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Post decommissioning monitoring of eleven uranium mines – the development of an integrated and adaptive environmental monitoring programme to address multiple sites over time

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Abstract

Rio Algom Ltd. and Denison Mines own and operated 11 uranium mines all within the Serpent River Watershed (Elliot Lake, ON). The mines operated from the late 1950s to the mid 1960s and again from the early 1970s to 1990s when the mines ceased operations. At the time of decommissioning, each mine had its own environmental monitoring programme which had evolved over the operating life of the mine and did not necessarily reflect the objectives associated with monitoring of decommissioned sites. In order to assess the effectiveness of the decommissioning plans to achieve predicted conditions and the cumulative effects within the watershed, a single watershed monitoring programme was developed in 1999: the Serpent River Watershed Monitoring Programme (SRWMP) which focused on water and sediment quality, and biological response over time. In order to integrate watershed conditions with source releases from the tailings management areas (TMAs) and the operations of the TMAs, two companion programmes were developed: 1) the Source Area Monitoring Programme (SAMP) and 2) the TMA Operational Monitoring Programme (TOMP). Through the development of programmes that were objective driven, more meaningful data have been provided to allow for informed decision making by the mines and the federal and provincial regulators which have jurisdiction at these sites. When the programme was developed, the removal of redundancies and inefficiencies in the existing monitoring programmes generated an initial cost savings of about 60 to 70% over operational monitoring costs. Through the incorporation of acceptability criteria and response triggers that allow the scope of the programme to retract in response to improvement in environmental conditions, the scope and cost of the programme has been further reduced by 30 to 40% while still generating relevant data for future decision making. Environmental conditions within the Serpent River Watershed have improved dramatically over the past ten years and through the effective implementation of the SRWMP, these improvements have been documented and accepted by regulators and the public.

1 Introduction

1.1 Site history

Uranium mining was undertaken in the Elliot Lake area of Northeastern Ontario for approximately forty years. The mines generally operated from the late 1950s to the mid 1960s and again from the early 1970s until the early 1990s when most of the mines ceased operations. In total, there are eleven decommissioned mining operations located in the Serpent River Watershed (Quirke I and Quirke II, Panel, Denison, Spanish-American, Can-met, Stanrock, Stanleigh, Milliken, Lacnor, Nordic, Buckles), and one other (Pronto) is located near the north shore of Lake Huron (Figure 1). Associated with the mine sites are eleven decommissioned tailings management areas (TMAs) of which seven are flooded (Denison TMA-1, Denison TMA-2, Panel, Quirke, Spanish-American, Milliken and Stanleigh) and four are vegetated (Lacnor, Nordic, Pronto and Stanrock). Tailings were also historically deposited in Buckles Creek adjacent to the Nordic TMA and Sheriff Creek adjacent to the Milliken Mine. These areas are included within licensed areas.

Final decommissioning and closure of the Quirke, Panel, Denison, Stanrock and Spanish-American properties was undertaken between 1992 and 1996. The Stanleigh Mine and the historic properties (i.e. mine sites that operated in the 1950s and 1960s) were decommissioned from 1997 to 2000 and, in the case of Stanleigh, decommissioning was not complete until 2002 (i.e. when flooding was completed). The TMAs are currently in long-term care and maintenance following closure that includes effluent treatment, source (i.e. TMA basins and seepage) and watershed (water, sediment and benthos) monitoring and TMA care and maintenance. All of the TMAs discharge to the Serpent River Watershed, except Pronto which discharges to the north shore of Lake Huron. The long-term care and maintenance of these sites is the responsibility of Rio Algom Ltd. and Denison Mines Inc.

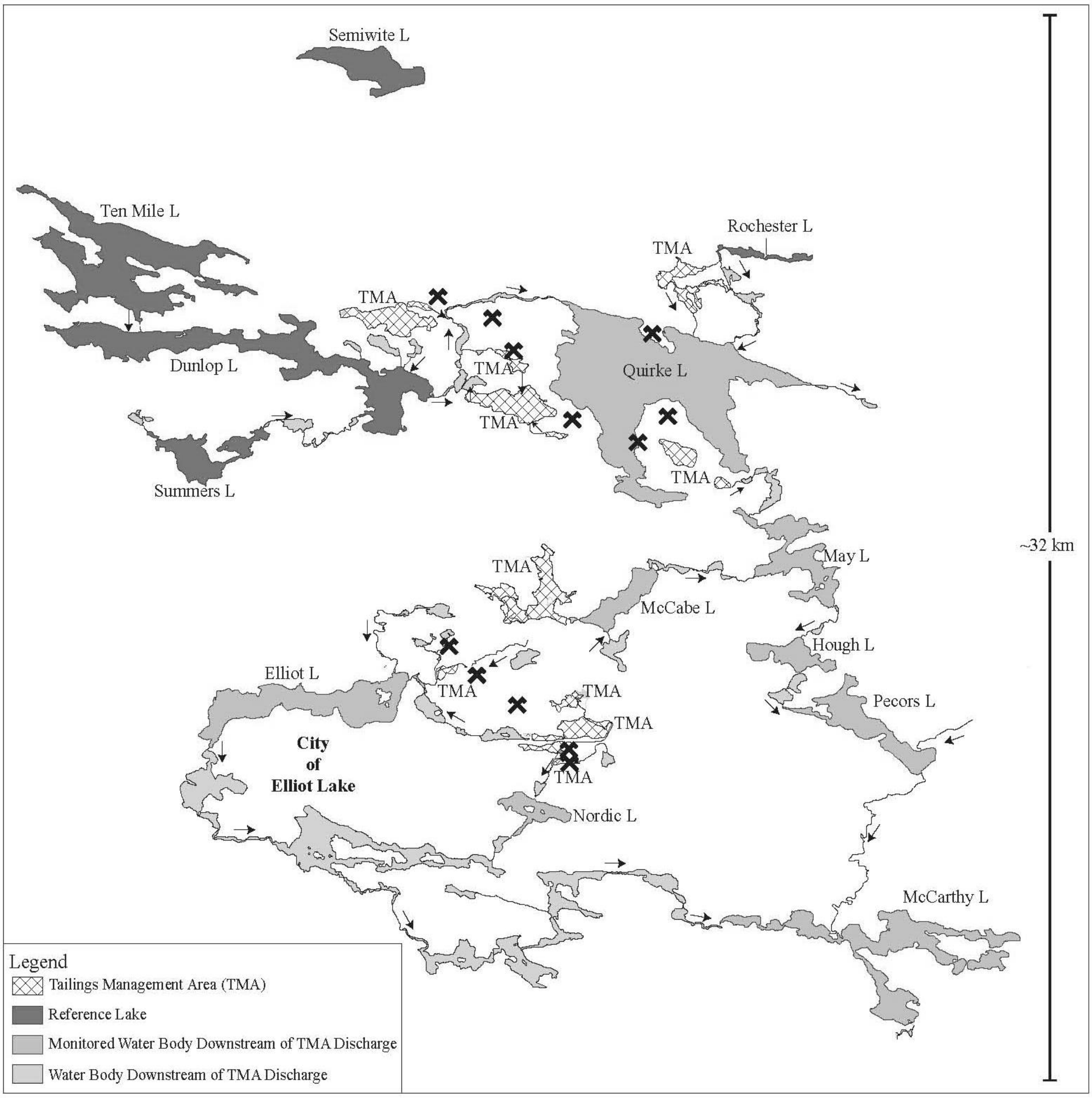


Figure 1 Lakes assessed within the SRWMP 1999–2009; TMAs assessed within the SAMP and TOMP 2003–2009

1.2 Development of a monitoring framework

At the time of closure, each mine had its own environmental monitoring programme conducted under an operating license from the Atomic Energy Control Board (AECB), the predecessor of the Canadian Nuclear Safety Commission (CNSC), and/or a Certificate of Approval (CofA) from the Ontario Ministry of the Environment (MOE). These programmes had been developed over the life of the mines with monitoring stations and parameters added to address specific concerns or interests at the time. There was no consistency in methods (parameters, stations, method detection limits) between programmes and the two companies were sometimes monitoring similar locations. Both mining companies and the regulators recognised that a new approach to monitoring was required post operationally. This provided an opportunity to design programme(s) for specific objectives that would generate environmentally relevant data and allow for a consistent approach to track the performance of the decommissioning plans. The revised approach to monitoring also allowed the opportunity to design monitoring programmes that could be modified over time to respond to changes in environmental conditions i.e. improved water quality.

In 1997, the two companies began reviewing the existing environmental data, together with predicted changes associated with decommissioning, the latter of which was outlined in Environmental Impact Statements (EIS). Through this process a monitoring framework was developed which integrated three monitoring programmes:

1. The Serpent River Watershed Monitoring Programme (SRWMP) (Beak International Inc., 1999) is a receiving environment programme that includes water, sediment, benthic invertebrates and fish (initially) monitoring at near-field and far-field locations within the watershed to assess mine-specific and cumulative mine related effects. Water is sampled routinely with sediment and biological monitoring conducted every five years. The programme was approved and implemented in 1999.
2. The Source Area Monitoring Programme (SAMP) (Minnow Environmental Inc., 2002a) was developed to monitor the nature and quantity of constituents being discharged from the TMAs to the Serpent River Watershed (SRW). Therefore, the programme focuses on monitoring stations that represent the final points of release from each TMA to the watershed. The SAMP was designed to complement the SRWMP terms of monitoring locations, variables and sampling frequency, and thus ensure that the overall monitoring framework is comprehensive and interpretable. The SAMP was approved in 2002 and implemented 1 January 2003.
3. TMA Operational Monitoring Programme (TOMP) (Minnow Environmental Inc., 2002b). The TOMP was designed to track TMA performance relative to predictions and support decisions regarding the management of the TMAs. The TOMP programme was implemented concurrently with the SAMP in January 2003.

The end result of the rationalised monitoring programmes for the Elliot Lake mine sites was the development of a comprehensive monitoring and management framework that clearly defined and delineated the purpose for all monitoring activities. The objective of this framework was to integrate monitoring data from the TOMP, SAMP and SRWMP to provide an assessment of TMA performance and the conditions in the downstream Serpent River Watershed relative to TMA sources.

Each of the monitoring programmes has been developed in consultation with and approved by the Elliot Lake Joint Review Group (JRG). The JRG is a multi-stakeholder committee comprised of representatives from the Canadian Nuclear Safety Commission (CNSC), Department of Fisheries and Oceans (DFO), Environment Canada (EC), Ontario Ministry of Environment (MOE), Ontario Ministry of Natural Resources (MNR), Ontario Ministry of Labour (MOL) and the Ontario Ministry of Northern Development, Mines and Forestry (MNDMF). The JRG continues to participate in the programmes through the review of monitoring and design reports for the SAMP, the TOMP, and the SRWMP.

1.3 Goals for programmes

Specific goals or design concepts were developed to ensure that the programmes would meet the long-term needs of the two mines to monitor TMA performance over-time. These design concepts included:

- The programmes need to be mine related in terms of locations, components and parameters.
- Remove redundancies such that each data point should provide unique information.
- The frequency of monitoring should be equal to the ability of the system to demonstrate change.
- Programmes should be able to demonstrate that data are valid and representative of conditions through the incorporation of a data quality management plan.

- The establishment of criteria for responding to data and modifying the programmes over time.

Through the incorporation of these concepts, the monitoring framework and its programmes were designed to be efficient, and effective, while incorporating data of known quality into the assessment of conditions within the TMAs and watershed. The concepts that formed the basis of the programmes are described in the following sections.

2 Design concepts and examples

2.1 Mine related

It is easy for monitoring programmes to get off track relative to their original objectives. Frequently, parameters are added because they are of interest to a regulator or they come in an analytical bundle i.e. ICP-MS, and therefore a prevalent attitude is "why not look at them all". However, including an extra 20 or 30 parameters in a programme forces the proponent to conduct assessment on a much larger set of parameters than necessary and can result in a loss of focus in a programme. The programmes designed for the Elliot Lake mines ensured that parameters and locations included in the programme remained "mine related". For example, parameters were selected through a screening process whereby existing water quality in the receiving environment was compared to a benchmark based on water quality criteria or background (95th percentile) whichever was higher. Both frequency of excursions and magnitude were considered. Values which exceed the benchmark in more than 10% of the samples were selected as mine indicator parameters to be included in the SRWMP. This process reduced the number of parameters monitored from more than 70 during operations to 13 during the first cycle of the SRWMP (Table 1).

Table 1 Changes in the number of parameters and locations in the SRWMP and SAMP over the past 10 years

Programme	Operationally	Cycle 1 1999/2002	Cycle 2 2004	Cycle 3 2009
Number of Parameters				
SRWMP	70	13a	10	8
SAMP	40–70	12	12	11
Number of Stations				
SRWMP	67	35	26	16
SAMP	64	24	24	24

During the first cycle of the SRWMP an ICP scan was undertaken to confirm mine indicator parameters.

2.2 Rationalising redundancies

Data collected for a programme had to provide unique information and on this basis both monitoring locations and parameter lists were rationalised. For example, in the SAMP, stations were selected to represent the final release (seepage, site drainage, effluent) to the SRW. Therefore, all stations upstream of these were either eliminated or relocated to the TMA operational monitoring programme (TOMP). This resulted in a reducing of the number of stations monitored by more than 50% (Table 1). Similarly, parameters were evaluated to remove redundancies. Correlation analyses were conducted and it was asserted that parameters which strongly correlated provided redundant information and thus correlates were eliminated. For example, sulphate, total dissolved solids (TDS) and conductivity were strongly correlated and so only sulphate was selected for the monitoring programme.

2.3 Frequency

The objective of the monitoring programmes was to track changes in conditions over time. This meant that monitoring should be conducted at a frequency equal to the ability of the system to demonstrate change. The

SRW is a lake chain system and thus most of the monitoring stations were located at the outlet of lakes. Changes in water quality within a lake are a function of the lake residence time or flushing rate. Thus monthly sampling of a lake with a two year residence time would result in sampling the same water quality condition 24 times before a full change could be demonstrated. Using simple models and standard first-order equations, the time required for a lake to reach steady-state condition following a change in chemical loading was estimated to be three retention times. Using McCabe Lake as an example (retention time 1 year), if a step change in concentration of 26 to 9 mg/L occurs at the end of year one, a trend could be established and new water quality projected in six sampling events at a frequency of half the residence time i.e. every six months. Therefore, the frequency of water sampling within the watershed was set at half the hydraulic residence time of the lake. To standardise sampling frequency, three time frames were employed: monthly for small lakes with short residence times i.e. less than 1 year, twice per year for lakes with a retention time between 1 and 2 years, and yearly for lakes with greater than a two year retention time. This significantly reduced the number of samples collected per year by the mines over operational conditions. In 2009, statistical analysis was conducted to compare monthly versus quarterly monitoring data; the conclusion was that there was no difference in the ability to detect trends or excursions above benchmarks i.e. water quality criteria or discharge limits, and thus monthly monitoring locations were reduced to quarterly monitoring.

The concept of relating frequency to the ability of the system to detect change was also used in establishing a monitoring frequency for sediment and benthos. Since the receiving environments downstream of the TMAs are lakes i.e. depositional environments, biological monitoring was focused on benthic invertebrates within the lakes. The condition of the benthic community within the lakes would be expected to be influenced by the sediment chemistry. Review of sediment deposition rates indicated that deposition of fresh sediment was about 2 mm/year (McKee et al., 1987). Thus the top 1 cm (a reasonable sampling interval) would be expected to represent fresh sediment every five years. Since we wanted to assess changes in conditions over time, sediment (top 1 cm) and biological monitoring (benthos and fish) was established at a five year interval.

2.4 Data quality management

For regulators and the public to have confidence in the findings of a monitoring programme they must be confident of the quality of the data, and have mechanisms for demonstrating the quality of the data, and establishing that it is representative of the conditions being monitored. To address this concept, a data quality management plan was developed for each of the programmes. This programme included:

- Establishment of responsibilities, controls and reporting channels.
- Requirements for standard operating procedures and training.
- Incorporation of quality control sampling in 10% of samples and data quality objectives for assessment of sensitivity, precision and accuracy.
- Data validation, management and archiving.
- Regular data quality assessments, i.e. annual for water and every five years for the full programme.

This ensured that data quality had been considered through all aspects of the programme from sample collection, laboratory analysis and data management, to reporting.

An example of measures incorporated into the data quality management plan was the development of a data validation procedure. Data validation procedures (Figure 2) ensure that all data is reviewed and validated in a timely manner. The data validation process ensures that only data that are considered reliable are entered into the database. The process flags any data falling outside of the primary assessment limits (mean ± 3 standard deviations) and trigger investigation of the possible cause. Potential causes may include:

- Sampling error.
- Laboratory analysis or reporting error.
- Data quality issue.
- Temporary system upset e.g. extreme flow event.

- System change e.g. flow by-pass.

Water quality data that is flagged is verified against other findings in a weight of evidence approach. More specifically, the data is evaluated in the context of other parameters measured in the same sample, data for upstream and downstream stations, and field conditions, based on considerations such as those listed below:

- Is the outlier isolated to one chemical parameter? If other parameters show extreme values too, then it is not likely an analysis error.
- Is there an extreme value upstream or downstream for the same parameter? Involvement of another station may indicate a change in the system rather than an analysis or sampling error.
- Are there similar outliers at unrelated stations? If the only outliers are at related stations, original outliers are corroborated; if not, a sampling or analysis error is likely.
- Do the data correspond to the expected geochemical evolution of upstream sources? If yes, the data points likely represent a real change.
- Is there evidence of a previous trend that was not detected until the data exceeded the assessment limits? If the outlier is a continuation of this trend, the data point can assume to be valid.
- Is there a trend at the source? If there is a corresponding change at source, the outlier is likely the downstream manifestation of this change and indicates a system change.

If the cause is known and/or repeated testing confirms a change in condition (step change or gradual trend), the data are accepted into the database and the monitoring programme continues. If the change in condition is confirmed an Environmental Response Plan will be initiated. This process ensures that all data within the database are valid and that any data outside of the range of expected conditions (mean ± 3 standard deviations) are investigated.

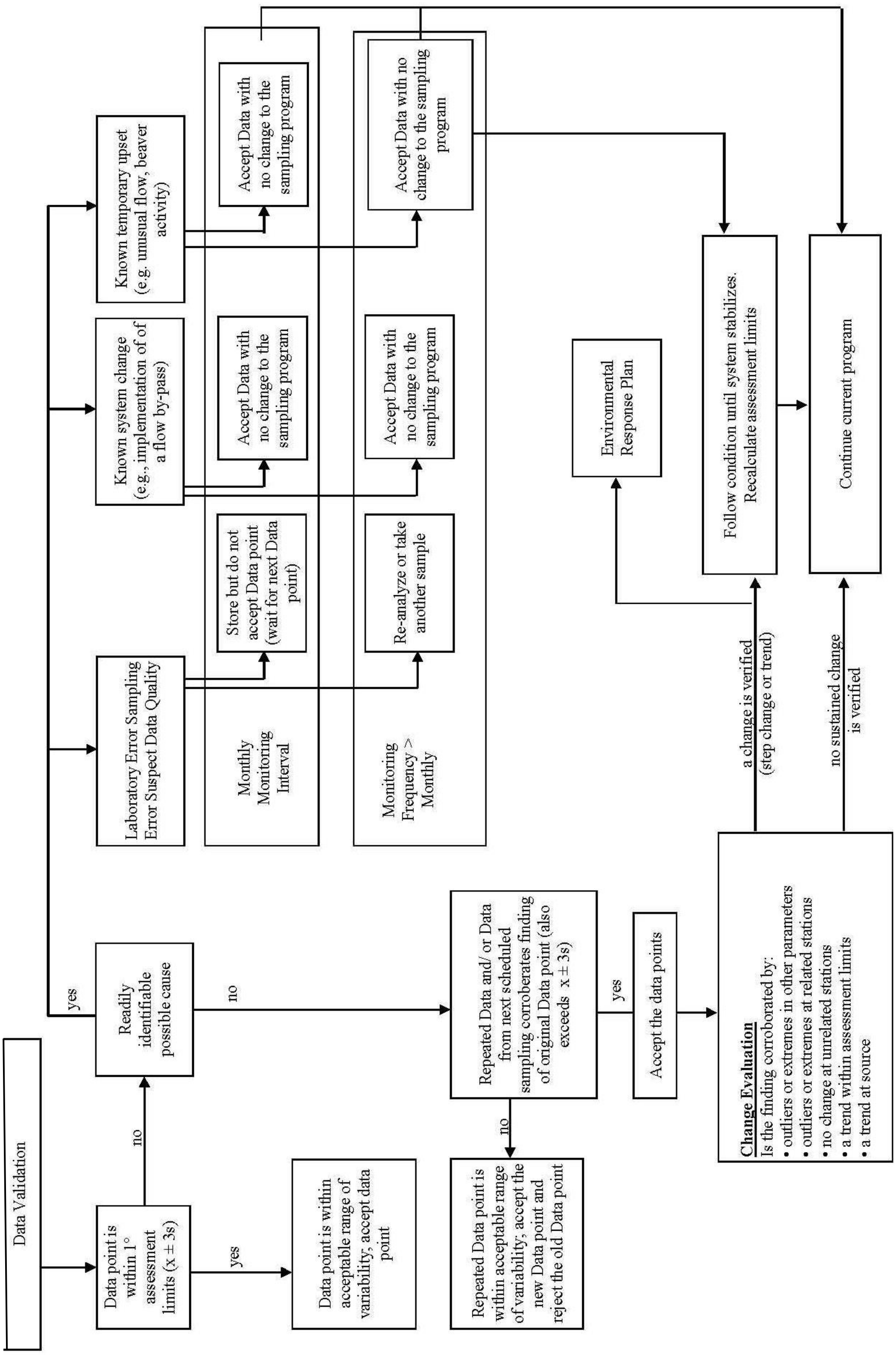


Figure 2 Decision path for data validation for SRWMP, SAMP, and TOMP

2.5 Criteria for change

At the onset of the SRWMP it was recognised that the programme would need to be modified over time and the requirement for monitoring should be reduced as the zone of influence of the decommissioned mines recedes and conditions in the watershed improve. Consistent with this understanding, the SRWMP was designed to evolve over time responding to previous study findings. Environmental acceptability criteria were developed and approved as the basis for assessing study findings and reducing/eliminating aspects of the programme (Beak International Inc., 1999). Given the long-term history of mine-related activities in the watershed, and existing knowledge of environmental conditions, a "weight-of-evidence approach" was approved by the CNSC for defining environmental acceptability. Criteria denoting acceptable environmental quality include:

- Contaminant concentrations in environmental media are below objectives or guidelines (e.g. Provincial Water Quality Objectives (PWQO) (OMOEE, 1994) or Canadian Water Quality Guidelines (CWQG) (CCME, 1999), Provincial Sediment Quality Guidelines (PSQG) (MOE, 1993)), or the Interim Sediment Quality Assessment Values (ISQAV) (CCME, 2001).
- Contaminant concentrations above guidelines, but within the natural range of background variability (i.e. as measured at reference stations).
- Contaminant concentrations demonstrating stable and/or decreasing trends or, if increasing, doing so in accordance with EIS predictions.

At the time the programme was developed (1999) it was expected that few areas of the watershed would reach guideline levels in the foreseeable future i.e. 30 to 50 years. Some near-field areas were expected to recover over a very long time frame i.e. 100 to 1,000 years, while recovery of far-field areas was expected on a shorter time frame i.e. less than 100 years. Therefore, acceptability criteria were expected to be different for different areas of the watershed. The SRWMP design document (Beak International Inc., 1999) stated that:

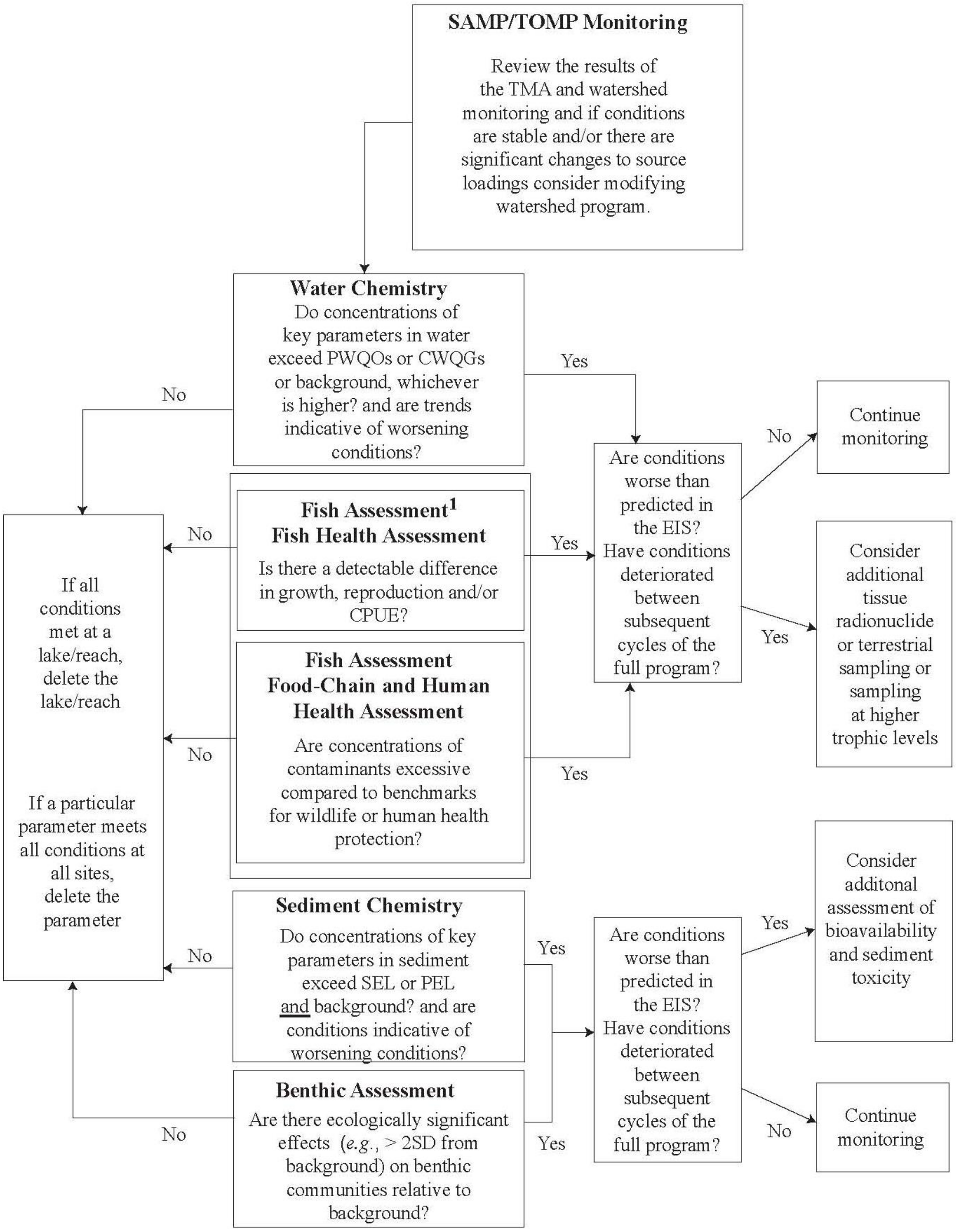
> *"Should monitoring demonstrate that an area is achieving relevant guidelines, then this should be defined as acceptable conditions, eliminating the need for further monitoring. In other areas, acceptability may be achieved when a stable or slowly-decreasing trend is documented".*

A rationale/decision path for modifying the programme was established and approved as part of the Implementation Document for the SRWMP (Figure 3). This decision path presents the criteria for acceptability of evaluation endpoints (i.e. water and sediment quality) and the ensuing change to the programme based on the findings of the previous study. Based on the decision path and the acceptability criteria, stations with below guideline concentrations of mine indicator parameters in water and sediment (or at background, if background exceeds the guideline), and with no ecologically significant effects on benthic and fish community parameters can be eliminated from the programme. Similarly, if a particular parameter meets criteria for water, sediment, and tissue quality, and there are no detectable effects on benthic and fish communities at all areas, that parameter can be eliminated from the programme. Ultimately, it is expected that the programme should retract spatially with improvement and only expand in response to ecosystem impacts.

Through the use of these acceptability criteria, the number of parameters has been reduced from 13 in 1999 to 8 in 2009 (40% reduction; Table 1). Similarly that number of stations has been reduced from 35 in 1999 to 16 in 2009 (54% reduction; Table 1). The scope of the biological monitoring programme has also been reduced over time as conditions achieve acceptability criteria (Table 2). Benthic monitoring areas have been reduced by 74% since 1999 and fish monitoring has been eliminated (Table 2).

Table 2 Changes in the number of locations monitored for benthic invertebrates and fish in the SRWMP over the past 10 years

Component	LOCATIONS Cycle 1 1999	Cycle 2 2004	Cycle 3 2005
Benthic invertebrates	49	42	13
Fish health	7	0	0
Fish tissue	20	4	0



[1] Removed from SRWMP following Cycle 1.

Figure 3 Decision path for modifying the SRWMP

3 Summary and conclusions

Through the development of considered monitoring objectives for each of the programmes included in this framework, an efficient and effective approach to monitoring post-decommissioning was developed for the Elliot Lake Mines. Monitoring concepts were developed to ensure the programmes remained focused and effective. Through the implementation of these concepts, the programmes were streamlined to focus on the specific objectives which resulted in significant reductions in the scope of the programme in terms of parameters, locations and frequency compared with when the mines were operational. The establishment of the monitoring framework resulted in a reduction in monitoring costs to the mines of 60 to 70% and yet yielded data which have proven more useful in demonstrating trends and conditions relative to criteria and predictions, and has been well accepted by regulators and the public. Since the inception of the SRWMP, SAMP and TOMP the programmes have been further reduced in scope in response to improved conditions. This monitoring framework is an excellent example of how source area and receiving environment monitoring can be integrated to provide a comprehensive assessment relative to predictions without the commitment to monitoring in perpetuity.

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