Decommissioning and Reclamation of the Beaverlodge Uranium Mine/Mill Operation: Ecosystem in Recovery

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Abstract

The Beaverlodge uranium mining and milling facility, located near Uranium City in northern Saskatchewan, operated for a period of thirty-two years between 1950 and 1982, making it one of the longest operating facilities of its type in Canada. Ore was extracted from the main underground mine and from smaller underground and open pit satellite deposits in a ratio of 94% and 6% respectively. Decommissioning activities consisted of four phases, shutdown, salvage and reclamation which occurred from 1982-1985, and the current transition monitoring phase from 1985 to present. Following transition monitoring to prove that the system is behaving as expected, licence revocation and hence completion of decommissioning is expected to occur.

The plan to achieve delicensing from the federal Canadian Nuclear Safety Commission and surface lease revocation from the provincial government is currently captured in a 10-year plan, 2003-2013. The main remaining objective of the decommissioning plan is to document the aquatic ecosystem recovery of the former tailings management facility (TMF), which consisted of two natural lakes, and of the two former underground satellite areas, Hab and Dubyna. Extensive environmental monitoring has been carried out in the receiving environment, Beaverlodge Lake, the former Dubyna mine area and the TMF. Recovery of the aquatic ecosystems is occurring within an environment containing above-background levels of natural radionuclides. This makes Beaverlodge, with its relatively clean ore and long history of natural recovery, one of the better places to study low-level radioactive environmental biological effects. The Dubyna area has above background uranium concentrations in the water, sediment and fish, and a benthic invertebrate community similar to reference. In the receiving environment, Beaverlodge Lake, metal concentrations are highest with the deeper sediment. This trend fits well with the increased impacts of 32-years of operation followed by reduced impact in 20-years of transition.

The assessment of ecosystem recovery and other aspects of the delicensing and surface lease revocation, allows for reflection on "lessons learned," from operational procedures as defined by the standards of the time and decommissioning activities carried out to date.

This paper documents the recovery of the aquatic ecosystems impacted during the operating phase, comparing the data to reference areas and current criteria. In addition, lessons learned for consideration by current operations are reviewed.

I Background

The Beaverlodge uranium mine site is located north of Lake Athabasca, near the northeast end of Beaverlodge Lake. Eldorado Nuclear Limited operated it for nearly 30 years beginning in 1952; however, in 1981 with the declining ore grade and mill recoveries, and increasing production costs, the decision was made to shut the operation down. The mill ceased production in August 1982 and reclamation work, leading to eventual decommissioning, was completed in 1985. Transition phase monitoring of the Beaverlodge site and satellite mines was initiated following the reclamation work, prior to final decommissioning and continues to present.

During the lifetime of the operation, ore was extracted from the main interconnected underground Fay/Verna/Ace mine (94%) and from small satellite mines, consisting of both underground and open pit mines (6%). Total recorded ore and waste rock tonnages were 10,161,400 and 4,800,000 respectively. Mill tailings were cycloned to remove the coarse fraction for placement underground as fill (40%), with the remaining placed in a series of natural lakes.

The areas impacted by the operation are located within two surface drainages which discharge to Beaverlodge Lake (Figure 1). The larger Ace Creek drainage, 152 km^2, includes all the mines and waste rock disposal areas. Water quality and flow for the area are monitored at Ace Creek (Station AC-14) as it enters Beaverlodge Lake. Major satellite mines, Hab and Dubyna, are located on Ace Creek sub-drainages monitored by Stations AN-5 and DB-6 respectively. The smaller Fulton Creek drainage, 17 km^2, includes the tailings management facility (TMF). The TMF consists of two lakes, Fookes and Marie, for primary and secondary settling respectively, where the majority of the tailings are confined, and one downstream wetland, which was used as an artificial after-treatment settling lake (Meadow Lake) during the operational period. Water quality and flows are monitored at Station TL-7, formerly regarded as the last point of control. Prior to entering Beaverlodge Lake, Fulton Creek enters Greer Lake with water quality monitoring on the outflow at Station TL-9.

Closure requirements and water quality objectives for assessing the acceptability of the decommissioned site are monitored at stations AC-14 and TL-7. Over the last 20 years monitoring has shown compliance for most criteria. Additional issues presently being investigated include radium-226 concentrations in the Fulton Creek drainage and historical biological impacts on off-site receptors (fish and benthic invertebrates). This paper provides a summary of the recovery of the areas impacted by the operation, describing the current level of impact, some 20 years since operations were terminated.

II Delicensing and Surface Lease Revocation

The current Beaverlodge federal license and the Government of Saskatchewan Provincial Surface Lease exercise authority over the site, which is collectively identified as the Beaverlodge mine/mill properties. In total, the properties cover an area of approximately 744 hectares or 1,838 acres and can be divided into three broad categories:

- Main Facilities Area (276.3 hectares);
- Tailings Management Area (300 hectares); and,
- Satellite Mines (167.7 hectares).

In 1988, Cameco Corporation was formed from the former federal Crown Corporation Eldorado Nuclear (and its successor Eldorado Resources Limited), and the Saskatchewan provincial Crown Corporation, Saskatchewan Mining and Development Corporation.

Cameco became responsible for the management of the Beaverlodge facility and is the current licence/lease holder. In 2003, Cameco developed the current overall management plan for the Beaverlodge properties covering the ten-year period from 2003 to 2013. This current plan was developed to provide an overall order of business and to systematically assess the current condition of each individual property in terms of the suitability for release from Canadian Nuclear Safety Commission (CNSC) licensing and from the Province of Saskatchewan Surface Lease. Broadly speaking the plan is to first seek closure on the low risk minor satellite properties, then the two major satellite properties (Hab and Dubyna) followed by the main mine site area. It is expected that the TMF will be the last to be de-licenced. Different forms of institutional control seem likely for the TMF relative to the satellite properties.

The objective of the current plan is for a complete release from all properties at the Beaverlodge site by 2013. However, should certain specific properties be judged not suitable for release to as yet undecided institutional control mechanisms, appropriate management of the properties will continue to ensure that the sites remain in a safe state.

III Former Tailings Management Facility

III (a) Introduction

The Fulton Creek watershed was formerly utilized as a TMF (Figure 1). Tailings were initially deposited in Marie Lake for a short period with the majority deposited in Fookes Lake, which was further upstream in the watershed. In 1976/1977, treatment of the discharge from Marie Lake commenced for radium-226 removal with barium chloride and ferric sulphate. Meadow Lake located downstream of the treatment plant, was created in 1978 after a dam was built to provide an area for the barium-radium-sulphate precipitate to settle. The decant water from Meadow Lake flows through Greer Lake and eventually discharges into Fulton Bay, Beaverlodge Lake. Studies of the area have utilized Fulton Lake, located upstream of Fookes Lake, as a reference lake.

Decommissioning of the TMF occurred over the period 1982 to 1985. The TMF is currently in its 20^{th} year of post-remediation and natural recovery. Post-remediation activities have included ongoing monitoring and maintenance. This involves regular water quality monitoring at stations within the area (Figure 1) and special aquatic investigations.

III (b) Water

From 1982 to 2004, the water quality-monitoring program has obtained data from one reference station and five exposure stations in the Fulton Creek watershed (Figure 1). Figure 2 displays the uranium, radium-226, and total dissolved solids (TDS) concentrations measured at these stations, as well as the originally accepted close-out objectives applied at Station TL-7 (Eldorado Resources Limited 1983). At all of the exposure stations, uranium and TDS concentrations have decreased substantially over time. As of 2003/2004 at TL-7, uranium (0.52 mg/L) is above the close-out objective of 0.25 mg/L while TDS (253 mg/L) only slightly exceeds the objective (250 mg/L).

Radium-226 concentrations have not shown declining trends at the exposure stations (Figure 2). The levels are consistently above the close-out objective of 0.11 Bq/L. Downstream of Greer Lake, Station TL-9, the concentrations quickly increased from 0.044 Bq/L in 1990/91 to 1.25 Bq/L in 1991/92 and have remained high since. Results of radium-226 sediment flux investigations conducted in 2001 suggest that radium-226 enters the water column from the sediment in Fookes, Marie, and Greer lakes (Golder 2002).

Metal and trace element concentrations in 2004 were below the Saskatchewan surface water quality objectives (SERM 1997) and the Canadian environmental quality guidelines (CCME 2004) in all study lakes, with the exception of selenium, which exceeded the federal guideline (0.001 mg/L). Selenium levels measured in the exposure lakes in 2004 ranged from 0.003 and 0.008 mg/L. However, selenium concentrations have decreased substantially over time in the exposure lakes from 1984 to 2004.

III (c) Sediment

Sediment chemistry has been investigated in all waterbodies within the TMF on several occasions, beginning in 1977 (Ruggles and Rowley 1978) and again in 1994 (TAEM 1995), 2001 (Golder 2002), and 2004 (CanNorth 2005). Sediment profiles (0-2, 2-4, 4-6, and 6-8 cm horizons) taken from Fookes, Marie, and Greer lakes in 2001 generally found that deeper sediment layers (2-4 and 4-6 cm) had higher concentrations of key parameters such as uranium, selenium, and radium-226 than the 0-2 cm horizon, suggesting some recovery has occurred. Radium-226 concentrations in Fookes Lake were slightly lower in 2001 and 2004 relative to 1977. However, in Greer Lake, the sediment concentrations of radium-226 were higher in 1994, 2001, and 2004 when compared to the data from 1976. These results support the water quality trends, which show an increase in radium-226 concentration following shutdown of the treatment system.

III (d) Benthic Invertebrates

In April 2004, benthic invertebrate communities were sampled at the reference site and at the three exposure sites: the Fookes Lake inlet and outlet, Marie Lake, and Greer Lake (Figure 1). The community descriptors were calculated and compared to the reference lake. Mean abundance of benthic invertebrates was significantly higher in Fookes Lake but lower in Marie and Greer lakes. Taxon richness was similar between Fulton, Fookes, and Marie lakes, but was significantly lower in Greer Lake.

Simpson's diversity and evenness measures at the genus/species level were generally indicative of stable and numerically even communities in all four-study lakes (>0.7). However, at the family level, the Simpson's diversity indices for the exposure lakes (<0.25) were significantly lower than in Fulton Lake (0.62), and evenness values at the exposure lakes were low (0.06-0.32). These differences are due to the overall dominance of chironomids in the exposure lakes. It is well documented that many genera of chironomids, including those dominating the communities in the exposure areas, are more pollution tolerant than other taxa of benthic invertebrates (Johnson et al. 1993; Beltman et al. 1999; Mandaville 2002).

III (e) Fish

During the operational period, the release of tailings into the Fookes and Marie area of the TMF significantly altered the physical, chemical and biological condition of the lakes. In the 1976/77 period, a fish study (Ruggles and Rowley 1978) examined lake chub at the outflow of the Fookes system. These fish exhibited eye abnormalities, especially cataracts. In mid-1990's, follow-up studies (CCWHC 1993; TAEM 1996) identified cataracts, fin and head deformities, distended abdomen (edema), haemorraging, and fungal infections present in lake chub. An assessment of potential causes was undertaken (TAEM 1996). Radiation dose estimates did not suggest radionuclides as primary contaminants of concern. However, symptoms (cataracts, bulging eyes, and edema) were indicative of a selenium exposure response (Lemly 1993), which suggests the issue is likely dietary and not just water concentration.

In the 2000 and again in 2004 monitoring of the recovery of these fish species was undertaken (Golder 2002; CanNorth 2005). An external assessment was completed on lake chub collected from Fookes Lake, Marie Lake, Greer Lake in both surveys. The results of the assessment identified cataracts as the most common abnormality in fish from each lake. There was no indication of abdominal distension, as was previously documented in Fookes Lake (TAEM 1996), as well there was an overall reduction in the presence of abnormalities over the two years. These results suggested an improvement within the Fookes Lake and Greer Lake fish populations (Table 1). In addition to the external assessment, in September 2004, a more detailed lake chub population survey/health assessment was conducted. The lake chub population in each lake were shown to be healthy, with comparable health endpoint measures similar to those found in the reference lake. One difference identified was that lake chub from within the TMF were larger at a given age then those in the reference lake; this is likely due to a lack of predatory fish in the exposure lakes.

The fish survey conducted in September 2004 found that the community in the reference lake, Fulton Lake, was more diverse and abundant than in the downstream exposure lakes. Six species (longnose sucker, lake chub, burbot, ninespine stickleback, round whitefish, and lake trout) were collected from Fulton Lake and four species (longnose sucker, burbot, round whitefish, and lake chub) were collected from Fookes Lake, the first lake downstream of Fulton Lake. Marie and Greer lakes contained only lake chub. Conversely, the lake chub populations in Fookes, Marie, and Greer lakes were larger than in Fulton Lake, which is likely a result of the lack of predation. During previous surveys done in Fookes Lake, species other than lake chub have been found, which is viewed as a positive outcome, as it demonstrates the potential for a sustainable diverse fish community in the TMF.

III (f) Summary and Conclusions

The long-term water quality monitoring data and recent sediment chemistry data generally demonstrate recovery over time in the lakes that were historically impacted by direct deposition of uranium tailings into the Fulton Creek exposure lakes. However, a remaining issue of concern is radium-226 levels, which is not yet declining. Sediment quality demonstrates an improving trend; however, the concentrations of metals remain high. The exact cause of the abnormalities observed in the lake chub in the exposure lakes has not been determined. Elevated selenium concentrations in the water and the sediment have been suggested as a possible cause for fish abnormalities. It is important to note that the number of lake chub abnormalities is likely strongly influenced by lack of predation, and appears be decreasing in the TMF through time. This trend appears to correspond with decreasing selenium concentrations in the water and recovery of sediments. Ecosystem impacts remain evident in the benthic invertebrate communities (comprised almost solely of chironomids) and the lower diversity of fish species in Fookes, Marie, and Greer lakes. Future studies will continue to monitor and assess the recovery of the aquatic ecosystem in the Fulton Creek watershed as the water and sediment contaminant concentrations are anticipated to continue to decline. There is a need to demonstrate, either through long-term monitoring or development of a strong geochemical argument that a longer term declining trend in radium-226 is going to occur.

IV Former Satellite Mine – Dubyna

IV (a) Introduction

The Dubyna satellite underground mine was active over the period 1979 to 1981. The ore was hauled to the mill located by the main Fay shaft. During the operational period, waste rock was stockpiled on the site and treated mine water was discharged into Dubyna Lake. Decommissioning of the site included removal of all surface structures, sealing of all openings to surface and contouring of the waste rock. In recent years, a borehole was found to be discharging water, likely from the former underground mine. Elevated uranium level in the borehole water suggests that the underground workings may be the major source of uranium measured in Dubyna Lake.

Preliminary environmental investigations were conducted on Dubyna Lake in 1977 and 1978 (SRC 1977, 1978). From 1981 to present, surface water quality has been routinely monitored at Station DB-6, the Dubyna Lake discharge to Ace Creek (Figure 1). In 2002, a comprehensive study of Dubyna Lake was completed in order to assess the current state of the aquatic environment (CanNorth 2002, 2003). The study focused on comparing water quality, sediment quality, benthic invertebrate communities, and fish communities, (health and tissue chemistry) in Dubyna Lake to reference sites, and to 1977/78-study information.

IV (b) Water Quality

A focussed water quality-monitoring program conducted in 2002 identified that radionuclide concentrations in Dubyna Lake were elevated compared to reference levels. For example, the uranium concentration in Dubyna Lake was substantially higher than the upstream reference sites in Schmoo Lake and Ace Creek (AC-17), as well as the sampling sites located downstream in Dubyna Creek and Ace Creek (AC-15) (Figure 1).

Long-term monitoring at Dubyna Creek (DB-6) demonstrates that mean annual water quality concentrations for radium-226 and TDS have been less than the close-out objectives (0.11 Bq/L and 250 Bq/L, respectively) (Eldorado Resources Limited 1983) since 1981. Current concentrations are 0.04 Bq/L and 140 mg/L respectively. The uranium concentration at DB-6 has decreased from a high in 1981 of 2.1 mg/L to 0.3 mg/L in 2004 just above the objective of 0.25 mg/L. These water quality trends indicate a system in recovery.

IV (c) Sediment Chemistry

In 2002 sediment samples were collected at stations located in deep and shallow areas of Dubyna (two sites) and Schmoo lakes. In each sampling area, five stations were sampled and the 0-2 cm, 2-4 cm, and 4-6 cm sediment horizons were chemically analyzed.

The deep site in Dubyna Lake contained statistically higher levels of a number of parameters than the deep site in Schmoo Lake. Of particular note were the elevated radionuclide levels measured in the sediment samples from Dubyna Lake, particularly uranium (35,000 ug/g); Schmoo Lake was 20 ug/g by comparison. There are no indications that the sediment in Dubyna Lake is in a recovery phase since the radionuclide levels, as well as the levels of numerous other analytes, were highest in the 0-2 cm sediment horizon. Similar to the deep site, the radionuclide levels at Dubyna Lake shallow sites were highest in the 0-2 cm sediment horizon and lowest in the 4-6 cm horizon, although concentrations were 15 times lower than at the deep site in Dubyna Lake.

Elevated uranium concentrations in the upper sediment layers suggest continued accumulation of metals and radionuclides even though downstream water quality would suggest a significant improvement.

IV (d) Benthic Invertebrate Communities

Benthic invertebrate samples were obtained concurrently with the sediment samples in the 2002-sampling program.

The benthic invertebrate communities were notably different between the Dubyna Lake and reference Schmoo Lake in deep lake sample sites with very low abundance, richness, and calculated biotic indices (Table 1). This is believed to be the result of the confounding factor of anoxic conditions at the deep site of Dubyna Lake, making it impossible to determine if the high radionuclide levels measured in the sediment are negatively impacting the invertebrate community. The tolerances of benthic invertebrates to low dissolved oxygen levels are species-specific and anoxic conditions have been shown to suppress some benthic invertebrate populations.

The benthic invertebrate communities at the Dubyna Lake shallow sites were similar to the reference shallow site in Schmoo Lake in abundance, number of taxa, and sample biomass (Table 1). There was no marked difference between the exposure sites and the reference site in community composition; however, there were more species types in the Schmoo Lake than in the Dubyna Lake samples whose populations were dominated by two species (Table 1).

Although the communities at the shallow sites in Dubyna Lake were dominated by two species, other types identified in the samples included organisms that are generally recognized as more pollution sensitive. In the 2002 study, certain types of aquatic organisms (e.g. Hyalella azteca) were identified in Dubyna Lake where the uranium concentrations exceed concentrations that laboratory studies consider toxic or lethal (BEAK 1998; Environment Canada and Health Canada 2001; Vizon Scientific Inc. 2004). It is possible that these species may have acclimatized or genetically adapted to the environment.

IV (e) Fish

A fish community survey was conducted in Dubyna and Schmoo lakes in September 2002. Although the composition of the fish community in Dubyna Lake is much smaller than in Schmoo Lake, the presence of juvenile predatory fish (northern pike) and forage fish (lake chub) in Dubyna Lake is a positive sign of a functioning ecosystem. A major limiting factor in Dubyna Lake is a well-established anoxic layer, which covers the lower one third of the lake. This characteristic may limit the establishment of a large and diverse fish community in the lake.

During the 2002 survey, five northern pike were retained from Dubyna Lake for a health assessment and chemical analyses. Since northern pike were not found in Schmoo Lake, five northern pike were obtained from another reference lake, Fredette Lake. They were larger than the northern pike from Dubyna Lake (Table 2). This difference may be a result of different food-webs and food resources, as the northern pike in Dubyna Lake likely rely more heavily on invertebrates due to lower numbers of forage fish in the lake. The differences in diet may have played a factor in some of the differences in the health assessment measurements between the reference and exposure fish. For example, when compared to northern pike measurements taken in 31 waterbodies located throughout northern Saskatchewan (CanNorth 2003), it was found that the average condition factor was high in Fredette Lake and within a normal range in Dubyna Lake. Although the samples sizes are small, the liver-somatic indices (LSI), an indication of fish health, were lower in the northern pike from Dubyna Lake compared to Fredette Lake. The lower LSI may be linked to higher contaminant levels, but it may also be a result of poor diet since starvation has been shown to decrease LSI values (Goede and Barton; Vigano et al. 1993).

The fish chemistry data demonstrate differences in the concentrations of certain parameters between the exposure and reference northern pike bone and flesh samples. Statistical tests showed that concentrations of manganese, polonium-210, radium-226, and uranium were significantly higher in the flesh and bone samples from Dubyna Lake compared to the samples from Fredette Lake. In addition, levels of barium, strontium, and lead-210 were significantly higher in the Dubyna Lake bone samples. When the 2002 data were compared to some 1978 baseline data, the concentrations of lead-210 and radium-226 in the Dubyna Lake northern pike bone samples were similar, but in the flesh samples, levels were slightly lower in 1978. Uranium levels were notably higher in 2002 compared to 1978 in both the flesh and bone samples. This is consistent with the water and sediment quality characteristics of Dubyna Lake.

IV (f) Discussion

Almost twenty years after the closure of the Dubyna mine site, the water quality data from Station DB-6 in Dubyna Creek show that conditions are improving although radionuclide concentrations remain elevated in the water, sediment, and fish in Dubyna Lake. The shallow areas of Dubyna Lake contain relatively diverse benthic invertebrate communities. The fish habitat in Dubyna Lake is somewhat limited since the lake's lower region is nearly anoxic and the food source consists predominantly of invertebrates. Despite these factors and the elevated radionuclide levels in the environment, northern pike have continued to successfully inhabit and reproduce in Dubyna Lake for numerous years.

V Receiving Environment – Beaverlodge Lake

V (a) Introduction

The former Beaverlodge mine/mill site was operated within the larger Beaverlodge Lake drainage basin. As such, Beaverlodge Lake forms the integration point for all upstream activities in the Ace and Fulton creek drainage sub-systems (Figure 1). During the early years of operation, the uranium mining and milling activities conducted at the Beaverlodge site were, like all other resource sectors, undertaken using what were considered acceptable procedures at the time. It was not until the mid 1970's, some twenty-two years after operations began, and that effluent treatment was initiated at the Beaverlodge site in response to discussions with provincial and federal regulatory authorities. These historical releases have influenced Beaverlodge Lake and continue to provide some influence even though environmental conditions in the lake are improving.

V (b) Water Quality

Sampling station BL-3 (Figure 1) is located within Beaverlodge Lake approximately 100 m from the Fulton Creek discharge. Sampling at this station was originally carried out during the operational mining and milling phase in order to monitor the "near field" impacts of operations on Beaverlodge Lake. Station BL-4 is located in the centre of the east basin of Beaverlodge Lake.

Key water quality parameters that have been monitored include radium-226, uranium and total dissolved solids (TDS). Selenium is also a parameter that is under investigation. Within Beaverlodge Lake, all four parameters have been below either the close-out objectives (uranium and TDS) or respective Saskatchewan Surface Water Quality Objectives (radium-226 and selenium). However, selenium is presently elevated above the CCME aquatic life protection guideline (0.001 mg/L) and uranium is above the interim CCME drinking water guideline (0.02 mg/L).

V (c) Sediment Quality

A detailed sediment chemistry program was completed in Beaverlodge Lake in 2001. Sediment core samples were obtained from Fulton Bay, Ace Bay and the more distant Keddy Bay (lake-specific reference area) within Beaverlodge Lake. The depth interval data demonstrates that Beaverlodge Lake is recovering. The highest concentrations are located in the deeper sediments. For example, parameters such as selenium (Figure 3) and uranium (Figure 4) show a consistent decline in concentrations from depth to surface. The deepest horizon (20-22 cm) is considered to be representative of background conditions. Both selenium and uranium demonstrate this recovery trend in the Fulton Bay sediments. In the Ace Bay sediments, however, the uranium concentrations demonstrate only a more recent decline. This is possibly due to lower sediment accumulation rates in the Ace Bay area, which may be a factor of the much higher flow rate from Ace Creek than from Fulton Creek and also the influence of the islands in the Fulton Bay area.

V (d) Benthic Invertebrate Community

Benthic invertebrate samples were collected from Beaverlodge Lake in April 2001.

The highest total abundance was measured at the Fulton Bay sampling area. Species richness was slightly lower at both Fulton Bay and Ace Bay relative to Keddy Bay. The Simpson's diversity and evenness indices were lower in both exposure areas relative to Keddy Bay, but indicated a good representation and distribution of species. In fact, the species diversity and richness found at all three areas in Beaverlodge Lake are similar to that measured at other non-impacted lakes in the area such as Schmoo Lake (CanNorth 2002).

The impact to the benthic invertebrate community in these areas was considered to be minimal.

V (e) Fish

Fish tissue chemistry was collected during a 2000 sampling program (Golder 2002). Muscle and bone tissues were collected from lake trout and white sucker. Fish were obtained from the Fulton Bay area as well as from Keddy Bay. Levels of radium-226 and uranium were higher in the Fulton Bay area relative to Keddy Bay. Elevated levels of these parameters reflect direct exposure from historical and possibly the generally lower current loads from the Beaverlodge mine/mill site. The concentrations measured did not indicate a potential risk to the fish, wildlife or human health.

Of particular interest is the selenium concentration measured in the muscle tissues (wet weight) of the lake trout and white sucker in Keddy Bay and Fulton Bay. Although other metals demonstrated a consistent difference between the reference and exposure areas, the selenium concentrations were similar in the two areas. The fact that fish from both stations had elevated tissue selenium concentrations suggests that selenium exposure is most likely related to food transfer than direct exposure and also is likely mainly historical as the entire lake shows similar levels in the fish tissues.

Elevated selenium concentrations in fish tissue indicate a potential threat to the viability of the population. As mentioned previously, selenium in fish is known to cause abnormalities in fish and thus potentially affect the fish community. Studies were completed in 2000 (Golder 2002) to assess the presence and spatial extent of fish abnormalities previously identified in the Fulton Creek drainage. The lake chub population in Beaverlodge Lake showed some indication of health effects (e.g., cataracts); however, the frequencies of these abnormalities were much lower than in the upstream lakes (Greer, Marie, and Fookes). The general health of the population and recruitment suggest that the population is sustainable.

V (f) Discussion

Following closure and decommissioning of the site, predictions were made as to the long-term recovery of the area. An overarching close-out objective for the decommissioning was to have no further impacts on Beaverlodge Lake. While historical effect is obvious in Beaverlodge Lake, water and sediment quality data suggests that it is recovering. The aquatic biota studies also suggest that Beaverlodge Lake is maintaining a healthy benthic invertebrate community. Some species of the fish community appear to be healthy and sustainable (lake chub), however it is unclear with regards to other larger species where selenium has been identified as a potential threat to the population.

VI Lessons Learned

The Beaverlodge mine was operated for approximately 30 years between 1952 and 1982 and has undergone ongoing maintenance and monitoring for some 20 years. During this period of about 50-years activities were conducted based on the best practices of the day. However, when reflecting back on those activities with the insight gained from the studies described above, there have been lessons learned. Some of these lessons support the activities of the day and also suggest that if we were to do it again the approach would be different:

1. Flow Data - collected on the Ace Creek and Fulton Creek watersheds over the period 1985 to 2005 have demonstrated that runoff rates estimated during the decommissioning phase (1982-1983) were seriously underestimated as only limited flow data were available at that time. Consequently the contaminant loading estimates calculated for the operating phase were also underestimated. Comparison of revised operating phase contaminant loads with measured post-operating phase loads has shown that the total loads to Beaverlodge Lake have decreased substantially as predicted would happen during the transition monitoring phase. The experience gained in reanalyzing contaminant loads has demonstrated the need to have good flow measurement instrumentation in place at key locations in local watersheds throughout the operating and post-operating phases. Baseline data, prior to the start of operations would enhance this long-term assessment even further.

2. Concentrations of Three Key Contaminants (uranium, radium-226 and total dissolved solids - TDS) - were predicted to decrease at all monitoring stations in the Ace Creek and Fulton Creek watersheds during the post-operating phase. These predictions were found to be valid with the exception of radium-226 on Fulton Creek (station TL-7). TDS and uranium have shown a steady decrease at all stations, as has radium-226 at the outlet of Dubyna Lake (station DB-6) and on Ace Creek (station AC-14) downstream of Ace Lake. Also, the concentrations of most trace elements have been

found to be consistently below the original benchmark Saskatchewan Surface Water Quality Objectives, where applicable, and often below analytical detection limits.

In-depth field and laboratory investigations in Fulton Creek have shown that the observed increase in the radium-226 levels in Fookes and Marie lakes is attributable to radium-226 release from calcite (calcium carbonate) precipitate in the tailings and in Greer Lake from re-dissolution of barite (barium sulphate) precipitate. The barite precipitate was formed after the effluent was treated with barium chloride, in the presence of sulphate, to form barium-radium-sulphate; some of the barite was released to Greer Lake. The results of routine and specific investigations after decommissioning at Beaverlodge have contributed significantly to an improved understanding of the geochemistry of lake sediments and in particular to the chemical behaviour of radium-226.

The lessons learned are to have a good understanding of the sediment geochemistry before decommissioning, and effective collection of after-treatment precipitates is necessary to minimize downstream impacts.

3. Uranium Concentrations in Beaverlodge Lake - has recently been identified to be of potential concern with respect to using the lake as a drinking water source, which was not anticipated during the transition phase monitoring period. Beaverlodge Lake has a retention time of about 50-years. The identification of this particular issue is attributable to a recent change in the drinking water guideline for uranium. This observation demonstrates the type of issue that can be identified after the fact as a result of change in a benchmark and the difficulty in bringing closure to a site that is under evaluation for long periods of time.

   The lesson to be learned is that site closure becomes more difficult as a result of time and changing expectations.

4. Air Quality - predictions made at closure have been found to be generally met. Radon levels at all monitoring stations have been well below operational levels and below levels that would pose a concern. Similarly, total suspended particulates, metal and radionuclide levels have been shown to be low and within acceptable limits. This observation demonstrates the adequacy of the atmospheric dispersion analysis method employed to predict air quality.

5. Risk Assessments - undertaken since closure to assess the risks to people and wildlife that may spend time at the satellite mines showed that the estimated doses were well below levels that could pose unacceptable risks. This observation confirms that the steps taken at closure to remediate the satellite mines were adequate.

   The lesson learned is that there can be value in re-evaluating the basic premises of the original assessment, once real data is available to replace model predictions.

6. Relocation of tailings – during the decommissioning phase in Marie Lake was done to minimize re-suspension of tailings, as they were originally located in the inlet channel of the lake. The tailings were moved to a deeper part of the lake over the winter. Although the original objective for moving the tailings was achieved, the relocation of the tailings released tailing porewater and re-suspended tailings into the water column. The result of this was activity was to set the lake back with regards to recovery.

   The lesson to be learned is that movement of material creates an immediate release of contaminants, which needs to be included in the risk assessment. It also means that one should think long and hard before undertaking relocation work if there are other alternatives.

7. Decommissioning activities – were completed using existing manpower and equipment. This resulted in improved project performance, from safety and timeline adherence perspectives. The work force understood the issues, and many people wanted to be part of the project to bring a good closure to something they have worked so hard to make-work well.

   The lesson to be learned is that at least for a remote site, the first choice for the conducting of the decommissioning is to use existing manpower and equipment if it is available and the timing supports this type of approach. This implies that decommissioning planning and the acceptance of the plans by the regulators, is required during the operating phase.

VII Summary and Conclusion

In 1981, when Eldorado Nuclear Limited was negotiating performance criteria upon which the reclamation work was to be based, two water principles were established. The first was the need to have loadings during the transition phase, below operating phase loadings. The second was the establishment of water quality performance objectives, based on SSWQO at specific locations that should be met after a reasonable period of time. Over the past twenty years, environmental expectations for decommissioning have changed. There are now Canadian as well as Saskatchewan surface water quality objectives, in some cases with more stringent criteria. There are the complications introduced when one goes from model forecasts to long-term collection of actual performance data. There is the degree to which conservative, precautionary principle based decision-making is applied. However, the biggest change has been in the addition of assessment and performance criteria that are no longer based solely on water quality. We now look at sediment quality, and a variety of population-level biological environmental effect indices. This additional level of analysis was not part of the regulatory licensing process twenty years ago, but must now be addressed. In essence we are faced not so much with a case of moving goalposts, but rather, a case of additional goalposts to meet regulatory and social expectations.

The good news is that consistent, positive trends are evident when considering the impacts and recovery of the areas associated with the Beaverlodge mine/mill site. A gradual improvement in water quality has been document at long-term water monitoring locations in the TMF, Dubyna Creek and in Beaverlodge Lake. Uranium, radium-226, TDS and other metals are on the decline at downstream locations since shutdown of the operation and completion of decommissioning activities. A shift to increasing levels of radium-226 over the past few years within the TMF surface waters triggered in-depth sediment chemistry investigations. Based on the results of this work and detailed geochemical modelling of lake water column/sediment interactions, it is anticipated that the present mass sources causing this increase will be depleted in the near term, and the anticipated long-term declining trend will commence.

In response to water quality improvements, sediment quality has demonstrated recovery in the TMF and Beaverlodge Lake. While concentrations remain elevated above pre-operational natural levels, the direction and rate of recovery is encouraging. In Dubyna Lake, the recovery rate may be longer than originally anticipated due to the influence of seepage from former underground workings contributing metal and radionuclide loads directly to the lake.

Biological recovery within all three areas has been positive. In the Dubyna area the shallow zone benthic invertebrate taxonomic composition is comparable to reference areas with some slight differences in the proportions of various metal-tolerant and sensitive species. The presence of both large predator fish species and forage fish is considered positive considering the historical metal concentrations in the lake.

In the TMF, the benthic invertebrate community is dominated by metal tolerant species, but sensitive species are also present at some locations. The fish community is showing potential for sustainability and diversity in the main tailings discharge waterbody of the TMF (i.e., Fookes Lake). This ongoing recovery of the system should continue spatially as fish migrate from upstream lake (Fulton lake) into the TMF. Fish health studies on forage fish within the TMF, Fookes Lake, suggest that fish health is comparable to reference fish. Although some indication of fish abnormalities remains the incident rates have been steadily declining through time.

In Beaverlodge Lake, water and sediment quality demonstrate an obvious improvement through time. Although some potential impacts may still be present as a result of historical contaminant loadings, benthic invertebrate community composition is consistent with non-impacted areas within the region. Fish populations are healthy and sustainable for some species, however for others it is unclear where selenium has been identified as a potential mid-term reproductive, population-level threat.

Overall, as water quality improves and sediments recover the biological community at the Beaverlodge mine/mill site will continue to re-establish. While the areas have not yet demonstrated a full recovery, the diversity and sustainability of biological resources is certainly on the right track.

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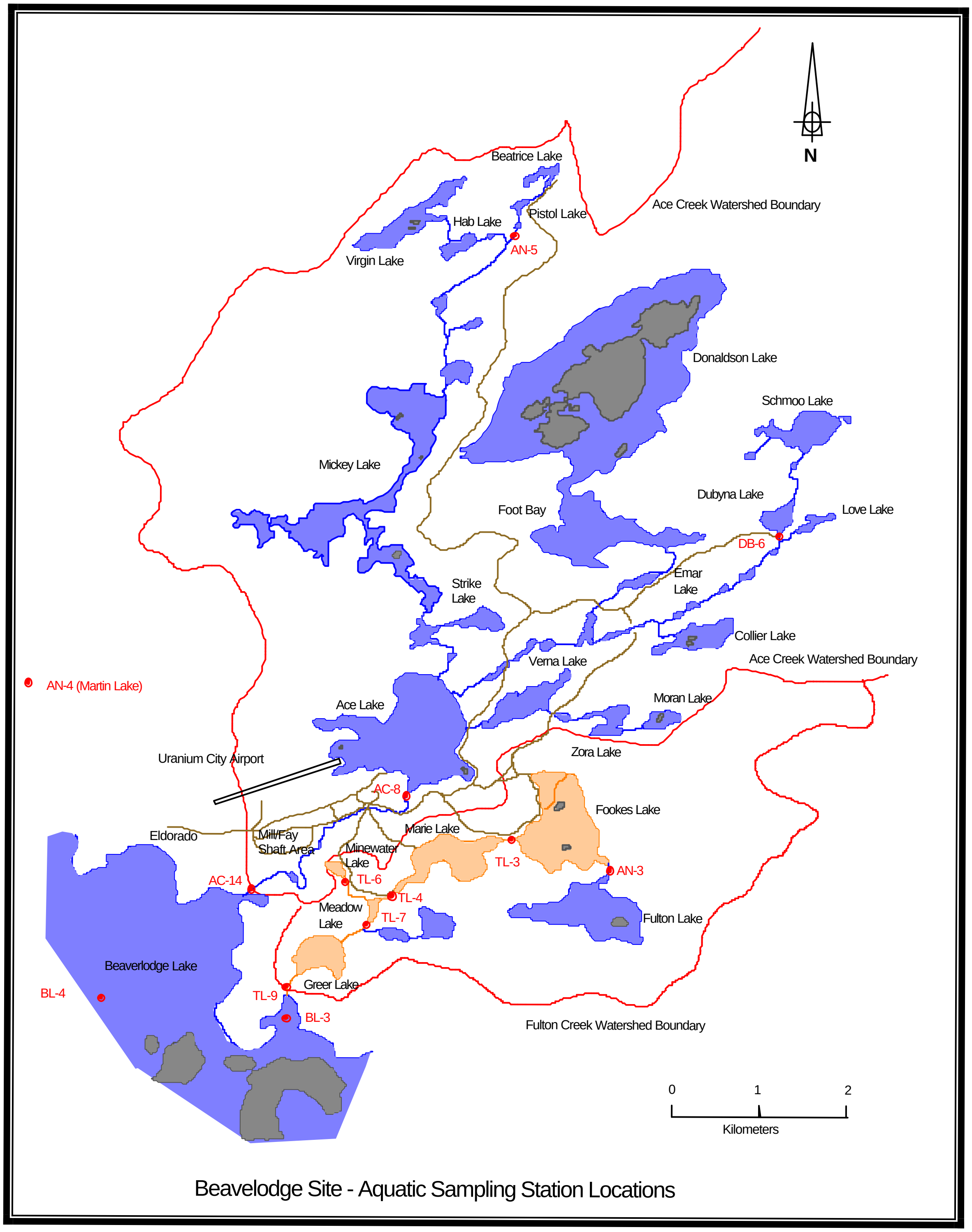
N
Beatrice Lake
Ace Creek Watershed Boundary
Pistol Lake
Hab Lake
Virgin Lake
AN-5
Donaldson Lake
Schmoo Lake
Mickey Lake
Dubyna Lake
Love Lake
Foot Bay
DB-6
Emar
Lake
Strike
Lake
Collier Lake
Ace Creek Watershed Boundary
Verna Lake
AN-4 (Martin Lake)
Moran Lake
Ace Lake
Uranium City Airport
Zora Lake
AC-8
Fookes Lake
Eldorado
Mill/Fay
Shaft Area
Marie Lake
Minewater
Lake
TL-3
AN-3
AC-14
TL-6
TL-4
Meadow
Lake
TL-7
Fulton Lake
Beaverlodge Lake
BL-4
TL-9
Greer Lake
BL-3
Fulton Creek Watershed Boundary
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Kilometers
Beavelodge Site - Aquatic Sampling Station Locations

Figure 1

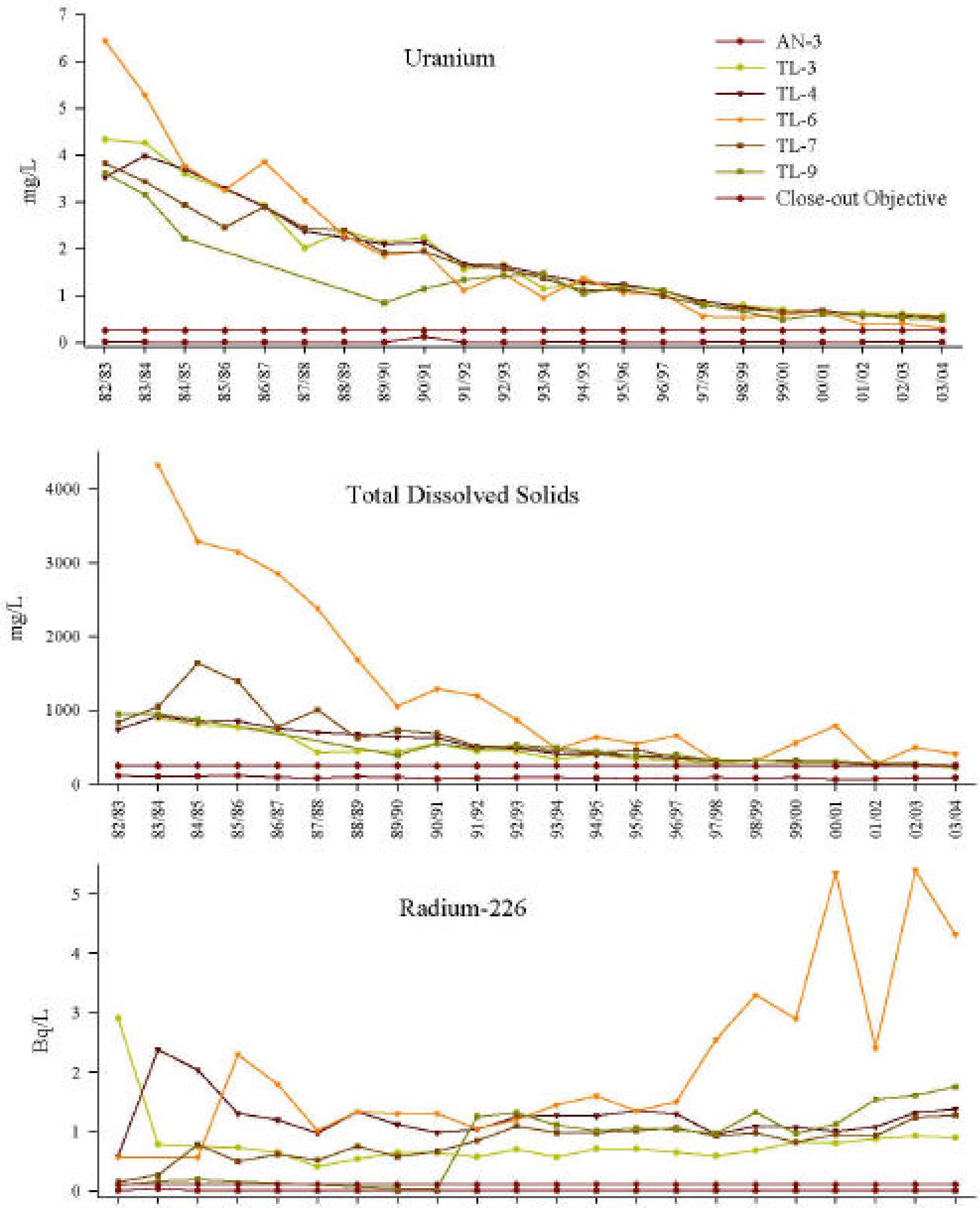

Figure 2
Average concentrations of uranium, total dissolved solids, and radium-226 measured at the water quality sampling stations in the Fulton Creek watershed.

Figure 3: Selenium concentrations in sediment profiles obtained from Fulton Bay, Beaverlodge Lake in 2001.

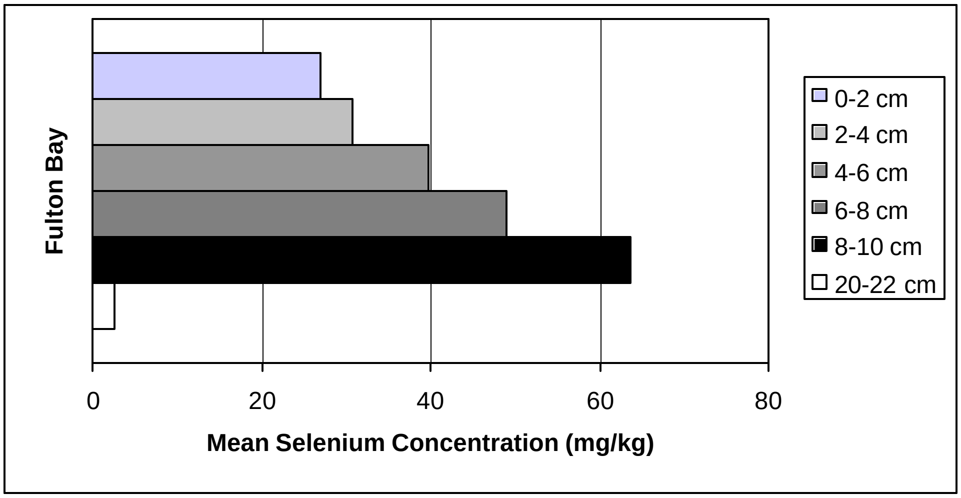

Figure 4: Uranium concentrations in sediment profiles obtained from Fulton Bay, Beaverlodge Lake in 2001.

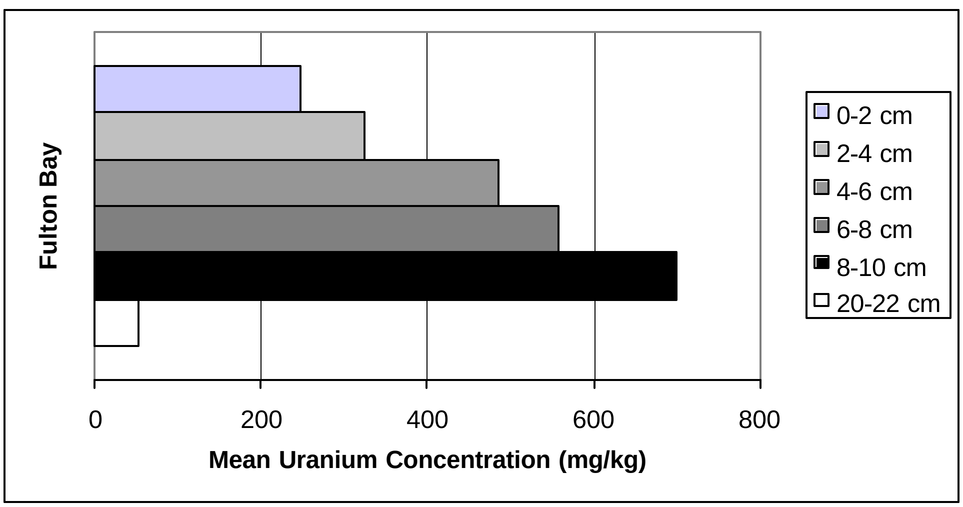

TABLE 1

Percentage of abnormalities in the lake chub examined from Fulton, Fookes, Marie, and Greer lakes, September 2004.

Abnormalities	Reference	Exposure		
	Fulton Lake	Fookes Lake	Marie Lake	Greer Lake
Eyes[1]	-	16%	73%	29%
Head[2]	2%	2%	1%	4%
Body Surface[3]	-	1%	12%	2%
Opercles[4]	-	1%	-	-
Fins[5]	10%	6%	-	14%
Internal Parasites	1%	2%	-	2%
Total number of fish evaluated	86	123	67	56
Total number of fish affected	18	39	57	21
% affected in 2004	21%[6]	32%	85%	38%
% affected in 2000	0%	48%	77%	89%
% affected in 1995	0%	97%	-	-

[1]cataracts, bulging eyes, bulging lens, misshapen pupil, and/or missing eye.

[2]shortened upper lip and/or shorted snout.

[3]hermorhaging areas.

[4]slight shortening of opercles.

[5]frayed fins, inequality in fin size, and/or split caudal fin.

[6]While lake chub abnormalities were present in fish from Fulton Lake, these types of abnormalities (frayed fins and internal parasites) are consistent with those expected to occur to some extent within all fish populations.

TABLE 2

Community metrics of benthic macroinvertebrate data collected in Dubyna and Schmoo lakes, April 2002.

Waterbody[1]	Site	Abundance (per m^2) (Mean ± StdDev)	Total # of Taxa	Number of Taxa (Mean ± StdDev)	Simpson's Diversity Index (Mean ± StdDev)	Shannon-Wiener Diversity Index (Mean ± StdDev)
Schmoo Lake	Deep	180.42 ± 162.16	5	3.00 ± 0.71	0.36 ± 0.18	0.84 ± 0.35
Dubyna Lake	Deep	2.31 ± 0.86	1	1.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Schmoo Lake	Shallow	269.66 ± 213.41	12	7.60 ± 1.67	0.74 ± 0.06	2.24 ± 0.28
Dubyna Lake	Shallow South	411.99 ± 196.53	13	7.00 ± 1.87	0.53 ± 0.16	1.50 ± 0.46
Dubyna Lake	Shallow West	288.13 ± 173.05	10	6.80 ± 0.84	0.64 ± 0.03	1.82 ± 0.11

Note: The values are a mean of five replicate samples with each sample a composite of 10 Ekman dredges. The samples were filtered through a 500 µm mesh.

[1] Schmoo Lake is the reference lake and Dubyna Lake is the exposure lake.