Addendum to Proposed Jericho Project Land Application (Spray Irrigation) Treatment System

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EXECUTIVE SUMMARY

The design of a land treatment (spray irrigation) system for the proposed Jericho Mine is presented. This design accounts for a recently revised water balance at the site. In addition, it incorporates concerns expressed in reviews of an earlier design.

The revised water balance indicates that a maximum of 1,000,000 m^3 of water may need to be treated annually from the PKCA. Evaporation of mine water during its application on land can reduce this volume to 600,000 m^3. This reduction in water volume can be engineered through judicious selection of pumps and spr inklers target, and it is readily supported by information in the published literature.

The predicted composition of PKCA water indicates that ammonia, copper and nickel will be elevated in relation to concentrations stipulated in the Diavik water license (used here as a provisional reference point)[1]. These predicted concentrations and the above annual water volumes are used to determine that a **5 hectare land area** is required for spray irrigation.

Based on predicted maximum ammonia concentrations of 2.9 mg/L (as NH_4-N), the annual load of ammonia to be treated is 1,700 kg. The land area that can remove this amount of ammonia is calculated to be 3 hectares, based on a conservative areal removal rate of 6 kg/ha/d and a treatment period of 100 days (end of June to end of September). The above removal rate is based on the measure rates from treatment wetlands located in Northern Ontario and Saskatchewan. The nitrate resulting from ammonia oxidation is expected to be removed more rapidly.

Copper is expected to be removed because of its strong affinity to organic matter. Using a conservative areal removal rate of 0.2 kg/ha/d obtained from a survey of treatment wetlands, an area of 0.4 hectares is expected to be sufficient to remove 8 kg Cu annually released in the PKCA discharge.

Nickel is also expected to be removed because of its strong affinity to organic matter. Using a conservative areal removal rate of 0.085 kg/ha/d measured in a treatment wetland in Northern Manitoba, an area of 4.9 hectares is expected to be sufficient to remove 42 kg Ni annually released in the PKCA discharge.

Assuming a maximum annual volume of 1,000,000 m^3 of PKCA water being treated, copper and nickel retained in soil during ten years of treatment may (conservatively) increase soil concentrations by a maximum of 32 ppm and 168 ppm, respectively. The increased copper concentrations are within the limits of soil concentrations measured in Arctic soils. However, the increased nickel concentrations would be elevated. This could result in potential impacts due to plant uptake and transfer in the food chain. Such a potential impact can be mitigated by segregating water that contains elevate nickel concentrations from water destined for the PKCA. Alternatively, water may be spray irrigated at a number of sites, thereby decreasing maximum soil nickel concentrations. Finally a pre-treatment that removes nickel could be used.

Estimated uranium concentrations could be elevated in the PKCA discharge, though there are no applicable water quality standards against which to gauge these concentrations. A simplistic risk assessment showed that, under a worst-case scenario, soil uranium concentrations could increase sufficiently to pose a risk to human health. However, a survey of the property shows that only two water sources may account for elevated uranium concentrations. Thus, it should be possible to segregate these water sources and treat them separately, thereby preventing substantial uranium

[1] This is not meant to imply that the Diavik water license limits are directly applicable to or should be adopted for the Jericho Project. These limits are used strictly for illustrative purposes.

accumulation in soil. As an additional precaution, PKCA water applied on land should be monitored for uranium to ensure that it never exceeds safe limits.

Results from field and laboratory studies summarized herein show that one area on the property is particularly suited for spray irrigation, based on its extensive vegetative cover, gentle slope, and favourable hydraulic properties. This area is delineated on the map appended to this report. A field study showed that a water application rate of 12 hours/day (3 hours ON/ 3 hours OFF) at this site can be sustained without causing water to sheet over land, as is necessary for effective treatment.

An analysis of soils from this area shows that they are acidic and often contain elevated salt (particularly calcium and magnesium) concentrations. Despite their acidic pH, these soils have been shown to support bacterial ammonia removal. The latter activity may be enhanced by applying lime on soil before land treatment starts.

A study addressing the potential harmful effects from chloride in mine water, as well as its predicted Sodium Adsorption Ratio (SAR), indicates that no harmful impacts are expected on vegetation from PKCA water applied on land. In fact, it is possible that spray irrigation will decrease salt concentrations in soils at the site due to reduced evapoconcentration.

A monitoring plan for the spray irrigation system has been delineated. The proposed monitoring programme would measure treatment performance as well as potential impacts from treatment. Thus, changes in the active layer induced by spray irrigation would be monitored, and a number of contingency measures have been outlined to counteract permafrost erosion, should it be detected. Other impacts on soil, plants and animals would also be monitored. Contingency measures have been proposed if metals begin to accumulate significantly in soils at the site.

Changes in plant community composition towards sedge grasses and water tolerant terrestrial plants are among the long-term impacts anticipated from the spray irrigation system. While these changes are likely to be reversible, this is not certain, on account of changes in drainage patterns that may occur during mining operation.

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Introduction

A spray irrigation system was proposed in the original Jericho Project EIS to remove ammonia from mine water. This system was designed according to the following assumptions:

- Volume of water to be treated is up to 300,000 m^3, based on estimates provided by SRK (maximum 316,000 m^3 worst case scenario MAR 250 mm)
- Ammonia concentration of water to be treated assumed to be 30 mg/L (worst case scenario)
- All water is to be treated and disposed of in a 90-day period

The area required for spray irrigation was calculated to be 14 hectares, based on an areal removal rate for ammonia. This amount of land is available between the proposed PKCA and Lake C3, as shown in the map appended to this addendum. The proposed maximum application rate of 160 m^3/hr over this area would not exceed the limit of 5 m^3/ m^2/day imposed by hydraulic and erosion considerations.

Upon review of this proposed treatment system and other information presented in the EIS, a number of deficiencies were identified. These deficiencies were to be corrected in a revised treatment system. More recently, a new water balance was derived and concentrations of potential contaminants in mine water, particularly metals, have been refined. All this information has implications on the spray irrigation system originally proposed.

This supplement to the Jericho Project EIS addresses the mitigation of potential impacts from contaminants produced during mining activity. The rationale for the proposed spray irrigation system will be presented first, in relation to the removal of contaminants from mine water. Then, concerns raised in the review of the original EIS and in a subsequent technical review session will be addressed.

Revised Water Balance

One of the key development following the EIS review was a revised water balance. In the following calculations, we used the predicted hydraulic and chemical at face value. The suitability of the proposed spray irrigation system is evaluated in relation to these changes.

Contaminants of concern

The revised water balance for the proposed Jericho Mine predicts that some contaminants will exceed environmentally-acceptable concentrations (Table 1). Other potential contaminants are predicted to be lower than the Diavik water license limits, presented here as a point of reference.

Table 1. Predicted concentrations of selected metals at various locations on mine site*.

Location	Nutrients			Physical	Total Metals						
	NH4-N	**NO3-N**	**P**	**TDS**	**TAl**	**TCu**	**TFe**	**TNi**	**TPb**	**TU**	**TZn**
Pond A	**4.0**	9.94	0.0100	980	0.8686	**0.0453**	1.5795	0.0284	0.0051	1.6439	0.0614
Pond B	**4.2**	10.48	0.0100	1026	0.8472	**0.0475**	1.6123	0.0298	0.0046	1.7220	0.0642
Pond C	**3.3**	8.16	0.0100	4252	0.6823	0.0048	1.0675	**0.1201**	0.0070	0.1426	0.0297
Pit Pond/Sump	**3.3**	8.20	0.0098	186	0.4818	0.0096	0.7379	0.0477	0.0048	0.0997	0.0090
PKCA	**2.9**	7.28	0.0831	1558	1.0401	**0.0206**	1.0149	**0.0695**	0.0042	0.6802	0.0335
Settling Pond	**2.8**	7.04	0.0532	1515	0.8683	0.0199	0.9873	**0.0591**	0.0041	0.6500	0.0323
Diavik WL Limits	2.00	na	0.2000	na	1.5000	0.0200	na	0.0500	0.0100	na	0.3000

*Jericho Project - Summary of Maximum Estimated Parameter Concentrations over Mine Operating Period. SRK Revision Sept 23, 2003.

It is assumed that acceptable concentrations will be comparable to the permissible levels stipulated in the water license of other diamond mines in the region. For the sake of argument, the Diavik water license limits is used to set these levels. Accordingly, contaminants predicted to exceed acceptable levels include:

1. Assuming maximum source conditions, ammonia concentrations (as NH_4^+-N) are predicted to exceed 2.0 mg/L (range 2.1-4.2 mg/L) from all sources.

2. Under the above conditions, copper (as Total Copper) is predicted to exceed 0.020 mg/L (range 0.020-0.048 mg/L) in Ponds A and B, the settling pond and the PKCA.

3. Under the above conditions, nickel (as Total Nickel) is predicted to exceed 0.050 mg/L (range 0.080-0.23 mg/L) in Pond C, the settling pond and the PKCA.

Every other contaminant is predicted to be at environmentally-acceptable concentrations in the mine discharge. Since all the water from the mine is proposed to be directed to the PKCA, the concentrations of ammonia, copper and nickel must be reduced to acceptable levels in order to prevent environmental impacts from mine discharges. In addition, the long-term effects of land application of lead and uranium will be considered.

Hydraulic loadings

Throughout the water balance calculations, the maximum monthly discharge at the mine is predicted to be 250,000 m^3 from June to September, regardless of low/average/high scenarios considered, for a total annual discharge of 1,000,000 m^3. However, this volume is only expected during the first two years of the operations and is a peak, not an annual norm.

During the EIS technical review session (Edmonton, June 17, 2003), concern was expressed about the potential erosion of permafrost due to the application of mine water over land. One way to minimize this impact is to decrease the amount of water applied on land. This can be done by engineering spray irrigation to enhance water evaporation[2]. In fact, spray irrigation can be engineered to: a) reduce ammonia loadings via ammonia diffusion to air from airborne water droplets (enhanced at higher pH); and, b) reduce hydraulic loadings to land via water evaporation.

Factors affecting the evaporative losses from agricultural sprinkler irrigation systems have been reported by numerous published studies[3]. Although these studies were concerned with minimizing the evaporative losses in agricultural irrigation applications, their results can be used to maximize water evaporation to either decrease hydraulic loadings (increasing the contaminant concentrations but leaving the contaminant loadings unchanged) or reduce the land area requirements by evaporating volatile substances such as ammonia gas. For the present purpose, it is conservatively assumed that there is no net loss of ammonia to the atmosphere during

[2] An application method that maximizes water evaporation is to use atomizers, as has been proposed at Ekati. This approach has advantages and drawbacks, but its suitability will not be discussed here.

[3] Dadiao, C. and W.W. Wallender. 1985. Droplet size distribution and water application with low-pressure sprinklers. Transactions of the ASAE 28(2):511-516

McLean, R.K., R. Sri Ranjan, and G. Klassen. 2000. Spray evaporation losses from sprinkler irrigation systems. Canadian Agricultural Engineering. 42:1-8.

Solomon, K.H., D.C. Kincaid and J.C. Bezdek. 1985. Drop size distribution for irrigation spray nozzles. Transactions of the ASAE 28(6):1966-1974.

Yazar, A. 1984. Evaporation and drift losses from sprinkler irrigation systems under various operating conditions. Agricultural Water Management 8:439-449.

spraying, and that the spray irrigation evapoconcentrates ammonia as it is applied to the soil (i.e. ammonia mass loading remains the same).

In general the 'above the canopy spray evaporation loss' (or ACSEL) is determined by equipment-related factors and weather conditions. Evaporative losses are enhanced by generating smaller droplets travelling greater distances, higher winds, higher water/air temperature ratio, and higher air vapour pressure deficit. All these factors can be manipulated in the engineering design of the sprinkler system by adjusting the sprinkler type, water pressure, nozzle design and size, and the water application schedule.

The reviewed studies, which were designed to conserve water and were conducted in various climatic conditions, and used several low-pressure agricultural sprinkler irrigation systems, reported evaporative losses reaching 30 to 50%. Although true site-specific evaporative losses need to be field-evaluated[4], it is expected that ordinary agricultural sprinkling equipment can be selected and adjusted to result in 40% reduction of water volumes due to evaporation.

This measure alone may not preserve permafrost on the land that is spray irrigated. However, permafrost engineering is well understood, and measures to preserve permafrost may be applied. Thus, water evaporation causes cooling, which can be used to protect permafrost. Other measures may be engineered f this is necessary. Damage from permafrost erosion will be prevented by implementing such measures and monitoring soil temperature profiles, as described in a monitoring plan, below.

Ammonia Removal

Although the annual volume of water to be treated has increased by 233% under the revised water balance, to 1,000,000 m^3, the overall load of ammonia has decreased from approximately 9,000 to **3,000 kg/yr**. The latter figure is calculated as follows:

Assuming a permissible discharge of 2 mg/L and maximum ammonia concentrations of 2.9 mg/L on an annual volume of 1,000,000 m^3, or 4.8 mg/L on an annual volume of 600,000 m^3 (assuming engineered evaporative losses of 40%), the *annual ammonia load (as NH_4-N) to remove prior to discharge is 4.8 – 2 = 2.8 mg/L x 600,000 m^3 = 1,700 kg/yr*.

The size of the land area that can remove ammonia from the discharge can be determined by dividing the ammonia loading rate (above) with an areal removal rates for ammonia. The latter rate is derived from information presented below.

There are no scientific reports on nitrogen removal that are specific to the Arctic. Several Arctic "treatment wetlands" were constructed to deal with sewage, but their performance with regards to nitrogen removal has not been documented. The best data on ammonia removal rates for mine water come from two treatment wetlands in Ontario. Although ammonia removal through wetlands differs from that on land, removal processes are very similar, justifying use of these data[5].

[4] Generally, the site has constant gentle breezes and low relative humidity, factors that favour evaporative losses.

[5] In fact, that aerobic natural of terrestrial soils favours ammonia removal compared with the anaerobic soils in wetlands.

Ammonia removal rates for water from the Musselwhite Mine in Northern Ontario are presented below[6]. Despite its Southern location, rates derived for water at 2.5 and 15 ºC (Table 2) are deemed relevant for the Jericho site.

Table 2. Areal removal rates for ammonia measured at the Musselwhite mine.

INFLUENT [NH_4-N]	TEMPERATURE	FLOW RATE	EFFLUENT [NH_4-N]	AREAL REMOVAL RATE
15 mg/L	2.5 °C	300 m^3/hr	7.8 mg/L	14.4 kg/ha/d
15 mg/L	2.5 °C	600 m^3/hr	9.8 mg/L	10.4 kg/ha/d
15 mg/L	15 °C	300 m^3/hr	2.8 mg/L	24.4 kg/ha/d
15 mg/L	15 °C	600 m^3/hr	5.2 mg/L	19.6 kg/ha/d

A treatment wetland at the Campbell Mine (also Northern Ontario) averaged ammonium removal rates of 6.8 kg/ha/d under steady-state conditions (flow range: 8,500 – 11,000 m^3/d; input NH_4-N: 5.8-9.6 mg/L). However, ammonia removal in the first two-thirds of the wetland averaged 10 kg NH_3/ha/day, closer to the removal rates for Musselwhite. A statistical analysis of data from the Campbell wetland showed that removal rates are correlated with ammonia concentration, decreasing substantially when its concentrations decrease below 2 mg/L.

Several natural wetlands, typical *Sphagnum* and sedge-dominated boreal fens (commonly referred to as bogs or muskeg), were used at Cameco's former Jolu and Star Lake/Jasper operations (Saskatchewan) to polish tailings pond overflow by removing residual cyanide and copper[7]. They provided seasonal treatment by spray irrigating mine water during the ice-free season.

Cyanide removal is relevant to this discussion because its degradation produces ammonia, as follows:

$$CN^- + ½\,O_2 \rightarrow CNO^- \text{ followed by: } CNO^- + H_2O + H^+ \rightarrow NH_3 + CO_2$$

Ammonia produced by this reaction was removed within the wetlands, whose vegetation is comparable with that at Jericho (muskeg, Labrador tea, sphagnum moss, etc). Thus, this example provides additional information to support the derivation of an areal removal rate.

The Star Lake/Jasper wetlands treated a total volume of 185,000 m^3 in 142 days in 1989, for a mean daily flow rate of 1,300 m^3/d. Two treatment wetlands with a surface area of 25,300 m^2 removed all the cyanide and ammonia. Cyanide removal by each wetland reached 95%, on loadings of 0.05-30 kg/ha/d. Accordingly, cyanide removal of >90% was achieved on loadings of between 3 and 8 kg/ha/d. This removal rate is also applicable to ammonia: equivalent removal rates for ammonia at this site are between 2 and 6 kg/ha/d.

Based on the above information, **an ammonia removal rate of 6 kg/ha/d** is used for the system design. This is less than the lowest rate at Musselwhite, but is comparable with the rates for Campbell and the Star Lake/Jolu Mines.

[6] Presented earlier in report titled "The Suitability of Wetland/Overland Flow Treatment and Spray Irrigation for Mine Water for the Jericho Project: Phase 1"

[7] Gormely, L., T.W. Higgs, R.U. Kistritz and A. Sobolewski. Assessment of wetlands for gold mill effluent treatment. Report prepared for the Mine Pollution Control Branch of Saskatchewan Environment and Public Safety, Saskatoon, SK. 63 pp. 1990.

Obviously, there are significant difference between Southern wetlands and an Arctic land treatment system. for instance, the acidic soils in the Arctic may initially produce a low removal rate, but this is expected to be mitigated by the alkaline water applied from PKCA[8]. In addition, plant growth rates are higher in Southern climates, and will account for a higher proportion of ammonia removal than in the Arctic. On the other hand, the spray irrigation system will proceed through wet-dry cycle, which favour high microbial ammonia removal rates compared with the permanently-flooded conditions in treatment wetlands.

Another important factor is that removal rates are concentration-dependent. The concentrations predicted in the PKCA discharge are in the range of 2 mg/L, much lower than the concentrations at the other mines. However, with an engineered spray irrigation system that enhances water evaporation, ammonia concentrations applied on land will increase to approximately 5 mg/L. This would support higher removal rates.

In the balance, the rate of 6 kg/ha/d appears to be reasonable. However, there is land available for wider application, should this rate prove too high, providing an additional safety margin.

Based on an annual ammonia load of 1,700 kg, an areal removal rate of 6 kg/ha/d, and on a treatment period of 100 days (end of June to end of September), the land area required for spray irrigation is calculated as follows:

1,700 kg ÷ [6 kg/ha/d x 100 days] = **3 hectares**

This is a fraction of the **14 hectares** originally calculated. Even if the removal rates are half of the above, there is still ample land available for treatment. This smaller land requirement affords more flexibility in the application of spray irrigation at the site, with regards to its timing and location. The latter (different, changing locations) is possible because spray irrigation is very flexible (pumps, lines, and sprinklers can be moved easily), which is a real advantage over fixed systems (e.g., atomizing towers).

Since nitrate removal rates are always higher and more rapid than those for ammonia, it is expected that the design will also be conservative for nitrate removal.

Metal removal

Metals are often attenuated in the environment by natural processes. Particularly relevant to the present circumstance is the fact that copper, nickel and uranium are removed very effectively by sorption on organic matter[9]. Thus, these metals will be removed in a land treatment system.

The first question to determine is what area is required for their removal. This is done as for ammonia, by first calculating the load to be removed, then dividing this by the areal removal rate and duration of application. A second question, to be determined later, is to ascertained whether their accumulation in soil could be harmful.

Copper and Nickel

The concentrations of both copper and nickel exceed slightly the levels set in the Diavik water license (Table 1). Their concentrations will increase by a factor of 1.67 when evaporative water losses are taken into account. These concentrations are:

[8] In addition, lime could be added to the site to neutralize the soil acidity.

[9] Sobolewski, A. 1999. A review of processes responsible for metal removal in wetlands treating contaminated mine drainage. International J. Phytoremediation *1*: 19-51.

1. For copper, predicted PKCA concentrations of 0.0206 will increase to 0.034 mg/L. Thus **0.014 mg/L** will need to be removed from mine water, assuming an acceptable limit of 0.0200 mg/L. Annual loadings will be **8 kg Cu**.
2. For nickel, predicted PKCA concentrations of 0.070 will increase to 0.12 mg/L. Thus **0.070 mg/L** will need to be removed from mine water, assuming an acceptable limit of 0.0500 mg/L. Annual loadings will be **42 kg Ni**.

Areal removal rates for copper have been developed from some natural wetlands. These removal rates must be used cautiously because several processes acting in treatment wetlands (adsorption onto iron/manganese oxides, precipitation as sulphides) may not occur during land treatment. However, both share the ability to adsorb metals onto organic matter, which typically accounts for 50% of total removal of copper and nickel in treatment wetlands. Thus, areal removal rates derived from treatment wetlands may be used, so long as they are applied conservatively.

Copper loadings of 0.2-8 kg/ha/d have been removed effectively in treatment wetlands[10]. Even using the lowest areal removal rate of 0.2 kg/ha/d, the annual copper load of 14 kg from PKCA will require the following land area:

$$8 \text{ kg} \div [0.2 \text{ kg/ha/d} \times 100 \text{ days}] = \mathbf{0.4 \text{ hectares}}$$

This is less than the 3 hectares calculated to be required for ammonia removal, suggesting that this area should be sufficient. Next, the land area required to remove nickel is calculated.

Nickel was retained very effectively in a natural wetland at the Birchtree Mine, Thompson, Manitoba[11]. Nickel was removed by 95-99% from mine water containing 5 mg/L Ni on loadings of 0.1-1.0 (average 0.3) kg/day (flows range from 1,000-11,000 m^3/day) over an area of approximately 1.8 hectares. This yields an areal removal rate of approximately **0.17 kg/ha/day**. In this wetland, adsorption onto organic matter accounted for 50% of all removal, so the above removal rate may be halved to be conservative.

Using the areal removal rate of 0.085 kg/ha/d, the annual nickel load of 42 kg from PKCA will require the following land area:

$$42 \text{ kg} \div [0.085 \text{ kg/ha/d} \times 100 \text{ days}] = \mathbf{4.9 \text{ hectares}}$$

This is more than the 3 hectares calculated to be required for ammonia removal. **Thus, the land area that should be used for treatment of PKCA water is 5 hectares.**

Metals retained in treatment wetlands do not enter the food chain because aquatic plants do not take up metals retained in their sediments. However, this will not be the case with land treatment. Thus, it is important to determine the final soil concentrations of metals applied on land during the entire project to determine if land treatment of PKCA water is suitable. This is calculated by dividing the total metal load during mine life with the total soil volume for the application area.

A total loading of 80 kg Cu is expected to be deposited during 10 years of mine life (8 years + 2 years post-closure). Assuming an average soil depth of 10 cm over an area of 5 hectares, and peat density of 0.5 kg DW/Litre, the increase in soil concentrations is calculated to be: [(80 kg (loading))/(50,000 m^2 x 0.1 m (soil volume))/0.5 (peat density)] x 1,000,000 (conversion factor

[10] Sobolewski, 1999. See above.

[11] Hambley, A.G. 1996. Removal of nickel from mine water by a natural wetland in Northern Manitoba. M. NRM. Thesis, University of Manitoba, Winnipeg, Manitoba, Canada.

kg to mg) = **32 ppm Cu** increase in soil concentrations (**as mg/kg DW**). This is a modest increase. For example, surveys of copper concentrations in ("unimpacted") soil across the Russian Arctic and in Greenland show that it ranges from 0.3 – 36.8 ppm, with an average of 7.6 ppm[12].

A total loading of 420 kg is expected to be deposited over 5 hectares during the 10 years of mine life (8 years + 2 years post-closure). Assuming an average soil depth of 10 cm over this area, and peat density of 0.5 kg DW/Litre, the increase in soil concentrations is calculated to be: [(420 kg (loading))/(50,000 m^2 x 0.1 m (soil volume))/0.5 (peat density)] x 1,000,000 (conversion factor kg to mg) = **168 ppm** increase in soil concentrations (**as mg/kg DW**). Unfortunately, no data are available on the concentrations and distribution of nickel in Arctic soils, obscuring the significance of this calculation[13].

The above soil concentrations result from nickel concentrations predicted under a maximum production from sources scenario. A scenario of average production from sources halves the nickel concentrations in PKCA, resulting in increased soil concentrations of approximately **80 ppm**. This is still a significant increase, though not as large as under the maximum production scenario. *Regardless, this finding alone would suggest that some step must be taken to mitigate potential impacts from nickel accumulation in soils during spray irrigation.*

Uranium

Uranium is predicted to be present in the PKCA discharge. If ingested in sufficient quantities, uranium may be chemically toxic (impairs renal function in humans) or radiologically toxic (emitting radiation that causes genetic mutations).

To determine if uranium in PKCA water could impact either the environment or humans, an assessment was made with the following calculations and assumptions. Note that conservative assumptions were generally made, to determine if there is a potential problem at the site.

1. Assuming that Total Uranium is equal to Dissolved Uranium in the September 22, 2003 revision of the water balance, and assuming that uranium will not be adsorbed onto clays deposited in PKCA, uranium concentrations ranging from **0.12 - 0.70 mg/L** are predicted to be deposited during spray irrigation of mine water.

2. Assuming that uranium is not present as a soluble complex (carbonyl or other complexes), it is assumed that *all the uranium will be retained on organic matter in the spray deposition area*[14], equal to **5 hectares**. Under this assumption, the potential increase in uranium soil concentrations from mining activity (10 years) is calculated as follows. Mass loading: 0.12 - 0.70 mg/L x 1,000,000 m^3/year x 10 years = **1,200 – 7,000 kg**. Soil concentrations from deposition over 5 hectares, assuming 10 cm average soil depth and peat density of 0.5 kg DW/Litre: [(1,240 – 6,800 kg (loading)) ÷ (50,000 m^2 x 0.1 m (soil volume))/0.5 (peat density)] x 1,000,000 (conversion factor kg to mg) = **480 –**

[12] Wilson, S.J., J.L. Murray, and H.P. Huntington. 1998. Heavy Metals, In: Chap. 7, AMAP (Arctic Monitoring Programme) Assessment Report: Arctic Pollution Issues. P. 374-453.

[13] As a comparison, average soil concentrations in a 25 km radius from Sudbury, where smelter depositions contaminated soils, is 200-250 ppm.

[14] S.C. Sheppard and W.G. Evenden. 1988. Critical compilation and review of plant/soil concentration ratios for uranium, thorium and lead. J. Environ. Radioactivity, *8*: 255-285.

2,800 ppm increase in soil concentrations (**as mg/kg DW**). These conservative assumptions that are unsupported by field data[15].

3. A key objective, for the sake of this calculation, is to protect human health: *caribou should be safe for consumption by local Innu*. According to the World Health Organization (WHO), the provisional tolerable daily uranium intake (TDI) is **0.6 µg/kg (body weight)/day**. Note that this TDI is based solely on the objective to protect from chemical toxicity. It is assumed that an Innu adult (average weight 70 kg) could consume 0.5 kg caribou meat in a day. Accordingly, the maximum amount of uranium that can be safely eaten by an adult in a day is 0.6 µg x 70 kg = **42 µg/day**. With a daily meat ration of 0.5 kg, this means that the maximum allowable tissue concentration in caribou is 42 µg/0.5 kg = **84 µg/kg wet tissue, or 840 µg/kg DW** (assuming 90% moisture content).

4. Now, the above soil concentrations must be correlated to caribou tissue concentrations. A simplified food chain is assumed: soil → plant → caribou → human. Though simplistic, this is sufficient for this calculation. A review paper[14] compiles plant/soil concentration ratios for uranium, as well as a regression on mean CR values (See Figure 1 reproduced below).

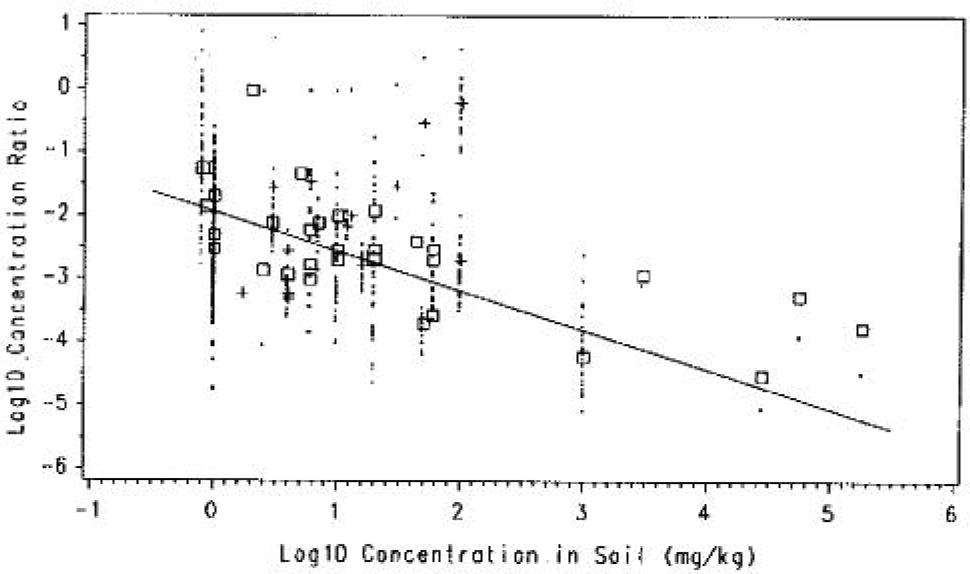


Figure 1. Regression of plant-soil concentration ratios (CR) on soil concentrations.

Figure 1 indicates that soil concentrations of 480-2,800 ppm have the $\log_{10}$ CR of roughly -3.5. Accordingly, plant concentrations are predicted to be 0.0003X soil concentrations (based on their Dry Weight), or around **144-840 ppb**.

Next, a plant → caribou CR is applied to estimate tissue concentrations in caribou. A published scientific study[16] concluded that the CR for lichen → caribou muscle in Northeastern Saskatchewan (near Cigar Lake and MacArthur River uranium deposits) ranged from 1 – 16%. Accordingly, caribou muscle concentrations may range from **1.4 – 134 µg/kg DW**. Circumstances for this field study may differ from those at the Jericho

[15] The highest measured uranium concentrations on the property, in "Tailings Lake" sediments, range from 22-48 mg/kg.

[16] Thomas, P.A. and T.E. Gates. 1999. Radionuclides in the lichen-caribou-human food chain near uranium mining operations in Northern Saskatchewan, Canada. Environmental Health Perspectives *107* (7): 527-537.

site (e.g., how much/how long caribou feed on uranium-enriched vegetation), but this value provides a reference point.

The above calculations, though simplistic and subject to many unverified assumptions, are nonetheless illustrative. The calculated range of caribou muscle concentrations is predicted to be approximately one order of magnitude lower than the maximum allowable tissue concentration, based on a provisional TDI from the WHO. More stringent TDI's (possibly based on radiological toxicity) may lower the TDI.

The issue may merit further study, such as collecting more data on uraniferous seeps, soil concentrations associated with these seeps, improving soil → plant → caribou CR's, and generally validating or improving the assumptions made herein. However, surveys of the property suggest that there are few water sources that contain uranium.

A single seep sample from water rock had elevated uranium. A sediment sample from Tailings Lake showed elevated uranium concentrations ranging from 22-43 mg/kg, indicating that some water draining into this lake has elevated uranium concentrations. Carat Lake sediments, which receives waters from the property, has slightly elevated uranium concentrations in its centre basin sediments (5.7 mg/kg vs 1.2-3.9 mg/kg in nearby lakes), suggesting that there might be a few water sources with elevated uranium concentrations draining into the lake. Leach extraction tests for waste rock produced very low uranium concentrations, while leach tests for kimberlite and tailings did not analyze for uranium[17]. These results suggest that uranium is not present in most water source on the property, but is elevated in a few.

Thus, a practical, feasible solution to this problem of increased soil uranium concentrations from spray irrigation, is to identify water sources with elevated uranium concentrations and segregate them from the water to be sprayed. As a further safety measure, uranium concentrations should be measured before PKCA water is applied on land, after a safe uranium level has been determined through a more detailed risk assessment.

Laboratory and Field Studies

Several studies were conducted in support of the development of spray irrigation treatment at Jericho. Some of them were presented earlier, but have been misinterpreted by reviewers. These are presented below, correcting misunderstandings if applicable, otherwise introducing new relevant information.

Laboratory study

A laboratory study was conducted on soils collected from the Jericho site[18]. This study intended to demonstrate that nitrification could occur in the acidic soils present at the site. It did not intend to derive removal rates, since it was understood that these would be of limited value in designing the treatment system.

Despite flaws identified by the reviewer in the Technical EIS Review (*Deficiencies in methodology and interpretation of laboratory scale data*), the results of the laboratory study remain valid within their limited, intended framework. It is not disputed that the laboratory temperature was higher than that in the field, that samples were largely, but not always iced, or

[17] Jericho Project EIS Appendices D.13-D.16, prepared by SRK.

[18] Sobolewski, A. 2001. Phase II Lab Study: Soils. Report prepared for Tahera Corporation by Microbial Technologies, Inc. 13 pp.

that CEC was not measured during the study, as indicated by the reviewer. All these problems may change somewhat the magnitude of the results, but they will not alter its main conclusion, that nitrification is supported in these acidic soils. This was a critical point to make because nitrification generally requires neutral-to-alkaline soils, whereas Arctic soils are generally acidic.

Soils were sampled at the Jericho site along three transects covering the anticipated spray irrigation area. Their composition is indicated in Table 3. While varied, all were similarly acidic. Thus, it was critical to demonstrate that nitrification can be supported by the acidic soils present at the site, and the laboratory study succeeded in this regard.

While the reviewer correctly indicates that the representativeness of soil samples used during the test was not discussed, the finding that nitrification occurs in acidic soils from the site is the central issue that needed to be demonstrated, and has been demonstrated.

While these data show that nitrification is possible in these acidic soils, it might be beneficial to apply lime to increase soil pH and alkalinity. Both changes from such an amendment will help nitrifying bacteria, as they favour neutral-slightly alkaline soil (for activity), as well as soils with significant alkalinity (for growth). Liming will also help to reduce metal uptake by plants.

Table 3. Chemical composition of soil samples collected during reconnaissance survey.

Sample	pH	Cond (mS/cm)	OM (%)	TN (%)	PO_4 (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	Na (ppm)
1 – Sandy	4.9	1.60	9.5	0.28	7.1	110	550	100	5.0
2 – Peaty	4.8	0.46	18.6	0.6	2.4	70	900	135	5.0
3 – Muddy	5.5	0.46	42.0	1.34	8.4	140	2500	420	45
4 – Peaty	5.7	0.52	65.0	1.31	26.3	465	3665	835	80
5 – Peaty	5.2	0.54	45.2	0.86	10.7	140	1400	430	10
6 – Sandy	5.6	0.42	94.3	0.96	15.7	315	5165	1250	70
7 – Sandy	4.7	0.50	7.5	0.16	2.9	60	500	80	10
8 – Sandy	4.8	0.32	2.2	0.06	2.4	25	150	25	5.0
9 – Peaty	5.1	0.50	75.7	1.30	8.3	370	1700	510	40
10 – Peaty	5.0	0.36	66.6	1.84	4.2	215	2335	465	62
Average	**4.9**	**0.65**	**26.4**	**0.54**	**5.6**	**129**	**867**	**213**	**13**
Median	**4.9**	**0.50**	**14.1**	**0.44**	**5.0**	**90**	**725**	**118**	**7.5**
Std Dev.	**0.19**	**0.47**	**28.5**	**0.47**	**3.6**	**125**	**588**	**204**	**14**

Site characterization

It has been suggested that the land for the proposed spray irrigation system must be characterized exhaustively to determine its suitability. In the Technical Review of the original EIS, the following list of required items was provided:

- Site grade/hydraulic gradient;
- Soil depth above permafrost – variation with location and depth of soil in the pilot trial;
- Soil porosity;
- Soil permeability investigation (both vertical and horizontal);
- Soil classification;
- Quantitative composition of soil including % boulders, gravel, sand, fines;

- Texture class;
- Stratification information;
- Wetness and texture;
- Cation Exchange Capacity (CEC) of soil in meq/m^3 ; and
- Complete chemical analysis of soil including ortho-PO_4, TOC, Na, K, Mg, and Ca

Some of this information was previously collected at the site, but most was not. This exhaustive list calls for far greater detail than required for the purposes of this review process. Even the detailed design of a spray irrigation system would not require such a laundry list of parameters, never mind the more conceptual design required in an EIS.

In our field work, candidate sites with gentle slopes (approximately 1-3%) and a high proportion (>70%) of continuous vegetative cover, as opposed to boulder fields were identified (See Map H). Ten soil samples were taken from areas with different plant covers where treatment was considered (see photographs below), to confirm the depth of soil that will provide treatment, and analyze soils for texture/classification, chemical composition (Table 3) and microbial counts. This was adequate for an initial reconnaissance survey.

Figure 2. Lichen/heather community over sandy soil.

Figure 3. Sedge grass community over peaty soil.

Figure 4. Grass community over sandy soil.

Figure 5. Sedge grass community over peaty soil.

Most of the above information is intended to predict the hydraulic properties of the site through a modeling exercise. While further surveying of candidate areas would generated these data, it is more direct and reliable to tested actual water flow patterns in the field at a representative site (See Figure 6. Notice the low relief of the area near lake C3).

Using a bromide tracer, the field trials[19] showed that continuous application of water will saturate soils and cause water to "sheet-flow" rather than travel through soil. **Intermittent application of water on a 3-hoursON/3-hours OFF cycle proved best for maximizing water contact with soil.** This defines the application rate for spray irrigation at this site.

Both the theoretical approach implied in the EIS review and our field study may arrive at the same answer, but ours is more direct and removes most of the uncertainty associated with the theoretical approach.

Figure 6. Spray irrigation test site at Jericho project, looking from Lake C3 towards Long Lake.

The field/laboratory studies defined the application rate for spray irrigation at this site, the site topology, defined areas of vegetation cover vs boulder fields, and soil depth and chemistry. The above review of ammonia and metal removal rates defined the size of the area needed for treatment, which we set at 10 hectares. The only additional information that is required is the seasonal depth of permafrost and its sensitivity to thawing from mine water applied on land. The latter will be defined later in the project and monitored during land treatment.

Environmental Impacts from sodium chloride

The issue of environmental impacts of salts – particularly chloride – on Arctic ecosystems was first raised during the review of Ekati's Misery project. Our initial review of the published literature indicated that there is limited information on this subject, save for experiments done with brines associated with the Arctic oil fields. The latter is not directly relevant, since their salt concentrations exceed by at least an order of magnitude any that will be encountered during mining of kimberlite ores. Tahera Corporation and BHP Diamonds co-sponsored a field trial, conducted in the summer of 2001 at the Jericho project site, to determine the potential impacts

[19] van Poppelen, P. and A. Sobolewski. 2000. The Suitability of Wetland/ Overland Flow Treatment and Spray Irrigation for Mine Water for the Jericho Project: Phase 1. Report prepared for Tahera Corporation by Microbial Technologies, Inc. 21 pp.

of sodium (through Sodium Absorption Ration, or SAR effects) and of chloride toxicity on common Arctic plants[20].

The salt tolerance study concluded that land treatment of mine water with 30 mM chloride, at a SAR of 3 or less, should not impair plant health, whereas water with 100 mM chloride could. Chloride concentrations in tailings supernatant are predicted to range from 5.4 to 37 mM, assuming that water from ore or overburden stockpiles, or dump areas are excluded from the PKCA. Of course, chloride concentrations will be lower if water from these sources is redirected to the PKCA. While this suggests that effects from chloride are unlikely, it would be prudent to monitor closely for effects on plants (such as those described in the salt tolerance study report).

Calcium chloride will not be used for de-icing roads at the Jericho project. Therefore, the only sources of chloride are expected to be the mined rock.

Monitoring Plan

The original description of the spray irrigation system omitted any description of a monitoring plan, and this was criticized in a technical review session of the EIS. Such a monitoring plan would focus on two key concerns:

1. Evaluation of treatment performance. This would include measurements of contaminant removal and hydraulic performance of the area where treatment occurs.
2. Evaluation of impacts from spray irrigation. This would involve measurements of soil and vegetation of the area where treatment occurs, and of Lake C3, which receives the treated mine water.

Developing a full monitoring plan is not called for at this stage of the permitting process. However, such a plan should comprise the following elements:

- Visual inspection, thrice weekly: equipment function, water ponding/chanelling, plant health;
- Water sampling twice/week: one source site (PKCA), two upstream Controls sites, two at lake C3, four in-field; measuring pH, alkalinity, conductivity, N (NH_4 & NO_3), ortho-P and metals (including Cu, Ni, U);
- Soil sampling bimonthly at 4-5 field sites + 1-2 control site for soil OM, pH, conductivity, chemistry (N & P, cations, metals, including Cu, Ni, U), temperature profile at depth, populations of nitrifying and denitrifying bacteria;
- Annual plant survey through 4-5 permanent field plots + 1-2 control plots for chemistry (i.e., N & P, chlorophyll content in leaves, ash content) and plant communities composition.
- Annual animal survey of both irrigated and non-irrigated land (lemming[21] survey) and Lake C3 (fish) for tissue metal concentrations

[20] Sobolewski, A. 2002. The Effect of Chloride and SAR on Growth of Arctic Plants. Report prepared for Ekati Diamond Mine and Tahera Corporation by Microbial Technologies, Inc. 33 pp. This report is appended.

[21] Lemmings are widely prevalent, easy to trap, and browsers, like caribou (though they have a different diet).

The sampling frequency for the above monitoring program may need to be adjusted in light of the operation of the spray irrigation system and the variability in water chemistry. The exact location of the sampling sites will be determined as part of the system design.

The spray irrigation area may be adjusted (increased or moved) as a consequence of the following:

- Breakthrough of nitrogen into Lake C3
- Evidence of channeling, ponding
- Signs of impaired plant health (though not changes in plant species composition)
- Salt build-up in soil
- Significant change in depth of active layer

The spray irrigation system is inherently flexible and allows for easy and rapid redeployment of pumps, lines and spray heads/spigots. This is a decided advantage over atomization systems or other fixed systems that cannot be modified once they are established. However, its success in treating mine water without impacting the environment depends on the rigorous implementation of a monitoring plan such as the one outlined above.

Long-term impacts from treatment system

In the long-term (5-10 years), the spray irrigation system is expected to changes in the landscape in a number of ways. The exact nature of these changes cannot be predicted, but a few general trends are expected.

The nutrient and water input will increase plant growth. Sedge grasses and other water-tolerant vegetation will be favoured in the wetter landscape, to the detriment of lichen/heather/grass communities. The former also produce more peat in wet environments (See Table 3). However, the slow plant growth in the Arctic assures that these changes will occur gradually, over 5-10 years.

Soils in the area will be affected by spray irrigation. The abovementioned increase in peat deposition suggests that the depth of the organic matter layer will increase. There was a concern expressed about an increase in salt concentrations resulting from inputs of mine water. However, salt concentrations are already high in some soils (Table 3), possibly due to evapoconcentration at the surface. It is just as likely that salt concentrations will *decrease* due to the increased soil wetness and decreased evapoconcentration.

The more abundant vegetation will draw herbivores, such as lemmings and Arctic hares. In turn, predators such as Arctic foxes may be attracted by their increased populations. Caribou may also be attracted to the area, but only as a prolonged stop along their migratory route.

Other potential impact from spray irrigation are the erosion of surface soils and of permafrost. These are long-term impacts that may develop if undetected. However, the monitoring plan proposed earlier will detect these changes before long-term impacts arise. Spray irrigation as proposed at Jericho is designed to be flexible and allows for adjustments in response to these changes, to prevent long-term deterioration of the landscape.

A more worrisome long-term impact is the potential build up of metals in soils, as indicated in the analysis of metal removal during land treatment. The greatest concern is with uranium deposition, but nickel inputs also bring cause for concern.

One measure suggested to mitigate these impacts are to remove metals before mine water is spray irrigated (e.g., by segregating seeps that contain these metals from waters destined for the PKCA). This may be achieved readily for uranium, as it was only detected in two sources at the site. It may also be done for nickel. This would be the simplest and best strategy.

Alternatively, lime may be applied to land, as this has been shown to reduce metal (copper, nickel) uptake by plants in acidic soils[22]. Such a potential solution would have to be field-proven before it is implemented.

Mine water will no longer be applied on land after mining ceases. This may begin a reversal in the plant community back towards the original, pre-mining composition from drier soils. However, drainage pattern will be altered by then, and it is difficult to predict the evolution of plant communities after mine closure.

Contingencies

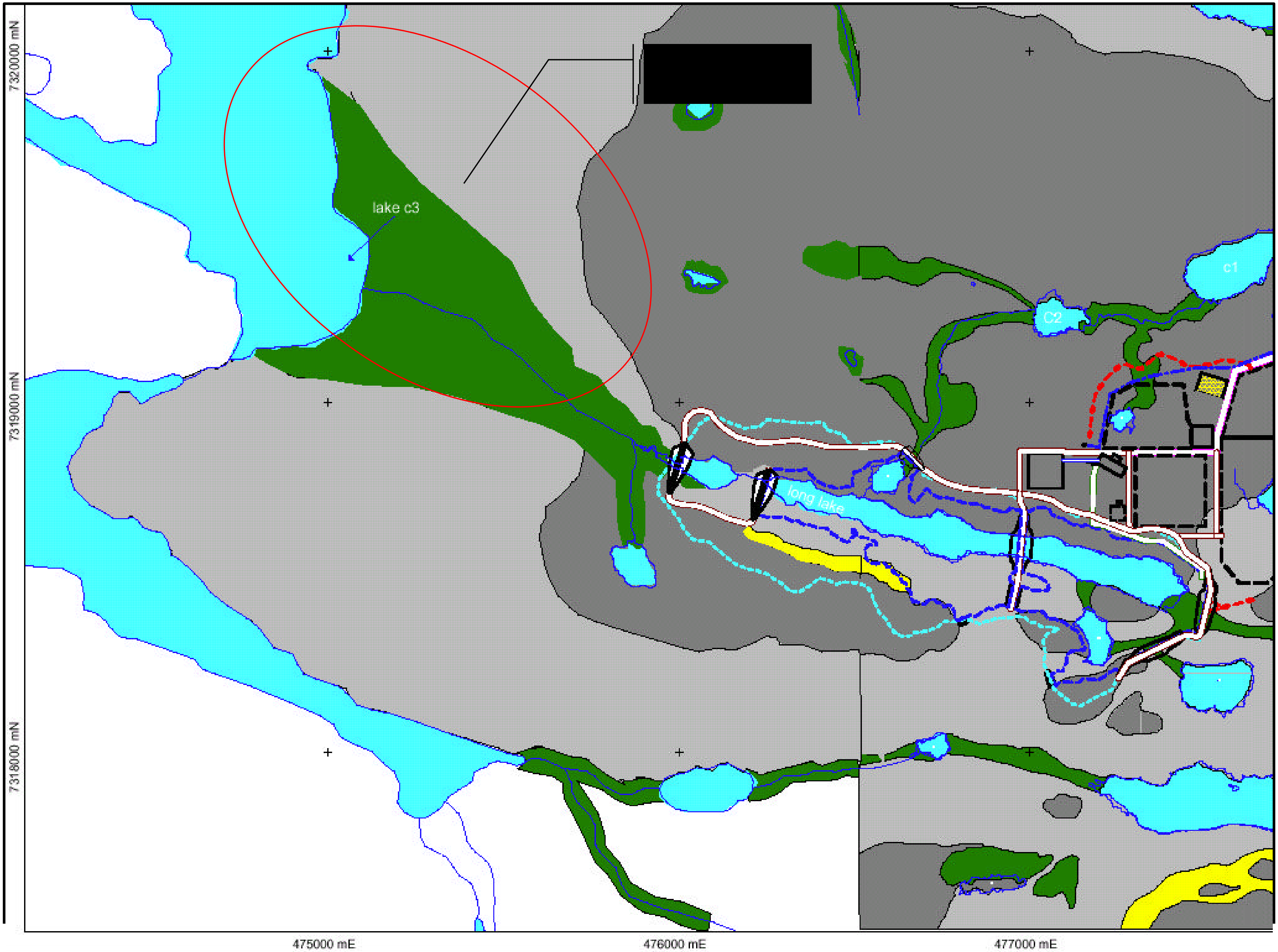
The key advantage of the proposed spray irrigation system is its flexibility. Pumps, lines, and sprinkler can be moved easily around the site in response to changing circumstances. For instance, water may begin to channel in one area, short-circuiting much of the treatment area. It will be an easy matter to rectify this problem by moving sprinklers around. Similarly, the monitoring program may indicate that treatment performance is insufficient (solution: expand the treatment area) or that permafrost is beginning to be eroded (solution: move sprinklers to new area, or increase evaporation rate to cool water).

Some problems may not be dealt with so easily. Thus, some additional pre-treatment will be required if metals begin to accumulate significantly in soils. This may be done by lime treatment or, preferably, by sulphide addition.

There is a possibility that the proposed spray irrigation will be ineffective in removing ammonia from mine water. Should this prove to be the case, it will be necessary to develop a treatment plant for ammonia removal.

[22] Winterhalder, K., P.J. Beckett, and M.R. Todd. 1984. Metal dynamics in a revegetated ecosystem at Sudbury, Canada. Proceedings of the UNEP International Conference on Environmental Contamination, London, July 1984. p. 499-504.

Map of Proposed Spray Irrigation Area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