SECTION B.15

PERMITTING MINING RELATED DISCHARGES: HOW TO ASSESS AND MANAGE RISK USING PRINCIPLES OF IMPACT ASSESSMENT BIOLOGY

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Permitting Mining Related Discharges

How to Assess and Manage Risk Using Principles of Impact Assessment Biology

A Mine Life Cycle Approach

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Mining and Regulatory Protection of Water Quality

The BC Ministry of Environment Lands and Parks (MELP) Pollution Prevention Program regulates mining discharges to aquatic environments through Waste Management Act (WMA) permits. For a new mine project to enter the permitting process for these discharges, it must first be certified under the BC Environmental Assessment Act. This certification is based on assessments which ensure that in concept, the mine can be built, operated and decommissioned using the best, most practical pollution control technology available, in a manner which safeguards people and the environment from unacceptable impacts. The test of certification is whether unacceptable impacts can be avoided or mitigated with known technology, should they occur. A variety of permits (including WMA permits) are then used to refine and assess final designs for mine infrastructure, operation and decommissioning and to provide ongoing regulation, monitoring and impact assessment.

Throughout these regulatory processes, environmental impact assessment tools are used. These include ecological risk assessment, definition of desirable receiving environment conditions related to the range of existing water uses (including protection of aquatic life), and environmental effects monitoring (EEM) programs. Desirable conditions in the receiving environment are defined in terms of water and sediment quality criteria and objectives, measures of ecosystem health and functioning and discharge toxicity testing. EEM programs use a range of methods to verify and refine judgements regarding whether mine influences on aquatic resources remain within the bounds of acceptability, and to provide "goal posts" around which mine pollution control works can be designed.

Fundamental to whether a mine is certified and permitted is whether it is possible to detect an unacceptable impact if it was to occur. This necessitates a thorough knowledge of hazards (impact mechanisms) and their occurrence probabilities, receiving environment resource values, impact sensitivities of aquatic resources and the application of impact monitoring and assessment science.

This presentation is an attempt to bring the above elements together in a description of how impact assessment biology is used as part of a multidisciplinary approach (including geochemical and geotechnical science) to mining regulation. Having participated in numerous mine certification reviews, permitting processes and closure planning forums where conflict among participants has occurred, it is my view that "perception is reality" (Sharpe's Credo). This means that the principles and processes used in impact assessment biology as well as the other relevant geoscience disciplines must be understood by the range of technical practitioners and stakeholder groups involved in mine development and environmental regulation. This will create a common understanding of the resources at risk and how we can ensure their ongoing protection through co-operation, instead of conflict.

Environmental Impact and Risk Assessment in Mine Certification and Permitting

Studies and assessments necessary to ensure environmentally safe mine planning, operation and closure can be placed in a number of broad categories, such as those used in the specifications developed for the Silvertip mine project, under the Environmental Assessment Act of BC:

- **characterise resources at risk** from mining related discharges to the aquatic environment. These resources are defined in terms of specified water uses such as protection of aquatic life, drinking water source, agricultural uses such as crop irrigation and livestock watering and industrial uses including food processing.
- **describe conditions in receiving waters which define ecosystem health**. Enough information must be collected and interpreted to establish thresholds of acceptable change in a variety of parameters which are known to provide indicators of ecosystem health.
- **make definitive statements regarding the types and severity of impacts which are likely to occur** during the life of the project and closure period. These statements will be made as a result of a risk assessment which incorporates the range and extent of uncertainties associated with identified probable outcomes.
- **demonstrate that hazardous conditions could be identified and mitigated** prior to the occurrence of unacceptable mining related impacts. For this part of a risk assessment to occur, there must be an understanding of the nature and extent of aquatic resources which may be at risk, current and potential stresses on them, and the potential hazards to these resources which may occur as a result of mining related activities. It is also necessary to consider whether and what kind of contingencies may be employed to avert impacts.
- **propose an EEM program** which will be capable of detecting impacts to aquatic resources, should they occur. These studies will be inclusive of water and sediment chemistry, suspended sediment loadings, flow rates and the range of aquatic life present in the receiving environment. They must be sufficient to determine whether conditions in the aquatic environment remain within the bounds of acceptability. This must be accomplished through the use of a rigorous experimental design which uses *a priori* determinations of the degree of effect or impact to be detected.[1]

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[1] It has been obvious for several years that carrying out EEM efficiently requires a high degree of technical knowledge and proficiency. As a result, CANMET, a federal government department, has conducted an extensive aquatic effects technology evaluation program (AETE), which has identified and approved a range of appropriate impact assessment tools. These tools are currently being incorporated in a national mining EEM framework under an amendment to the Metal Mining Liquid Effluent Regulation of the Canada Fisheries Act. This standardised system is being applied across Canada to augment and improve existing provincial and federal EEM requirements. The basis of the new EEM system is to determine whether mining related contaminants are finding their way into the aquatic environment and whether they are causing a measurable negative response. Once this is determined using the range of sanctioned EEM tools, then permitting authorities (provincial) will be advised, and expected to act to eliminate or reduce impacts.

- **develop a database which will serve as a baseline (time "0") for an EEM program** spanning the life of the project, and into the post closure period. The adequacy of this database for the purpose must be judged by it's predictive power.
- **propose a safe discharge plan with concentration and volume limits that are protective of identified aquatic resources**. The plan and proposed limits will be reviewed by MELP and used as a basis for WMA permit limits to be applied to mining related discharges. Limits should be proposed so that there is no acute lethality to aquatic organisms at the point of discharge, and so that changes in the immediate receiving environment (initial dilution or mixing zone - IDZ) remain within acceptable limits.

Ecological Risk Assessment and Discharge Permitting

The goal of risk assessment is to establish the probability that impacts to valued resources may occur as a result of exposure to stressors. Once this has been done, risks may be managed to avoid impacts. Risk assessment identifies potential hazard conditions, estimates probabilities of the range of these conditions occurring and assesses ecologic, economic and societal consequences or costs (Risk = probability of occurrence x cost). Once risks associated with mining related discharges have been assessed, they may be managed in a number of ways, including the use of permit limits which restrict discharge volumes and contaminant concentrations. These limits are based on what is achievable using pollution control technology, and receiving environment conditions which will ensure that valued resources are not impaired for use.

Steps in ecological risk assessment as outlined by Karr and Chu (1997)[2] are as follows:

- **Identify Potential Hazard Conditions** - Create an inventory of potential impact causing pathways. This should include all possible mechanisms of physical and chemical effects on aquatic resources.
- **Dose Response Assessment** - Develop a database to establish relationships between level of disturbance or contamination and the degree of degradation of the resource(s) which may be at risk in the receiving environment.
- **Exposure Assessment** - Gain an understanding of the degree to which valued receiving environment resources (receptors) may be exposed to mining related physical or chemical influences. The degrees of exposure should be defined in time and space.
- **Evaluate Absolute and Relative Risk** - Using empirical means, best professional judgment and past experience, estimate the probabilities of occurrences of each impact pathway/exposure level combination. Once this has been done, statements regarding the degree of damage (ecologic, societal and economic cost) associated with, and probability of each hazard can be made. The hazards can then be placed in a matrix of probability vs cost to provide an indication of the range of possible outcomes in terms of relative acceptability. Portions of the matrix can then be segregated in terms of priority for risk management.

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[2] Karr James R. and Ellen W. Chu 1997. Biological Monitoring and Assessment: Using Multimetric Indexes Effectively. University of Washington, Seattle.

- **Manage Risk -** Although it is convenient to separate risk assessment from risk management, it is necessary to follow risk assessment with a risk reduction options analysis. This will ensure that resources are employed efficiently to reduce exposure to the full range of costs (economic, ecological, societal) of impending impacts.
- **Monitor / Evaluate Performance** Once decisions regarding risk reduction have been made (permit discharge limits for example), it is time to evaluate risk management performance and to revise the risk assessment accordingly. In addition to this cyclic process, evaluation and revision may be done whenever operating parameters change, or when new information for any of the process components becomes available.

Setting Receiving Environment Objectives

Whenever there is a concern regarding the impact of mine drainage on water quality, regulatory conditions are set to protect aquatic life, and other water users. These conditions usually include mechanisms to ensure that concentrations of contaminants do not exceed pre-established maximum permissible concentrations in the receiving environment. This is accomplished by setting objectives based on measurable attributes of water, sediment and/or biota to be applied at specific locations where valued resources exist in the receiving environment. In most cases the parameters of interest for formal objective setting are the concentrations of water-borne contaminants, including heavy metals, blasting and milling residues . Other parameters including measures of sediment quality and quantity and ecosystem health (abundance and diversity of aquatic life such as fish, invertebrates and algae for example) may also be used in a weight of evidence approach to environmental effects monitoring (EEM), depending on the site specific conditions and the type of discharge.

The receiving environment objectives set maximum allowable contaminant quantities, with the assumption that even if these concentrations are reached, the most sensitive water use of a specific body of water will still be protected. Attainment of each site- specific objective is verified by a program of monitoring. Objectives are also used in mine planning as a yardstick against which predicted or proposed future contaminant releases and the effectiveness of mitigation strategies can be compared. The setting of objectives on a site specific basis coupled with the predicted discharge scenario determines which mitigation strategies may be needed to protect valued aquatic resources.

The following section describes the information requirements for and methods used to set receiving environment objectives for receiving waters affected by mine discharges .

Regulatory Instruments for Protection of Water Quality

In BC there are three types of regulatory instruments in use to control or provide guidance for contaminant discharges. These are water quality and quantity discharge limits, water quality criteria (WQC) and water quality objectives (WQOs). Contaminant-specific discharge concentration and volume limits are the focal point of permitting. Once limits are set as Waste Management Act Permit conditions, they become standards, enforceable under the Act. The other two regulatory instruments are not standards in the legal sense, unless incorporated into a permit or Regulation, but are used as guidelines to set and fine-tune discharge limits. In cases where non-point source type discharges occur, and discharge limits are not possible, WQC and/or WQOs can be used as "goal posts" for pollution control decisions. They (WQC/WQOs) also provide a basis for EEM programs, and are based on the assessment of potential and actual impacts on aquatic resources.

WQC and WQOs are set to define "safe levels of contaminants for the protection of a given water use" (MELP Water Quality Branch, 1995. Approved and Working Criteria for Water Quality). WQC are provincially set and include a factor of safety to ensure that contaminant concentrations at or below the WQC should protect the specified water use at the most sensitive place in the water body. WQOs are site-specific, based on physical and chemical conditions in a localised area. A WQO for a given contaminant once approved supersedes the provincially set WQC.

Water Quality Criteria

Provincial WQC are being developed on a substance-by-substance basis for application across the province and are used in instances where WQOs based on site-specific studies have not been developed. Two types of WQC exist: "approved" and "working".

Approved mining related WQC include those for pH, Al, Cu, Hg, Mo, Pb, and Ag as well as other parameters unrelated to metal leaching (NO_2, NO_3, NH_3, cyanide DO, Fl, and total suspended solids). WQC are being prepared for Zn, SO_4, Mn, Ba, Be, and Fe. Working WQC for the protection of freshwater aquatic life have been published as part of the Approved and Working Criteria document for As, Be, Bo, B, Cd, Cr, Fe, Ni, Ti and U. For those mining-related contaminants that do not have WQC (for example, SO_4 and Sb), discharge standards must be based on site specific WQOs or by using WQC from other sources such as Canada Council of Ministers of the Environment (CCME), Canadian provincial governments (for example, Ontario and Manitoba) or the U.S. Environmental Protection Agency (USEPA).

When do WQOs Need to be Developed?

Some water courses and or land use scenarios do not lend themselves to the use of WQC and therefore site specific WQOs may be developed in their place. Examples of such situations include:

- Ambient concentrations of one or more contaminants already exceed published criteria in the natural environment. This is often the case in natural drainages from highly mineralised areas where aquatic organisms may have adapted to these stresses. Mining operations are usually concentrated in such areas.
- A combination of physical and chemical conditions reduce the bioavailability of contaminants. One common contributor to this is the presence of organic acids whose complexing capacity significantly reduces the toxicity of some dissolved metals.
- High metal concentrations in existing discharges are not amenable to further treatment and it is suspected that existing aquatic life may be tolerant of these stresses.

In each of these cases, if WQOs were set higher than WQC then it would have to be shown through site specific studies that no unacceptable impacts to aquatic life would occur. Results of such testing would allow provincially sanctioned site specific WQOs to be developed.

Methods

Setting Water Quality Objectives

The process of setting site specific WQOs is documented in Principles for Establishing Water Quality Objectives in BC, MELP 1986. WQOs are set through a process of determining the site specific tolerance of an aquatic ecosystem and established water uses to a range of contaminant concentrations. For the protection of aquatic life, which is generally the most sensitive water use, this is done in the following stepwise fashion:

- Determine what resources may be at risk, their locations in time and space relative to the proposed discharge(s). This information is used to determine where and when WQOs will be applied. WQC are used as a starting point in determining which contaminants are likely to cause impacts to the resources at risk.
- Determine what toxicological information is available in "the literature" for the parameters of concern.
- Evaluate the available toxicology and biological information to determine potentially mitigating and exacerbating influences on the toxicity of the contaminants in question.
- Collect any site specific environmental effects monitoring results available to date. Interpret the information to estimate the concentration and volume ranges within which each parameter specific objective will fall.
- Conduct site-specific toxicology and water quality studies to determine site specific ecosystem sensitivities to the possible contaminant concentration ranges under consideration. Assess the results to determine what threshold concentrations may be set for each contaminant and under what conditions they will apply as WQOs.
- Using an appropriate margin of safety, set each new objective on a provisional basis, and begin validation studies. The validation studies can be incorporated into the attainment monitoring program.
- Conduct periodic attainment monitoring. The effort required may be reduced (for example, limit monitoring season) as the degree of understanding increases.

In addition to individual contaminant studies, site-specific toxicity studies should determine whether additive and/or synergistic effects of a number of contaminants in discharges may exist. Synergistic effects are not incorporated in WQC, since studies used for their establishment are largely based on single contaminant effects. In instances where there are several metals of concern, it is common to use a combination of WQC and WQOs, depending on site-specific conditions.

WQOs are set for each of the contaminants of concern and can be set in terms of total and/or dissolved forms (metals, nutrients etc.), depending on site specific conditions. Investigations are currently underway to determine whether there are better measures of bioavailability (total extractable metals for example), which may be substituted for total or dissolved concentrations, to be used as WQC and WQOs .

Toxicity Tests

Toxicity bioassays can be separated into two categories. Acute toxicity tests determine if test solutions are lethal to a test organism in a specified period of time. Chronic toxicity tests determine if the test solutions cause other effects such as a reduction in growth, reproduction and/or development.

Acute toxicity bioassays, which measure the death or survival of the test organisms are used to understand where site-specific toxicity thresholds may lie. An example of such a bioassay is the Rainbow trout 96 hour LC50 test. It establishes the contaminant concentration(s) which cause 50% mortality in the test organism population. Rainbow trout is a good test organism because it is found throughout the province, is an economically important species, is easily maintained under laboratory conditions and is more sensitive to mining related contaminants than many other fish species. Another common acute bioassay uses the pollution sensitive water column dwelling invertebrate, *Daphnia magna,* in a 48 hour exposure.

Chronic toxicity is measured using highly sensitive bioassay tests which determine reductions in growth, reproduction and other forms of development. One commonly used chronic bioassay is the *Daphnia magna* 20-day growth and reproductive impairment test. Other chronic bioassay tests using a range of water column and substrate dwelling organisms may also be used.

In most instances toxicity studies (chronic or acute) include more than one species so that a range of trophic levels (such as algae, water and sediment-dwelling invertebrates and fish) and pollution sensitivities are included in the assessment. Test organisms may be subject to stresses that are an artefact of the test and not relevant to the contaminants and discharge in question. Consequently the tests must include appropriate uses of controls, quality assurance and control (QA/QC) and repetition. This is ensured through the use of nationally and provincially sanctioned protocols.

Ideally there will be both laboratory and *in situ* versions of the chosen toxicity tests. This ensures that a balance between the controllability of laboratory conditions and the realism of *in situ* conditions is struck. In addition, this "weight-of-evidence" approach has the best chance of success in obtaining useable results in a reasonable amount of time.

A critical problem for most mine proposals is finding a way to test discharges before the operation begins. At the project proposal stage, the proponent must approximate at a bench scale, discharges that will occur under operating conditions. An accepted way to deal with this problem is to conduct bioassays using the effluents created in pilot scale metallurgical testing, with verification studies carried out at start-up using the actual discharge. This approach limits the exposure of aquatic resources to risks associated with discharge toxicity. Frequent discharge bioassays are required in the initial stages of impact assessment to determine if there is any seasonal variation.

Impact Prediction

Water quality criteria and objectives applied as impact predictors through mass balance modelling provide an indication of whether unacceptable impacts may occur at specific locations in the receiving environment. This modelling exercise is also used as a means of back-calculating discharge concentration and volume limits by "plugging in" contaminant specific WQC/WQOs as target values in the mass balance equation. In predicting impacts, this mass balance approach must be augmented by considering the timing and types of discharges, their location(s), post-discharge geochemical conditions, dilution and attenuation mechanisms at work and the location and sensitivity of receiving environment resources at risk. Ultimately, the determination of whether WQOs and WQC are likely to be attained downstream of a discharge is an excellent first approximation of whether impacts will be minimised. As understanding of the chemical, physical and ecological dynamics of a specific setting improves through ongoing impact assessment work, a lower degree of conservatism in discharge regulation may be possible.

The amount of available or effective dilution which may lessen impacts depends on the relative flow volumes and contaminant loadings from ambient and land use caused sources. Attenuation results from precipitation and complexing reactions as well as absorption and adsorption along the flow path. This can occur in the water column, on substrates, or through biological processes.

The use of dilution and attenuation in discharge planning and regulation is premised on the notion that impacts which may occur in the initial impact or dilution zone (IDZ) where mixing takes place will not be severe, and will be localised in extent. Regulatory "tests" of whether dilution in the receiving environment is allowable are routinely made. Acute toxicity testing of undiluted effluent(s) as it enters the receiving environment is the first test. According to the Canada Fisheries Act, the discharge of a "deleterious substance" into fish bearing waters (or waters contributing to fish habitat) is prohibited. The "deleterious" condition is commonly defined in terms of a 96-hour Rainbow trout LT_{50} or LC_{50} bioassay test result. If it is determined that >50% of the test organisms survive for

96 hours in 100% effluent, then the discharge is non-lethal, and some dilution may be allowed. In addition to this "end of pipe" test, a range of impact assessment tools including measures of water and sediment quality as well as ecosystem functioning are used. Much of this work is focused on determining the size of the affected area and degrees of impacts within it. Where discharges can mix with receiving waters upstream from fish bearing waters or other water uses, or where the discharge immediately enters a large body of water, the best opportunities for using the ameliorative effects of attenuation and dilution occur.

In the case of bio-accumulateable contaminants such as Hg, Se, Cd and Pb, it is important to add ecosystem objective setting and assessment components which cover off this mechanism of impact, as well as the potential for these contaminants to cause water column toxicity. An example of this is the use of BC Criteria for Hg, specific to human consumption of fish in instances where this contaminant may be present in discharges associated with mining.

Prediction of downstream water quality is often hampered by the large number of variables. Iterative mass balance modelling can be used to analyse the sensitivity of the system, indicating:

- which contaminants may be problematic, and under what conditions,
- the rigor of the mitigation mechanisms which may be required to limit impacts,
- performance thresholds and complexities which may influence impacts and,
- what additional baseline and/or operational data are needed to improve on decision making abilities.

Discharge Locations and Initial Dilution Zones

Water quality objectives and criteria are commonly applied at the first occurrence downstream of the discharge source of any water use, such as the presence of significant fish habitat. Where possible the discharge is located to minimise impacts to aquatic life and water uses, while utilising some of the available dilution and attenuating capacity of

the aquatic environment. Natural dilution and attenuation is to be used only after best available control technology (BACT) has been employed.
Discharge quality must be sufficient to prevent acute toxicity (lethality) to any organisms within the IDZ. After dilution and attenuation has occurred in the IDZ, it is expected that no measurable toxicity in the water column will occur beyond the IDZ boundary. This is verified through the use of tests which measure chronic toxicity. To reduce the potential impact, any permitted IDZ must be of the smallest size possible to afford the appropriate amount of mixing, dilution and contaminant attenuation.

At most discharge locations, the risks associated with exceeding WQO/WQC are greatest during certain times of the year, usually coinciding with seasonal requirements of aquatic life or water users and/or specific flow conditions (low flow or freshet periods). In most instances, this is determined through biological and hydrological monitoring and modelling supported by a number of years of record. Once the period of greatest concern is identified, decisions can be made regarding when to discharge and monitor. In some instances, it can be stipulated that a given set of WQOs only apply on a seasonal basis (due to the presence of sensitive resources at that time).

For example at Equity Silver and Samatosum mines, where discharges are allowed in fish bearing waters, discharge is only permitted at prescribed volume ratios of discharge to receiving waters and at times when the critical resources are less sensitive to toxicity related impacts.

Sediment Quality Criteria/Objectives

In some instances sediments contained in liquid discharges may cause unacceptable impacts in the aquatic receiving environment, due to their affinity for certain contaminants. This may occur through chemical toxicity or physical means (smothering of habitat or abrasion of tissues) in depositional zones. The methods and principles applied to establish the use of sediment quality criteria (SQC) and site-specific sediment quality objectives (SQOs) in pollution control decision making is similar to those applied to WQC and

WQOs. The main difference is that different types of mass balance modelling approaches (using partitioning coefficients for example) must be used in predicting sediment impacts to aquatic ecosystems. SQC/SQOs may be applied once sedimentation patterns, rates of deposition and impact mechanisms are determined through a combination of sediment chemistry, sediment accumulation and benthic biological monitoring techniques. Since the same types of procedures as for water column objective setting are used, only the latter will be discussed.

Establishing Aquatic Ecosystem Health

Employing water quality standards, criteria and objectives and associated monitoring helps to identify and define bounds or limits of acceptable change in the receiving environment. Additional studies are required to determine the fate and cumulative impact of contaminants. This usually includes biological inventories and sediment studies designed to develop a more complete understanding of the effects of discharges on ecosystems. As the number of contaminants in a discharge increases, so does the chances for unforeseen additive and even synergistic effects on aquatic life. This is especially true if bio-concentrateable metals such as Hg, Cd, Se and Pb are involved.

The standard toxicity tests described earlier establish the concentration ranges of concern. Field studies of the dynamics of aquatic species diversity and abundance are required for more detailed impact assessment. The species studied may include fish, algae (periphyton and pelagic species), aquatic macrophytes and invertebrates, both water column and substrate dwellers. The results may be used to validate the conclusions of the toxicity tests and to develop more conclusive indices of aquatic ecosystem health. If this greater level of understanding can be achieved, ecosystem objectives may be set and used as performance goal posts. These goal posts are different from end-of-pipe discharge limits in that they are generally not enforceable permit conditions (standards), but are instead used to indicate whether impacts may occur (guidelines) and to refine enforceable limits.

Attainment /Environmental Effects Monitoring

Monitoring is required to determine whether receiving environment objectives are met. The approach to WQO and WQC monitoring will depend on the discharge, the physical and biological resources and the hydrological, chemical and toxicological conditions and the discharge objectives. For example, if average and maximum concentrations are used as objectives, monitoring must occur at a high enough frequency and for a long enough duration to provide meaningful maximum and average values. The requirements to enable detection of extremes and to evaluate whether the objectives have been met will depend on site-specific variabilities of receiving environments and discharges.

In addition to providing a measure of objective or criteria attainment, monitoring should be carried out to verify the judgements made in choosing WQOs and IDZ boundaries. This latter process often becomes part of an operational or post-closure environmental effects monitoring (EEM) program, whose objective is to assure the public and the government that predicted outcomes are continuing to occur. The frequency of EEM studies must be sufficient to provide an early warning of unacceptable impacts and to allow implementation of pre-defined contingencies. The most efficient EEM program is a small scale monitoring program focused on the critical aspects of discharge and water quality, with pre-defined triggers for more detailed assessment studies should they be needed. There are many variations on this phased approach, depending on the aquatic resources at risk and the degree of risk associated with the nature of the discharge(s).

Statistical Principles

Monitoring studies must be carried out with an acceptable degree of statistical rigour. This may be assured by using accepted experimental design, such as an "areas by times factorial design" and by using statistical techniques such as analysis of variance (ANOVA). With this approach, temporal and spatial changes in water quality associated with mining-related discharges can be quantified. Whatever the approach, users are cautioned to check all assumptions regarding the validity of the test (for example, normal distribution, absence of autocorrelation for ANOVA). Regardless of which experimental design is chosen, uncertainty may be lessened by increasing the sampling frequency and optimising sampling timing, lowering analytical detection limits, increasing the number and location of "influenced" and control sites sampled and improving the quality assurance and control (QA/QC) program for field and lab components of the monitoring program. Where possible the proponent should determine the extent to which experimental error may affect the predicted outcome, using appropriate statistical formulae. For example, given a specific statistical design, it may be decided that a sufficient sampling frequency (n) must be used in a given season to detect a minimum of a 25% change in the concentration of a given contaminant with Type I error set at 0.05 (probability of rejecting the null hypothesis in error, a.k.a. "false negative" result) and Type II error set at 0.2 (probability of accepting the null hypothesis in error, a.k.a. "false positive" result), given compliance with the conditions set out in a QA program.

Additional Help in Setting and Using WQOs

Further clarification of the methods which may be used for site specific WQO setting are outlined in the Water Quality Branch publication "Developing Water Quality Objectives in British Columbia - A Users Guide", 1996. This publication also provides advice on developing the QA/QC program required at all phases of WQO setting and attainment monitoring work. Two recent BC government publications are recommended as case studies in developing and proposing WQOs - "Water Quality Assessment and Objectives for Tsolum River", by Deniseger J. and L. Pommen, 1995, and "Water Quality Assessment and Objectives for Yakoun River and Tributaries, by Nijman R., 1993.

Water quality is regulated by BC MELP staff who specialise in this discipline. Biological work conducted by mining companies and their consultants leading to WQO development and monitoring for their attainment should be carried out by, and/or supervised by registered professional biologist(s), with experience in mining related impact assessment. This is especially important in project design and interpretation of results leading to proposed WQOs.

Definitions

attainment monitoring - is any monitoring leading to a comparison of a stated quantifiable objective and actual conditions.

available/effective dilution - "Available" refers to the volume of dilution which may mix with a discharge to dilute it. "Effective" dilution describes whether the receiving environment waters intended to mix with a discharge actually have the capacity to dilute. For instance, ambient water containing 0.008 mg/l dissolved Cu will have limited capacity to dilute a discharge of 0.01 mg/l, and therefore provides little effective dilution.

best available control technology (BACT) - refers to equipment and pollution control processes which are deemed to be most effective in reducing or eliminating discharges of contaminants to the environment, in a given instance. Factors associated with cost and effectiveness are weighed by the ministry, and the Regional Waste Manager determines whether a given proposal meets the definition of BACT.

bioassay - is a test which uses responses of live organisms to physical or chemical stresses to gain information about the impact of the stress on the receiving environment.

bioavailability - is a property of a substance which makes it able to affect an organism's health through chemical mechanisms under site specific conditions.

bioconcentration/bioaccumulation - is the process of concentration or accumulation of a contaminant within an organism. Mechanisms which may cause this to occur can take place at the cellular, body organ or whole organism level. Pathways for this to occur can include simple diffusion into cells or tissues from the water column or substrate, or through food consumption. Metals which may bioaccumulate include Hg, Cd and Pb.

discharge limits - are set in a Waste Management Act permit. They establish the maximum allowable concentrations of contaminants and/or volumes of discharges, including wastewater and associated contaminants. They may also specify conditions under which discharges may take place.

environmental effects monitoring (EEM) - is a type of monitoring which focuses on determining the effects of land use (mining discharges to water bodies in this instance) on aquatic resources and uses. Quantitative means are used to establish whether changes to aquatic resources remain within acceptable limits.

initial dilution zone - (also called initial impact zone or mixing zone) is defined spatially by the volume of water required to dilute an effluent sufficient to reach a specified set of contaminant concentrations in the receiving environment. These specified concentrations which are applied at the boundary of the zone are defined using the BC Criteria for protection of aquatic life and other water uses. Where these are not appropriate, (due to high ambient concentrations for example), site-specific water quality objectives are developed and used. In this zone, full strength effluent is allowed to dilute in ambient waters. Dilution may take place by simple diffusion and dispersion. Dispersion mechanisms include turbulent flow in a river or creek setting, or currents and wind generated mixing in lakes.

limit of acceptable change - is a threshold of change in the degree of environmental effects of a given discharge beyond which the effects are deemed unacceptable. Such a threshold must be determined prior to impacts occurring, if it is to be of value in planning discharges. An example of the use of limits of acceptable change follows:

- Full strength effluent discharges to the environment must not be acutely lethal to rainbow trout as measured in a 96 hour acute lethality bioassay.
- At a point 100 meters downstream of the discharge the effluent and ambient water mixture must not cause more than a 20% reduction in growth or reproduction in a 48 hour *Ceriodaphnia dubia* chronic bioassay (this endpoint is an EC20 - "EC" means Effect Concentration .
- At a point 500 meters downstream of the discharge, there must be no measurable difference in the concentrations of Cu, Fe, and Pb from the upstream control site. The differences (or lack of them) will be established using a running average of the last 7 sets of water samples at the 2 locations. Whether there are differences in the average measured concentrations will be established using a t-test.

mass balance model - is a mathematical representation of the mixing of contaminant loading sources. The model determines a new concentration of a contaminant after complete mixing. The volume and concentration of an effluent are combined with the volume and concentration of ambient waters at the point of discharge. A new volume and concentration is the resultant term of the model. The calculated concentration of a given contaminant corresponding to the completely mixed condition is then compared with a WQC or WQO to determine whether the discharge as modelled would be acceptable in terms of meeting receiving environment objectives. Each term in the mass balance model will have its own experimental error associated with it, and the output term of the model will be subject to the sum of all errors associated with each input term. Interpretations of these models for impact assessment purposes must incorporate this uncertainty.

quality assurance/quality control (QAQC) - programs provide information about the reliability of water quality data. They employ systematic efforts to produce environmental data sets with the least amount of measurement and sampling (contamination, degradation while shipping etc.) error possible. Protocols govern field and laboratory procedures and extra diagnostic sampling, to identify and quantify experimental error when it occurs. Laboratories conduct their own QA/QC programs using rigorous instrument calibration procedures, replicate (duplicate and triplicate) samples and standard reference samples. Each laboratory uses a set of protocols which are used throughout Canada. Field investigators conduct QA/QC programs, with the addition of hidden samples (duplicate, standard reference, trip and field blanks), as well as known replicates samples. Field QA/QC programs are designed separately for each investigation. In general, about 15% of a given sampling program's cost should be directed to field QA/QC. Results of QA/QC programs must be interpreted in the context of the impact assessments made. For instance, if it is determined from the QA/QC program that the aggregate experimental error associated with a given contaminant concentration measurement may be as high as 20%, then this potential error should be factored into the interpretations for WQO setting, attainment monitoring, or mass balance modelling.

receiving environment objectives - refer to any "target condition" or "goal post" which may be set to provide a quantifiable means of determining whether environmental protection measures are effective. In the aquatic setting these quantitative objectives may be set in terms of physical and chemical attributes of water and sediment, species diversity and abundance of a range of aquatic organisms, including fish, invertebrates and algae, or toxicity as determined through a variety of bioassays.

sediment quality criterion (SQC) - is a threshold concentration of a contaminant in sediment which if attained, ensures that the water use in question (usually aquatic life) remains in a safe condition. Such criteria are set provincially, for wide application. No provision for site specific conditions is included, but each one includes a factor of safety consistent with the state of toxicological knowledge of the contaminant in question.

sediment quality objective (SQO) - is a site specific threshold concentration of a contaminant in sediment which if attained, ensures that the water use in question (usually aquatic life) remains in a safe condition. Objectives are set on a site specific basis when SQC do not apply. SQOs are necessary when ambient (natural) concentrations of a given contaminant already exceed the SQC, and a contaminant related impact to sediment or sediment dwelling organisms is likely.

synergistic and additive effects - refer to environmental effects caused by multiple contaminants contained in water or sediment. Additive effects are those which can be predicted by adding the effects of one contaminant onto those of another, when the effects are determined separately. Synergistic effects refer to situations where aggregate effects are greater than the sum of each effect considered separately.

toxicity test - (acute and chronic) - is a means of creating an index of toxicity for a given wastewater discharge situation through the use of bioassay techniques. A sample (or samples) of water or sediment under study is used as a medium for testing the survival, growth, reproduction or other measure of health (bioluminescence of bacteria, evidence of histopathology or tissue/organ damage) of a population of organisms. There are a range of accepted aquatic species representing 4 trophic levels (fish, invertebrates, algae and bacteria) commonly in use for aquatic impact assessment purposes. Protocols exist for each toxicity test to limit experimental error and ensure repeatability. An acute test is one that uses mortality (usually over a short term) as an endpoint, while a chronic test is one which uses other endpoints such as long term mortality, growth or reproduction impairment, or reduction or inhibition of in physiological processes (organism functioning). Tests usually include a battery of test vessels, each containing a serial dilution of the test solution, beginning with full strength, and diminishing to 0% as a control. End points are typically expressed in terms of the test solution concentration (either actual concentration of a single contaminant or % strength of the test solution) which causes a specified condition in 50% of the test organisms in a specified time period. For example, a 96 hour Rainbow trout acute bioassay result is expressed as an LC50, or lethal concentration which will cause mortality in 50% (5 out of 10) of the test fish in 96 hours. A variant of this is an LT50, or the time elapsed (within a maximum 96 hour period) in which 50% of the test fish die, when exposed to undiluted (100 % strength) test solution (usually effluent). For chronic tests endpoints are often expressed in terms of EC50, (effect concentration) which refers to the concentration required to cause the specified condition in 50% of the test organisms. Three other calculated endpoints for this type of test are the NOEC (no observed effect concentration), LOEC (lowest observed effect concentration) and the TEL (threshold effect concentration), which is similar to the EC50.

water quality - is broadly defined in terms of measurable attributes of water, sediment and aquatic life. These attributes can be chemical or physical.

water quality criterion - is a threshold concentration of a contaminant in water which if attained, ensures that the water use in question remains in a safe condition. Water uses for which BC Criteria have been written include protection of aquatic life, potable water source, livestock watering, agricultural irrigation, and industrial applications. Such criteria are set provincially. No provision for site specific conditions is included in a given criterion. Each one includes a factor of safety consistent with the state of toxicological knowledge of the contaminant in question. They establish a reference against which the state of water quality is checked, and are used to prepare Waste Management Act Permits or Plans, and to measure their effectiveness.

water quality guideline - is a "target condition" such as that established as a WQC or WQO. A guideline may be used to establish an enforceable standard to be applied as a discharge concentration or volume limit established under Waste Management Act Permit. A guideline although not strictly enforceable may also be used to make pollution control decisions in both the planning and regulatory contexts.

water quality objectives (WQOs) - are safe conditions or threshold levels of a substance which will protect the most sensitive water use of a specific body of water. They establish a reference against which the state of water quality is checked, and are used to prepare Waste Management Act Permits or Plans, and to measure their effectiveness. Water quality objectives take the place of WQC where WQC do not apply. This often occurs in mining situations, where WQC may be exceeded due to natural leaching of metals into ambient waters. WQOs are established through the interpretation and assessment of water quality and toxicological study results. They can be established on a provisional basis for a period of time while validation studies are completed. Once this has occurred, then WQOs may be approved by the Minister.

water quality standard - is an enforceable limit of acceptable change. They may be written as part of a Regulation under the Waste Management Act, or incorporated in a Waste Management Permit. Such standards may be contaminant concentration based, and/or discharge volume based.