ABSTRACT

The “one size fits all” concept has frequently been applied by regulators to environmental decision-making, much to the frustration of environmental managers. Governments at all levels are often well intentioned but also under pressure to render decisions that are regionally, nationally or even internationally consistent. However, the environment that we are attempting to conserve, protect, and/or manage is rarely, if ever, consistent from site to site. Risk-based approaches rely on conceptual and operational methods that are widely accepted in British Columbia and internationally for managing contaminated sites. Moreover, these approaches provide regulators with the necessary confidence that a proposed discharge meets provincial and federal expectations for pollution control. End-of-pipe standards often lack flexibility and can stall reclamation work. For example, the treated effluent discharge at the former Britannia Mine in Howe Sound did not meet effluent permitting expectations based on conventional permitting practices. Therefore, a risk-based approach was used to develop a study program in which the characteristics of the environment, the form of the metals in the effluent, the interaction of the effluent with ecological receptors, and scientific uncertainty were all considered. The outcome of the assessment was that the discharge was acceptable from an environmental risk perspective. The biological tools used in risk assessment offer defensible and environmentally appropriate solutions for many substances, including those for which standards/guidelines do not exist or for which recognized analytical methods are unavailable (e.g., flocculants and coagulants).

INTRODUCTION

The birth of modern pollution control efforts are often traced back to the middle of the 19th century. The “Great Stink” of the River Thames disrupted the operation of the British Parliament, which promptly passed a law that led to sewage treatment. In Canada, the discharge of contaminants has been regulated since shortly after Confederation, when the Fisheries Act (FA) was passed. This legislation remains a major part of the effluent control strategy across Canada. Of particular relevance to the mining industry, the FA controls effluent discharges from metal mines through the Metal Mining Effluent Regulation (MMER). Each of the provinces, which are responsible for waste management, have their own effluent control statutes. In British Columbia, the Environmental Management Act (EMA) is the relevant legislation.

Mine reclamation work involves considerable changes to a mine site, including changes to area drainages, pond discharges and other sources of runoff, some of which may be impacted by acid rock drainage (ARD) or other sources of metallic constituents. Notwithstanding the beneficial outcomes intended by
reclamation work, such discharges are regulated and require either formal permits or due diligence measures to verify that the discharges are in compliance with general prohibitions against pollution.

Approaches to Regulating Effluents

Historically, there have been many approaches to regulating discharges. The purpose of this paper is not to provide a critical overview of these approaches, which have been effective in taking society from a situation such as the 19th century River Thames to its present day condition in which it supports fish. However, the economy and technology have modernized and the state of scientific knowledge regarding the environment enables more refined environmental decision-making.

In Canada and its provinces, one might broadly classify effluent control approaches as being either “end-of-pipe” approaches or “receiving environment” approaches. End-of-pipe approaches entail the setting of limits that apply to the material being discharged. Consistency at regional and national levels can be achieved using a fixed schedule of numeric limits, promoting a sense of equitable decision-making. The origin of these limits is often based on what is achievable based on available and practicable treatment technology (as of the date the regulation is written). Some methods for setting limits have been production based, for which allowable contaminant loadings were calculated on the basis of produced product tonnage (i.e., the more that was manufactured, the greater the permitted discharge). Effluent limits may also be set on the basis of hazard (which differs from risk); in these cases, numeric limits are set on the basis of known acute lethality levels or on the outcome of an acute lethality test carried out on the full strength effluent.

An example of an end-of-pipe approach is the MMER, which defines a “deleterious substance” for the purposes of a metal mine, and uses numeric limits for this purpose. The numeric limits in the MMER are based on a review of available control technology (see for example SENES, 1999) that may or may not align with environmental protection needs. These limits apply to the effluent discharged at the point at which the operator no longer exercises control over the effluent. Figure 1 compares each of the substances or parameters regulated by the MMER to two different environmental criteria: (1) the acutely lethal (i.e., 96-h rainbow trout LC50) concentration of the substance and (2) the Canadian Water Quality Guidelines (CCME, 1999). Bars beneath the line indicate a degree of possible “underprotection” while those above the line indicate a degree of possible “overprotection”. These comparisons are illustrative only because: (1) the application of WQG to an effluent would not be appropriate and (2) regulation of total suspended solids (TSS) on the basis of acute toxicity would ignore the physical smothering and other impacts that would occur at lower concentrations.

Receiving environment approaches can be either “top-down” or “bottom-up”. In a top-down approach, the basis of the enquiry starts at the environmental quality objective—the desired limits at the edge of the initial dilution zone (IDZ), a defined cylinder of water with a 100 m radius around the end of an outfall pipe. Next, the available dilution is identified and used to back-calculate effluent limits at the end of the pipe. In a bottom-up approach, effluent limits, set through some means as described above, are evaluated to identify if the limits are likely to be protective, as determined by dilution modelling and ambient water quality guidelines (WQG) at the edge of the dilution zone.
Pollution control statutes exist for the purpose of preventing harmful impacts in the receiving environment. However, in the above evaluation, the specific characteristics of a receiving environment are given scant consideration. Even in the commonly used receiving environment approaches, the majority of the evaluation effort is an attempt to identify the effectiveness of the receiving environment as a dilution “chamber” and less so as an ecosystem. It is possible, and often necessary, to more precisely define and evaluate potential impacts.

**Figure 1:** A comparison of the technology-based effluent limits in the MMER with a calculated ratio between MMER limits and either (a) ambient WQG or (b) acute toxicity benchmarks (EVS, 2001)

Differing Perspectives

A common perception is that federal and provincial approaches to effluent regulation are in conflict. This perception may arise from the constitutional division of powers between Canada and the provinces. Canada is responsible for the seacoast and inland fisheries (S. 91[12] Constitution Act [1867]; which includes their habitat), the provinces are responsible for the management of land and wastes, including liquids (S. 92[13] and S. 92[16] Constitution Act [1867]). The differences in their respective legislation, which have grown from the Constitution Act, will shape the perspective with which effluents are approached. Federally, the end-of-pipe approach is dictated by the FA and the courts have confirmed that the FA applies to the substance that is added to water and not the water with the substance diluted into it (R. V. MacMillan Bloedel [Alberni] [1979] Ltd.; R. V. Kingston [City] [2004]; both of which were upheld on appeal to superior courts). In British Columbia, the EMA prohibits a party from causing pollution. Administratively this usually means that the WQG (i.e., the water with the substance added) must be met at the edge of the IDZ, which appears incompatible with the federal law. A top-down approach is even less likely to gain multi-agency acceptance as it starts by looking at the water with the substance added. Fundamentally, however, both agencies have the same objective of regulating so that waters that do not harm aquatic life and ultimately the EMA and FA both regulate at the end of the pipe.

The final statutory instrument issued under EMA is an effluent permit and the limits prescribed in a permit are the maximum allowable concentrations of constituents in the discharge. The evaluation at the IDZ can provide a check that the effluent permit limits are not causing pollution, at least as defined by “attainment” of WQG at the edge of the IDZ. Provincially, it is rare (although within their authority) to
closely examine habitat issues within the IDZ. However, at a federal level the habitat conservation provisions of the FA and related national policy mean that the areas within the IDZ are important because they could be of consequence for spawning, migration, or other ecological uses.

Despite the complexity and confusion surrounding these different perspectives, risk-based methods offer a framework by which effluent impact studies can be used to support an evaluation of effluent impacts in the receiving environment, and simultaneously address the requirements of both federal and provincial agencies.

**RISK-BASED APPROACH**

The term “risk-based approach” has been used to describe various scenarios, some of which are hazard-based but not risk-based. Although toxicity testing of effluent provides a biological measure, it is not a measure of risk, as explained below. This paper defines a risk-based approach as one that evaluates the relationships between the effluent, organisms residing in the receiving environment, and the pathways between the effluent and the organisms that result in exposure. Unless a stressor, a pathway, and a receptor coincide, risk can not occur (Figure 2). In this approach, the receiving environment is viewed as an ecosystem and the effluent needs to be considered in terms of how it relates to that ecosystem. This means that the resident organisms, their habitat and ecology, and nature of how they are exposed to the stressor all need to be considered.

![Figure 2: The risk-based approach in concept, depicting the relationships between the contaminant (source), the receptor and the pathway that connects them.](image)

In an operational sense, risk assessment seeks to identify the pathways by which organisms may become exposed to an effluent, the extent to which they are likely to be exposed, and the effect that exposure is likely to have on them. A number of ecological risk assessment guidance documents are available that outline a framework that is appropriately comprehensive for the situation under study. In general, the process includes a problem formulation, an exposure and effects assessment, and a synthesized risk characterisation. A problem formulation emphasizes study components that correspond to the environmental values that need to be protected, within the context of legislative and policy requirements. The details of the risk assessment consist of identifying the concentrations of effluent constituents in spatial reference to the receptors of concern and predicting (in advance of a permitted effluent) the likely
effects on the receptors of concern. Where these study components have been constructed around a well
designed problem formulation, the data required to characterise likely effluent impacts to aquatic
resources can readily be made. The general framework for a risk-based approach to effluent impact
assessments is shown in Figure 3.

**Problem Formulation:**
- What data are needed?
- What is the risk assessment setting out to evaluate (assessment endpoints) and how (measures of effect)?
- What organisms need to be studied?
- What contaminants are important?
- What are the exposure pathways?
- How do the contaminants relate to the environment studied and the organisms in that environment? (Conceptual model)

**Exposure Assessment:**
- Characterisation of the conditions to which receptors are exposed.

**Effects Assessment:**
- Evaluation of bioavailability
- Evaluation of the outcomes of being exposed to effluent constituents

**Risk Characterisation:**
- Assessment of effluent impacts
  - Quotient methods (spatial)
  - Characterised in biological terms
- How certain are we and how might that influence our characterisation of risk (uncertainty assessment)?

**Figure 3: Implementation of a risk-based approach**

An important part of risk characterisation is an assessment of uncertainties. Uncertainties in effluent
impact studies depend on the study methods but may include such factors as the anticipated effluent
quality (n.b., there are usually differences between bench-scale effluent and full-scale effluent), the
accuracy of plume dispersion modelling, acclimation of organisms, seasonal changes in water
movements, temperature or effluent quality and various other factors specific to the assessment. By
evaluating the uncertainties in the assessment, an efficient and prioritised monitoring program can be
developed to verify the accuracy of the impact predictions.
The case studies presented below provide examples of some of the challenges of using numeric effluent limits and highlight alternative, risk-based means of undertaking effluent impact assessments.

**CASE STUDY: TREATED ACID ROCK DRAINAGE EFFLUENT**

The former Britannia Mine (45 km north of Vancouver, adjacent to Howe Sound) operated primarily as a copper and zinc mine from the early 1900s to 1974. Mining operations have led to generation of acid rock drainage (ARD), which was historically released from two point discharges (2200 level and 4100 level portals) into Britannia Creek, as well as the release of other non-point sources of contaminated surface water. Reclamation works at the mine site diverted untreated ARD into a subsurface outfall located at a depth of -26 m, adjacent to the mouth of Britannia Creek. A major part of the planned mine reclamation work involved the construction of a high density sludge lime treatment plant. This plant removes dissolved metals from the ARD by producing a metal-hydroxide precipitate that is then removed in a clarifier. However, even low levels of particulate matter yield high levels of metals in the effluent. This resulted in an effluent that, under conventional “end-of-pipe” or “receiving environment” approaches would not receive an effluent permit for the following reasons:

- The concentration of total copper in the treated effluent, predicted on the basis of a bench-scale effluent, was 0.4 mg/L and exceeded the rainbow trout species mean acute lethality value (0.022 mg/L) by 18 times.

- The concentration of total copper at the edge of the IDZ was approximately 4 times higher than the WQG under certain scenarios (Figure 4). A requirement of the MOE is that WQGs are met at the edge of the IDZ.

![Modelled total copper concentration in the effluent plume from the Britannia WTP](image)

*Figure 4: Modelled total copper concentration in the effluent plume from the Britannia WTP*

**Approach**

A review of the physical environment, oceanography and ecology of Howe Sound identified oceanographic conditions affecting effluent plume behaviour (e.g., trapping depths) and identified important environmental attributes to protect. The photic zone, including those portions within the IDZ,
was identified as an area requiring special consideration. Various exposure conditions were modeled using the existing outfall configuration (located at minus 26 m) and a new one at minus 50 m using total and dissolved metals. Exposure conditions were predicted at the edge of the IDZ and at the bottom of the photic zone, which was conservatively assumed to extend to a depth of minus 15 m.

The effects assessment was supported by chemical speciation modeling using the software MINEQL+ to identify the bioavailable fraction of metals and also by a battery of chronic toxicity tests on the bench-scale effluent using algal, invertebrate and fish species selected to represent the identified receptor groups:

- Algae: 72-h marine algal, *Dunaliella tertiolecta*, growth inhibition (Environment Canada, 1992a);
- Pelagic invertebrates: Echinoid fertilization, *Strongylocentrotus purpuratus* (Environment Canada, 1997b); and

Findings

The dispersion modeling predicted that with the existing minus 26 m outfall pipe, concentrations of total copper within the photic zone approached 200 µg/L; dissolved concentrations were about eight times the WQG. Where the effluent was discharged through an outfall located at minus 50 m, the minimum trapping depth was 16.2 m, resulting in minimal interactions of the effluent with the photic zone. At a depth of 20 m, dissolved copper was predicted to be no greater than 1.4 times the WQG under the worst-case scenario; however, total copper concentrations were elevated by more than an order of magnitude.

The effects assessment provided support for use of dissolved metal concentrations rather than total metals concentrations that are normally required by the Ministry of Environment. Although total metals in the effluent exceeded acutely lethal levels as reported in the literature, there were no adverse effects in any of the toxicity tests. Dissolved metals concentrations were therefore used in a quotient method characterization of risks at the IDZ and at the approximate bottom of the photic zone (minus 20 m). When dissolved were used metals (rather than total metals), their concentrations at the IDZ were lower than the corresponding WQG. Minor increases in dissolved copper in the photic zone were considered acceptable because effluent tests were negative and because speciation model predictions indicated which found that only 0.2% of copper and 5% of zinc was predicted to be in the bioavailable form.

The use of commonly applied effluent assessment methods resulted in a conclusion that would otherwise not support the granting of a permit. However, the use of a risk-based approach addressed federal and provincial concerns with the effluent because it demonstrated that the ecological values of the receiving environment were not at risk (i.e., the effluent was not likely to cause pollution). The study also demonstrated that dissolved metals could be conservatively used as an exposure metric for this effluent as a means to regulate the discharge under a permit.
CASE STUDY: TREATED PROCESS WATER

The Greater Vancouver Regional District (GVRD) will operate a drinking water filtration plant to remove suspended particulate matter from the Seymour and Capilano Lake sources. The purpose of the plant is to deliver safe, high quality drinking water at all times and in particular during periods of heavy rainfall when there is a potential for increased water turbidity. As part of the filtration process, a metal coagulant such as alum ($\text{Al}_3\text{[SO}_4\text{]}_2$) or ferric chloride ($\text{FeCl}_3$) is used along with an organic polymer. During the removal of solids from the water and backwashing processes, treated process water is produced and discharged to Burrard Inlet through a subsurface outfall.

Flocculants and coagulants are often a necessary part of water treatment and have been used to treat potable water for decades. Some of the chemicals used are metallic in origin whereas others are organic polymers of various composition. The chemical nature of these organic treatments is often proprietary; analytical procedures are not readily available and little is known about their potential ecological impacts (Rowland et al., 2000). However, Beim and Beim (1994) tested various water treatment polymers to a number of freshwater organisms and found that toxicity ranges of cationic polymers were in the range of 0.08 to 2.05 mg/L for $\text{Daphnia magna}$. When used in mixtures with metallic (alum and ferric chloride) water treatment chemicals cationic polymers have been found to interact in a way that is more-than-additive (Fort and Stover, 1995). Water treatment chemicals are often custom-designed on the basis of the surface charges of the particles being removed. This means that the mixture of chemicals present is likely to be discharge-specific.

As identified in an environmental assessment carried out by GVRD, the selection of a filtration plant as part of drinking water infrastructure has considerable fish protection advantages over some other alternatives, in addition to health protection advantages. However, obtaining consent to discharge such an effluent using conventional approaches to effluent permitting was hampered by the following:

- Lack of WQG to compare against ambient concentrations;
- Synergistic toxicity of water treatment polymers in common mixtures; and
- Lack of analytical methods for assessing residual concentrations of treatment chemicals in the effluent.

**Approach**

A risk-based approach was used to evaluate the environmental significance of the treated process water discharge to Burrard Inlet. The approach involved an evaluation of the marine habitat biological communities present in the area of the discharge and quantification of their exposure to effluent constituents. Due to the above constraints to effluent permitting and chemical characterisation, exposure was evaluated on the basis of effluent concentration. For risk characterization, the environmental properties of the effluent were expressed in biological terms using the toxicity tests identified below.

Bench-scale effluent was produced using organic polymer and either alum or ferric chloride to evaluate the feasibility of using either of these treatment chemicals. Because acceptable concentrations of this
effluent mixture are unknown, biological testing was initiated to characterise the toxicity of the mixture. The relationships between the identified receptors and the measures of effect used were as follows:

- Algae: 48-h giant kelp, *Macrocystis pyrifera*, germination and growth test (USEPA, 1995);
- Pelagic invertebrates: 48-h *Mytilus galloprovincialis* larval development toxicity test (USEPA, 1995);

**Findings**

The effluent met the most commonly applied minimum federal requirements (non-acutely lethal) at the end-of-pipe. In the receiving environment, there are no effects expected at the edge of the IDZ. The abundance and diversity of marine species in the area of effluent discharge is of ecologically high quality and thus potential adverse effects to marine habitat should be evaluated within the IDZ.

Although significant adverse effects were not identified in either the acute or sublethal fish toxicity tests, effects were observed on giant kelp and mussel larvae. Within the IDZ, neither chronic nor lethal effects were expected to occur beyond 2 to 7.5 m from the outfall terminus, depending on the tidal current effects on plume geometry. Within this radius, interaction of the effluent plume with the sea bed was not expected as the plume is buoyant in sea water.

Using common permitting approaches, this discharge would have been difficult to authorise because its constituents lack the underlying data on which such concentration-based approaches rely. The general expectations of “no chronic effects” at the edge of the IDZ were demonstrated by characterizing the treated process water’s potentially harmful properties (hazard) in biological terms, which also enabled an evaluation of the plume’s interaction within the IDZ. The biological resources in this area were found not to be at risk from the treated process water and consent to construct the outfall and discharge was provided. An ambient monitoring program has been proposed to verify the predictions of the impact assessment.

**SUMMARY**

Risk-based approaches provide a means for evaluating the potential impacts of effluents on the actual resources that statutory controls intend to protect. They provide a more precise evaluation of the potential for impacts relative to technology-based end-of-pipe standards; the latter may have limits that are either under- or over-protective.

Two case studies have been presented highlighting two different regulatory “hurdles” involving effluents. In such cases, most would agree that the authorizations are in the public interest, yet such may not be approved using “conventional” approaches. The tools available in the risk assessment area of practice provide a means by which to provide a defensible assessment.
Our experience has been that agencies in British Columbia have been open to risk-based approaches because the studies are designed to provide information they need to address their legal and administrative requirements; revisions to legislation are not necessary. However, the problem formulation needs to result in a study design and assessment endpoints that are compatible with both federal and provincial requirements whether of a statutory or policy nature.

REFERENCES


Regina v. Kingston (City) (2004), 185 C.C.C. (3d) 446, leave to appeal to the Supreme Court of Canada refused.

