substrate minimizes the variance between samples greater than the representative substrates.

Costs: There are several types of standardized artificial substrates available ranging in price from $15.00 to $100.00.

References:

See Chapter IV: Section 4.6	APHA 1992
Merritt and Cummins 1984	Rosenberg and Resh 1993
Cuffney et al. 1993	DFO and Env. Can. 1995b

4.3 Environmental Characterization

Application : Environmental characterization of a study area is the description and quantification of the abiotic (i.e., habitat) and biotic (i.e., organisms) components of the environment. This involves habitat classification and biological inventorying. Habitat classification and biological inventorying, while different processes, are so closely interrelated that they are discussed together for the purpose of convenience and to avoid confusion. Often the required field work may be completed at the same time to reduce costs.

Background: AMD effects have the potential to alter the nature of aquatic habitat in the receiving environment and its associated biota. Pre-operational habitat classification and biological inventorying provide a baseline against which the results of operational monitoring may be compared. Aquatic habitat, specifically fish and benthic invertebrate habitat, is classified according to physically descriptive parameters that are measured in the field. The methodology is similar for both lakes and streams but there are some differences owing to the dissimilarity in hydrologic regimes between moving and flowing water.

Methods: Habitat and biological information are generally presented through the use of maps and tables specific to the data. Where possible, spatial data should be incorporated into a GIS to aid in the interpretation of the data and to facilitate further spatial analysis.

1. ***Habitat Classification:*** The habitat of the study area is classified in a hierarchical manner after the framework developed by the U.S. Fish and Wildlife Service (Cowardin et al. 1979; Busch and Sly 1992). Using this method freshwater aquatic habitat is divided into three major system types: riverine, lacustrine, and palustrine. The habitat (except palustrine) is subdivided into subsystems based primarily on hydrologic characteristics; for example, lacustrine systems are subdived into littoral and limnetic subsystems. The habitat is further classified using the dominant vegetation type (e.g., emergent macrophytes, forested wetland) or bottom substrate (e.g., rocky shore, gravel streambed) in cases where vegetation is sparse or obscure. If required the habitat may be further subdivided based on a more detailed examination of substrate or vegetation characteristics.

2. ***Biological Inventorying:*** Inventorying of aquatic organisms is generally restricted to aquatic macrophytes, benthic invertebrates, and fish. However, regulatory agencies generally require site specific monitoring as part of a mine's operating licensing requirements. Therefore, the components that will be monitored will vary from one site to another. Specific procedures for the inventorying of aquatic macrophytes, benthic invertebrates, and fish are found in TSN 4.1, 4.2, and 4.4, respectively.

Costs:

The costs associated with habitat classification or biological inventorying are variable and should be determined on a site specific basis. Factors that influence the cost include the size of the study area, the amount of data already available, and the level of detail (or statistical significance) required.

References:

Bovee 1978
Cowardin et al. 1979
Env. Can. 1993a
Hawkins et al. 1993
Busch and Sly 1992
DFO and BC MEP 1987
Harrelson et al. 1994
Newbury and Gaboury 1993

4.4 Fish Sampling/Surveying

Application: Fish may be collected for tissue analyses, or fish population or community assessments. The role of fishes in AMD monitoring is addressed in detail in ChIV:5.0 of the main document. Discussions in this section of the Technical Summary Notes are restricted to field collection procedures.

Methods.- Fish collection methods may be subdivided into three basic categories, 1) passive, 2) active, and piscicides.

Passive sampling techniques include gillnets, trap or downhaul nets, fyke and hoop nets and minnow traps. Gillnets are one of the main passive capture techniques for capturing fishes. Gillnets may consist of one or more panels, of the same or varying mesh sizes which operate by passively entrapping fish attempting to move through the net. A measure of size selective sampling may be achieved by using a specific range of mesh sizes.

Certain standard protocols are required if catch results are to be used to determine population parameters or community relative abundance estimates for the intensive baseline investigations' (Ch.IV:5.2.1). The data from baseline population investigation should be used to identify the general sex specific size class at which sexual maturity is reached. This will identify the appropriate mesh or mesh sizes required in the operational monitoring program thereby minimizing stress and/or mortality to non-target species or size classes. Netting protocols should be standardized as much as possible between the routine sampling periods if catch per unit effort is to be of value as a parameter. The net set locations, time of day, and duration in the water should be recorded and roughly standardized between net sets and sampling locations. Fishes tend to exhibit specific movement patterns over a 24 hour period, with most species increasing movement rates during dawn and dusk. Therefore, nets are most effective when they are set overnight and emptied each day (Hubert 1983), though the shorter the net set the lower the fish mortality.

Passive netting techniques other than **gill nets** involve the use of devices that entrap the target fish and include trap or **downhaul** nets, fyke and hoop nets and minnow traps. These types of nets usually utilize wings and/or leaders to direct moving towards collection net boxes or hoops.

The **trap** or **downhaul nets** are most often used in lakes to depths of approximately 12 m. Fish are directed into the body of the trap net through the use of a long leader set perpendicular to the shore. **Fyke** and/or **hoop nets** are often set in rivers and streams and are anchored with poles driven into the bottom of the stream. Leaders and wings are used to direct the fish into the body of the net which consists of funnelled compartments promoting unidirectional fish movement into a final holding bag or compartment. **Minnow traps** are small portable rigid traps with funnel neck entrances. Minnows enter the baited trap through a conical neck.

Active fish capture methods involve a variety of techniques that take fish by sieving them from the water or by stunning the fish with an electrical shock. The suitability of these techniques are influenced by a variety of factors briefly mentioned in the following paragraphs.

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[1] May commence collecting this data during the Environment Characterization Phase.

Gear selection for active sampling using nets is primarily dictated by the habitat to be sampled. Factors to be considered are water depth, bottom substrate, water transparency and the presence of currents as well as the the response of the target fish to the gear being fished.

Nets which are dragged or towed are referred to as **trawl nets.** Trawl nets are dragged along the bottom or through the water column and essentially strain fish from the water. Trawls can range from small hand-operated nets towed by small boats to large mechanically operated commercial nets requiring large boats and equipment. Trawling is not commonly used in freshwater and is generally restricted to large lakes.

Seine nets are used to encircle fish with a fence-like wall of net. Beach or haul seines are used in littoral zones and worked by wading or from small boats. These nets are best suited for habitats that have firm bottoms that are relatively free from snags or vegetation. Small haul nets can be pulled by two people along the shore in the littoral zone in lakes or in streams. Purse or lampara nets are used in deep waters and require mechanical equipment and large boats. Consideration must be given to the size of mesh in relation to the size of the target fish. The amount of effort may be determined by the length of shoreline that is sampled or by the length of stream. The length of stream or shoreline sampled can then be compared to the total length of habitat available. This ratio can be used to determine the total number of fish present in the habitat.

Electrofishing is most often used in streams or along the margin or littoral zone of lakes. Factors influencing electrofishing may be grouped into one of three categories: fish characteristics, habitat characteristics, and operating conditions (Reynolds 1983). These must all be considered when comparing results from different areas or from different times of the year. Electroshockers should only be utilized by trained personnel due to the risk to the operator and the potential for damaging the fish (e.g., spinal fractures). The references listed in the Section bibliography should be consulted for further information on electrofishing.

Piscicides or **ichtyocides** are chemical compounds that are lethal to fish under specific conditions. The most commonly used piscicide is rotenone, an extract from rotenone bearing plants in the family Leguminosae. Rotenone kills fish by interfering with oxygen uptake resulting in suffocation. Provincial and federal fisheries should be contacted prior to planning any piscicide operations.

Limitations/Advantages: Gillnets are more suited to open water habitats that are free from snags. They have limited effectiveness in lotic habitats with moderate to fast flowing currents. Mortality also tends to be high compared to other sampling techniques. Mortality is usually greatest during the summer months when the water temperatures are the highest and tends to vary between species.

In general trap type nets result in less mortality than entangling nets. Trap or downhaul nets set deeper than 21 m may result in injury to the fish when they are hauled to the surface due to the change in pressure. Spiny-rayed fish species such as walleye are especially prone to this type of injury because their swim bladder is not connected to the esophagus, thus adjustments to changes in pressure are slow. Trap nets are also less size and species selective than gill nets (Hubert 1983).

Hoop and fyke nets are ideal for collecting fish during spawning migrations" Migrating and cover seeking species of fish are most vulnerable to these types of gear. These nets minimize fish mortality and stress, but have poor size selective capabilities. They are ideal for collecting fish during spawning migrations. They are however, poor for collecting species in deep water or for fish which exhibit limited movement patterns.

Seine nets are best used to capture littoral fish species in areas where littoral debris (e.g. deadfall) and macrophytes are not a problem. They are ideal for small, slow moving schooling species. Mortality is low if proper fish handling procedures are used.

Electroshocking is suitable for capturing large shoreline species. The tendency for fish to orientate and swim towards the anode (when using direct current) improves capture efficiency in turbid waters or under condition of moderate debris or macrophyte cover. The efficiency of electroshockers is seriously influenced by the water conductivity and hence, is a poor sampling method in very soft waters. Electrofishing can be dangerous, hence, safety procedures must be adhered to. Inappropriate current settings can result in haemorrhaged tissues, ruptured swim bladders and fractured vertebrae.

Piscicides should not be used when the objective is to collect fish for biochemical responses or tissue residues. They best suited for removing undesired fish from a waterbody prior to stocking with a preferred species.

Recommendations: The selection of the most appropriate capture method will be habitat, species, and study specific, however, certain basic recommendations can be made. Hoop or fyke nets are best used for collecting fish during spawning migrations. Gill nets are usually the most cost efficient sampling method when fish mortality is not a concern. Littoral shallow water species are best captured using seine nets or electroshocking. Piscidides should rarely be used.

Cost: The cost of nets depends on the size, material and complexity of the nets. Gill nets will start at approximately $180.00 for 30.5 m of net, increasing as a function of net depth, length, number of meshes per tie, overall length and twine material. Hoop nets with leaders and wings can start at a minimum of $260.00, increasing in price with twine and mesh size, hoop diameter and overall net length. Seines can start at approximately $1.50 per foot increasing in price with net material, net depth and smaller mesh sizes. Fyke nets, trawls and purse seines generally have to be custom made. Complete backpack electrofisher units generally start at $2000.00, shore side generators start at approximately $300.00 plus accessories and a complete electrofishing boat will range from $14,00.00 and up.

References:

See Chapter IV: Section 5.10
Johnson 1983
Reynolds 1983
Craig et al. 1986
Fausch et al. 1988
Hubert 1983
Hill and Willis 1994
Lyon 1992
Angermeier and Smogar 1995
Davies 1983
Hayes 1983

4.5 Sediment Sampling

Application: Compliance and/or diagnostic monitoring for the evaluation of contaminant accumulation in bottom sediments within the receiving environment. Increased loadings of contaminants into a water body can result in the accumulation of sediment contaminants at levels harmful to aquatic organisms.

Background: Physical and chemical parameters are analyzed from sediment fractions for determining the concentration and bioavailability of contaminants within the sediment. Samples are compared with baseline values and reference station collections. Additional sediment should be collected for sediment toxicity assays and should be performed in conjunction with benthic macroinverebrate collections to allow for comparisons as the sediment quality triad.

Methods: There are two types of commercially available sediment samplers:

- grab samplers - to collect surface sediments for the determination of horizontal distribution;
- core samplers - determining horizontal and vertical distribution of parameters.

There are several types of grab samplers and core sampling devices. The effectiveness of several models of each are stated in Table IV: 3.4-3 and Table IV: 3.4-4 of the main document. Samples collected for sediment toxicity test should be stored in a sealed container to prevent extensive oxidation of sediments, and kept at 4 C.

Core samples collected for acid volatile sulphides (AVS) should be kept in an anoxic environment and split within a glove bag purged with nitrogen (i.e., oxygen free atmosphere).

Limitations / Advantages: Refer to Tables IV: 3.4-3 and 3.4-4 of the main document for information on the advantages and disadvantages of the various sampling equipment.

Recommendations: Core samples are recommended as better maintain the integrity of the sample and can be sectioned to provide a historical record of sediment contaminant levels through time.

Costs: Core samplers can range from a base of approximately $1,200.00 to $2,000.00, while grab samplers can range from $650.00 to $1,600.00 depending on the type and size. Field time expenses will depend site and study design characteristics such as the depth of the water column, number of samples and the substrate type, ans sample stratification. Analytical costs will depend on the parameters to be analysed. Metal analysis by ICP/AES costs usually approximate $60/sample. Additional charges for ammonia, radionuclides and other parameters will increase costs substantially. Maximum cost for all analyses should be around $300/sample.

References:

Mudroch and Azcue 1995	Mudroch and MacKnight 199 1
Env. Can. 1994a	Plumb 1981
Tetra Tech. 1986a	U.S. EPA. 1985b

4.5 Bioconcentration Investigations

There is often confusion over the terms bioaccumulation, bioconcentration, and biomagnification. These are defined below.

Bioaccumulation	A general term describing a process by which chemicals are taken up by organisms from their environment.
Bioconcentration	The net accumulation of a contaminant within an organism which occurs as a result of uptake exceeding elimination.
Biomagnification	When the processes of bioaccumualtion, and bioconcentration at the organism level result in an increase in tissue contaminant concentrations as the contaminant passes up through two or more trophic levels, the contaminant is said to biomagnify. Hence, a contaminant is said to biomagnify when residue concentrations increase systematically from one trophic level to the next.

AMD trace contaminants predominantly bioconcentrate and tend not to biomagnify.

While increased contaminant loads in water and sediment are evidence of increased exposure to contaminants, they provide no information on biological uptake.

Bioconcentration investigations involving tissue chemical analysis are the most commonly used means of identify contaminant transfer to biological organisms. These investigations are usually focussed on aquatic macrophytes, benthic macroinvertebrates, and/or fishes.

When collecting materials for chemical analyses vinyl gloves should be worn. The powder used for many latex gloves can contain high concentrations of trace elements, especially zinc. If powder free latex gloves are to be used they should first be assessed by the contract laboratory for their potential for contamination of samples.

4.5.1 Aquatic Macrophytes

Application: Monitoring of contaminant bioconcentration in aquatic macrophytes is best applied when wetlands are used for "polishing" released treated effluent and may be of special interest as monitors of Ra-226 resulting from uranium mining activities. Radium-226 acts as a calcium mimic with various organisms exhibiting differing propensities to select one or the other. Macrophytes tend to preferentially select Ra-226 over calcium and as a result, accumulate this radionuclide to a greater extent than other organisms (Hesslein and Slavicek 1984).

Methods: The plant growth form and the potential contaminant source (e.g., sediment or water) must be considered when selecting macrophyte species and structures. Rooted plants will extract some contaminants from the sediment and some from water (Mayes et al. 1977, Cushing and Thomas 1980, Hart et al. 1983). Free-floating macrophytes will obtain contaminants from the water and suspended sediments. Translocation of contaminants to different tissues of the plant, occurs to varying degrees in aquatic plants and can be species specific. Translocation from roots to leaves for some elements is minimal, hence, comparisons should be limited to similar plant tissues (Crawford and Luoma 1993). It has been shown that roots and shoots concentrate many sediment-associated contaminants to a greater extent than stems and leaves (Heisey and Damman 1982). However, leaves and stems are likely to play a more significant role in the cycling of contaminants as they are a source for contaminants in food webs, especially during decomposition (Crawford and Luoma 1992). Hence, despite the potential for increased bioaccumulation of some sediment contaminants in the roots (Heisey and Damman), stems and leaves may be the most appropriate tissues for sampling more readily bioavailable contaminants.

When using structures in contact with sediments (e.g. roots) care must be taken to remove precipitated iron-oxides and fine sediment particles. If using leaves or stems sampling should be restricted to the apical portions of the plant as contaminant concentrations have been shown to significantly differ with leaf age and senescence (Brix and Lingby 1983).

Epiphytes and microorganisms on the surfaces of leaves and roots can bioaccumulate contaminants and should be removed prior to analysis.

Basic Sampling Procedures (from Crawford and Luoma 1993)

- Collect and thoroughly wash samples in the water at the collection site.
- Soak in filtered site water (1 hour) to remove sediment, debris, algae and organisms.
- Change water and soak plant material for an additional hour.
- Freeze using dry ice and ship to analytical laboratory.
- Collect voucher specimens for taxonomic confirmation.

References:

Crawford and Luoma 1993	Mayes et al. 1977
Cushing and Thomas 1980	Hart et al. 1983

4.5.2 Benthic Macroinvertebrates

Application: Benthic macroinvertebrates can serve as biological sentinel monitors for streams or lakes receiving AMD. These may include mollusks (bivalves and gastropods), aquatic crustacea, and insects (Zauke 1982, Lynch et al. 1988, Ingersoll et al. 1995). Bioaccumulation in these organisms provide evidence that contaminants in abiotic compartments (sediment and water) are being transferred to biological compartments of the aquatic system. Hence, these organisms can serve as a significant food chain pathway for the transfer of contaminants from the abiotic compartments to fish.

Limited mobility, ease of capture once detected and the relatively large body mass of some species make mollusks excellent candidates as sentinel species. Unfortunately the majority of work has been completed on marine mussels with only limited use of freshwater species. The use of freshwater mussels is often restricted to large rivers as it is unlikely that enough mussel biomass could be collected from headwater or mid-order streams (Crawford and Luoma 1993). The best candidates are likely to be of the family Unionidae, especially the genus *Anodontu,* Due to their sensitivity to acidic conditions, mussels will only be of use for AMD tissue trace metal monitoring where AMD acidity has been buffered by the receiving environment.

In headwater streams and mid-order streams, aquatic insects will generally be available in greater biomass than mussels. Some aquatic insects possess a number of characteristics considered beneficial for sentinel organisms including, their relative abundance, tendency to move only short distances, and their potential for long term exposure to local contaminants in the sediment, and on suspended particles. In addition, studies have shown that they accumulate metals in proportion to concentrations present in the environment (Nehring 1976; Spehar et al. 1980).

The benthic aquatic insect community consists of a wide range of organisms varying in feeding ecology, life histories, and size. The following were identified as the most suitable insect sentinel taxa (for trace elements) for the U.S. National Water Quality Assessment Program.

Trichoptera (Caddisflies)	**Chironomidae (Midges)**	**Plecoptera (Stoneflies)**
▪ Net spinning, free living	*Chironomus* sp.	Perlidae
Hydropsyche sp.		mostly predators
Brachycentrus sp.		Perlodidae
		predators
▪ Cased caddisfly		Pteronarcyidae
Limnephilus sp.		detritivores and shredders

Preliminary investigations should be completed to determine the most appropriate site specific sentinel taxa. In systems with low productivity or when radionuclides are part of the parameter list, it may not be possible to restrict the analysis to a single taxa due to analytical weight limitations. This scenario is best handled by collecting sample composits of functional feeding groups, such as filterers, shredders, scrapers, etc. (Merritt and Cummins (1978).

Methods: Bivalves may be collected using clam rakes and underwater viewing devices or divers, depending on the depth. A sample should consist of enough individuals to meet the analytical weight requirements. A minimum of 5 to 10 g soft tissue wet weight is usually required for a comprehensive analyses of trace elements, though this should be confirmed with the contract laboratory. Attempts should be made to collect individuals similar in size. Each individual bivalve should be rinsed in ambient site water to remove attached algae and debris. The shell length of each should be recorded as the greatest anterior-posterior dimension. the samples should be sealed in sample jars or bags, frozen and shipped to the laboratory. A few individuals should be collected as voucher specimens.

Insects may be captured by whatever means is practical for the site. This may range from simple kick sampling to the use of grabs and artificial substrates (especially for Simulids). To account for variation in contaminant burdens among individuals a minimum of 20 organisms is recommended per composite (Crawford and Luoma 1993). Due to the small size of most insect species, more than 20 individuals per sample will usually be required to meet the usual requirement of 5 to 10 g wet weight for trace element analyses (confirm with contract laboratory). They may then be frozen and shipped to the laboratory. In the laboratory they should be thawed, cleaned of debris, rinsed with distilled water, and screened for taxonomic accuracy. The number of individuals in a composite should be recorded and the composite weighed prior to analysis.

Purging or depuration: Investigators will need to decide whether the sample organisms (mussels or arthropods) need to be purged of their gut contents. Gut contents can account for a significant proportion of an unpurged organisms total contaminant load for some organisms (Elwood et al 1976, Hare et al. 1989, Lobe11 et al. 1991, Brooke et al. 1996) and not for others (Weeks and Moore 1991, Phillips and Rainbow 1988, Rainbow et al. 1989). If the desired study objective is to determine the concentration of assimilated contaminants then the organisms should be purged. If the study is interested in food chain transfer of contaminants then purging may not be required as most predators will ingest the whole organisms including gut contents.

Mollusks can be purged by keeping them alive in cooler filled with cool, aerated water from the collection site for approximately 24 hours (Crawford and Luoma 1993). Insects should be kept alive in aerated cool water from the collection site for a minimum of a 4 to 6 hour depuration period (Crawford and Luoma 1993), with a 12 to 24 hour period recommended (Brooke et al. 1996). Care should be taken to keep predacious species in groups of similar size classes to minimize cannibalism.

References:

Crawford and Luoma 1993
Hare et al. 1989, 1991
Miller et al. 1992, 1993
Brooke et al. 1996
Hare and Campbell 1992

4.5.3 Fishes

Application: The role of fish bioaccumulation investigations in AMD monitoring is addressed in detail in ChIV:5.0 of the main document, hence, discussions here will be brief. Fish bioaccumulation studies for AMD monitoring should incorporate analysis of bone metal concentrations to indicate long-term AMD exposure, and gill, liver or kidney as a measure of recent metabolic activity relating to AMD exposure. Fish muscle tissue is often included in mine monitoring programs, however, the utility of fish flesh for AMD monitoring purposes is questionable (BC AMD 1990), since fish regulate a number of trace elements.

Method: Fish may be captured using a wide range of techniques a long as the method does not influence the contaminant content of the fish. Electroshocking, seining, or hoop or nets are ideal, though gill nets may be used if checked frequently to prevent deterioration of the specimen. Ideally a sample should consist of the desired tissue from a single fish. If compositing is required it has been recommended that a sample consist of a minimum of six individuals (Tetra Tech 1986, in Crawford and Luoma 1993). A minimum of 5 g is required for trace elements. To analyse for Pb^{210} and Po^{210} a minimum of 10 g is recommended for bone and 20 g is recommended for soft tissue (pers. com. Saskatchewan Research Council Analytical Services hereafter SRC). Minimum recommended sample weight requirements for Ra^{226}, Th^{230} and U are high requiring 135 g wet weight for bone and 425 g wet weight for tissue if a suitable detection level is to be achieved (Pers. Com. SRC). This is based on an approximation of the wet weight required to achieve 1 g for both flesh and bone for each of Ra^{226} and Th^{230}, respectively and 1 - 2 g ash weight for both flesh and bone for uranium (Pers. Com. SRC).

Each fish should be sacrificed and rinsed with water from the collection site. The following points outline the standard procedures for all fish tissues.

- Record length and weight.
- Ageing structure collected (See Table IV:5.2-4 main document) and placed in labelled scale (coin) envelope.
- Complete a visual external fish health assessment (ChIV:5.2.1.2).
- Dissecting tools should be stainless steel with plastic or teflon coated forceps. Ceramic instruments are ideal but are also very expensive.
- An external set and an internal set of instruments should be used. Instruments used externally (e.g. to open the fish) are assumed to be contaminated by the external surface of the fish.
    - Remove gill filaments if required for chemical analysis, place in sample bag, freeze and transport to lab.
- Open the fish to expose the body cavity using the external instruments.
- sex fish.

Procedures for collecting livers

- Once the body cavity has been opened the liver should be isolated using the internal instruments.
- When removing the liver care must be taken to avoid puncturing the gallbladder.
- Place the excised liver into a tared precleaned sample container. Excise and add additional livers if required.
- Record fish ID number for each liver in a composite and record weight of each composite.
- Freeze with dry ice and ship samples to the laboratory.

Procedures for collecting kidneys.

- Once the body cavity has been opened the kidney, located immediately ventral to the spine, should be exposed using the internal instruments.

- The granular kidney should be scooped out with a microspoon or other stainless steel spoon-like instrument.
- Place excised material into a tared precleaned sample container. Excise and add additional livers if required.
- Record fish ID number for each kidney in a composite and record weight of each composite.
- Freeze with dry ice and ship samples to the laboratory.

Procedures for collecting bone and flesh.

- Once the desired internal organs have been excised these fish can be prepared for any bone or flesh sample requirements.
- For trace element and radionuclide analyses the method developed by SRC[2] is recommended as the most efficient means of separating bone and flesh. This involves removing the remaining viscera and skin in the filed (or filed laboratory).
- The samples are then bagged and frozen for shipment to the laboratory.
- In the laboratory the flesh and bone are separated by placing the fish in sealed bags and boiling until the bone can be easily separated from the flesh. Liquid released from the fish during the boil is added to the flesh sample.

Procedure for collecting fish samples for organic contaminants are provided in Crawford and Luoma (1993).

References:

See Section Chapter IV: 5.2.4
Crawford and Luoma 1993
Tetra Tech 1986d

4.5.3.1 Fish Metalothionein

Application: The use of metalothionein as a monitoring tool is addressed in ChIV:5.2.7.5. Information herein is restricted to field sampling protocols.

Methods: Fish tissues for metalothionein analyses must be removed immediately after sacrificing the fish, hence, fish that have died during capture are not suitable. As a result gill nets are only suitable with brief net set periods. In Canada there are no commercial laboratories routinely conducting metalothionein analysis on biological tissues. Analytical procedures must be confirmed with a suitable laboratory. The following field sampling/processing recommendations are based on TAEM metalothionein field

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[2] This method maximizes the amount of flesh and bone which is important when completing radionuclide analyses due to the high wet weight requirements.

experience and discussions with Dr. Klaverkamp of the Canadian Department of Fisheries and Oceans (FWI Winnipeg).

The most common fish tissues collected for metalothionein analyses are gills, liver and kidney. When using small fish (e.g. young-of-the-year or minnows) whole fish may be collected and immediately frozen with viscera removed later in the laboratory. Fish of 0.8 kg or larger have usually been found to possess enough kidney and liver material to provide a single sample for both heavy metal and MT analysis. Standard procedures are as detailed above up to and including the point of removing the liver, kidney or gill.

- The liver, kidney or gill samples should be split in two to provide an approximate minimum of 2.0 to 2.5 g for metal analysis and 0.5 to 1.0 g for MT analysis (Pers. Corn. Klaverkamp DFO) Note: Detection levels will improve if more tissue is available.
- Place samples in individually labelled small bags (e.g. Whirlpak) and store in dry ice for shipment to the laboratory. If possible, immediately freeze samples with liquid nitrogen, prior to placing on dry ice.

References:

See ChapterIV: Section 5.8.4.1 and 5.10

5.0 COLLECTING SOLID SOURCE SAMPLES

Application: The collection of solid materials from AMD sources ranges from simple surface grabs using a shovel to complex exploration/bedrock drilling techniques such as wireline core drilling to retrieve a continuous core sample. Drilling is used to collect samples within waste rock piles and TMFs, as well as to provide access for the installation of monitoring devices for investigative monitoring of gas, temperature, and groundwater/porewater. Drilling techniques most suitable for establishing monitoring wells are addressed in greater detail in TSN 14.3.2. Procedures for the collection of submerged samples are addressed in TSN 4.5 dealing with sediment collections. The techniques for drilling in overburden, waste rock, tailings and bedrock differ due to the nature of the material and are briefly addressed in the following sections.

5.1 Waste Rock and Consolidated Materials

Methods: Powerful large diameter drills such as water well drills are required to penetrate waste rock piles or consolidated materials. More information on these procedures is provided in TSN 14.3.2 for drilling monitoring wells. The most common drilling method used for waste rock is the down-the-hole hammer technique with button bits or roller bits that are concentric with the casing. A variation of this technique which utilizes eccentric bits, referred to as ODEX bits, is also common. Drag bits and tri-cone bits are used much less frequently. For shallow requirements (up to 6 m deep), trenching or test pitting is suitable instead of drilling.

Limitations /Advantages: Down-the-hole hammer provides the best sample recovery in waste rock piles and least likelihood of encountering problems with drill hole alignment, but may not work below 40 metres. Drag bits are only suitable for very soft sedimentary rocks. Cone-type bits are more suitable for bedrock drilling, as maintaining drill hole alignment can be a problem within coarse waste rock piles. For deep sampling requirements or very difficult waste rock, ODEX is used, but sample recovery is poor compared to concentric down-the-hole hammer bits.

Recommendations: Down-the-hole hammer drilling is preferred because it provides good sample recovery, good production rates and is the least likely method to cause drilling problems.

Cost; Costs of drill and operators range from $50 - $1 00/metre for down-the-hole hammer. Geologist for drilling supervision also required. Typical drilling rate is 4 metres/hour. Test pits cost $300-$500/day for backhoe plus geologist (10-1 5 3 metre pits/day, or 2-6 6 metre pits/day).

5.2 Tailings

Methods: The collection of submerged tailings from a subaqueous deposition TMF or in decommissioned flooded tailings is similar to sediment sampling in the receiving environment as is addressed in greater detail in TSN 4.5.

The selection of the appropriate tailings sampling techniques will be strongly influenced by the stability of the tailings. In active TMFs heavy equipment may not be utilized or may only be of use along the margins of the TMF due to the instability of the tailings. The collection of solid tailings samples can be subdivided into shallow (hand operated equipment) and deep (> several metres: heavy equipment) sampling techniques. These are briefly discussed below.

5.2.1 Shallow Samples

Surface Grab (Hand or Trenching)

Description: Hand sampling by shovel is restricted to shallow surface samples from 0 to 1 m deep. Trenching allows sampling from 3 to 6 m but will be restricted by the ability of the tailings to safely support a backhoe. Both methods allow the collection of disturbed solid phase samples while digging. Undisturbed samples may be collected from the bottom or walls of a shallow trench. Serves for preliminary examinations of the tailings particle characterization) and tailings surface surveys. Pit or trench bottom or walls may be further sampled using other solid sampling procedures such as hand augers or piston samplers.

Limitations/Advantages: Large samples can be collected from shallow depths relatively quickly and inexpensively. Coarse stratification is possible. Consolidated tailings will be more difficult and time consuming to collect. Sampling creates physical disturbance and results in atmospheric exposure thereby altering geochemical composition.

Hand Operated Augers, Piston Samplers or Thin-Walled (Shelby) Tube Samplers

Description: These devices are hand driven devices which are screwed or pushed into the tailings or soils. Augers drill holes by drawing disturbed particles upwards on the auger flights. Hand piston samplers and tube samplers contain the sample as a core or within a sample tube. The sample is extracted by withdrawing the sampler and bagging the core or in some cases removing the core intact in a sample tube.

Limitations/Advantages: All of these devices are relatively light weight and samples can be collected relatively quickly. Augers are primarily restricted to basic particle physical characterization due to the extent of physical disturbance and atmospheric exposure. They may also be used to install shallow piezometers, wells or gas sampling installations. Piston or tube samplers better maintain sample integrity allowing for more detailed characterization, especially if the sample is retained in a sample tube. Thin-walled tube samplers may be used to collect relatively continuous undisturbed samples to a maximum of 5 m in unconsolidated materials.

Shallow Sampling Recommendations

Surface grabs are suitable for simple surface particle characterization. Augers are best utilized for drilling shallow installation holes (e.g., piezometer placement) or for establishing pilot holes for further piston or tube sampling. Pits or trenches may also be dug to provide the starting points for further piston or tube sampling. Piston or tube samplers should be utilized whenever detailed characterization is required. Thin-walled tube samplers should be used whenever detailed physical and chemical characterization is required.

5.2.2 Deep Samples

Split-Spoon and Core-Barrel Samplers

Description: Core barrel or split-spoon samplers are thick walled samplers mounted on drill rods and extended through a hollow stem auger or casing to the bottom of a borehole. The sampler is then driven by a hammer through the floor of the bore hole to collect an undisturbed sample at selected drilling intervals. The sampler is then withdrawn to the surface for removal of the core. A split-spoon sampler can be split open into two halves to expose the sample. Most core tubes contain an inner and outer tube with the outer tube removed and the inner tube split similar to a split-spoon sampler.

Limitations/Advantages; These samplers are restricted to unconsolidated materials with the core sampler somewhat more robust than the split-spoon. They collect relatively undisturbed cores for measurement of physical characteristics and detailed stratigraphy with determination of geochemical characteristics enhanced by the use of a plastic sample liner. Core length is restricted to 0.2 to 0.6 m for a split-spoon and 1.5 to 6.1 m for a core barrel depending on how consolidated the sample material is. Consolidation of the core during placement can result in some alteration of physical characteristics and some pressure induced geochemical alterations.

Shelby Tube

Description: The Shelby tube consists of a short length of thin-walled (relative to split-spoon and core tubes) metal pipe attached to drill rods. Sample collection is similar to that of split spoon samplers, however, the sampler is manually or hydraulically advanced through the bottom of the borehole rather than hammered. This minimizes disturbance but limits core length to approximately 0.75 m. The tube is retrieved and the core is preserved in the tube.

Limitations/Advantages: The relatively low cost of the sampling tube allows the sample to be preserved and stored in the tube minimizing handling disturbance and atmospheric exposure. This helps to maintain the samples physical and geochemical integrity and also prevents cross contamination, which can occur when sample tubes are reused in the field. The most significant drawback is the short core length and the inability to examine the core in the field if it is kept in the sample tube.

Piston Sampler

Description: The piston sampler is similar to the Shelby sampler with the addition of a fixed piston. The apparatus is placed at the bottom of the borehole. The piston is held stationary while the outer sample pipe or sleeve is advanced manually or hydraulically through the floor of the borehole. By maintaining the piston in place relative to the sample sleeve, a vacuum is created which aids in advancing the sleeve and in holding the sample in place during retrieval. The sample is then stored in the replaceable sample sleeve. Piston samplers may collect samples up to 3 m in length depending on the length of the sampling tube and the physical characteristics of the sample material.

Limitations/Advantages: Limitations and advantages are as reported for the Shelby sampler with the added of increased core length and retention due to the vacuum created by the piston.

Long Thin-Walled Tube Samplers

Description : Long thin-walled tube samplers consists of a thin walled sample tube placed within the foremost hollow stem auger in such a manner that the auger rotates around the stationary tube. A wireline drum hoist is used to retrieve the sample tube when full. This produces a long (up to 10 m) continuous, relatively undisturbed core.

Limitation/Advantages: Limitations and advantages are as reported for the Shelby sampler with the additional benefit resulting from the long, continuous core. However, the very length of these cores makes them difficult to handle and store.

Deep Sampling Recommendations

The preferred sampling option is primarily dependent on the length required for the core. The ease of opening and examining split-spoon cores serves well in the field if geochemical characteristics are not required. If short to medium length cores of high sample integrity are required, Shelby or piston sampling will be the best option, as they result in less sample compression than a split-spoon with a liner. Long thin-walled sample tubes are ideal for detailed assessment of deep tailings stratigraphy but are more equipment and time intensive.

References:

ASTM 1991b
Electric Power Research Institute 1985
Munch and Killey 1985
Driscoll 1989
MEND 4.1.1 1989
National Uranium Tailings Program 1985

6.0 CHARACTERIZATION OF SOLIDS

6.1 Elemental Content

Application: Chemical and physical characterization waste rock or tailings, is required for most AMD investigative programs.

Background: Chemical characterization and static AMD tests are normally conducted on the same samples. Waste rock samples can be obtained through boreholes drilled in waste rock piles or into rock that will become waste. Waste rock dumps may also be sampled without drilling by surface sampling or from test pits. Tailings samples can be obtained directly from the mill effluent, or from surface sampling or boreholes in the TMF. Some samples can be subjected to a particle size analysis, and the different size fractions should then be tested for elemental content and AMD potential.

Methods: The most common technique used to determine elemental content is acid digestion followed by multi-element determination by ICAP/AES (Inductively Coupled Argon Plasma Atomic Emission Spectrophotometry) or an equivalent method. Alternate methods such as LECO furnace and atomic absorption spectrophotometry are used for elements that are not properly determined by ICAP/AES.

Limitations /Advantages: ICAP is limited in that ICAP sulphur analysis may not be reliable unless a quality assurance program is included (i.e. correlation with LECO furnace sulphur). Also, other elements such as arsenic and mercury have to be assessed by alternate methods such as wet chemistry or atomic absorption.

Recommendations: ICAP/mass spectrometry is a simple, cost-effective method to obtain a large amount of useful data. The digestion method should be specified. Normally a total acid digestion is used. Low cost, low quality labs should be avoided. For arsenic, mercury, sulphur, etc. alternative analysis methods should be selected. A quality assurance program is required and adequate limits of detection should be specified.

Cost: Complete sample preparation and analysis is \$75-\$200/sample. Sulphur speciation is approximately \$25/sample. Major elements cost ~\$65/sample.

6.2 Mineralogy

Application: Information on the sulphide and buffering mineral content and distribution is necessary for accurate characterization and geochemical modelling of potential acid generating materials.

Background: Selected representative samples are taken in conjunction with the elemental sampling program described above. From an acid generating perspective an understanding of the distribution of sulphide minerals, especially pyrite, pyrrhotite, chalcopyrite, sphalerite, and arsenopyrite, within the exposed materials is important as they differ in their chemical and biochemical oxidation rates. Information is also required on the distribution and quantity of buffering minerals (e.g., calcite, dolomite, siderite, aluminum, and iron hydroxides) due to their influence on pH and hence, oxidation rates. For waste rock, mineral form (massive, nodular, disseminated, etc.) and the degree of crystallinity, weathering and secondary mineralization is often determined in conjunction with the mineralogy, using observations with a petrographic microscope, a scanning electron microscope, or in some cases through visual observations.

Methods: X-ray diffraction (XRD) is the most common technique. Automated scanning electron microscopy (SEM) and petrographic microscopic observations are also commonly used. For waste rock visual observations may be used.

Limitations /Advantages: X-ray diffraction has the advantage of being less costly and can be used for powdered/crushed samples and for identification of secondary minerals. For waste rock, advantage of petrographic microscopic analysis is that it also can provide information on mineral forms. Advantage of SEM is that images can be produced of very fine-grained secondary minerals.

Recommendations: All techniques listed above.

Cost: Petrographic microscope examination costs approximately $1 00-$200/sample. X-ray diffraction costs $100-$150/sample. SEM costs ~$250/sample.

References:

Fletcher 198 1	Levinson 1980
Thompson 1986	

6.3 Particle Size

Application: Important for predictive modelling. The particle size distribution and the concentration of sulphides in each particle size classification is required to estimate the surface area of sulphide minerals. This is important because the production of ARD is proportional to the specific surface area of sulphide minerals.

Methods: Particle size is commonly measured using standard soil sieves combined with hydrometer analysis (ASTM 1990a) to estimate surface area of finer particles (less than 0.075 mm). For waste rock, where particles over 15 cm are common, large scale sieves or grizzlies are used, or a visual estimate can be made. A hydraulic shovel may be required to take samples if large particle sizes are present.

Golder Associates has devised an alternative technique for characterizing the grain size of large fragments, that is in the development stage. A photo of the waste rock with a reference scale is used in a computer program called "Goldsize" to develop a grain size distribution based on manual traces of grains made on a digitized image. The grain size distributions is then corrected for fine-grained material that cannot be identified in the photographs.

Limitations / Advantages: Standard soil sieves are only suitable between a particle diameter of 15 cm and 0.075 mm. If a significant portion of the sample is smaller than 0.075 mm, hydrometer analysis is required to adequately characterize the sample. If a significant portion of the sample is greater than 15 cm in diameter, large scale sieves will also be needed to adequately characterize the sample. Visual estimates of the distribution of particles larger than 15 cm are acceptable, as these larger particles are not as important for acid generation. The **Goldsize** program would be enhanced by integrating actual sieve data with the **Goldsize** program results. This however, adds another level of effort and cost.

Recommendations: For modelling purposes, both the proportion of fine particles (i.e. percentage <2 mm) and the particle size distribution are important. Representative sampling is very difficult. Large scale sieves and soil sieves should be used. Elemental, mineral, and static ARD tests should be conducted on each sieve fraction to determine the distribution of AP and NP with grain size. A large number of characterizations are not required, as long as characterizations are conducted for each distinct unit. within the tailings or waste rock dump.

Cost: Costs range from between $60 to **$100/test** for simple sieve analyses. Costs can be much higher for coarse waste as machine time, **labour** for hand picking, etc., will be required. This raises costs to $500 to **$1,000/sample.**

References:

ASTM 1990a

7.0 FLOW MONITORING

7.1 Surface Water Flow

Application: Routine streamflow monitoring to collect basic surface hydrology data required for the evaluation of AMD on water quantity and quality.

Background: Surface water flow monitoring is required anywhere water quality is measured to enable the calculation of flood and low flow magnitude and frequency, flow duration, water balances and contaminant loadings.

Methods: Standard methods have been developed to monitor streamflow in a consistent, reliable, and safe manner. Measuring discharge generally involves four steps: 1) measurement of stream stage (i.e., water level); 2) measurement of stream discharge (i.e., water volume per unit time); 3) the establishment of a mathematical relationship between stage and discharge (i.e., the rating curve); and 4) the periodic recording of stage and subsequent calculation of discharge from stage data only.

1. Measuring Stream Stage: Stream stage is simply the water level of the stream relative to a fixed reference elevation, or benchmark. The bench mark may be a known geodetic datum or it may be a point which is simply assigned an arbitrary datum. Stream stage is always measured on a staff gauge and, additionally, may be measured continuously with a stage recorder (i.e., chart recorder or probe/data logger).

A **staff gauge** is a long ruler which is anchored vertically in the stream such that the vertical movement of the stream may be measured easily and accurately (i.e., typically ± 1 mm). Staff gauges are usually permanently attached to a length of steel rod or rebar that has been driven into the stream bed. The staff gauge should be surveyed relative to the benchmark with a surveyor's level and rod when it is installed and checked at least annually thereafter (i.e., usually after spring break up) to ensure that the staff gauge remains at the same elevation.

Stage recorders are instruments which measure stream stage on a continuous or periodic basis. There are two main types: 1) paper chart recorders which use a float/counterweight system and 2) pressure actuated recorders that measure hydrostatic pressure which is directly related to water depth. Hydrostatic pressure may be measured directly by a pressure transducer or by a bubble gauge wherein nitrogen gas is slowly bubbled out of a tube and the pressure required to force the gas out is related to water depth. The stage data generated by either method should be calibrated relative to the staff gauge to ensure that it is reliable. Chart recorders use a float/counterweight system to plot stage information on a paper chart. They are quite reliable but require the installation of a stilling well to ensure that the floats and counterweight are not influenced by current. The float/counterweight system cannot be operated where icing in the stilling well would prevent float movement. In addition, the data recorded on the chart require a manual conversion from paper to digital Pressure transducers are easier to install and can translate pressure to voltage which is stored in a data logger in a digital format. Stage recording done with data logger/probe setups record stage at some user-defined interval (e.g., hourly, daily). Both types of stage recorders have advantages and disadvantages which are summarized in Table IV: 1 .1- 1.

2. **Stream Discharge**: Stream discharge is the volume of water passing through a given point in a stream per unit time (e.g., m^3/s). It is derived by multiplying the area of a stream cross section by the velocity of the water at that cross section. The area of the stream is calculated by dividing the stream cross section into regularly spaced intervals (typically 20-25) and multiplying the width of the interval by the depth of the interval. The volume of water moving through the interval is calculated by multiplying the velocity at the interval by the area. The sum of all the volumes across the stream is the discharge. Details of this method are provided in Terzi (1981) and Harrelson et al. (1994).

The equipment required to measure discharge usually consists of a fibreglass surveyor's tape or tag line for measuring the channel width and a current meter/top setting wading rod for measuring stream velocity and depth. Current metres come in various styes but fall into two broad categories: 1) revolving bucket wheel type and 2) propeller type. The revolving bucket wheel type are the traditional current meters and are the most common. They come in several sizes with larger sizes being used for higher water velocities. There main disadvantage is that they do not perform well in turbulent flows. Propeller meters tend to perform better in turbulent flows and are generally both smaller and lighter than revolving bucket wheel models. Factors such as high turbidity and extreme velocities (i.e., very low or very high) may influence meter accuracy.

3. Rating Curve: The rating curve is a mathematical relationship between stage and discharge. Once a number of stage/discharge measurements have been completed discharge may be correlated to stage so that discharge may be estimated from stage alone. At least 6 stage/discharge measurements over a wide range of flows before a rating curve may be established. It is important to note that once a rating curve is established stage/discharge measurements should continue to be made periodically to ensure that hydraulic conditions have not changed and to improve the accuracy of the curve. Once the rating curve is developed, discharge can calculated from stage data without measuring instream discharge. Stream discharge should not be extrapolated from the rating curve outside of the range of points that were measured because reliability becomes .

Costs:

Staff Gauges	\$20 - \$100
Stage Recorders	\$2000 - \$8000
Current Meter/Wading Rod	\$1500 - \$5000

References:

Terzi 1981	Harrelson et al. 1994
Dunne and Leopold 1978	

7.2 Groundwater Flow

Application: Groundwater flow may be measured: within tailings management areas; in overburden or bedrock underlying and surrounding AMD sources; and where groundwater seepages discharge to a stream or lake bed.

Methods: Groundwater flow velocity is calculated using differences in water level elevations from a network of monitoring wells (piezometers) (See TSN 14.3.4.2), and permeability information (See TSN 3.4.1). Additional study design information is provided in ChIV:1.2 of the main document. For shallow groundwater flow, within or outside of TMFs, manually installed mini-piezometers may be used. Tracer studies may be used to determine flow rates, dispersion, and a number of other physical and chemical characteristics of surrounding formations. Tracers studies involve the introduction of a dye or salt in one well and timing its arrival at downgradient well(s). Seepage metres may be used to measure seepage where it discharges to stream or lake beds (See TSN 7.3.1).

Limitations /Advantages:

If preliminary data is available for basic assumptions concerning flow paths, tracers studies are relatively straightforward. The time required to complete a single test depends on the proximity of the dye introduction and sample sites and the flow velocity. The following table outlines the advantages and disadvantages of the more common tracer dyes.

TRACERS	ADVANTAGES	DISADVANTAGES
Dyes: Uranine, Rhodamine B, Suforhodamine G Extra	Easy to use and safe. Concentrations may be measured in the field.	Dyes may be affected by pH, temperature or absorbed by clays and organic soils.
Strong Electrolytes: Sodium Chloride Potassium Chloride Ammonium Chloride Lithium Chloride	May be measured in the field or lab using electrical conductivity or resistivity. Lower concentrations may be measured by atomic absorption spectroscopy .	Requires large amounts of salts if ordinary analytical methods are used.
Radioactive Isotopes: Tritiated Water Iodine Ion Others	May be used in small quantities that have no effect on the physical or chemical properties of the water Concentrations easily measured by sophisticated equipment Titriuated water inexpensive.	May pose some radiation danger (except for tritiated water). Requires expensive detection equipment.
Detergents: Alkylbenzol-sulphonates	Easy to use and safe.	May be confused with sewage related detergents. Disperses aggregated soils thereby changing permeabilities.

Recommendations: Normally piezometer water level are used to measure groundwater flow. This may be improved by using a tracer the most common of which is Rhodomine B.

References:

Driscoll 1989
Brassington 1990
Freeze and Cherry 1979

7.3 Groundwater Contaminant Seepage to Surface Water

Determining points of entry of contaminated groundwater into surface waters is a common concern for AMD monitoring purposes. In streams this can be achieved by bracketing the suspected point of seepage with upstream and downstream stations and analysing water samples for contaminant markers (e.g., conductivity). It is more difficult to identify groundwater seepage points into lakes. This can be accomplished using seepage metres or an electrical conductance bottom contacting probe.

7.3.1 Seepage Meter

Application: Seepage meters may be used to measure the rate of groundwater discharge into, or recharge from a surface waterbody. They may also be used to collect a sample of the discharging groundwater.

Method: A seepage meter consists of a collection chamber completely open at one end with a sample hole or port on the other end. The collection chamber is inverted (open-end down) and pressed into the sediment. The sampler is left until the discharging groundwater flushes the collection chamber. A collapsed sample bag is then attached to the sample port and allowed to fill with the groundwater.

Advantages/Disadvantages: Seepage meters are inexpensive, and simple to construct and install. The can only be installed in soft sediments and preparation time is required for flushing and settling of disturbed sediments.

Recommendations: This is a relatively inexpensive way to sample known discharges. Special attention should be paid to selecting construction material that will not contaminant the water sample.

Cost: Costs will be relatively low and will be primarily related to the selected construction materials and personnel time for installation and collection.

7.3.2 Electrical Conductance Bottom-Contacting Probe

Application: The probe is a new, experimental reconnaissance technique used for locating groundwater contaminated by AMD where it discharges to surface waters, and estimating the impact of the contaminated groundwater. It is used to detect areas of discharge and to quantify the discharge.

Description: The sediment probe consists of a bottom-contacting tube towed from a small boat. The tube contains instruments to measure conductivity, pH, and radiation. The probe is dragged along the bottom in areas where groundwater discharge is expected. Continuous data from the probe is transmitted via the cable to a data acquisition system aboard the boat. A shore-based laser positioning system can be used to determine the boat location.

Limitations /Advantages: This probe is the only practical reconnaissance method for locating contaminated groundwater discharges to surface water. The alternatives, such as piezometer installations or seepage metres are not suited to reconnaissance investigations.

For the survey to be useful, there must be a good contrast between the contaminated groundwater and the surface water. Also, follow up sampling using piezometers is necessary to identify chemical characteristics of any pH/conductivity anomalies identified by the probe. Ice cover in winter is another limitation.

Recommendations: This is a technique that should be considered for the early stage of any investigation where there is a concern regarding contaminated groundwater seepages discharging to surface waters, especially when the potential discharge area is large.

Cost: Much lower than the alternative of installation and monitoring of groundwater wells or seepage metres.

References:

MEND 4.8.2 1994

8.0 GEOPHYSICAL MONITORING TECHNIQUES

Introduction: The main applications for geophysical techniques in environmental monitoring for AMD are:

- to locate, define and monitor conductive AMD groundwater plumes emanating from waste rock piles, tailings areas, or other minesite contaminant sources; and
- to characterize sulphide content of in-situ rock destined to become waste rock.

Because geophysical surveys are not routine, they are most commonly completed by specialized contractors. Some surveys require special expertise and equipment, while it is possible to conduct others using in house staff without prior geophysical experience. Many mining companies will have staff experienced with geophysical surveys within their exploration departments who may be able to provide advice, equipment or even conduct the required surveys.

Geophysical surveys can be used as part of a larger study that includes borehole investigations and monitoring. Geophysical surveys are not a substitute for boreholes because no direct sample is obtained, but they can be used to minimize the number of boreholes required. This is done by using the geophysics data to precisely determine borehole placement in specific areas of interest, and to correlate between boreholes. For these purposes, geophysical techniques are faster and cheaper than the additional drilling that would otherwise be required.

For any geophysical technique to work, there must be a contrast between the material of interest and the background material. This should be evaluated on a case by case basis.

Electromagnetic (EM) surveys are most commonly used for measuring conductivity in the subsurface. This is a well proven technique used to find conductive massive sulphide ore deposits. It is now being adapted to detect and characterize conductive groundwater plumes containing conductive AMD products such as sulphate and metal ions. EM surveys can be complete from the air, on the ground, or down boreholes.

EM surveys utilize a transmitter coil and a receiver coil. An alternating electromagnetic field generated by the source coil induces alternating secondary currents in the ground, which vary depending on the presence of any conductors. The resulting ground current is then detected at the receiving coil. No physical contact with the ground is required for EM surveys, which allows them to be conducted from the air as well as from the ground. EM survey results can be complicated by the presence of naturally conductive groundwater, conductive bedrock or clay soils.

Induced Polarization (IP) surveys are most useful for detecting disseminated sulphides. This is a proven technique for finding and characterizing ore deposits comprised of disseminated sulphides, such as porphyry copper deposits. Typically waste rock with the potential to develop AMD would contain disseminated sulphides, and therefore IP is useful for characterizing the waste rock. IP is also being used experimentally to characterize disseminated sulphides within tailings areas.

IP surveys measure the time decay of a voltage applied to the earth after a pulse of current has been turned off. Two electrodes are placed into the soil, one transmitting the current, and the other receiving. The receiving electrode provides a measure of electrical polarization or chargeability of the subsurface. The strongest source of the IP effect is polarization at the boundary between electrolytic conduction in groundwater and metallic conduction in sulphide grains. The two electrodes are moved along a line to measure the chargeability at different locations to generate a profile. Different electrode spacings are used to determine changes in electrical polarization with depth.
EM and IP monitoring techniques are described in more detail below.

8.1 Airborne EM

Description: Airborne EM surveys are most commonly performed by helicopter and are in common use in the exploration industry. A boom is towed underneath the helicopter which contains multiple coil configurations which operate at multiple frequencies. This allows the collection of multiple data sets with one pass. The different frequencies and coil orientations provide information about conductive materials surveyed. Lower frequencies penetrate further into the earth. Different coil configurations respond best to different conductor geometries with thee differing responses provide information on the type of conductor. Horizontal coplanar coils respond best to flat lying conductors such as contaminated water-saturated overburden, while vertical coaxial pairs have a maximum response typical of subvertical sulphide or graphitic conductors in Canadian Shield bedrock.

Application: Detection and definition of conductive groundwater plumes. Detection and definition of conductive rock, either in-situ or in a waste rock dump.

Limitations /Advantages: Airborne surveys are best suited to providing data over large areas at a relatively low cost. Apparent conductivity maps are valuable tools for reconnaissance mapping of groundwater quality. They are very useful in focussing follow-up investigations into well-defined areas. Airborne geophysical data has been used in the Sudbury area to quickly locate AMD groundwater plumes for follow-up using ground-based methods.

For any EM technique to be effective, there must be a contrast between background and target materials. The presence of conductive clay deposits could reduce the usefulness of airborne EM surveys. Man made structures such as rail lines, buildings, power lines also can create local areas of anomalous conductivity which can obscure areas of interest.

Airborne EM data may already be available for a minimal reprocessing cost if the area has been flown for exploration applications, either by government or privately. Historic airborne data can be compared to recent data to determine any changes over time.

Recommendations: Excellent technique for reconnaissance investigations. Useful in defining specific areas where follow-up ground surveys are required, and therefore minimizing the cost of ground surveys.

8.2 Ground EM (Frequency)

Description: Frequency domain EM surveys are the most common. There are a variety of systems in use for environmental applications with various coil orientations and spacings which allow for depth penetration up to 48 m. All systems use circular transmitting and receiving coils, which may be held in a vertical or horizontal orientation. The smallest systems are operated by one person and utilize coplanar transmitting and receiving coils linked with a rigid boom.

An example is the EM3 1, which is one of a series of EM units Geonics has developed specifically for environmental applications. This unit gives a depth penetration of up to 4m. Two man units consist of a transmitting and receiving coil linked by a cable, such as the EM34 which can be used with separation lengths of 10, 20 or 40 m and can give information on depths up to 48 m. Both these units read directly in conductivity units (mS/m).

Application: Follow-up to airborne EM anomalies. Useful for defining locations for boreholes/monitoring wells.

Limitations /Advantages:

- Fast, easy to operate and relatively inexpensive.
- Do not necessarily require geophysical specialists to operate.
- Not suitable for environments with high background conductivity (transient EM is preferred).
- Limited to maximum detection depth of 48 m.

Recommendations: This is the preferred ground geophysics-based method for detection of contaminated groundwater, unless the background environment is very conductive, or the target is deep.

8.3 Ground EM (transient)

Description: Unlike the frequency EM where a continuous current is transmitted, with transient EM discrete current pulses are transmitted. The decay with time of induced secondary currents is measured. Later signal values correspond to deeper zones. The measured voltages are converted to apparent resistivity for the various depths. The equipment differs from frequency EM systems. A large transmitter loop is laid out on the ground (minimum diameter of 20 m). The smaller receiver can be put anywhere except near the transmitter. For large transmitter loops, the receiver is put in the centre of the transmitter loop. For smaller transmitter loops, the receiver can be put outside the transmitter loop.

Application: For use in high conductivity environments or for deep targets.

Limitations /Advantages:

- Deeper depth penetration than frequency EM.
- More costly and slower than frequency EM.
- A conductivity target at depth may be masked by surface conductive material, such as clay deposits.

Recommendations: Due to higher cost, only use for targets where frequency EM systems are not suitable.

8.4 Induced Polarization (IP)

Description: IP surveys measure the time decay of a voltage applied to the earth after a pulse of current has been turned off. A DC electrical current is passed between two current electrodes set on a survey line. Two potential electrodes are set up, typically inside the two current electrodes. The DC current is shut off and the time decay of the voltage in the ground is measured. This provides a measure of the electrical polarization or chargeability of the subsurface. The strongest source of the IP effect is polarization at the boundary between metallic conduction in disseminated sulphide grains and electrolytic conduction in groundwater.

The electrodes are moved along a line to measure the chargeability at different locations to generate a profile. Different electrode spacings are used to determine changes in electrical polarization with depth. Typically numerous readings from various electrode configurations are collected at each station to collect depth specific information which is plotted as a pseudosection that can be correlated to sulphide content.

Measurements of resistivity (and conductivity) can be made using the same electrode set up, with the current left on. Frequency domain IP systems are also used, in low signal, high background noise environments.

Limitations /Advantages: The advantage of geophysical methods such as IP is that a large volume of rock can be characterized more economically through a combination of drilling and geophysics, than through a drilling only program. Geophysical methods must be used in combination with borehole investigations to correlate geophysical responses with measured parameters such as sulphide content.

IP does not work well in areas with resistive dry surface layers which limit the current that can be put into the ground. Also, IP does not work well in very conductive environments or where high voltage power lines cause interference.

Recommendations: Utilize existing exploration *surveys* of *in-situ* rock destined to become waste rock, to assist in characterizing sulphide content of a waste rock pile. IP can be used to characterize the sulphide content of TMFs if no better information is available from other sources such as mill records.

8.5 Piezo-Cone Penetration Testing

Application: This is a state-of-the-art technique that can provide geological, hydrogeological and geotechnical information on unconsolidated deposits such as sands, silts, clays and tailings. The information that can be obtained includes: stratigraphic information; groundwater pressure and gradients; hydraulic conductivity; density; and strength. Resistivity, which is governed mainly by pore fluid chemistry, may also be measured. This type of information has historically been obtained from borehole logging, from laboratory testing of borehole samples, and from monitoring of wells installed in a borehole. The piezo-cone technique may be used to supplement standard borehole information, or may replace standard boreholes entirely.

Description: The piezo-cone penetrometer (CPT) consists of a narrow rod with a conical tip containing electronic sensing elements that continuously measure tip resistance and side sleeve friction using load cells, and porewater pressure using a pressure transducer behind a porous disk. The unit may also be equipped with a resistivity module. Measurements are made as the unit is pushed at a constant rate into the ground using a drill rig. As the unit is pushed, porewater pressure greater than the in-situ pressure is generated. Periodically the unit is stopped, and the decay of the porewater pressure to the in-situ pressure is used to calculate hydraulic conductivity. Hollow rods are added as the tip is pushed deeper. An ultrasonic transmitter or a cable is used to transmit data to surface through the hollow drill rods. A second tip designed to collect water samples can be used in conjunction with the CPT. The tip contains a porous filter element. Samples are collected using glass vials, which are lowered to the tip by a wireline within the rods. The sampling locations can be determined based on the stratigraphy etc. defined by the CPT.

Limitations /Advantages: The limitations are:

- The technique does not have the depth penetration of a drill, however with typical unconsolidated materials, a 30 m depth penetration is common.
- It is not suitable for consolidated sediments.
- No solid samples are taken.
- Groundwater chemistry and water level changes over time can only be measured by coming back with the probe.

The advantages include:

- The time and cost of piezo-cone testing are significantly lower than what would be required to obtain similar information from conventional drilling.
- It can reduce or eliminate more costly traditional methods.
- The piezo-cone gathers reliable, detailed, repeatable, and continuous stratigraphic information that may be missed by conventional borehole sampling. Detection of thin weak layers and more pervious layers is improved. This is important because these weaker layers are important seepage pathways, and are important to geotechnical evaluations such as slope stability, liquefaction analysis, and foundation design.
- Piezo-cone data is easy to interpret.
- No drill cuttings are generated. This is an advantage if disposal of contaminated material is an issue.

Recommendations: The CPT is a promising technique that should. be given consideration for characterization of tailings and unconsolidated sediments, to reduce costs and/or increase data quantity, quality and repeatability.

Cost: Information comparable to, or in some cases better than that obtained with conventional drilling and logging techniques, can be obtained for approximately 25-50% of the cost of conventional investigations.

Ontario Ministry of Northern Development and Mines (MENDO) 1994.

8.6 Other Geophysical Methods

Other geophysical techniques, that may be applicable to AMD for special situations, or are useful indirectly, are described briefly below:

Seismic Refraction: surveys can be used to map bedrock contours when bedrock is covered by overburden or tailings. This is indirectly useful for prediction of groundwater flowpaths when the underlying bedrock topography controls groundwater flow.

Radiometric: surveys measure the total natural gamma radiation, emitted by uranium, thorium and potassium, and can be used to estimate the radioactive content of tailings/waste rock, which is relevant to AMD monitoring of uranium mines or mines that contain high levels of uranium associated with other metals. Down-hole gamma surveys are also used to log soil types; as finer-grained soils usually contain more gamma emitters.

Resistivity: is another method of measuring conductivity (inverse of resistivity). The IP set up is used to measure it. If an IP survey is being conducted, resistivity information should also be obtained. In a case where only conductivity is required, EM techniques are preferred over resistivity due to the ease and speed of EM surveys, which do not require electrodes to be placed in the earth.

Self Potential (SP): surveys measure voltages present within the earth. A tailings area undergoing oxidation is a large electrochemical cell with a SP difference between the oxidizing top and the reduced bottom. Although this technique is experimental with respect to AMD monitoring, there may be some application in the future for providing data for predictive modelling of tailings. Self potential measurements can be made with minimal extra work while an IP/resistivity survey is being conducted.

VLF (Very Low Frequency): surveys are another type of EM survey. For these surveys, distant US navy radio signals are utilized as the transmitter, and the receiver is operated by one person. These surveys are in common use in exploration, however for environmental applications, EM surveys are more common.

References:

MEND 4.6.1 1994
Telford et al. 1976
MEND 4.6.3 4994

9.0 POSITIONING AND RELOCATION OF SAMPLE SITES

Application: Diagnostic and/or investigative monitoring often examines the change of some environmental monitoring parameter over time. This type of monitoring requires sampling at the same location(s) during different time periods. Sampling stations must be accurately located (i.e., positioned) to ensure that monitored samples are comparable in terms of their geographic location.

Background: The required accuracy of the positioning of the sample site is a function of the type of sampling (i.e., purpose and objective), size and topography of the study area, distance between stations, and economic and technical constraints. Selection of the positioning method be part of the study design to ensure the method is appropriate to the nature of the data collection, is cost effective, and technically feasible. Ideally, two positioning methods should be used to ensure accuracy. If the initial results of the two positioning methods are found to be comparable, then the least cost efficient method may be dropped.

Methods: The methods and technologies used for positioning sample sites fall into the three major categories of optical, electronic, and satellite. These are discussed briefly below and are delineated further in the following table (Pages TSN 54a-b).

1. **Optical Positioning Systems -** These systems generally use line-of-sight optics and shore-based targets of known and fixed positions to triangulate an unknown position. They are relatively inexpensive and are generally quite accurate when performed by an experienced operator. Optical positioning systems include traditional navigation and surveying instruments such as theodolites and sextants as well as computer-based surveying instruments (e.g., total station). The disadvantages of these systems include the necessity for shore-based targets, some procedures require the use of shore parties (e.g., shore based theodolite survey), and a range typically limited to 5 km from targets.

2. **Electronic Positioning Systems -** Most electronic systems are analogous to optical systems in that they both use line-of-sight triangulation techniques. However, as the name suggests, electronic systems use microwave or radio signals, rather than visible light, for positioning. The accuracy is very good with typical values in the order of several metres. Electronic systems tend to be expensive and may require shore-based stations that may not be available in the study area (e.g., LORAN-C).

3. **Satellite Positioning Systems -** Satellite based systems use networks of earth orbiting satellites to accurately fix positions on the earth's surface. These systems have unlimited ranges and do not require any shore targets or stations. Depending on the system, accuracies to within 1 m can be expected over large areas. The cost for satellite based systems varies from inexpensive to moderately expensive depending, in part, on accuracy.

Limitations /Advantages: Refer to the table following this page (Pages TSN-53a and TSN53b) for a list of methods and their respective advantages and disadvantages.

Recommendations: Sources for information regarding the availability and/or applicability of certain methods for the study area may include government agencies, geomatics companies, local marinas, and land survey companies. The following general recommendations are made based upon the current technologies and their associated costs.

1. **Monitoring of Large Open-Water Areas such as Large Lakes or Marine Areas**

Normally, monitoring over large areas does not require a high degree of accuracy. GPS[3] and LORAN-C are inexpensive positioning methods which provide accuracies in the range off 100 m. DGPS is recommended for large areas where high degrees of accuracy are required (i.e., ± 1 m).

2. **Monitoring of Near-Shore Marine Environments or Large Rivers**

For accuracy ± 100 m GPS or LORAN-C are suitable and cost effective. If shore targets are available then RADAR could be used for accuracies off 10-l 00 m or Trisponder for ± l-l 0 m. DGPS will also provide ± 1 m accuracy.

3. **Monitoring of Small Areas with Closely Spaced Stations**

When monitoring small areas with numerous closely spaced stations a high degree of accuracy is required. The methods of choice are Miniranger, Trisponder, and DGPS. Alternatively, optical methods utilizing a sextant or theodolite could be used.

4. **Small Rivers, Lakes, Ponds, or Urban Waterfronts**

In these circumstances a method employing visual triangulation (e.g., sextant) will provide cost effective accuracy. Alternatively, DGPS could be used in cases where shore targets are inadequate.

Costs: Costs are highly dependent upon the method chosen and may involve instruments, personnel, and data. Instrument costs very widely; for example, a handheld GPS unit with an accuracy of ±100 m can be purchased locally for as little as $300. Personnel costs associated with certain methods may also add significantly to the cost. For example, fixing the position of a boat with two shore-based theodolites incurs the additional cost of the two theodolite operators. Certain methods in some areas, such as

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[3] At the time of writing the accuracy of GPS is typically ± 100 m. However, the United States Department of Defence may begin removing the 'selective availability' from the GPS satellite signals beginning as early as the year 2000 (US NSC 1996). This will effectively increase the accuracy of GPS to about ± 30 m at no additional cost to the user.

DGPS, may require the acquisition of data that may not be in the public domain and, therefore, may have to be purchased from a commercial source.

References:

Information regarding the applicability and/or availability of specific positioning methods in the study area should be obtained from the appropriate government agencies, geomatics companies, land survey companies, and local marinas. Other information sources as found in the literature are noted below.

Env. Can. 1985
Mudroch and Ma&night. 199 1
Tetra Tech. 1986c
US EPA 1987a
US NSC 1996

10.0 METEOROLOGICAL MEASUREMENTS

Application: Meterological data is necessary to carry out predictive modelling. On-site measurements are used if a nearby climate station or other sources of meteorological data are not available.

Parameters: The following are most important for typical monitoring: rainfall, snowfall, air temperature and surface soil temperature, and evaporation. Wind speed and direction, relative humidity and solar radiation may also be required.

Limitations / Advantages: The selection of appropriate locations for meteorological measuring devices is important; A climatologist should be consulted.

Recommendations: Meteorological data are essential. Need for on-site measurements will be site-specific. Some parameters are simple to measure (e.g., air temperature, relative humidity, soil temperature) and can be compared with nearby stations.

Cost: An automated weather station ranges from $5,000 to $10,000, depending on measurements required, power source, etc. Cost for monitoring is variable, depending on how much data collection and recording is automated.

References:

Manufacturers of meteorological instrumentation should also be contacted for detailed catalogues/brochures describing instrumentation available.

U.S. EPA. 1989b

11.0 PHYSICAL STABILITY OF WASTE ROCK

11.1 Hardness

Application: To assist in evaluation of physical stability of waste rock, which may have a significant impact on the rate and extent of acid generation. Hardness testing is not commonly performed, and is experimental when applied to AMD assessment.

Background: Representative samples of each rock type would typically be selected for physical testing in conjunction with drilling/sampling program.

Methods:

The ASTM C131-89 Los Angeles Abrasion test for small-size coarse aggregate, and ASTM C535-89 Los Angeles Abrasion test for large-size coarse aggregate are the most common methods. These abrasion tests, developed for testing aggregate for construction purposes, involve measuring the percentage of fines generated while the sample is churned in a cylindrical drum containing steel balls. The Rock Quality Designation (RQD) is a simple method of hardness assessment used when diamond drilling in-situ rock, which involves counting the number of pieces of drill core that are 10 cm or longer in 1 m of core length.

Limitations /Advantages: The tests provide an indication of rock stability rather than a quantitative estimate regarding rock weathering rates.

Recommendations: No preferred method.

Cost: Costs for abrasion testing are usually about $200 or $300/sample.

11.2 Weathering

Application: Investigative monitoring to assist in evaluation of physical stability of waste rock, which may have a significant impact on the rate and extent of acid generation. An understanding of potential effects of weathering on sulphide oxidation and buffering availability is important for AMD prediction. Weathering of rocks creates fines which increases the surface area of available sulphide minerals. In contrast weathering could also cause high fines contents which increases moisture retention and reduces oxygen flux to the pile.

Background; Representative samples of each rock type would typically be selected for physical testing in conjunction with drilling/sampling program.

Methods: Weathering is most commonly qualitatively estimated by visual observation of staining, fractures where the original material has been dissolved, waste rock that crumbles easily, etc. Weathering is also fairly commonly assessed in dynamic acid generation tests where the initial and final weathered state of the waste rock samples are documented and compared visually and/or using SEM and microprobe analysis.

Another method is the magnesium sulphate test (ASTM C88-90), also referred to as the slake durability test. This is a standard construction-industry test where a sample is immersed in a magnesium sulphate solution for about 17 hours and then dried. This cycle is repeated several times, and then the percentage of fine particles resulting from the disintegration of the original sample is calculated.

Limitations /Advantages; Tests are qualitative, not quantitative, and results are difficult to relate to field conditions for all methods. Advantage of humidity cell tests is that information on weathering can be obtained whenever humidity cells are used for dynamic test work. Advantage of other tests is low cost and faster turnaround time.

Recommendations: No recommendation. This is a major area of deficiency in current state-of-the-art waste rock sampling programs which seem to focus on static and dynamic test work.

Cost: Weathering tests cost $200/sample, excluding sample collection. Costs for humidity cells range from $1 ,000-$5,000/test, including sample analysis.

References:

ASTM 1989a
ASTM 1990d
ASTM 1989b

12.0 STRUCTURAL INTEGRITY

Application: Monitoring of the structural integrity of control structures and or AMD sources should be a routine component of any on-site monitoring program during the operational and decommissioning phases. Standard geotechnical techniques should be used to monitor cover integrity and the stability of tailings dams, rock piles and similar structures. Cracking of dry covers or slope slumping of tailings dam or rock piles can result in increased AMD generation and release due to greater exposure to oxygen and water.

Methods: Structural integrity should be assessed through simple observation surveys and the use of geotechnical techniques. Visual surveying techniques, especially of dry covers, should involve the inspection of the surface for:

- settlement or burrow holes;
- surface changes such as slumping, sliding, cracking, or bulging;
- air venting (especially evident under cold weather conditions);
- signs of surface erosion or soil loss;
- notes on significant changes in vegetation, and
- a significant change in the appearance of seepage (e.g., cloudy).

Observations should be made by the same inspector over time with accompanying photographs and notes. More detailed geotechnical surveys involving the use of installed survey stakes and pins should be used to measure horizontal and vertical movement of structures, while survey hums and inclinometers may be used to measure deformation occurring within the structure. Piezometers and pore gas samplers could also be installed in the AMD structures to detect significant increases in water or oxygen ingress.

Limitations/Advantages: Routine observational surveys are a quick inexpensive way to complete ongoing assessments of structural integrity. However, they will not detect small scale shifts in slope that may be detected by geotechnical surveying techniques prior to actual slope failure.

Costs: Observational survey costs are minimal and will primarily consist of the inspectors hourly expense. The installation of geotechnical equipment is usually incorporated into the construction of the structures. Hence, monitoring costs would be restricted to maintenance and surveying personnel.

References:

Hanna 1973

Dunnicliff and Green 1988

13.0 WATER QUALITY SAMPLING

13.1 Field Analysis

Application: Field analysis is generally completed for parameters which can be easily measured in the field or for parameters which will alter during transportation or storage.

Common Tests:

a) pH.
b) Specific Conductance
c) Temperature.
d) Dissolved oxygen.

Limitations /Advantages: With the exception of specific conductance, all of these parameters are at risk of changing during transportation or storage. These parameters are easily determined in the field using relatively inexpensive field metres or kits. These parameters and a few others, as shown in Table III: 2.5-l of the main document, may be determined using continuous time probes and data loggers (TSN 14.0).

Recommendations: The minimum field parameter list should include pH, dissolved oxygen, specific conductance, and temperature. Regular maintenance and standardization procedures should be followed and documented for the equipment.

Cost: Varies widely depending on whether field metres are used or continuous time probes and data loggers. Multi-capability field metres generally range from $800.00 and higher, while continuous time probes with data loggers can cost in excess of $2, 000.00.

13.2 Sample Preservation and Container Preference

Application: Preserve sample so that laboratory analysis results reflect original composition of sample.

Methods and Recommendations: Table IV:2.1-2 of the main document provides collection methods, minimal sample sizes, container types and storage/preservation requirements for the most common water quality parameters. Preservation is important for establishing measurement of in-field conditions which can alter with collection, ‘storage, and transport (e.g. ferrous/ferric iron ratio can be altered by change in oxygen conditions associated with sample collection).

Surface water samples may or may not require filtering, depending on whether total or dissolved concentrations are of interest. Porewater and groundwater are filtered (0.45 m) prior to preservation to remove suspended solids not representative of material dissolved in the porewater.

Recommendations: Follow appropriate provincial/federal standards and consult the laboratory to confirm minimum sample, container and storage/preservation requirements for the site specific water quality parameters.

Cost: Sample container and preservative costs are minimal and are usually provided by the laboratory with the price incorporated into the analytical costs. Filtering completed in the laboratory is usually an additional expense is ranging from $5.00 / sample and up depending on the solution being filtered.

13.3 Laboratory Analysis

Common Tests:

a) pH.
b) Major ions.
c) Sulphate.
d) Acidity.
e) Alkalinity.
f) Total dissolved solids.
g) Total suspended solids.
h) Elemental scan.

Laboratory analysis of water samples commonly involves all of the parameters listed above.

Detection limits for trace elements are depended on the analytical procedure. The following table provides the detection limits for the range of available analytical procedures for the most commonly analysed trace elements. These procedures are 1) flame atomic absorption spectrophotometry (FAAS), 2) inductively-coupled argon plasma/atomic emission spectrophotometry (ICAP/AES), 3) graphite-furnace atomic absorption spectrophotometry (GFAAS), 4) hydride-vapour atomic absorption spectrophotometry (HVAAS), 5) cold-vapour atomic absorption spectrophotometry (CVAAS). The detection limits in **bold** indicate the primary analytical method.

ELEMENT	UNITS	FAAS	ICAP/AES	GFAAS	HVAAS	CVAAS
Aluminum	mg/L	0.1	0.2	0.005		
Arsenic	mg/L	5	0.2		0.0001	-
Cadmium	mg/L	0.005	0.01	0.0002		-
Chromium	mg/L	0.01	0.015	0.001		
Copper	mg/L	0.005	0.01	0.001		
Iron	mg/L	0.03	0.03	0.005		
Lead	mg/L	0.05	0.05	0.001	-	-
Mercury	mg/L	-	-	-	-	0.00005
Nickel	mg/L	0.01	0.02	0.001	-	-
Selenium	mg/L	-	0.2	-	0.0005	-
Zinc	mg/L	0.005	0.005	0.001	-	-

Limitations / Advantages: Laboratory analysis for above constituents are fairly standard. Contract laboratories will automatically run standard procedures that may not provide a suitable detection limit for your specific investigation. It is the responsibility of the person/group submitting the samples to ensure the selected analytical technique provides a detection limit that is below concentrations suspected of having ecological effects (See Canadian Surface Water Quality Guidelines CCME 1996).

Recommendations: Requirements are site-specific. See the main text (CHIII:2.5, ChIV:2.0) for more detailed discussions on required water parameters. Other parameters should be added where warranted (e.g. sulphide solids, arsenic, radionuclides). Always specify limits of detection and request a copy of written procedures and quality assurance documents. Charge balances should be used as a simple check on the precision of the data.

Cost: Cost for a complete analysis ranges from $100-200/sample.

14.0 WATER SAMPLING METHODS

14.1 Surface Water Sampling Methods

Methods: Grab samples are the most common sampling method. Automatic programmable samplers that collect samples on a flow or time dependent basis and samplers utilizing continuous time probes attached to data loggers are also available. At a minimum, samples should be taken from the middle of the flow if possible, at mid-depth. Care should be taken to avoid stirring up sediments, or if this is not possible, samples should be taken upstream of any disturbance.

Collections from the water column can be completed using discrete samplers such Van Dorn, and Kemmerer samplers or pumps. If pumps are to be used, peristaltic pumps are preferred as they are less vulnerable to contamination. Depth integrating samplers collect water throughout the water column as they are retrieved. The analysis of composite samples should be carefully reconsidered in light of the loss of information relating to variable water chemistry due to stratification (e.g., oxygen, contaminant plume density etc.).

Limitations /Advantages: Advantage of grab and manually collected composite samples is that field analysis can be done immediately. For programmable samplers, there is a delay between collection of sample and field analysis, which can affect results. Continuous time probes with data loggers have a restricted parameter list (See Table III:2.5-1). Programmable samplers and continuous probes have the advantage of establishing a sampling regime based on specific triggers. For example, samples could be collected, either by the automatic sampler or by a technician called by an alarm, whenever the pH declines below a specified level.

Small flows from seepages may be difficult to sample. Seepage may be diluted by surface run-off or wash-through flow associated with precipitation events, therefore, the location, time of sampling and a record of rainfall is important for seepage monitoring.

Recommendations: Automatic programmable samplers and/or continuous time probes should be utilized for effluent monitoring. They may also be of value for significant high risk, on-site AMD flows. Grab samples are suitable for most on-site and receiving environment water collections. See Chapter III:2.5 and Chapter IV:2.1 of the main document for more information.,

Cost: Expenses are related to equipment costs and field time. Field time depends on site specific weather conditions and station accessibility. Kemmerer and Van Dorn samplers range from $200.00 to $900.00 depending on the construction material. Programmable automatic samplers can range in base price from $2,000.00 to $8,000.00 depending on their capabilities.

14.1.1 Subsurface Water

Subsurface water may be subdivided into the phreatic zone, more commonly referred to a the zone of saturation[4] or groundwater, and the vadose zone. Large waste rock piles which develop a water table may also be subdivided into these two zones.

Vadose zone pore water and ground water collections are complicated by the likelihood that, *in situ,* they will not be in equilibrium with the atmosphere. Hence, the geochemical composition will be altered (e.g., formation of precipitates, changes in pH) with pressure changes and exposure to oxygen as the samples are brought to the surface.

14.2 Vadose Zone Pore Water Sampling

The vadose zone consists of the zone bounded by the planet surface and the phreatic or groundwater saturation zone. Vadose zone water sampling usually involves the collection of pore water from the unsaturated zone within a waste rock pile, TMF, or the soil surrounding or underlying a rock pile, heap leach pad or TMF. See Chapter IV: 2.2.3 of the main document for further information. Vadose zone pore water collections are complicated by the likelihood that, *in situ,* they will not be in equilibrium with the atmosphere. Hence, the geochemical composition will be altered (e.g., formation of precipitates, changes in pH) with pressure changes and exposure to oxygen as the samples are brought to the surface.
The most common techniques involve the sampling of wetted waste rock, gravity lysimeters, core squeezing, or a range of pore water suction samplers.

14.2.1 Waste Rock Washing

Application: Waste rock dumps tend to consist of large particles and hence have large interstitial pore spaces. Unless a water table has formed in the pile, these interstitial spaces will hold little water other than ice. The retained water in unsaturated zones of waste rock piles is present either as a surface film on the rocks or in cracks or voids in the rock particles. This water is most commonly collected using a wet washing procedure outlined below.

Methods: Sampling of pore or surface film water in a wasterock pile is difficult. The most common means involves determining the difference in weight between wet and oven-dried samples, and reported as the ratio of weight of water in the sample to weight of the solids (ASTM D22 16-90). Water content can be determined from drying samples

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[4] More accurately defined as the zone containing water that freely enters wells under both confined and unconfined conditions.

prior to other test work, e.g., particle size classification, elemental analysis, etc. A weighed sample of the wetted waste rock is washed with a measured volume of distilled water, while a second sample is dried and weighed. The resultant data from chemical analysis of this water may then be corrected to the original volume of pore water.

Limitations / Advantages: Wet washing has the undesirable potential to remobilise secondary precipitates, resulting in non-representative samples. It is also a destructive sampling technique, hence repeat measures cannot be collected for the same sampling site. If repeat sampling is not considered essential then it is a relatively inexpensive means of collecting water quality data where interstitial spaces are large.

When using water content information, **care** should be taken to ensure the **water content** being used is the difference in weight between wet and oven-dried samples, as described above. This should not be confused worth similar measurements such as: **volumetric water content (sometimes called volumetric moisture content),** which is defined as the volume of water divided by the total volume of the sample; **moisture content,** defined as the weight of water divided by the total weight of the sample; or **percent saturation.** To eliminate confusion, the calculation method used should be listed with the results.

Cost: Cost for analysis is approximately $20/sample.

References

ASTM 1990c

14.2.2 Gravity Lysimeters

Application: Gravity lysimeters may be used in material containing large to small pore spaces They are most often utilized within rock piles where they provide a composite sample of the water percolating downwards through the pile over the sampling period.

Methods: Gravity lysimeters passively intercept pore water migrating downward through the vadose zone under gravity. The water is intercepted by a collector and held until it is retrieved, usually by suction or peristaltic pump. In waste rock piles or other sites where excavation will have little effect on the overlying particles structure, gravity lysimeter can be placed at the desired depth and backfilled with the appropriate material. To collect samples from undisturbed sites without altering the overlying soil structure, gravity lysimeters can be installed within the wall of an excavated trench.

Limitations /Advantages: In addition to their use for collecting water quality samples, gravity lysimeters may be used to collect information on infiltration rates and water budgets. Once installed they may be used for repeat sampling. The disturbance of the overlying materials during installation will influence water quality and flow patterns and rates until settling is completed.

14.2.3 Core Extraction

Application: If the pore water is to be extracted from fine materials (e.g., soils or tailings) a core sample may be collected and the pore water removed by squeezing or displacement.

Methods: Pore water may be extracted from cores by centrifugation, consolidation (squeezing), or displacement. In centrifugation the pore water is separated from the solids by spinning the sample in a centrifuge. The required centrifuge speed and time will depend on the retention capacity of the solids and the size of the sample. Pore water may also be removed by placing the core in an apparatus designed to squeeze the core either mechanically or with gas pressure. Pore water may also be displaced by pouring an immiscible liquid over the sample and forcing the liquid through the sample to flush out pore water.

Limitations / Advantages: Core extraction methods are destructive sampling, hence repeated sampling at exactly the same site is not possible. Exposure to the atmosphere and any significant pressure changes associated with sampling, can also alter geochemical characteristics of the pore water samples. Heat and extended centrifugation times can result in physico-chemical changes in pore water. Displacement techniques may produce more pore water, however, the procedure is slow and only suitable for sandy or coarse grained materials. Care must also be taken to ensure the displacing liquid does not influence pre water composition.

References

Kinnlburgh and Miles 1983
Mudroch and Azcue 1995
National Uranium Tailings Program 1985
MEND 4.1.1 1989
Munch and Killey 1985

14.2.4 Suction Lysimeters

Application: Suction lysimeters, such as porous cup lysimeters, vacuum plates and tubes, and membrane and filter samplers provide *in situ* samples of pore water from the **unsaturated** zone of coarse tailings or soils.

Methods: These devices utilize vacuum pressure to draw pore water through a water saturated, slightly permeable plastic or ceramic base cup. The water saturated cup requires hydraulic contact with the tension-held water in the pores of the testing matrix. When vacuum pressure is applied the pore water is drawn through the base cup into the vacuum cylinder.

Limitations /Advantages; Once properly installed sample collection is relatively simple. These samplers work best in moist relatively coarse grained materials. Fine materials require longer sampling times and can impair the permeability of the cups by clogging pore spaces in the base cup. Hydraulic contact may be difficult to maintain, especially in materials that experience freeze-thaw cycles. There are also difficulties related to geochemical changes in pore water composition. These devices can also create a distortion of the localized drainage pattern due to application of the suction. They do however, provide the closest measurement of *in situ* pore water and can support repeated sampling of the same localized site.

References

Bond 1995	Ritcey and Silver 1982
Robbins and Gemmell 1985	Wilson et al. 1995

14.2.5 Vadose Zone Recommendations

The selection of the most appropriate technique will be site-specific. Rock piles consisting of large particles with corresponding large interstitial spaces will require wet washing techniques or gravity lysimeters. Gravity lysimeters have the advantage of also providing information on infiltration rates and water budget. Rock piles consisting of small particles, tailings and soil sampling where interstitial spaces are smaller are best sampled using core extraction methods or suction lysimeters. Core extraction methods may be used for preliminary screening or monitoring with suction lysimeters installed under identified high AMD risk scenarios or where more accurate data is required for modelling purposes. Suction lysimeters may be of special value beneath or surrounding heap leach pads to identify any loss of pregnant solution.

14.3 Phreatic or Groundwater

The phreatic zone more commonly referred to a the zone of saturation[5] or groundwater, is best defined as the point at which groundwater freely enters wells under both confined and unconfined conditions. Large waste rock piles which develop a water table may also be sampled using small well designs.

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[5] More accurately defined as the zone containing water that freely enters wells under both confined and unconfined conditions.

Like vadose zone porewater, ground water collections are complicated by the likelihood that, *in situ,* they will not be in equilibrium with the atmosphere. Hence, the geochemical composition will be altered (e.g., formation of precipitates, changes in pH) with pressure changes and exposure to oxygen as the samples are brought to the surface.

The sampling of groundwater in the saturated zone within, and up, or down-gradient of, an AMD source is usually completed using sampling wells. Sampling wells can serve a number of purposes including:

- providing a sampling point for water quality collections;
- providing a means of determining water table or potentiometric elevations and the hydrogeologic properties within a rock pile, TMF or a geological formation; and
- providing a sampling point to monitor the movement of a contaminant plume.

14.3.1 Siting of Wells

Prior to installing a sampling well or well network a review of potential flow paths and subsurface conditions should be completed. This should include local and regional hydrogeology and surficial geology.

The required number and design of the well network will depend on site specific requirements. The most difficult decision is likely to be selecting sampling depth rather than sampling site. This will be influenced by such factors as contaminant density, the anisotropic characteristics of the aquifer, the slope of the water table and the potentiometric surface (Driscoll 1989). Due to the expense of establishing wells the use of geophysical methods (See TSN 8.0) to assist in locating the well in relation to an actual or potential contaminant plume may prove cost effective.

The most common practice, and a minimum requirement, involves locating a well near the centre of an identified contaminant plume with an additional well sited down-gradient outside the present limit of the plume. An additional well should also be located up-gradient of the source. Should the source be located at a high point for the local landscape, leachate flow may occur in a number of directions, thereby requiring multiple well sites. Wells may need to be installed at more than one depth in an aquifer to determine whether vertical flow is occurring or whether the contaminant spread varies at different depths (Driscoll 1989).

When establishing a monitoring well the most appropriate drilling technique should be selected for the on-site sub-surface conditions. Proper well development and design is also essential if the well is to be used for water quality purposes. Note that the cost of well installation and construction is only a fraction of the long-term expense of groundwater analysis and interpretation, hence, the most suitable construction practices and well materials should be utilized when installing a well.

14.3.2 Drilling for Monitoring Wells

Application: When drilling wells for monitoring purposes care must be taken to ensure that water quality is not influenced and that consistent water samples can be retrieved. Of special concern is minimizing cross-contamination and contamination due to cuttings and drilling fluids.

Methods: The most common drilling techniques for installing monitoring wells are hollow-stem augers, cable tool, **becker** hammer and direct rotary, air rotary and diamond drills.

Limitations/Advantages: Table IV: 2.2-l of the main document summarizes the advantages and disadvantages of these drilling options.

Recommendations: selection of the most appropriate drilling option is site specific and must consider factors such as, whether geophysical logging is required, the type of geological formation, well depth, required well diameter, potential for contamination by drilling fluids, or casings. For monitoring AMD where acidity and trace metals are of key interest the potential for contamination by drilling fluids and from steel casings is a significant concern.

14.3.3 Well Design

The design of a monitoring well will be dependent on:

1) whether the well is to be used to measure the elevation of the water table or the potentiometric surface, or for contaminant recovery;
2) the hydrogeologic environment;
3) the chemical nature of the contaminants; and
4) and whether the well bore will be used to conduct geophysical investigations (Driscoll 1989).

The most common casing and screen diameters for monitoring wells are 51.8, 102, 152, and 203 mm (2, 4, 6, and 8 in. diameter, respectively). A well diameter of 51.8 mm is suitable for shallow monitoring wells or for wells restricted to measuring water level. Casing and screen diameters of 102 mm or greater are required for more accurate sampling due to their better well development. The larger casing and screen diameters are also required for deeper wells, or if pumping tests or geophysical logging is also to be completed.

Well Casing and Screen Materials (Driscoll 1989)

TYPE	ADVANTAGES	DISADVANTAGES
Stainless Steel	Least absorption of halogenated and aromatic hydrocarbons High strength at a great range of temperatures Excellent resistance to corrosion and oxidation Readily available in all diameter and slot sizes	Heavier than plastics May corrode and leach chromium in highly acidic waters May act as a catalyst in some organic reactions Screens are > cost than plastic
PVC **Polyvinyl-** chloride	Lightweight Excellent chemical resistance to weak alkalies, alcohols, aliphatic hydrocarbons, and oils Good chemical resistance to strong mineral acids, concentrated oxidizing acids, and strong alkalis Readily available and low priced compared to stainless steel and Teflon	Weaker, less rigid and more temperature sensitive than metallic materials May adsorb, react with or leach some constituents from groundwater Poor chemical resistance to ketones, esters, and aromatic hydrocarbons
Teflon	Good resistance to attack by most chemicals Lightweight and high impact strength	Screen slot openings may decrease in size over time Tensile strength and wear resistance low compared to other engineering plastics Expensive relative to other plastics and stainless steel
Mild Steel	Strong, rigid; temperature sensitivity not a problem Readily available Low priced compared to stainless steel	Heavier than plastics May react with and leach some constituents into groundwater Not as chemically resistant as stainless steel
Polypropylene	Lightweight Excellent chemical resistance to mineral acids Good to excellent chemical resistance to alkalies, alcohols, ketones, and esters Good chemical resistance to oils Fair chemical resistance to concentrated oxidizing acids, aliphatic hydrocarbons, and aromatic hydrocarbons Low price compared to stainless steel and Teflon	Weaker, less rigid and more temperature sensitive than metallic materials May react with and leach some constituents into groundwater Poor machinability - cannot be slotted as it melts rather than cuts
Kynar	Greater strength and water resistance than Teflon Resistant to most chemicals and solvents Lower priced than Teflon	Not readily available poor chemical resistance to ketones and acetones

Recommendations: Stainless or mild steel **should not** be used for AMD monitoring purposes as leaching of chromium or other metals may occur. For AMD purposes 5 1.8 mm PVC is generally used. PVC should not be used when organic contaminants such as methyl ethyl ketone, toluene, trichloroethylene, or xylene are also of concern. In all cases the laboratory completing the chemical analysis should be informed of the materials used in the construction of the well.

References:

See Main Text Bibliography (Chapter IV: Section 1.4)