IGF INTERGOVERNMENTAL FORUM on Mining, Minerals, Metals and Sustainable Development

SURFACE WATER MONITORING FOR THE MINING SECTOR:

Frameworks for governments

Secretariat hosted by

IISD

Secretariat funded by

Canada

Kingdom of the Netherlands

The International Institute for Sustainable Development (IISD) is an award-winning independent think tank working to accelerate solutions for a stable climate, sustainable resource management, and fair economies. Our work inspires better decisions and sparks meaningful action to help people and the planet thrive. We shine a light on what can be achieved when governments, businesses, non-profits, and communities come together. IISD's staff of more than 120 people, plus over 150 associates and consultants, come from across the globe and from many disciplines. With offices in Winnipeg, Geneva, Ottawa, and Toronto, our work affects lives in nearly 100 countries.

IISD is a registered charitable organization in Canada and has 501(c)(3) status in the United States. IISD receives core operating support from the Province of Manitoba and project funding from governments inside and outside Canada, United Nations agencies, foundations, the private sector, and individuals.

IISD HEAD OFFICE

111 Lombard Avenue
Suite 325
Winnipeg, Manitoba
Canada R3B 0T4

IISD.org
@IISD_news

IISD
International Institute for Sustainable Development

The Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development (IGF) supports more than 75 nations committed to leveraging mining for sustainable development to ensure negative impacts are limited and financial benefits are shared. It is devoted to optimizing the benefits of mining to achieve poverty reduction, inclusive growth, social development and environmental stewardship.

The IGF is focused on improving resource governance and decision making by governments working in the sector. It provides a number of services to members including: in-country assessments; capacity-building and individualized technical assistance; guidance documents and conferences which explore best practices and provide an opportunity to engage with industry and civil society.

The International Institute for Sustainable Development has served as Secretariat for the IGF since October 2015. Core funding is provided by the governments of Canada and the Netherlands.

IGF/IISD OTTAWA OFFICE

220 Laurier Avenue W.
Suite 1100
Ottawa, Ontario
Canada R3B 0T4

IGFMining.org
@IGFMining

IGF
INTERGOVERNMENTAL FORUM
on Mining, Minerals, Metals and Sustainable Development

Surface Water Monitoring for the Mining Sector: Frameworks for governments

February 2022

Written by Lauren Timlick in collaboration with Matthew Gillman and Greg Radford

EXECUTIVE SUMMARY

KEY WATER SECURITY ISSUES IN MINING

Key water security issues are broken down into three main categories: water quality, water quantity, and social impacts. In mine water issues, water quality often supersedes quantity, as other industries, particularly agricultural, consume more water. Quantity issues related to mining may still arise in areas with unstable water resources and poor mine water management. These issues may contribute to the drawdown of the water table and downstream drought and thereby limit resources for local communities. Regulatory approaches for mitigation include requirements for detailed management plans, site audits, optimized water usage plans, technological upgrades, and accounting for seasonal variability and climate change in mine water management planning. Quality issues are often the area of main concern for mine process-affected waters. The three main categories of concern for mining water quality are acidification, sedimentation, and contamination by other deleterious substances. These effects can be mitigated through proactive assessment and modelling; external review of detailed operation plans, including closure planning; and regulations that set trigger values for endpoints associated with contamination. Water-related social issues linked to mine establishment often include concern about the scarcity and degradation of available water resources. Main concerns include unequal distribution of water support systems, effects on the environment and associated traditional livelihoods, inadequate regulations and/or enforcement of such, and the potential effects causing displacement of established settlements. Ensuring the accessibility of data, transparency in reporting, communication between all stakeholders, and accountability to a government or another non-industry organization can help build trust within communities. For more information on water security issues and how governments may address each area of concern, see Sections 1.1–1.3.

Participatory monitoring programs (PMPs) are a key step in building the aforementioned trust between communities, governments, and industry. PMPs are a collaborative method that governments can implement within environmental regulations as a means of ensuring the collection, analysis, and communication results of a water monitoring or environmental effects monitoring program. PMPs are most effective when they begin at the earliest possible stage of mining development and may include established lines of communication moderated by a neutral party, regular committee meetings that invite and include concerns and ideas from the community, or community members participating directly in the development and execution of the monitoring programs. When enacted thoughtfully, PMPs increase the sense of agency within a community, business-climate stability for the company, and support for governments. The overarching benefits can be best described as linking iterative engagement to community, industry, and regulatory acceptance. See Sections 1.4, 1.5, and 2.2 for more information on PMPs and how they benefit all stakeholders within a mining program.

REVIEW OF INTERNATIONAL BEST PRACTICES AND STANDARDS

Many governments have established frameworks for water monitoring that utilize best practices, but few of them specifically address it in the context of the mining industry. The Environmental Effects Monitoring program and accompanying legislation established by the Canadian federal government in the 1990s provide a detailed outline of the monitoring and reporting required of mining companies. Due to the specificity of this program to mining companies, it is applied in this review as a rubric to examine other programs from other governing bodies—the European Union, Australia, and the United States—as well as an example for non-government organizations. The summary of all these programs can be found in Table 2, and they are detailed in Section 2.1.

Multistakeholder engagement is an important part of best practices for mine water management and should be considered by governments as a mitigation tool for risks to water security and associated social issues. "Multistakeholder engagement" is an overarching term that encompasses several key components of participatory monitoring, including transparent data communication, adaptive management, and community-based water monitoring. Tools for effective and transparent data communication include staging online forums, including third parties or community members in all phases of monitoring, and providing data in an accessible and unbiased manner.

Adaptive management is a systematic approach that continuously aims to improve resource management and the corresponding monitoring programs. A well-structured adaptive management program cycles through identifying risks and associated thresholds, monitoring plan performance, and continuing to improve management strategies based on previous outcomes.

Community-based water monitoring (CBWM) is a component of participatory water monitoring that involves the gathering of specific information of scientific interest by local residents over a given period of time. This is especially beneficial in areas that are difficult to access and as a vector for the merging of Traditional Ecological Knowledge and modern scientific studies. CBWM can be the physical gathering of samples by community members or the gathering and dissemination of knowledge. For examples of proactive and reactive multistakeholder monitoring programs, see Section 2.2.4; for an example of government actions, see Figure 1.

ROLES OF GOVERNMENTS

Governments are in the position to establish regulations and policies that require monitoring and reporting of water impacts from mining entities. These frameworks can be complementary to regulations and policies that impose accountability on industry and provide assurance to communities. Jurisdictional and international guidelines are available for governments to draw on in the development of these frameworks. While drawing on these existing frameworks is a useful tool, it is important that governments consider jurisdictional concerns and limitations when creating their own specific policy and monitoring program requirements. Water frameworks pertaining to environmental effects monitoring in mining (i.e., water monitoring frameworks [WMFs]) should cover the ministries and agencies responsible for implementation, enforcement, the government's environmental objectives and goals, the required content of and review process for Environmental and Social Management Plans and Environmental and Social Impact Assessments, permitting conditions and requirements, specific criteria for environmental protection, financial assurance requirements (particularly for mine closure), and penalties for non-compliance. Technical guidance documents are a common tool to include with WMF policies and regulations that serve as compliance support for mining companies and branches of government. Table 4 provides a summary of some of the tools available to governments; more information is available in Section 3.

FIGURE E1. SUMMARY OF MINE WATER MONITORING AND MANAGEMENT TOOLS AVAILABLE TO GOVERNMENTS WHICH ARE DISCUSSED IN THIS GUIDANCE DOCUMENT

Monitoring requirements	• Define the structure of a monitoring program. • Outline requirements for chemical and biological monitoring. • Define sampling frequency and location. • Outline steps for quality control and quality assurance.
Baseline monitoring	• Set requirements to define benchmark conditions and baseline study requirements. • This will aid in the assessment of hydrological variability within a region. • If baseline data cannot be collected, define alternatives such as a reference site. • Baseline sampling does not replace the inclusion of reference sites throughout the life of the mine.
Thresholds for response	• Define trigger levels and adaptive management. • Identify how data is to be interpreted and what threshold results will trigger a result. • Predefine quality limits for water and biota. • Adaptive management plans should include stakeholder engagement.
Reporting requirements	• Review results and track compliance. • Frequency should balance identification of risk with resources available to review the report. • Outline an approved style of data communication for consistency. • Required reporting style should be conducive to trend analysis.
Participatory monitoring	• Engage communities and stakeholders. • Help in the promotion of community trust in government and industry. • Engagement should exist from permitting all the way into the mine closure process. • Can be financially supported by the mining company.

TABLE OF CONTENTS

ACRONYMS AND ABBREVIATIONS

AMD	acid mine drainage
ARD	acid rock drainage
BMP	best management practices
CWA	Clean Water Act
CWBM	community-based water monitoring
ECCC	Environment and Climate Change Canada
EEM	Environmental Effects Monitoring
ESIA	Environmental and Social Impact Assessment
ESMP	Environmental and Social Management Plan
EU	European Union
IFC	International Finance Corporation
IGF	Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development
IISD	International Institute for Sustainable Development
IRMA	Initiative for Responsible Mining Assurance
MMER	Metal Mining Effluent Regulations
MDMER	Metal and Diamond Mining Effluent Regulations
NGO	non-government organization
PMP	participatory monitoring programs
USEPA	United States Environmental Protection Agency
WFD	Water Framework Directive
WMF	water monitoring framework
WQMF	Water Quality Management Framework

1.0 INTRODUCTION

Mining sector development has the potential to impact many aspects of the environment, and the responsible management of these natural resources is key to preserving them for future generations. Water, in particular, is a critical resource for which competing demands may often be the root source of conflict and tension within and between communities, societies, and nations. Governments play the critical role of balancing competing demands for water between mining, agriculture, industry, recreation, and household usage, among others. Within the context of the mining sector, governments are responsible for overseeing water extraction, use, discharge, and quality at the site, watershed, and regional levels.

The Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development (IGF) has put out several guidance documents that outline the responsibilities of governments with respect to water issues associated with mining. The IGF *Mining Policy Framework* recommends governments have appropriate environmental management standards in place with the ability to enforce them (IGF, 2013). Integrating these standards into a legal framework ensures that mining entities have practices in place that promote secure waste storage and prevent impacts beyond the mining site. They also recommend member governments regulate the quality and quantity of mine effluent streams discharged to the environment. The *Environmental Management and Mining Governance* (IGF, 2021) document outlined several key actions for governments with respect to water resources management in the context of mining. These action points include 1) developing watershed-level water management policies, 2) setting criteria for effluent and receiving waters and conditions for water usage, 3) reviewing mine water management plans, 4) monitoring and evaluation of mine water management, and 5) enforcement of compliance to the standards of water protection.

The focus of this document is water monitoring frameworks (WMFs) and is most related to the fourth key action for government identified in IGF (2021): monitoring and evaluation of mine water management. WMFs have been implemented in many nations with developed mining sectors, and this document will review these existing programs to provide details on commonalities between them. The document will review key issues of mine water impacts on the aquatic environment along with international standards for WMFs. The document will then move on to review the role of governments aiming to develop and implement WMFs. Lastly, Table 4 summarizes tools for governments.

The document will also review the implementation of participatory monitoring programs (PMPs) under the umbrella of a WMF. PMPs describe a higher level of stakeholder engagement through community inclusion during the design, implementation, and reporting of environmental monitoring. We will review how these programs can positively affect stakeholder relationships and create a collaborative management program that can mitigate water-related conflict during the lifetime of a mine. Discussion of PMP implementation is also discussed in the context of the roles of government and associated tools (**SECTION 3**).

2.0 KEY WATER SECURITY ISSUES IN MINING

Water is a key welfare security concern in every community worldwide, and water security is intrinsically connected to the security of energy and food. The interdependent water–energy–food system was classified as a serious global risk by the World Economic Forum (WEF) (2011). Concerns regarding freshwater security are often one of the main sources of apprehension for communities adjacent to mining operations. Water security concerns are often divisible into three main categories: water quality, water quantity and social impacts. With respect to mining operations, water quality is often of greater concern than quantity, but this will vary depending on water availability in the region (International Institute for Sustainable Development [IISD], 2015).

For additional information on the interconnected concerns involving water, energy, and food resources in the context of mining, refer to the *Water-Energy-Food Resource Book for Mining* compiled by IISD (2015).

For the purposes of this review, we will focus on the security of surface water quality and quantity and how this may be affected by developing mining sectors. It is important to note, however, that in many regions, water security is dictated by the quality and quantity of groundwater. Groundwater may also be affected by mining activity, resulting in drawdown, sinkholes, well water quality changes, and other effects that may cause concern among communities relying on this resource. Concerns regarding water resources may escalate to conflict when combined with a lack of communication and community engagement. Tensions in this regard will have cascading effects on all stakeholders within a project from communities to companies and through to regional and federal governments. In this section, we will discuss key issues around water security associated with mining development and how governmental facilitation in monitoring and community engagement affect both the water and all stakeholders involved.

2.1 WATER QUANTITY

Water resource availability (i.e., water quantity) can be impacted by mining in numerous ways. Mines need water for many reasons, such as grinding ores to separate minerals, washing or transporting materials, drilling, controlling dust, cooling machinery, pit flooding, properly executing mine closure, and supporting the needs of workers. These needs must be balanced with water security for agriculture, energy, industry, sanitation, and communities in the surrounding area. Quality of life for these citizens is also dictated by the state of the environment, which may be affected by any and all water usage.

If inefficiently managed, mine water use may contribute to drawdown of the water table, drought downstream, or flooding of upland areas through the diversion of flow pathways. Reduction in available water can result in limited or altered water supplies for local communities or adjacent sectors. Diversion of existing streams may result in changed or inaccessible migration routes for fish species, reduced riparian habitats, flooded lands that were previously dry, and a corresponding change to the CO_2 budget in the area. Water use can be managed through thorough site audits, optimized water usage plans, investing in efficient technologies that reduce the water needed for a given task, and accounting for seasonal variability in water quantity when planning for a higher water use event. This management can be assisted by governments through the required submission of water usage plans, including modelling of any potential changes to the flow regime accounting for drought or flooding conditions, seasonal variations, and climate change scenarios covering the expected life of the mine. Mines may use less water than other industries, particularly agriculture, but depending on the water security in the region, the impact of mine water usage may have a significant effect on water availability.

2.2 WATER QUALITY

The potential effects of mining on surface water quality in the receiving environment are often more prevalent than those on water quantity (IISD, 2015). The main water quality issues caused by mines that could impact a receiving environment can be broken down into three categories: acidification, sedimentation, and contamination. All of these effects can be mitigated by assessment and modelling of potential scenarios prior to mine opening, submission and review of detailed operation plans, submission of a detailed closure plan to account for potential environmental effects after mine closure, and regulations that set trigger values for endpoints associated with these water quality effects (see **SECTION 2** and **SECTION 3**). Water monitoring should occur in the effluent, downstream, and at an uncontaminated reference site. This monitoring will provide information on the state of any water quality issues and should be regularly reported and made suitably available to stakeholders.

Acidification of downstream water bodies is commonly referred to as acid rock drainage (ARD) or acid mine drainage (AMD). These effects are typically caused by sulphur-rich waste rock and ore being exposed to water, air, and bacteria. Downstream acidification effects occur when runoff and seepage from AMD is not captured in the mine water management system and treated accordingly. Acidified water may cause organism illness and death, structural ecosystem changes, unsuitability of water for human use, and degradation of soil quality that can be environmentally and agriculturally damaging. Acidified water is also capable of dissolving and incorporating metals that may be bioavailable and increase the potential toxicity of ARD. This review will discuss ARD in the context of downstream monitoring;

however, more information on ARD and best management practices (BMPs) can be found within the *Global Acid Rock Drainage (GARD) Guide* developed by the International Network for Acid Prevention (2014). This resource includes guidance on how to predict, prevent, mitigate, treat, manage, communicate, and consult about ARD and metal leaching, both significant challenges for mine sites.

Sedimentation is caused by erosion due to increased surface area and decreased vegetation in the mine site itself and also from creating access routes to and from the site. Overland flow from rain events may incorporate and carry sediments into nearby water bodies where they will be deposited based on grain size and flow rate. The sediments will reduce water clarity and increase turbidity, which may cause structural ecosystem changes and increase the cost of water treatment for human use. When deposited, the sediments may smother vegetation, animals, and habitats. They may also restrict flow downstream if deposited in large enough quantities, resulting in upstream flooding and lowering of water levels in downstream receiving waters. Sedimentation can be prevented through the revegetation of cleared areas and geotechnical stabilization of the site infrastructure and the downstream environments.

Contamination of downstream water bodies can occur through accompanying AMD metal contamination, leaching from tailings ponds, or discharging of effluent, which may include processing chemicals like cyanide, arsenic, or nitrogen species (e.g., ammonia), depending on the type of mine. These chemicals and metals may bioaccumulate within the food web, causing organism death and illness, degradation of downstream soil quality, and unsafe drinking water for nearby communities. The leading way of mitigating this contamination is to ensure proper containment of waste, seepage, runoff, and treatment of effluent. Leading-edge treatment of chemical and metal contamination involves active and passive methodologies, which can include nanotechnology, specifically nanoparticle adsorption and electrocoagulation (see Box 1).

For more information on nanotechnology and its various applications in mining, please consult Chapter 10 of *Nanotechnology for Water Treatment and Purification* (Hu & Apblett, 2014).

BOX 1. NANOTECHNOLOGY AND MINE CONTAMINANT NEUTRALIZATION

Nanotechnology is a promising tool in the optimization of remedial methods for mine process-affected waters. Their potential lies in the affordability and potential for improved performance of existing treatment technologies for contaminants such as metals, process chemicals, AMD, alkaline mine drainage, radioactive contaminants, and salinization.

Nanofiltration, nanocatalysis, and nanomagnetism are some of the most promising nanotechnology applications that were originally designed for wastewater but could be or have been adapted and applied to mine process-affected waters. Nanofiltration mechanically excludes contaminants by passing water through an enhanced membrane made from a nanomaterial like dendrimers, zeolites, or nanoporous ceramics. Some of these systems can detoxify a variety of contaminants based on the hydrophobicity of the material and the nature of the compound of interest. Nanocatalysis uses nanoparticles to chemically degrade pollutants, which could be a very effective method for removing contaminants that are dangerous, even at low levels. Nanomagnetism uses nanoparticles with large surface-area-to-mass ratios that bind well to contaminants such as arsenic. These magnetic particles complex with the contaminant and can then be removed from the solution using strong magnets.

TABLE 1. SUMMARY OF DIFFERENT PASSIVE AND ACTIVE WATER TREATMENT SYSTEMS AND WHICH CONTAMINANTS THESE SYSTEMS TARGET

Treatment type	Method	Target contaminants
Passive systems	Anoxic alkaline drains	AMD
	Constructed wetlands	Salinity, AMD, metals
	Microbial reactor systems	AMD
	Biosorption systems	Metals
Active systems	Aeration	AMD, metals, ammonia
	Neutralizing and hydrolysis	AMD
	Metal removal	Metals
	Chemical precipitation	Sulphates
	Membrane treatment	Salinity, ammonia
	Ion exchange	Metals
	Biological removal	Sulphates, metals, ammonia
	Sulphide precipitation	Metals
	Biomineralization	AMD, metals
	Breakpoint chlorination	Ammonia

2.3 SOCIAL IMPACTS OF MINING AND WATER

Social issues associated with establishing mines typically include concerns about the potential scarcity and degradation of available water resources. Conflicts between communities, companies, and governments can arise from a number of areas, but the most common sources are unclear or absent communication between stakeholders and erosion of trust due to previous experiences with mining or other industry. The main concerns of communities near established or developing mining efforts tend to include inequality in the distribution of water support systems, effects on the environment and subsequent impacts on traditional livelihoods, inadequate regulations or enforcement of such, and potential displacement or relocation of established settlements. If any of these impacts have occurred previously, either to the community or in a public enough forum that it is common knowledge, the concerns are amplified. Similarly, if the community is not receiving clear communication from both government and industry, then the mistrust of development increases as well. In many cases, simply communicating the results of monitoring, modelling, or risk assessments is not enough to alleviate the concerns of relevant stakeholders. Communication and trust breakdowns between stakeholders can have lasting effects on society, including civil unrest, riots or protests, lack of community support for future mining endeavours, and increased distrust of the mining industry and the government entities that support it.

Unbiased results from monitoring programs or modelling regimes will often be published in peer-reviewed papers and, although these are a reliable source of information, may not be easily accessible to interested communities. Communications directly from the mining entity may be met with distrust, especially if the trust of the community has been previously eroded. For this reason, it is important to provide clear, unbiased communication between industry and communities. In some cases, it is possible that governments could provide this mediation, but in other circumstances, a neutral third party such as a non-government organization (NGO) or an academic institution may provide a more impartial evaluation of the monitoring program and results. It is important that these third parties ensure that their communications reach all interested stakeholders and note that this may require alteration of the initial report, whether that be from a digital to print format or producing the document in additional languages. Open access information hubs, such as the Mackenzie DataStream (Box 2), are also useful for the increasing accessibility and clarity of available data regarding water quality monitoring programs.

Accessibility is equally important for communication from governments on what regulations the mining companies are beholden to. Adequate understanding of the regulations that a government has pledged to enforce increases a community's sense of agency and understanding of their rights with respect to the operation and establishment of a nearby mine. Governments may also benefit from consultation with communities in some form of open forum to provide a clear line of communication for suggestions, concerns, and feedback on regulations and enforcement. For companies, one of the most advantageous methods of ensuring clear communication with stakeholders is to employ a respectful participatory monitoring strategy that involves representatives from all relevant parties throughout the life of a mine and acknowledges the advantages and limitations of the participatory groups.

BOX 2. THE MACKENZIE DATASTREAM OPEN ACCESS WATER DATA HUB

The Mackenzie DataStream operates as an online platform for sharing water quality information pertinent to the Mackenzie River Basin in northern Canada. This system was developed collaboratively by the Government of the Northwest Territories and the Gordon Foundation to provide an accessible platform for data collected from over 30 communities within the basin. The conglomeration of this wide array of data through one central hub allows for increased collaboration and understanding of the larger-scale impacts on the Mackenzie River Basin. The central hub is crucial, as it facilitates consistency within the data formatting and thus comparability between collection sites and stewards. A specific goal of the data stream is to incorporate collected data with traditional environmental knowledge to support evidence-based decision making within the basin. The datastream site is clear, free of scientific jargon, and provides detailed tutorials on everything from entering data to fully online courses for water monitoring training.

This model has been so successful that it has been applied to additional basins in Canada, including in the Atlantic region and the Lake Winnipeg basin. Using their experience with the Mackenzie DataStream, the Gordon Foundation collaborated with Living Lakes Canada and the World Wildlife Fund Canada in 2018 to provide actionable recommended steps for the federal government of Canada with respect to supporting community-based water monitoring (CBWM). *Elevating Community-Based Water Monitoring in Canada* provides recommendations in the areas of capacity building, monitoring, data management, collaboration, and using data to inform policy and decision making (WWF-Canada et al., 2019).

2.4 THE VALUE OF PARTICIPATORY MONITORING PROGRAMS

When established correctly, PMPs can be effective and beneficial for all stakeholders. PMPs are a collaborative method of collecting, analyzing, and communicating the results of a water monitoring program. This provides an opportunity to expand beyond monitoring for legal compliance to addressing the concerns of local communities. PMPs can help build a system that supports cooperative engagement and collective ownership between companies, governments, and communities. A traditional monitoring program will often operate with a top-down approach, which can be effective but may not foster credibility and trust within local communities. This monitoring program style would typically result in communities receiving information in the form of data that has already been collected, analyzed, and reported on by a contractor of the mining company. This information may not be presented in a way that is accessible to the average citizen or address the specific concerns of the community. If the presence of this type of monitoring program is not communicated efficiently to the community, then it is possible that, by the time citizens receive any of this data, trust in the company or government may have already been eroded.

PMPs help reduce the power imbalance between government, industry, and communities and provide an efficient route of communication between stakeholders. There are a variety of different levels of participation, and the capacity of communities should be taken into account when initiating the program. Participation can happen at any stage of mine development, but it is beneficial to begin as early as possible in order to establish a positive relationship between stakeholders from the start. Participation can be anything from the inclusion of community members in monitoring committees, established lines of communication mediated by a neutral party, or training of community members to conduct monitoring themselves.

When this collaborative effort produces good data, all parties benefit. Communities benefit from an increased sense of agency and understanding of the impacts that a particular mining endeavour may have on their region. Companies benefit from a stable business climate fostered by increased social licence and community respect. This, in turn, lowers the risk of project stagnation or delay by reducing conflict through clear communication. Governments receive additional support for their monitoring resources and benefit from improved credibility due to increased transparency and accountability. Quality data from PMPs that account for both legal compliance and the concerns of the stakeholder communities also provide governments with the background to make more effective policy decisions with respect to future mining operations.

These benefits are notable, but any good PMPs must also address the potential limitations and challenges. Notably, community monitoring volunteers may require a substantial amount of training to develop the technical capacity needed to collect quality water samples and data. It is also vital that there be a mediated and clear channel of coordination and communication between government, industry, and communities.

For a detailed outline of considerations for the implementation of PMPs as well as some introductory technical sampling methods, please refer to the International Finance Corporation (IFC), Multilateral Investment Guarantee Agency and Members of the World Bank Group's advisory note *Participatory Water Monitoring: A Guide for Preventing and Managing Conflict* (Office of the Compliance Advisor/ Ombudsman, 2008).

2.5 LINKS BETWEEN ITERATIVE ENGAGEMENT AND COMMUNITY, INDUSTRY, AND REGULATORY ACCEPTANCE

The link between iterative engagement and acceptance by stakeholder communities can be best described as a dispelling of a company or mine's "otherness." By engaging with stakeholders at all phases of mining, a company increases transparency and connection between community, government, and industry. Participatory programs have the potential to increase company accountability and transparency while simultaneously benefiting the mining program by increasing a sense of involvement and responsibility for the mine within the community. If a community is directly involved in the design and execution of a monitoring program, it provides an opportunity to both connect with the data and trust the results.

This same level of transparency is beneficial among all stakeholders, including between governments and communities or companies. If governments at local, state/provincial, and federal levels produce a consistent and transparent set of regulations, companies understand what is required of them, and communities understand what they should expect from both companies and governments in terms of environmental accountability and enforcement. Additionally, governments can facilitate, or at minimum participate, in a public forum at which communities can present questions, concerns, or suggestions on regulations and regulatory enforcement directly to a government official or representative. This link between engaging communities and increased community acceptance of a mine is clear in the case studies included in **TABLE 3**.

Iterative engagement can be used both to keep communication clear and open and prevent distrust and conflict between stakeholders and as a responsive or remedial measure to repair damaged trust. The former is preferable when at all possible, as it engages stakeholders throughout the life cycle of the mine and encourages acceptance through the development of mutually beneficial pathways. A proactive system of community engagement is preferable wherever possible, as it prevents the need to rebuild the trust that may have previously been eroded. The main tools of this engagement include transparent data communication, adaptive management, and CBWM (**SECTION 2.4**).

3.0 REVIEW OF INTERNATIONAL STANDARDS AND BEST PRACTICES

3.1 REVIEW OF WATER MONITORING FRAMEWORKS OF ESTABLISHED MINING NATIONS AND NGOS

Many governments have established frameworks and best practices for water management within their borders, and many international agencies and NGOs have similar recommended frameworks for cross-border water management. Of these existing frameworks, few specifically direct the responsibilities of mining entities, whether through regulations or legislation. A majority of governmental or NGO documents provide only a general framework for water monitoring that mining entities may be directed to follow as an outline of what is required by the local governing bodies.

An exception to this generalization is the Environmental Effects Monitoring (EEM) program that was established in Canada in the 1990s. This program and its accompanying legislation provide a detailed outline of the expectations for environmental monitoring and reporting conducted by both mining organizations and pulp paper mills in two separate technical documents. These frameworks have been referenced internationally, both in the development of new frameworks and in providing enhanced detail to existing frameworks. In this section, we will describe some of the existing water monitoring frameworks (WMFs) by governments from countries with established mining sectors, as well as frameworks presented by certain NGOs with a vested interest in mining sustainability. These will be discussed primarily in comparison with the Canadian EEM program, as this program is directly tied to the mining industry.

3.1.1 CANADA

The mining branch of the EEM program was created in the 1990s under the umbrella of the federal Fisheries Act, specifically their Metal Mining Effluent Regulations. It is worth noting that in 2018, the Metal Mining Effluent Regulations were amended to incorporate diamond mines and thus became the Metal and Diamond Mining Effluent Regulations (MDMER). The cited purpose of the EEM framework and accompanying legislature was to detect and measure changes to aquatic ecosystems by evaluating the effects of effluents on fish, fish habitat, and fisheries resources.

The main reference document for the EEM framework is *Metal Mining Technical Guidance for Environmental Effects Monitoring* (Environment and Climate Change Canada [ECCC], 2012), and there was a parallel publication for pulp and paper mills (ECCC, 2010). The 2012 guidance document published by ECCC is not a legal interpretation of the MDMER within the federal Fisheries Act but rather a guidance document that speaks directly to mines and mining companies on how they can meet the regulatory requirements dictated in the MDMER. The technical guide includes a detailed methodology for effluent characterization, water quality monitoring, sublethal toxicity testing, sediment monitoring, and biological monitoring. Should any of these studies find significant effects, the technical guidance document also outlines the requirements for an investigation of cause study. It also details the regulatory expectations for study design, reporting deadlines, data assessment, and information management. This is a useful resource for companies wishing to ensure their compliance with the MDMER requirements, but it is not an exhaustive list of the possible means for conducting EEM. Thus, the document does include an overview of different monitoring methods and acknowledges situations in which modifications or substitutions to this framework may be necessary. Although the details of how these studies are conducted remain flexible, EEMs must always comprise an effluent and receiving environment water quality monitoring component and a biological monitoring component (Section 2.1.6). This provides context to stakeholders on both the potential immediate and long-term effects of mine effluent on downstream water bodies and the steps being considered or taken to prevent and mitigate potential detriment.

The Canadian EEM guidelines are most relevant to Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development (IGF) member states because they are specifically directed at mining entities in addressing their obligations toward federal regulations in the host country. It has also been demonstrated that this program has the potential to be implemented as a model in other countries, including Brazil (see Box 3), which again increases its relevance to member states interested in implementing this type of framework in the future.

For a detailed review on the challenges and lessons from the past 30 years of EEM in Canada and how these may be applicable to countries seeking to establish similar programs, we recommend *Principles and Challenges for Multi-Stakeholder Development of Focused, Tiered, and Triggered, Adaptive Monitoring Programs for Aquatic Environments* (Munkittrick et al., 2019). Compiled by leading Canadian scientists with decades of experience in environmental monitoring, Munkittrick et al. (2019) summarize the steps of program design in all aspects of water monitoring and provide clear instruction for governments and other entities interested in implementing a national standard for environmental monitoring.

BOX 3. BRAZILIAN NATIONAL PROGRAM OF WATER QUALITY EVALUATION

In an effort to create a unified environmental monitoring model in Brazil, Canadian scientists collaborated with local scientists and communities to prove the potential for implementing a form of the Canadian EEM. The authors note that other countries, including Australia, Chile, the United States, and Sweden, have used this monitoring model as well. To encourage governmental implementation of a similar system in Brazil, a series of pilot studies were implemented under the name of the *Fish Guide Project* (de Mata Pavione et al., 2019). This project included sites on three important tidal rivers of different conditions (Benevente, Jucu, and Santa Maria da Vitória) where fish health, bioaccumulation, benthic invertebrates, and the physicochemical aspects of water and sediment were evaluated. The applied methodology confirmed the known relative states of health for each river and revealed a legal gap in relation to quality standards in tidal rivers. The authors state that the implementation of this methodology allowed for efficient comparison between rivers that previously had been monitored in a disjointed manner.

3.1.2 EUROPEAN UNION

The European Union's (EU) Water Framework Directive (WFD) (2000/60/EC) was developed beginning in the mid-1990s as a means of preserving, protecting, and improving the quality of the environment with a specific focus on the accountability of those entities not managing effluent effectively (European Parliament & Council of the European Union, 2000). Although not specific to metal mining, the directive provides the framework for all member states to preserve water resources and constitutes an informal consensus to adhere to these best practices. The monitoring portion of the WFD was launched in 2000 as Working Group 2.7 and eventually produced WFD Guidance Document No. 7, *Monitoring Under the Water Framework Directive*, which is a living document that will continue to evolve over time (European Communities, 2003). The document was created with the purpose of establishing monitoring programs with consistent design that will provide guidance to member states as they work to adhere to the requirements of the WFD. Guidance on the selection of endpoints, best practices for implementing different monitoring programs, and BMP examples of current monitoring programs within member states are also considered. Guidance Document No. 7 notes that, although this is a framework approach to monitoring under the WFD, appropriate implementation of the methodology will require tailoring based on specific circumstances. The annex to the WFD takes these recommendations and applies them to specific member states as national priorities.

Although the WFD does not specifically address mining companies, it provides a framework of EU requirements that governments of member states may refer to when delineating the responsibilities of mining companies operating within their borders. WFD Document No. 7 includes tables detailing recommended parameters for biological, hydrological, and physicochemical quality metrics in specific types of surface water bodies (e.g., rivers, lakes, coastal), as well as recommended sampling regimes, methods, and the potential pressures to which these endpoints respond. Individual member states are required to submit reports on the progress of their river basin management plans to the European Commission at predetermined dates (see Box 4). These reports are drafted based on data from a member state's jurisdiction and submitted to the Water Information System for Europe electronically.

BOX 4. EU MEMBER STATES' IMPLEMENTATION REPORTS

Reports on the implementation of the WFD are submitted by all EU member states and Norway for each cycle of the program. Reports also exist for the United Kingdom up to 2019 (European Commission, 2019). All of these reports are translated and available on the European Commission website (2019). An important aspect of these reports is that multiple member states may report on the same international river basin district in the same format and adhere to the same monitoring standards, allowing for comparison between reports and a fuller picture of the state of international waters. Each report includes a summary of the strengths and weaknesses of the state's current river basin management plans, as well as improvements since the last report and recommendations for implementation going forward.

Following submission of the report, the member state provides a detailed report assessing the compliance with the WFD, main changes since the previous cycle, and progress with previous recommendations for 16 required topics. These topics include governance and public participation in WFD compliance; monitoring of the ecology and chemistry of surface water; quantity and chemistry of groundwater; and characterization of river basin districts, protected areas, and heavily modified or artificial water bodies. They also include a program of measures and measures related to water scarcity, hydromorphology, and pollution from agriculture or other sectors, including mining. There is also discussion of progress in the areas of environmental objectives and adaptation to climate change.

3.1.3 AUSTRALIA AND NEW ZEALAND

The governments of Australia and New Zealand provide their 10-step Water Quality Management Framework (WQMF) as an interactive web guide (Australian and New Zealand Guidelines for Fresh and Marine Water Quality, n.d.). This includes an outline of the steps of the framework and a guide for water monitoring within it. The monitoring process outlined in the interactive guide is not directed specifically at mining companies, but within the WQMF there is a section on applying for development approval that is applicable to all areas of industry. This section outlines that the minimum required monitoring and reporting must be determined for the relevant regulator in the area where this development is being proposed. In many cases, this may be a state or regional regulatory body.

An example of a monitoring framework at the state level is the Queensland Government's *Monitoring and Sampling Manual for Environmental Protection (Water) Policy*. The WQMF provides guidance on how to approach the process of choosing analytes, determining the guideline values for your region, methods of analysis, data processing, and reporting. The document from the Queensland Government goes into detail comparable to the Canadian EEM on the actual process of sampling and monitoring, although it is not directed specifically at the mining industry (Queensland Department of Environment and Science, 2018). The WQMF and Queensland state documents may be used in conjunction in order to provide an overview of Australian governmental recommendations for water monitoring. It is important to note that, unlike the Canadian EEM program, these documents do not outline exactly what a sampling regime should look like in order to follow federal or state regulations but rather act as a base from which to work toward the conditions of specific permits or licences to which a company may be beholden.

3.1.4 UNITED STATES

Unlike their North American neighbour, the United States does not have a designated set of regulations applying specifically to mining companies and their responsibility to protect water resources. BMPs tend to be implemented at the state level, and many of these actually reference the Canadian EEM program (e.g., EPA/600/R-99/064). One example of national BMPs for water resources would be the *National Best Management Practices for Water Quality Management on National Forest System Lands* (United States Department of Agriculture, 2012). Additionally, similar to the EU, there are numerous guidance documents from the United States Environmental Protection Agency (USEPA) covering how to adhere to the requirements of the Clean Water Act (CWA; summarized in Copeland, 2016). These include the *Primer on Using Biological Assessments to Support Water Quality Management* (USEPA, 2011) and the *Water Quality Standards Handbook* (USEPA, 2017). It is difficult to delineate a conclusive set of parameters that are required of mining companies in the United States due to the wide variety of available documents.

Using a combination of the aforementioned documents, there are several sets of monitoring criteria we can establish as U.S. best practices. Within National Forest System Lands, mines are encouraged to create site-specific BMPs that adhere to their recommended practices. These monitoring practices include disposing of produced water in compliance with the CWA and Safe Drinking Water Act, determining water quality, quantity, flow regimes, water levels, and quality standards. The USEPA encourages all states and authorized tribes to develop and implement monitoring for nutrients, temperature, biocriteria, and sediment benchmarks, as well as those metrics used for human health and recreation. Monitoring of these elements is encouraged to be implemented on a site-specific basis based on criteria outlined in various USEPA guidelines (i.e., Table 304(a); USEPA, 2021). Methodology is rarely detailed within these documents and seems to be at the discretion of local regulatory bodies.

3.1.5 NGOs

There are numerous international organizations that provide support and guidance for water monitoring, responsible mining, and the intersection of those two objectives. The IGF has released guidance documents, outside of their *Mining Policy Framework*, that cover *Environmental and Social Impact Assessments* and *Environmental Management*. These documents are on the specific importance of balancing resource extraction and environmental protection and provide guidance to participating governments on how to create and enforce these guidelines within their jurisdiction. However, they do not provide specific endpoints or criteria and are directed instead at the decision-making process. Similar guidance documents have been created by the International Council on Mining and Metals (2021), the Initiative for Responsible Mining Assurance (IRMA, 2018), and the International Organization for Standardization (2018) to provide assistance or outline expectations to member states or groups. Depending on the organization, members may be mining companies, nations with mining sectors, or other parties involved in regulation and compliance within the mining industry.

The IRMA framework has been selected as an example for this review since membership is open to all stakeholders, not just industry. In addition, their framework provides the most detail on water monitoring expectations and is thus most comparable to the Canadian EEM and other governmentally invoked monitoring guidelines. Chapter 4 of the *IRMA Standards for Responsible Mining* covers the environmental responsibility requirements of members, with Section 4.2 covering water management. Although this document does not cover the methodology of the monitoring to the extent of the Canadian EEM program or Australia's state environmental protection plans, it provides guidance to members on what they are required to do by IRMA to adhere to their standards. This includes outlining the basic scope of background data, as well as pollution prevention methods and an outline of the monitoring and adaptive management that must be implemented. Within the monitoring section, there are basic requirements for monitoring sites and frequencies as well as establishing trigger levels. The IRMA guidelines also require that the companies use "credible methods and appropriate equipment" in their monitoring and that the samples be processed by accredited labs. The guidelines are accompanied by end-use tables that detail the target values for a suite of contaminants that should be analyzed during monitoring. Additionally, IRMA requires that the operating company publish reports on water quality and quantity annually or at another rate agreed upon by all stakeholders.

3.1.6 SUMMARY TABLE OF EXISTING ENVIRONMENTAL MONITORING PROGRAMS

TABLE 2. SUMMARY OF ESTABLISHED SURFACE WATER MONITORING FRAMEWORKS FROM SEVERAL COUNTRIES AND INTERNATIONAL ENTITIES AS THEY COMPARE TO THE STANDARDS SET THROUGH THE CANADIAN EEM PROGRAM

	Canada	**Australia & New Zealand**	**United States**	**European Union**	**International**
Program name	Environmental Effects Monitoring Program (EEM)	Water Quality Management Framework (WQMF)	USEPA Water Quality Standards	EU Water Framework Directive (WFD)	Initiative for Responsible Mining Assurance (IRMA)
Accompanying legislation	Fisheries Act (Government of Canada, 1985); Metal and Diamond Mining Effluent Regulations (Government of Canada, 2002)	Commonwealth Water Act Resource Management Regulations (LI 2020/174; SR 1998/208) (Government of Australia, 2007; Government of New Zealand, 2020)	Clean Water Act (CWA) (Copeland, 2016)	Directive 2000/60/EC (Articles 8 & 11; Annex V) (European Parliament & Council of the European Union, 2000)	NA, but requires that companies abide by host country laws
Reference document(s)	Metal Mining Technical Guidance for Environmental Effects Monitoring (ECCC, 2012)	WQMF Interactive Web Guide; Queensland Monitoring and Sampling Manual (2018)	A Primer on Using Biological Assessments to Support Water Quality Management (2011) Water Quality Standards Handbook (2017)	WFD Guidance Documents No. 7, 8, 19, 21, 25, 32 (European Commission, 2003, 2008, 2009a, 2009b, 2009c, 2010, 2014)	IRMA Standard for Responsible Mining IRMA-STD-001 (2018)

	Canada	Australia & New Zealand	United States	European Union	International
Cited purpose(s)	"Detect and measure changes in aquatic ecosystems by evaluating the effects of effluents on fish, fish habitats, and fisheries resources."	"Provide authoritative guidance on the management of water quality in Australia and New Zealand."	"Improve agency performance and accountability in managing water quality consistent with the Federal CWA and state water quality programs."	"Establish a framework for community action in the field of water policy and assisting member states in ensuring that the articles are implemented in accordance with the requirements of the directive."	"Specify a set of objectives and leading performance requirements for environmentally and socially responsible mine practice."
Mining specific?	Yes	No	No	No	Yes
Main study design points	• Conducted according to Schedule 5 requirements • Conducted using documented and validated methods • Reported using accepted standards of good scientific practice • Results submitted to the Minister of the Environment according to Schedule 5	• Examine current understanding • Define relevant indicators • Determine water/sediment quality values • Assess if draft water/sediment quality objectives are met	Undefined	Undefined Not designed to provide exact methodology but acts as a guide for developing and implementing monitoring and assessment systems.	• Baseline monitoring • Establish trigger levels • Record quality and quantity of waters destined for reuse • Credible methods • Appropriate equipment • Accredited laboratories • Adaptive monitoring • Community engagement

	Canada	Australia & New Zealand	United States	European Union	International
Monitoring timeline	**<6 months after mine activation** • Monitoring begins **Quarterly, >1 month apart** • Effluent characterization[1] • Water quality monitoring **Biannually for the first 3 years/annually thereafter[2]** • Sublethal toxicity tests **36–72-month phases[2]** • Biological monitoring • Sediment sampling (alongside benthic invertebrates)	• Baseline sampling prior to impact when possible • Account for seasonal and spatial variations • Use peer-reviewed literature to establish interim sampling strategy until variation is understood • Frequent enough to meet the program requirements but mitigate costs	• Timelines dictated at the state or local level • States and local jurisdictions report water quality monitoring and pollution to the USEPA under Section 305(b) of the CWA.	**Real Time[3]** • Water flow quantity **2 to 4-week intervals[3]** • Base water quality[4] • Nutrients[5] **1 or 3-month intervals[3]** • Phytoplankton **3 or 6-month intervals[3]** • Benthic algae **6 or 12-month intervals[3]** • Benthic Inverts • Macrophytes **12-month intervals[3]** • Fish	Frequent enough to account for seasonal and temporal variations
Effluent characterization	Detailed in Schedule 5 • Base water quality parameters[4] • Nutrients[5] • Metals[6] • Arsenic • Cyanide • Total suspended solids • Radium 226 • Chloride	Unspecified Refers to a case study of the Ranger Uranium Mine	Detailed list based on target resource in the USEPA's effluent guidelines for mineral mining (Costle et al., 1979). Includes: • Acidity (mandatory) • Total suspended solids • Fluorite, sulphur, iron, zinc • Turbidity	Not included Requires that point source pollution will monitor along the predicted flow path	• Mercury • Cyanide • Whole effluent toxicity Full list based on reuse purpose in the IRMA Water Quality Criteria End Tables (IRMA, 2018a)

	Canada	Australia & New Zealand	United States	European Union	International
Water quality monitoring	Detailed in Schedule 5 • Base water quality parameters[4] • Nutrients[5] • Metals[6] • Arsenic • Cyanide • Total suspended solids • Radium 226 • Chloride	• Base water quality parameters[4] • Salinity • Total dissolved solids • Turbidity • Transparency • Nutrients[5]	Detailed in USEPA Numeric Nutrient Water Quality Criteria (304a) (USEPA, 2021) • Base water quality parameters[4] • Nutrients[5] • Total/dissolved organic carbon • Hydrocarbons • Photosynthetic pigments • Spectral absorbance • Zeta potential • Turbidity	• Base water quality parameters[4] • Nutrients[5] • Biological/chemical oxygen demand • Dissolved organic carbon • Turbidity • Total suspended solids • Transparency	• Base water quality parameters[4] • Nutrients[5] • Dissolved organic carbon • Fluoride • Sulphate • Hydrogen sulphide • Cyanide • Chlorine • Chloride • Total suspended and dissolved solids • Metals[5]
Sediment monitoring	• Temperature • pH • Redox potential • Dissolved oxygen • Particle size distribution • Total organic carbon • Total metals • Sediment toxicity (optional)	• Pore waters • Mercury • Bioavailable metals • Particulate metals • Extractable organics • Volatile inorganic compounds	Detailed in EPA/600/R-99/064 (USEPA, 2020) May include: • pH/ammonia in pore water • Total organic carbon • Particle size distribution • Chemical/biological oxygen demand • Metals • Hydrocarbons	Select compounds based on water solubility (Log K_{ow} >5) Commonly include: • Organochlorinated compounds • PAHs • TBT • Trace Metals	Not included

	Canada	Australia & New Zealand	United States	European Union	International
Hydrologic monitoring	• Volume of effluent deposited from the final discharge point • Flow rate of effluent	• Timing • Frequency • Duration • Variability	Detailed by the United States Geological Survey (USGS, n.d.)	• Morphological conditions • Tidal regime • Flow dynamics and quantity • Residence time • Groundwater connectivity • Depth variation • Structure of shore and substrate[3]	• Enough water monitoring locations and frequencies to understand temporal changes • Flows and levels of surface water and springs/seeps • Volume of water discharged and extracted/pumped
Biological monitoring	• Fish populations/health • Benthic invertebrate communities • Mercury concentrations in fish tissue • Determine the magnitude/geographic extent and cause of effects	• Microalgae and blooms • Macrophyte transects • Seagrass monitoring • Mangrove forest health • Zooplankton sampling • Macroinvertebrate sampling and richness indexing • Fish tissue analysis • Fish communities • Habitat classification	See the USEPA Biological Assessment Tools for examples of biological surveys and indicator species.	• Phytoplankton • Benthic algae • Macroalgae • Angiosperms • Macrophyte transects • Benthic invertebrates • Fish composition, abundance, and age structure[3]	• Key biodiversity or other indicators • Sufficient detail and frequency to evaluate effectiveness of mitigation strategies • Timely and effective corrective action in consultation with relevant stakeholders

	Canada	Australia & New Zealand	United States	European Union	International
Sublethal toxicity testing	**Exposure** • Final discharge effluent **Metrics** • Survival • Growth • Reproduction **Species** • Algae • Plants • Invertebrates • Fish	Refers to ASTM (2002) *Standard Guide for Conducting Acute Toxicity Tests*	Refer to USEPA (2021) Aquatic Life Criteria	**Exposure** • Caging experiments **Metrics** • Contaminant analysis of tissue **Species** • Invertebrates	Not included
Participatory monitoring or community engagement	Recommended that the public be involved to the fullest extent possible at all mine sites in one of these capacities: • Shared authority • Joint planning • Public consultation • Information feedback • Provided Information	Not expressly included Queensland Monitoring and Sampling Manual states the purpose of water monitoring is to inform stakeholders and the community (Queensland Department of Environmental Science, 2018)	Unclear	• Detailed in WFD Guidance Document No. 8 (European Commission, 2009c) • Information supply and consultation with the public ensured. • Active involvement of stakeholders encouraged.	• Monitoring plans shall include consultations with stakeholders, including affected communities and external experts. • Stakeholder participation in assessments and management plans should be included.

	Canada	Australia & New Zealand	United States	European Union	International
Reporting requirements	**Study Design** • <1 yr after mine is subject to regulations[7] • Final study design <6 mo after notice of closure **Annual Reports** • Due March 31 of the following year **Interpretive Reports** • < 30 mo from becoming subject to regulations • 36–72 mo thereafter	Defined by state or territory environmental regulators Acceptable compliance reporting methods: • Raw data • Detailed discharge monitoring • Receiving environmental monitoring reports	States and local jurisdictions report water quality monitoring and pollution to the USEPA under Section 305(b) of the CWA.	• Covered in WFD Guidance Document No. 21 (European Commission, 2009b) • Reporting for all aspects of monitoring is required, including participatory monitoring.	Monitoring data shall be publicly available or made available to stakeholders upon request and be subject to independent review.

Note: These frameworks are best viewed in their entirety through the provided links.

[1] Acidity (pH) must be measured weekly >24 hrs apart

[2] Based on the results of the previous cycle

[3] Will vary slightly between environments (e.g., river, lake, transitional, coastal)

[4] Base water quality parameters = temperature, dissolved oxygen, conductivity, acidity, alkalinity

[5] Nutrients = total phosphorus, total nitrogen, ammonia, phosphates, nitrates, other metrics of phosphorus and nitrogen.

[6] Metals = aluminum, cadmium, iron, molybdenum, zinc, copper, lead, selenium, mercury (may include others).

[7] Biological monitoring study design submitted >6 months before it is conducted

3.2 MULTISTAKEHOLDER ENGAGEMENT

3.2.1 TRANSPARENT DATA COMMUNICATION

Transparent data communication between companies, governments, and communities is not simply making data publicly available. It is equally as important to ensure that data made available to the public is unbiased, free of jargon, and supported by a forum for questions and feedback. The aspect of a forum is especially vital in situations where access to the Internet may be limited, and dissemination of data may need to also occur simultaneously to dialogue on the results. Increased data transparency begins with collection, transport, and testing. Including community members throughout all stages of monitoring ensures tangible transparency that is clearly communicated between stakeholders. Part of transparent data communication is to ensure that the processing of samples into usable data is unbiased, and this typically will involve using external third-party testing. Many existing PMPs include community members in the transportation of samples from the site to the testing facility in order to ensure complete transparency throughout the chain of custody.

Governments can contribute to transparent data communication within the mining industry through leading by example. Transparency and accessibility of government-managed water monitoring databases allow the public to understand more about the natural environment while also providing companies with a best-practices methodology for creating their own accessible databases. Governments can also support companies and communities by providing training in data management to participatory monitoring groups and offering the centralization capacity needed for effective data management. On a legislative level, governments can support community engagement through making legal requirements for mining companies to follow best practices and consult with the public through all stages of a project.

3.2.2 COMMUNITY-BASED WATER MONITORING

CBWM and PMPs are often referred to interchangeably, but in fact, the former is only one component of the latter. CBWM refers to the gathering of specific information by local residents over a given period of time and is one of the most inclusive levels of stakeholder engagement that can be employed in a water monitoring program. CBWM is beneficial in many ways and has been used historically in areas that are remote or difficult to access in order to build up an understanding of that region's ecology and water quality. CBWM can also be an ideal vector for combining Traditional Ecological Knowledge with scientific studies. This allows communities access to scientific reinforcement for observed phenomena and companies or governments access to historical knowledge of the area as a measure of change. It is vital that clear terminology and transparent communication are established between the stakeholders in order to ensure comparability between methods.

CBWM can be the physical gathering of samples by community members, or it can be the gathering and dissemination of knowledge, experience, and suggestions. Methods that can be used to establish and run a CBWM program include independent or technically assisted surveys and sampling regimes, meetings and forums for knowledge exchange, and written or orally recorded observations. Governments can support the implementation of CBWM programs through legal requirements within permit conditions and by providing training to the public and companies on effective data management, sampling methodology, and scientific practice.

FIGURE 1. GOVERNMENT ACTIONS IDENTIFIED THROUGH COLLABORATIVE ENGAGEMENT SUPPORTED BY THE GORDON FOUNDATION, LIVING LAKES CANADA, AND WWF-CANADA

Capacity building	• Youth engagement and access. • Provide relevant training through existing programs or implement new ones. • Improve individual and organizational understanding of Indigenous Traditional Knowledge systems and the impacts of colonization. • Provide in-kind support to the programs by subsidizing monitoring and lab expenses.
Effective monitoring	• Governments should participate alongside other stakeholders in the design of water monitoring plans. • Promote and make available existing infrastructure including long-term datasets. • Indigenous Traditional Knowledge and local perspectives should be used as a tool for designing effective monitoring programs. • Resulting data should be open and accessible.
Data management	• Provide technical support for a clear and accessible combined data repository. • Establish data systems that reflect social and organizational information in addition to the scientific data. • Lead by example in maintaining transparent and available results from government monitoring programs. • Train CBWM participants in best practices for data management .
Regional and national collaboration	• Create positions that liase between regional and federal governments, companies, communities, and other stakeholders. • These positions may also be responsible for promoting CBWM, hosting collaborative meetings, and ensuring data accessibility. • Facilitate collaboration between NGOs, boards and councils, communities, and companies.
Using data to inform policy	• Coordinate support for CBWM throughout and accross applicable governmental jurisdiction(s). • Integrate results from CBWM programs into government-run databases and federal decision-making processes. • Promote engagement through tri-agency partnerships or similar government funded research.

Source: Pareja et al., 2019.

In 2019, the Gordon Foundation, Living Lakes Canada, and WWF-Canada produced a collaborative document that outlined recommendations for the federal government of Canada on the implementation and support of CBWM programs. This document, entitled *Elevating Community-Based Water Monitoring in Canada*, was produced by over 50 of the leading CBWM practitioners in Canada, including Indigenous and non-Indigenous community members, water scientists, and policy and data experts. The result is a set of actionable steps that the federal government can take to ensure that CBWM programs within Canada are encouraged, supported, and expanded. These steps include capacity building, effective monitoring, data management, regional and national collaboration, and using data to inform decision making (Figure 1). Although this document was specifically curated for the Canadian government, the suggestions made therein can be tailored to other countries and provide a good baseline for governments seeking to improve CBWM programs within their borders.

3.2.3 EXAMPLES OF PROACTIVE AND REACTIVE MULTISTAKEHOLDER MONITORING PROGRAMS

There are many examples globally of monitoring programs that involve community participation and engagement. As described previously in this section, these programs can be extremely beneficial for the mine in building community confidence, building understanding and trust between communities and governments, and providing a transparent forum through which communities can engage and be heard. In reviewing numerous case studies, a pattern of initiative emerged. In general, these programs are either implemented proactively, whether by the will of the company or imposed by governmental legislation, or reactively, either in response to an incident or to changing legislation or company values during the life of the mine. The results of the implementation are often similar, but wherever possible, it is recommended to incorporate participatory monitoring into a company's environmental protection plan as early in the life of the mine as possible. This prevents any initial erosion of trust between stakeholders and gets ahead of any spread of misinformation by increasing transparency. Summaries of two examples of proactive and reactive participatory monitoring program initiation are included in **TABLE 3**.[1]

1 For additional case studies, please refer to *Participatory Environmental Monitoring Committees in Mining Contexts* or *Participatory Water Monitoring: A Guide for Preventing and Managing Conflict*.

TABLE 3. REAL WORLD EXAMPLES OF PARTICIPATORY MONITORING PROGRAMS THAT WERE IMPLEMENTED IN THE EARLIEST STAGES OF MINE DEVELOPMENT (PROACTIVE) OR LATER IN THE LIFE OF THE MINE (REACTIVE)

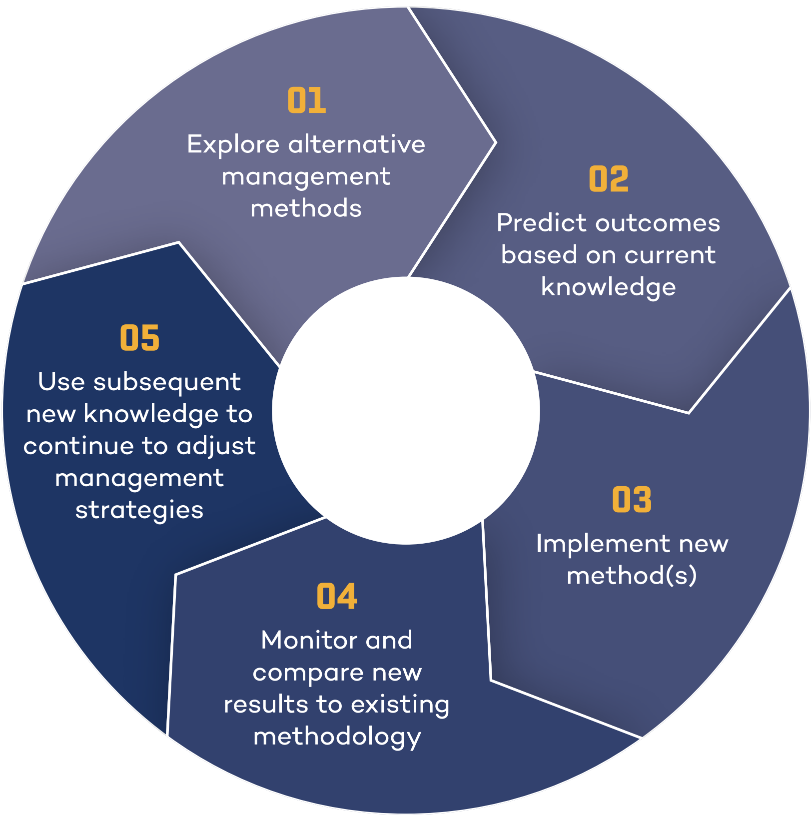
	Example reactive participatory monitoring programs		**Example proactive participatory monitoring programs**
Company/mine	**AngloGold Ashanti Cerro Vanguardia SA**	**Faro Mine, Yukon**	**Dominion Diamond Mines, Ekati**
Country	Argentina	Canada	Canada
Mine type	Gold and silver	Open-pit lead-zinc	Diamond, open pit
Implementation timeline	1990: Exploration begins 2003: An isolated leak resulted in elevated cyanide levels downstream 2008: Doors open policy implemented 2009: PMP begins	1969: Mining begins 1998: Bankruptcy declared and Government of Canada steps in 2003: Closure and remediation plan development begins 2004: Joint agreement between Canadian/Yukon governments, Ross River Dena Council, and Selkirk First Nation 2009: Responsibility for closure plan now through Yukon Environmental and Socio-Economic Assignment Act, Denison Environmental Services, and Indigenous/Northern Affairs Canada 2010: Participatory monitoring implemented through community updates 2016: Kaska Faro Secretariat established 2017: Public consultation forums begin	1994: Project referred to environmental impact study 1995: Environmental Impact Statement submitted 1996: Socio-economic and impact benefit agreements, including environmental protection measures, signed between the territorial government, local Indigenous communities, and mine operators 1997: Independent Environmental Monitoring Agency watchdog established and Environmental Agreement signed 1998: Production begins 1997-2021: Watchdog agency continues environmental monitoring and reports effects to be remediated 2020: Dominion enters insolvency protection due to COVID-19 shutdowns

	Example reactive participatory monitoring programs		Example proactive participatory monitoring programs
Company/mine	**AngloGold Ashanti Cerro Vanguardia SA**	**Faro Mine, Yukon**	**Dominion Diamond Mines, Ekati**
Assessed endpoints	• Heavy metals • Cyanides • Physical/chemical water parameters	• Sulphate • Zinc • Iron • Manganese • Lead • Mercury • Physical/chemical water parameters	• Fish populations • Microscopic waterborne animals and plants • Stream flows • Water samples • Wildlife effects monitoring program • Air quality monitoring program
Participatory monitoring	• Advertised by newspaper, TV, and radio • Volunteers are given training on objectives and methods of water monitoring • Monthly sampling events include participation of local volunteers along with the environmental staff at the mine • Sampling events include a preliminary question and concern forum • Participants may travel with the samples from the mine to the lab in Buenos Aires • Results are made available through the Rural Society of Puerto San Julian • Regular stakeholder meetings include results presentation and a forum for discussion and consultation	• Kaska Faro Secretariat represents the interests of local First Nations groups • Arrange community meetings, providing updated reports • Ensure community members are significantly represented in the workforce • Facilitate strategies to minimize negative community impacts • Public consultations on potential effects, proposed mitigations, site remediation, and the socio-economic assessment process	• Independent Environmental Monitoring Agency is an impartial third-party entity that represents local communities and First Nations • Compile and analyze environmental data and make recommendations to the company based on the results • Government compliance monitoring reports • Integrate Traditional Knowledge • Disseminate information to the public and concerns to the company

	Example reactive participatory monitoring programs		Example proactive participatory monitoring programs
Company/mine	**AngloGold Ashanti Cerro Vanguardia SA**	**Faro Mine, Yukon**	**Dominion Diamond Mines, Ekati**
Results	• Company benefited from positive change in public perception • Compliance with the International Cyanide Management Code and the International Organization for Standardization 14001* standard • Increased transparency, community confidence, and controls on pollution • Generation of employment opportunities • Community proposed initiatives	• Site remediation to begin in 2022	• Program is ongoing, and results will be communicated through the Independent Environmental Monitoring Agency website.
Source	AngloGold Ashanti, n.d.	Government of Canada, 2017	Environmental Monitoring Agency

3.3 ADAPTIVE MANAGEMENT

FIGURE 2. EXAMPLES OF EFFICIENT ADAPTIVE MANAGEMENT CYCLES



Adaptive management can be described as a systematic approach that continuously aims to improve resource management and adjacent monitoring programs through both planning for alternative management strategies and learning from previous management outcomes. This is more involved than simply tracking and changing management strategies when a policy is ineffective. Structured adaptive management follows the path shown in Table 1: identifying risks and associated thresholds for adaptive management response, monitoring performance and requirements for adaptive management implementation, and continuing to improve management strategies based on previous outcomes. It is important to include this level of managerial flexibility throughout the mine life cycle to ensure that the best practices are being tested and implemented at every opportunity. This process relates directly to participatory monitoring in taking feedback from communities and other stakeholders and applying this to alternative methodologies that will be implemented in the future to improve monitoring and prevention of potential contamination. This can also cycle into policy and legislation through the same feedback loop. A key step for government for the implementation of adaptive management in mining is defining and enforcing requirements for adaptive management throughout the mine life cycle (**SECTION 3**).

4.0 THE ROLE OF GOVERNMENTS

Governments are in a position to establish a framework through which mining companies are required to monitor and report on the impacts of their activities to regulating bodies and communities of interest. Integrating WMFs and associated requirements within governing policy and regulations can impose accountability, avoid confusion among stakeholders, and improve transparency and engagement with communities. Moreover, governments can adapt these monitoring requirements to specific risks associated with the nature of mining in the governing jurisdiction and require the development of adaptive management plans.

The overarching objective for government in the context of environmental management is to ensure that mining activities are carried out in ways that are protective of ecosystems and human health and the natural resources upon which they are dependent. Regarding mine effluent discharge, in particular, environmental protection is accomplished through two complementary steps. First, setting effluent quality and quantity criteria, and second, ensuring monitoring is conducted in a manner that validates that those effluent criteria are protective of the environment. Effluent criteria guidelines are not a focus of this document; however, they are discussed within IGF (2021). Furthermore, guidelines pertaining to mining effluent criteria are broadly available for governments to draw from, including international guidelines (e.g., the International Finance Corporation's [IFC's] *Environmental, Health, and Safety General Guidelines for Mining*, 2007) and jurisdiction-specific guidelines (e.g., the Government of Canada's *Metal and Diamond Mining Effluent Regulations*, 2002). These guidelines are typically based on scientific investigations of aquatic and human health thresholds, toxicity limits, downstream water uses, and best available (and economically viable) treatment options. This section will draw on international standards to identify several key actions that governments can take to forward the latter step: ensuring monitoring is conducted in a manner that validates effluent criteria as protective of the environment. Moreover, the section will discuss the implementation of WMFs and conclude with a discussion of tools available for governments.

4.2 IMPLEMENTATION OF WATER MONITORING FRAMEWORKS

4.2.1 GOVERNING STRUCTURE AND HIGH-LEVEL IMPLEMENTATION

Effective WMFs are simple, clear, consistent, and easy to implement—including consideration of whether the guidelines are appropriate to the scale and diversity of implementation. Water frameworks pertaining to EEM in mining (i.e., WMFs) should cover the ministries and agencies responsible for implementation, enforcement, the government's environmental objectives and goals, the required content of and review process for Environmental and Social Management Plans (ESMPs) and Environmental and Social Impact Assessments (ESIAs), permitting conditions and requirements, specific criteria for environmental protection, financial assurance requirements (particularly for mine closure), and penalties for non-compliance. It is important that there is coordination across ministries to be efficient, effective, and consistent. This may include centralizing functions, designating a lead agency, or training and education.

Country-specific conditions and capacities for implementing the legal framework for EEM should be an underlying theme when developing and revising the legal framework. Implementation of the legal framework will have the most chance of achieving a country's sustainability goals if it is simple, clear, consistent, and easy to implement. Opportunities should also be considered in the legal framework for requiring financial and independent technical support from mining proponents for information review and assessments, should the government be lacking the resources needed to fully carry out these functions.

4.2.2 SITE-LEVEL IMPLEMENTATION

Beyond the higher-level legal framework, ESIAs and ESMPs (Box 5) are both critical tools for ensuring environmental effects objectives can be met and have sufficient mitigation measures in place pertaining to associated risks. Governments should provide clear guidelines to proponents on what is required from them in their ESIAs and ESMPs; these guidelines will help to align the ESIAs and ESMPs with the government's own environmental management objectives (IGF, 2020).

Further information regarding ESIAs and ESMPs can be found within IGF's two *Guidance for Governments:* *Improving Legal Frameworks for Environmental and Social Impact Assessment and Management* (2020) and *Environmental Management and Mining Governance* (2021).

BOX 5. ESIAS AND ESMPS

ESIAs are used to identify and evaluate the potential environmental and social impacts of a proposed mining project prior to the granting of a mining licence or permit (IGF, 2020). While the legal frameworks that guide the development of ESIAs will vary across jurisdictions, broadly, these assessments should describe in ample detail the baseline conditions at the site, possible risks and impacts associated with proposed project-related activities, and proposed mitigation and management actions required to limit impacts to acceptable levels. ESIAs, as with all environmental management, are grounded in risk management: systematically evaluating the risks that might emerge around particular project activities or interventions.

The proposed mitigation and management measures to respond to and address project risks and impacts will form the basis of the project's ESMP (IGF, 2020). This plan, or plans, should provide the details of how the proponents will implement across the mine life cycle the protection and mitigation measures they have committed to, including any relevant legal commitments.

Detailed discussion regarding ESIAs and ESMPs is found within IGF (2020).

4.2.3 TECHNICAL GUIDANCE DOCUMENTS

As reviewed throughout **SECTION 2**, it is common for governments to publish technical guidance documents to accompany governing WMF policies and regulations. Issuance of technical guidance is a beneficial mechanism to facilitate WMF implementation and promote consistent practices. The purpose of a technical guidance document is not to stipulate regulations or requirements but instead to support mining companies and various branches of government in understanding how best to adhere to and remain compliant with governing WMFs.

Examples of technical guidance documents that include the EEM framework are *Metal Mining Technical Guidance for Environmental Effects Monitoring* (ECCC, 2012), the EU WFD Guidance Document No. 7 (European Commission, 2003), the Australian and New Zealand WQMF web guide (Queensland Government, 2018), and various guidance documents published from the USEPA covering how to adhere to the CWA. These guidance documents are described in the context of associated legislation in **SECTION 2** and are briefly summarized in the context of applicability as resources to IGF member governments in **SECTION 3.3**. Typically, technical guidance documents will cover the following themes: steps to promote study design compliance with requirements; detailed methodology for effluent characterization, water quality monitoring, sublethal toxicity testing, sediment monitoring, and biological monitoring; BMPs and standard operating procedures; and steps for investigation of cause studies required should the monitoring program find significant effects.

Technical guidance documents should be considered living documents, which may be updated when improved methods or additional scientific knowledge warrants modification thereof. Publication of guidance documents should be encouraged among governments, and where possible, should take advantage of the wealth of scientific literature and pre-existing guidance documents already published by fellow governing bodies.

4.3 TOOLS FOR GOVERNMENTS

The following table provides links to and descriptions of resources for governments aiming to develop and implement WMFs and PMPs pertaining to EEM in the mining sector. Although the bulk of the cited resources are targeted at specific jurisdictions and/or industries, the principles and guidelines are generally universal and are thus transferable to governments looking to develop or implement WMFs and PMPs within the legislation, policy, and regulation specific to their jurisdictions.

TABLE 4. SUMMARY OF RESOURCE DOCUMENTS AVAILABLE TO GOVERNMENTS COVERING DIFFERENT TOPICS IN MINE WATER QUALITY AND MONITORING

biological monitoring | water monitoring | administration and management tools | community engagement

Resource	Content Description	Key topics
British Columbia Ministry of Environment (Charmichael et al., 2016) *Water and Air Baseline Monitoring Guidance Document for Mine Proponents and Operators*	• Requirements and considerations for baseline monitoring studies associated with new mine development. • Directed at mining entities within British Columbia, Canada; however, it provides a review of standards that act as a guideline for governments on baseline monitoring.	biological monitoring, water monitoring
Crown-Indigenous Relations and Northern Affairs Canada (Zajdlik et al., 2009) *Guidelines for Designing and Implementing Aquatic Effects Monitoring Programs for Development Projects in the Northwest Territories*	• This guidance provides detailed technical guidelines for designing and implementing aquatic EEM programs.	water monitoring
ECCC (2012) *Metal Mining Technical Guidance for Environmental Effects Monitoring*	• A guidance for mining companies aiming to implement EEM regulations. • Although directed at mining companies, this resource provides universally applicable technical guidelines for EEM that can be a resource for governments.	biological monitoring, water monitoring, administration and management tools
European Commission (2003) *Guidance Document No. 7: Monitoring under the Water Framework Directive*	• Although directed toward member states aiming for compliance with the EU WFD, this guidance reviews in detail what is required for effective monitoring of, among other things, surface water monitoring, including what, when, how, where, and why.	water monitoring, administration and management tools
European Commission (2009c) *Guidance Document No. 8: Public Participation in relation to the Water Framework Directive*	• As with the suite of WFD Guidance Documents, No. 8 is directed at EU member states; however, it reviews in detail what is required for effective public participation in watershed-level water management. These principles are transferable to governments and agencies with similar goals of public participation.	administration and management tools, community engagement

Resource	Content Description	Key topics
European Commission (2009a) Guidance Document No. 19: Guidance on Surface Water Chemical Monitoring under the Water Framework Directive	• This guidance aims to clarify chemical monitoring issues concerning priority substances and other chemical substances discussed in Guidance Document No. 7. • It reviews a detail-oriented approach to sampling, analysis, and investigatory methods.	
European Commission (2010) Guidance Document No. 25: on Chemical Monitoring of Sediment and Biota under the Water Framework Directive	• Although directed at EU member states, regarding the WFD, this guidance remains a valuable guide for external governments for defining monitoring regimes to monitor sediment and biota as EEM tools.	
European Commission (2014) Guidance Document No. 32 on Biota Monitoring under the Water Framework Directive	• This resource elaborates on EU WFD Guidance Document No. 25 by providing supplementary guidance on the design and implementation of biota monitoring. It covers the design of monitoring programs, sample collection, expression of data, and how data are used to undertake compliance assessments.	
The Gordon Foundation (2018) Elevating Community-Based Water Monitoring in Canada	• Actionable steps that government can take to show leadership and support in advancing community-based monitoring of freshwater ecosystems—aimed at the Canadian federal government; however, they are generally universal strategies.	
IFC (2007) Environmental, Health, and Safety Guidelines	• Review of key issues in mine water management, effluent quality guidelines, assimilative capacity and monitoring of receiving environment, and guidelines for community consultation.	
IFC (2008) Participatory Water Monitoring: A Guide for Preventing and Managing Conflict	• Discusses the need for PMPs and the components of effective PMPs pertaining to the extractives industry and the large-scale agricultural industry.	
IRMA (2018) Standard for Responsible Mining IRMA-STD-001	• Standards on baseline monitoring, adaptive management, quality control and assurance, and community engagement. • The standard is focused on the industry scale; however, principles are transferable and can be applied at the legislative scale.	

Resource	Content Description	Key topics
Queensland Government (2018) *Water Monitoring and Sampling Manual: Environmental Protection (Water) Policy 2009*	• Detailed methods and standards for sample collection, quality assurance and control, and data management for use by government agencies and other organizations. • Additional focus to ensure that monitoring data available to all stakeholders is consistent and scientifically accurate.	
United Nations Development Programme (2019) *Participatory Environmental Monitoring Committees in Mining Contexts*	• A series of case studies pertaining to PMP in the mining sector. • The case studies reviewed are focused on Latin America; however, this provides an example of universally applicable best practices.	
USEPA (2011) *A Primer on Using Biological Assessment to Support Water Quality Management*	• A discussion of technical tools and approaches for developing strong biological assessment programs. • Presents examples of successful application of those tools.	

5.0 CONCLUSIONS

This document acts as a repository and synthesis of international resources on the interaction between mining entities and governments with respect to EEM. The main purpose is to serve as a nexus point for governments seeking to enact or improve mine water EEM within their jurisdictions. Combining existing programs, international standards, and site-by-site adaptations and alterations will ensure that these implemented methods will address local concerns but maintain cross-border comparability.

Effective WMFs clearly identify the requirements for monitoring, reporting, adaptive management, and stakeholder engagement. When properly defined and integrated within legal frameworks, these components create a transparent and inclusive system that detects and measures changes to aquatic ecosystems by evaluating the effect of mine effluents on water quality, fish, fish habitat, and fisheries resources. The following list identifies five key actions for governments that also act as the main takeaway points from this report.

KEY ACTIONS FOR GOVERNMENTS

1. Monitoring requirements: Defining the structure of the monitoring program

- Requirements should be consistent with the risk imposed by the mining operations.
- Requirements should consider the sensitivity of different receiving environments and risks specific to a given jurisdiction.
- Water chemistry metrics should be included but cannot be used in place of biological monitoring to determine biological impacts.
- Water chemistry and biological monitoring are best used as complementary metrics, and biological monitoring should include multiple trophic levels.
- Sampling frequency should encapsulate seasonal and hydrological variability of the specific area in question, which can be determined through baseline monitoring.
- Sampling locations should include points of effluent release, multiple points within the potentially affected area, and reference sites that are similar to but hydrologically separated from the potentially affected area.

- Identify required quality control and quality assurance practices, including sampling procedures, analytical methods, laboratory accreditation, duplicates, and blank samples.
- For more information, see **SECTION 2.2** and **SECTION 3.3**.

2. Baseline monitoring: Setting requirements to define benchmark conditions

- Governments should clearly define baseline study requirements in legal frameworks, policies, and regulations.
- Baseline data should be collected prior to any mining or construction activities to establish a benchmark condition.
- Baseline data is used to assess the hydrological variability of a region and subsequently establish sample regimes.
- Informative to dilution and plume modelling, which supports ESIAs and risk assessment components of the permitting process (see Box 5).
- Requirements for baseline studies should describe monitoring parameters and the length of time an area should be monitored.
- If baseline data was not collected prior to the establishment of an existing mine, alternatives should be defined (e.g., reference sam-pling sites).
- Baseline sampling does not replace the inclusion of reference sites throughout the mine, as the latter allow for continued monitoring of changes in reference conditions caused by effects extraneous to the mine.
- Please refer to IRMA Chapter 4.2 for more information.

3. Thresholds for response: Defining trigger levels and adaptive management

- Monitoring programs should identify how data is to be interpreted and at which threshold or level of significance results trigger a response.
- International standards are available to support governments in defining these thresholds (e.g., IRMA, 2018).
- Incorporate broader guidelines at the regulation level that trigger changes to monitoring requirements based on past results.
- Pre-defined thresholds of water quality or biological response should trigger adjustments to sampling frequency and/or sites.
- Adaptive management requirements should ensure that monitoring efforts are commensurate with the degree of risk to the receiving environment.
- Include requirements for adaptive management plan submission and review during the permitting and ESIA phases and for the remainder of the mine's life.
- Development and revision of adaptive management plans should include community and stakeholder engagement.
- For tools to support governments in identifying response thresholds, see **SECTION 3.3**.
- For best practices and international standards, see **SECTION 2**.

4. Reporting requirements: Reviewing results and tracking compliance

- Define a schedule of reporting frequency.
- Frequency should be tailored to ensure timely identification of potential risks but also consider the availability of government resources to review the data.
- Outline an approved style of reporting and data communication.
- Required reporting style should include a clear analysis of temporal trends.
- Trend analysis allows for identification, mitigation, and prevention of potential environmental effects.
- An in-depth interpretation of data and progress of the monitoring program should be required on a less frequent basis (e.g., annually).

5. PMPs: Engaging communities and stakeholders

- Engagement within a water monitoring program helps promote community trust in government and industry.
- Governments must ensure that mining companies are beholden to take appropriate steps in community and stakeholder engagement.
- Engagement should exist from the permitting stages through to the closure of a mine and any subsequent monitoring.
- Participatory monitoring can range from information sessions and data sharing to direct participation in sample collection and transport.
- Degree and nature of a PMP should be based on environmental risks of an operation, community interest, and community proximity.
- Community context can be defined through a series of qualifiers defined within legal frameworks.
- Results from PMPs should be reviewed and evaluated alongside all EEM data on a regular reporting schedule.
- Online tools can be a key part of a PMP and can be beneficial in consolidating water data, tracking regional trends, and improving regional planning.
- PMPs can be financially supported by the mining company.
- For more detailed information, refer to **SECTION 2**.

REFERENCES

AngloGold Ashanti. (n.d.). *Case study: Mine has healthy relationship with environment in Patagonia*. https://www.aga-reports.com/12/os/case-study/patagonia-biodiversity

ASTM International. (2002). *Standard guide for conducting acute toxicity tests on test materials with fishes, macroinvertebrates, and amphibians* (E 729-96). http://www.poseidonsciences.com/ASTM_E_729.pdf

Australian and New Zealand Guidelines for Fresh and Marine Water Quality. (n.d.) *Water quality management framework: Assessing discharges from a uranium mine*. https://www.waterquality.gov.au/anz-guidelines/resources/case-study/ranger-mine

Charmichael, B, Hudson, P., Matscha, G., Schell, C., Stewart, C., Tamblyn, G., Weinstein, B., Wilkes, B., & van Geloven, C. (2016). *Water and air baseline monitoring guidance document for mine proponents and operators*. Ministry of the Environment, Government of British Columbia. http://www2.gov.bc.ca/assets/gov/environment/waste-management/industrial-waste/industrial-waste/water_air_baseline_monitoring.pdf

Copeland, C. (2016). *Clean Water Act: A summary of the law* (7-5700, RL30030). Congressional Review Service. https://sgp.fas.org/crs/misc/RL30030.pdf

Costle, D. M., Jorling, T. C., Davis, S. T., Schaffer, R. B., & Kirby, R. G. (1979). *Development document for effluent limitations guidelines and new source performance standards for the mineral mining and processing point source category*. United States Environmental Protection Agency. https://www.epa.gov/sites/production/files/2015-09/documents/mineral-mining_dd_1979.pdf

de Mata Pavione, P. Gonçalves da Costa, K., Perônico, C., McMaste, M. E., Parrott, J. L., Hewitt, L. M., Munkittrick, K. R., Candido Cardoso Baretto, F., Hollanda Basilo, T., Paes HGomes, M., Reis Filho, R. W., & Furley, T. H. (2019) Development of environmental effects monitoring protocol in Brazil: A fish guide study of three river estuaries. *Environmental Monitoring & Assessment, 191,* (11). https://pubmed.ncbi.nlm.nih.gov/31630267/

Environment and Climate Change Canada. (2010). *Pulp and paper environmental effects monitoring (EEM) technical guidance document*. Government of Canada. https://www.canada.ca/content/dam/eccc/migration/main/esee-eem/3e389bd4-e48e-4301-a740-171c7a887ee9/pp_full_versionenglish-5B1-5D-final-2.0.pdf

Environment and Climate Change Canada. (2012). *Metal mining technical guidance for environmental effects monitoring* (Cat no. En14-61/2012E-PDF). Government of Canada. https://www.ec.gc.ca/esee-eem/AEC7C481-D66F-4B9B-BA08-A5DC960CDE5E/COM-1434---Tec-Guide-for-Metal-Mining-Env-Effects-Monitoring_En_02%5b1%5d.pdf

European Commission. (2003). *Guidance document No. 7: Monitoring under the Water Framework Directive*. Water Framework Directive (2000/60/EC). https://circabc.europa.eu/sd/a/63f7715f-0f45-4955-b7cb-58ca305e42a8/Guidance%20No%207%20-%20Monitoring%20(WG%202.7).pdf

European Commission. (2009a). *Guidance document No. 19: Guidance on surface water chemical monitoring under the water framework directive*. Water Framework Directive (2000/60/EC). https://circabc.europa.eu/sd/a/e54e8583-faf5-478f-9b11-41fda9e9c564/Guidance%20No%2019%20-%20Surface%20water%20chemical%20monitoring.pdf

European Commission. (2009b). *Guidance document No. 21: Common implementation strategy for the water framework directive*. Water Framework Directive (2000/60/EC). https://circabc.europa.eu/sd/a/253e424b-591b-4ad9-b9b1-4dd64ff4f45c/Guidance%20document%2021_Guidance%20for%20reporting%20under%20the%20WFD.pdf

European Commission. (2009c). *Guidance document No. 8: Public Participation in relation to the Water Framework Directive*. Water Framework Directive (2000/60/EC). https://circabc.europa.eu/sd/a/0fc804ff-5fe6-4874-8e0d-de3e47637a63/Guidance%20No%208%20-%20Public%20participation%20%28WG%202.9%29.pdf

European Commission. (2010). *Guidance document No. 25: On chemical monitoring of sediment and biota under the Water Framework Directive*. Water Framework Directive (2000/60/EC). https://circabc.europa.eu/sd/a/7f47ccd9-ce47-4f4a-b4f0-cc61db518b1c/Guidance%20No%2025%20-%20Chemical%20Monitoring%20of%20Sediment%20and%20Biota.pdf

European Commission. (2014). *Guidance document No. 32: On biota monitoring (the implementation of EQSBiota under the Water Framework Directive*. Water Framework Directive (2000/60/EC). https://circabc.europa.eu/sd/a/62343f10-5759-4e7c-ae2b-12677aa57605/Guidance%20No%2032%20-%20Biota%20Monitoring.pdf

European Commission. (2019). Water Framework Directive and Floods Directive Implementation Reports. https://ec.europa.eu/environment/water/water-framework/impl_reports.htm#fourth

European Parliament & Council of the European Union. (2000). Directive 2000/60/EC: Water Framework Directive. *Official Journal of the European Communities*. https://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX%3A32000L0060

Government of Australia. (2007). Commonwealth Water Act. No. 137, 2007.

Government of Canada. (1985). Fisheries Act (R.S.C., 1985, c. F-14)

Government of Canada. (2017). *Background on the Faro Mine Remediation Project*. https://www.rcaanc-cirnac.gc.ca/eng/1497875747120/1537555534918#sec1

Government of Canada. (2002). Metal and Diamond Mining Effluent Regulations (SOR/2002-222).

Government of New Zealand. (2020). Resource Management (National Environmental Standards for Freshwater) Regulations 2020. LI 2020/174.

Hu, A. & Apblett, A. (2014). Nanotechnology for water treatment and purification. *Lecture Notes in Nanoscale Science and Technology, 22*. https://link.springer.com/book/10.1007/978-3-319-06578-6

Initiative for Responsible Mining Alliance. (2018). *IRMA Standard for Responsible Mining* (IRMA-STD-001). https://responsiblemining.net/wp-content/uploads/2018/07/IRMA_STANDARD_v.1.0_FINAL_2018-1.pdf

Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development. (2013). *IGF mining policy framework: Mining and sustainable development*. https://www.igfmining.org/wp-content/uploads/2018/08/MPF-EN.pdf

Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development. (2020). *IGF guidance for governments: Improving legal frameworks for environmental and social impact assessment and management*. https://www.iisd.org/sites/default/files/publications/igf-guidance-for-governments-esia-en.pdf

Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development. (2021). *IGF guidance for governments: Environmental management and mining governance*. https://www.iisd.org/system/files/2021-05/igf-guidance-governments-environmental-management-mining-en.pdf

International Council on Mining and Metals. (2021). *Environmental stewardship*. https://www.icmm.com/en-gb/environmental-stewardship/water

International Finance Corporation. (2007). *Environmental, health, and safety guidelines*. World Bank Group. https://www.ifc.org/wps/wcm/connect/topics_ext_content/ifc_external_corporate_site/sustainability-at-ifc/policies-standards/ehs-guidelines

International Institute for Sustainable Development. (2015). *Water-energy-food resource book for mining: Assessing and tracking the benefits and impacts of mining on water-energy-food security*. https://www.iisd.org/publications/water-energy-food-resource-book-mining

International Network for Acid Prevention. (2014). *Global acid rock drainage guide*. Global Alliance. http://www.gardguide.com/images/5/5f/TheGlobalAcidRockDrainageGuide.pdf

International Organization for Standardization. (2018). *ISO and water*. https://www.iso.org/files/live/sites/isoorg/files/store/en/PUB100293.pdf

Initiative for Responsible Mining Assurance. (2018a). *IRMA Water Quality Criteria End Tables*. https://responsiblemining.net/wp-content/uploads/2018/08/IRMA_WATER-QUALITY-TABLES_2018.pdf

Initiative for Responsible Mining Assurance. (2018b). *The standard for responsible mining*. https://responsiblemining.net/resources/

Munkittrick, K. R., Arciszewski, T. J., & Gray, M. A. (2019). Principles and challenges for multi-stakeholder development of focused, tiered, and triggered, adaptive monitoring programs for aquatic environments. *Diversity, 11*(9). https://www.mdpi.com/1424-2818/11/9/155

Office of the Compliance Advisor/Ombudsman. (2008). *Participatory water monitoring: A guide for preventing and managing conflict*. International Finance Corporation. https://commdev.org/publications/participatory-water-monitoring-a-guide-for-preventing-and-managing-conflict-advisory-note/

Pareja, C., Xavier, A., & Daitch, S. (2019). *Participatory Environmental Monitoring Committees in mining contexts: Lessons from nine case studies in four Latin American countries*. United Nations Development Programme. https://www.undp.org/content/undp/en/home/librarypage/poverty-reduction/participatory-environmental-monitoring-committees-in-mining-cont.html

Queensland Department of Environment and Science. (2018). *Monitoring and sampling manual: Environmental Protection (Water) Policy*. Department of Environment and Science Government. https://environment.des.qld.gov.au/__data/assets/pdf_file/0031/89914/monitoring-sampling-manual-2018.pdf

United States Department of Agriculture. (2012). *National best management practices for water quality management on national forest system lands*. Volume 1: National Core BMP Technical Guide. Forest Service, FS-990a. https://www.fs.fed.us/naturalresources/watershed/pubs/FS_National_Core_BMPs_April2012.pdf

United States Environmental Protection Agency. (2000). *Methods for measuring the toxicity and bioaccumulation of sediment-associated contaminants with freshwater invertebrates* (2nd ed.) (600/R-99/064). https://nepis.epa.gov/Exe/ZyPDF.cgi/30003SBA.PDF?Dockey=30003SBA.PDF

United States Environmental Protection Agency. (2011). *A primer on using biological assessments to support water quality management*. EPA Office of Water, Office of Science and Technology. https://www.epa.gov/sites/default/files/2018-10/documents/primer-using-biological-assessments.pdf

United States Environmental Protection Agency. (2017). *Water quality standards handbook* (EPA-823-B-17-001). EPA Office of Water, Office of Science and Technology. https://www.epa.gov/wqs-tech/water-quality-standards-handbook

United States Environmental Protection Agency. (2021). *National recommended water quality criteria: Aquatic life criteria table.* https://www.epa.gov/wqc/national-recommended-water-quality-criteria-aquatic-life-criteria-table#table

United States Geological Survey. (n.d.). *How the U.S. Geological Survey monitors water.* https://www.usgs.gov/special-topic/water-science-school/science/how-us-geological-survey-monitors-water?qt-science_center_objects=0#qt-science_center_objects

United States of America Federal Safe Drinking Water Act (1996). Title XIV of Public Health Service Act. P.L. 116-92.

United States of America Federal Water Pollution Control (1972). P.L. 92-500.

World Economic Forum. (2011). *Water security: The water-food-energy-climate nexus*. World Economic Forum Water Initiative. http://www3.weforum.org/docs/WEF_WI_WaterSecurity_WaterFoodEnergyClimateNexus_2011.pdf

WWF-Canada, Living Lakes Canada & The Gordon Foundation. (2019). *Final recommendations: Elevating community-based water monitoring in Canada*. https://datastream.cdn.prismic.io/datastream/cdda94bb-36f6-4f9f-9b26-8d2dbebac2b4_EN_Recommendations_Final_web.pdf

Zajdlik B, MacDonald DD, & INAC Water Resources (2009). *Guidelines for designing and implementing aquatic effects monitoring programs for development projects in the Northwest Territories: Recommended procedures for developing detailed designs for aquatic effects monitoring programs* (Vol. 4) (AEMP Technical Guidance Document). https://www.enr.gov.nt.ca/sites/enr/files/aemp_technical_guidance_document_volume_4.pdf

IGF

INTERGOVERNMENTAL FORUM
on Mining, Minerals, Metals and
Sustainable Development