order further monitoring? The appropriate response depends on how closely the observed environmental change approaches a significance threshold. Environmental measurements that reach the threshold would constitute a significant adverse effect, while measurements below the threshold would not, even if they were not predicted in the EA.

If significance is not explicitly defined during the EA, the Response Framework would be the vehicle for setting significance thresholds during the regulatory phase of a project. The Framework envisions the proponent recommending significance thresholds based on project-specific details, including information from the EA. The WLWB would then seek stakeholder input on the proposed thresholds before a Response Framework document is approved.

Setting the significance threshold, during either the EA or the regulatory phase of a project, can be a difficult process. For example, many stakeholders are reluctant to define a limit of acceptable change because they fear that it will become a ''pollute up to'' limit or an excuse not to take any mitigative action until the limit is reached. The Response Framework would require, however, that action be taken well below the significance threshold and thus maintain the intent of pollution prevention. Furthermore, although it will be challenging to predefine significance thresholds (and associated action levels) for a project, the alternative is having the debate only after some environmental changes or effects have already been measured. In the latter case, unnecessary delays in implementing appropriate management response actions may occur, hindering our ability to minimize project-related effects in a timely and effective way. Finally, although the WLWB already has the ability to assess monitoring results on an on-going basis and decide what action to take, the establishment of a Response Framework—with a well-defined significance threshold and action levels—makes the process more transparent and consistent for all parties.

[Note that the guidelines are in draft form and have not been approved by the WLWB. Please contact K. Racher - racherk@wlwb.ca - if you wish to receive a copy].

LINKING INCINERATION TO DIOXINS AND FURANS IN LAKEBED SEDIMENTS (OR, THE CASE OF THE MISSING WATER LICENSE CONDITION)

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Remote mining developments in Canada's North typically have camp accommodations housing from 200 to 1100 persons and use incinerators to dispose of camp waste. Air emissions from waste incinerators account for a significant portion of dioxins and furans entering the environment (Su and Christensen 1997; CCME 2001a). Operators are encouraged to meet the Canadian Council of Ministers of the Environment Canada-Wide Standards for Dioxins and Furans (CCME 2001b), using appropriate technology and diligent operation to minimize harmful emissions. However, air emissions in the Northwest Territories and Nunavut fall into a regulatory gap, unregulated by land use permits and water licenses. Regulators issuing water licenses to large-scale mining developments have been reluctant to include license conditions, which are seen to fall outside direct water-related aspects.

To draw the link between compounds deposited on land and lake surfaces from incinerator stacks, and their transport to and potential accumulation in aquatic systems, Environment Canada conducted a limited sediment sampling program for dioxins and furans in the vicinity of the Ekati Diamond Mine camp incinerators. Activity at the Ekati mine site began in the early 1990 s with an exploration camp and progressed to completion of the mine camp by 1998. Waste incineration has been practiced throughout this period and continues today. The mine camp and incinerators are situated on the north shore of Kodiak Lake, which has a drainage area of 28.7 km^2.

Sediment cores were collected 7–9 April 2008 from Kodiak Lake and Counts Lake (a reference site) using a Glew sediment corer. Kodiak Lake samples were collected from 2 sites, designated K1 and K2. K1 samples were taken from near the deepest basin of the lake (7175581E and 518243N), from holes that were between 2 and 3 m apart, with water depths of 9.8 to 10.5 m. K2 was located in an area with a small 6-m deep basin (7175851E and 518231N). Reference samples were taken from water depths of 10.5 to 11.0 m in Counts Lake (7169852E and 533690N). Five replicates were collected from each site. Sampling and sample handling followed protocols specified by the Environmental Science and Technology Centre (ESTC) laboratory to ensure that contamination of the samples did not occur. Cores were frozen and shipped with dry ice to the ESTC for slicing and analysis of the top layers for dioxins and furans. Freezing of the cores resulted in ''mounding'' of the sample within the tube, which precluded precise slicing of the sample. Instead, approximately the first 5 cm (1.0 g dry weight) of each core was separated manually, with the visually distinct top layer scraped off for analysis. The second visually discrete layer (0.75 to 1.25 cm) was removed and stored separately. The underlying third and fourth slices were each 1 cm in thickness. The ESTC provided analytical results for 17 polychlorinated dibenzo-*p*-dioxin (PCDD) and polychlorinated dibenzofuran (PCDF) congeners, with detection limits of 0.3 to 0.9 pg/g dry weight. Toxic equivalencies (TEQs) were calculated using toxic equivalency factors for fish (CCME 2001a).

What We Found

Figure 1 shows the mean TEQs for each depth layer at each site. Table 1 provides mean total TCDD and TCDF concentrations for each sampling site. Total PCDD and PCDF concentrations in surficial sediments were generally an order of magnitude higher at the exposure site than at the reference site. Surficial sediment TEQs of total PCDDs and PCDFs exceeded the Canadian Sediment Quality Guidelines (CCME 2001a) at both Kodiak Lake stations. These compounds are chemically stable, persist in lake sediments, and are expected to continue to accumulate as long as there are ongoing inputs from combustion sources. Snowfall can influence accumulation and subsequent transport of hydrophobic, low volatility

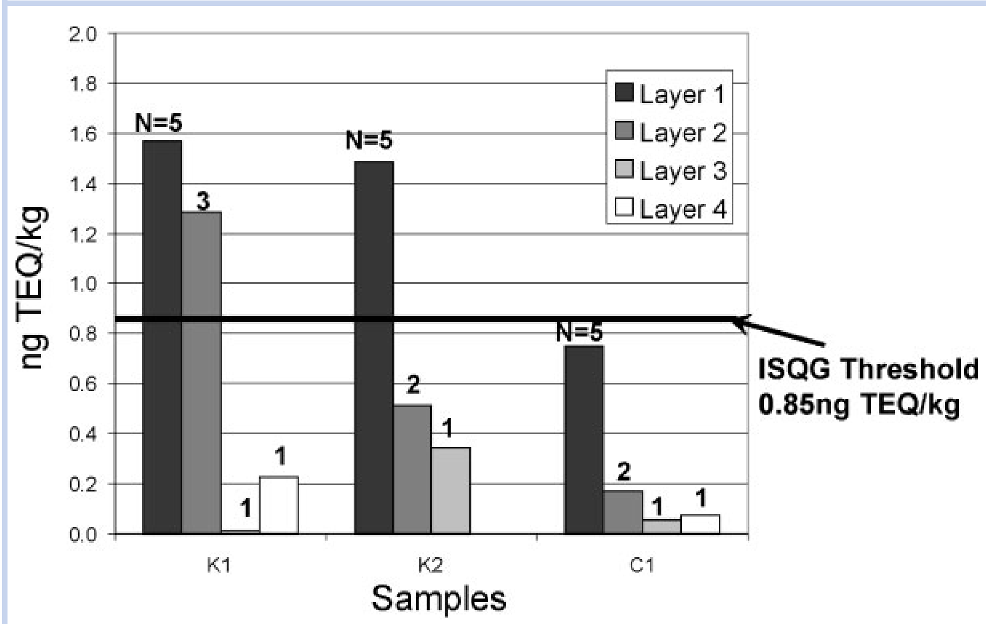

Figure 1. Mean toxic equivalencies (TEQs) for each depth layer at each site.

compounds (Blais et al. 2003), such as the PCDD/Fs, and can contribute to lake inputs through freshet and runoff.

TCDD/F increases in the top layers of the sediments are consistent with the period of operation of the incinerators. As cores were not dated, estimates of the time frame represented by each layer are based on sedimentation rates for Arctic lakes and a sedimentation event in 1997 that marked a visible horizon in the Kodiak Lake cores. Accordingly, the first layer would represent a period of between 10 and 11 years. In Kodiak Lake the second layer, which represented between 0.75- and 1.50-cm depth below the top 5 cm, included fine particulate materials from the Panda Diversion Channel mixed with lake sediments. Each of the two 1-cm layers below represents a period before 1997 of 1 to 2 decades at estimated depositional rates of 0.1 to 0.6 mm/year (Hermanson 1990).

Table 1. Total PCDD and PCDF (pg/g)

PCDD			PCDF		
K1	**Mean**	**SD**	**K1**	**Mean**	**SD**
Layer 1	146.4	14.1	Layer 1	52.4	4.4
Layer 2	97.6	13.5	Layer 2	33.3	2.6
Layer 3	25.0		Layer 3	10.5	
Layer 4	37.2		Layer 4	11.7	
K2			**K2**		
Layer 1	122.4	55.5	Layer 1	43.3	19.9
Layer 2	91.7	44.5	Layer 2	30.5	18.6
Layer 3	41.2		Layer 3	15.4	
C1			**C1**		
Layer 1	45.8	48.6	Layer 1	11.1	7.3
Layer 2	47.0	4.3	Layer 2	10.1	2.0
Layer 3	15.8		Layer 3	11.9	
Layer 4	10.5		Layer 4	7.1	

PCDD = polychlorinated dibenzo-*p*-dioxin; PCDF = polychlorinated dibenzofuran; K1 = Kodiak Lake sample site 1; K2 = Kodiak Lake sample site 2; C1 = Counts Lake reference site.

Detection of PCDDs and PCDFs in Counts Lake was not unexpected and may be attributable to a combination of long-range atmospheric transport (Su and Christensen 1997), and the infrequent occasions when it may be downwind of the mine site. Sampling results suggest that incinerator emissions are affecting PCDD/F concentrations in Kodiak Lake. Spatially, the sediments from the lake closest to the mine incinerators, Kodiak Lake, had higher concentrations of PCDD/Fs than sediments from the reference lake, Counts Lake. Temporally, the concentrations of PCDD/Fs in lake sediments were higher during the period in which the mine has been operating than predevelopment.

The elevated sediment concentrations are consistent with predictions from modeling work (Webster and McKay 2007) investigating the environmental fate of dioxins and furans from remote camp waste incineration.

In this case, to mitigate the release of contaminants from waste incineration and limit further PCDD/F accumulation in the environment, the mine is installing new incineration equipment and will be developing an incineration management plan to ensure that best operating practices are followed. Environment Canada has developed a Technical Document for Batch Waste Incineration to provide guidance on appropriate incineration equipment and operating practices that, if followed, should minimize the release of contaminants, such as PCDD/F, from waste incineration and thereby reduce the accumulation of incineration contaminants in the environment. Following on this study's evidence linking incinerator emissions and lake beds, the ''missing water license condition'' has been found, in the form of a license requirement for incineration management plans which follow the guidance document recommendations.

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USE OF LIFE CYCLE ASSESSMENTS FOR IMPROVED DECISION MAKING IN CONTAMINATED SEDIMENT REMEDIATION

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The selection of remedial alternatives for contaminated sediments is a complex process that balances environmental, social and economic aspects. The decision to remediate and the identification of relevant remedial options are often based on quantitative ecological risk assessment (ERA) (Bridges et al. 2006) with qualitative consideration of other factors within frameworks of feasability studies and environmental impact assessments. While ERA is suitable for assessing whether contaminated sediments constitute an unacceptable environmental risk or whether remediation may reduce this risk below acceptable threshold levels, the life cycle impact of a remedial action is often overlooked. Specifically, environmental consequences associated with the use of energy and other resources and environmental impacts incurred during remediation may differ between different remedial strategies. Furthermore, any beneficial uses of removed sediments are not integrated in the ERA. We argue that quantitative Life Cycle Assessment (LCA) can supplement ERA in this respect, to create an enhanced systems approach to sediment management.

LCA Methodology and Use

LCA is a well-known quantitative method to assess the impacts associated with all the stages of a product or a product system. In this ISO-standardized approach, the inputs, outputs, and potential environmental impacts of a system are compiled and evaluated throughout the system's entire life cycle. In contrast to ERA, which generally addresses risks associated with a specific chemical or stressor, LCA aggregates multiple impacts associated with defined product or management alternatives across the project or product life cycle in space and in time to comparatively assess the overall potential for environmental damage.

An LCA consists of 4 steps: goal and scope definition, inventory analysis, impact assessment, and interpretation. Goal and scope definition is important since it determines the content and methodological choices for the subsequent steps. The inventory analysis aggregates the various inputs and outputs into cumulative numbers, whereas the impact model converts these numerical data into potential effects as environmental and human harm and resource depletion. Finally, the impact results are interpreted, and uncertainty and sensitivity in the results are addressed.

The use of LCA has evolved significantly over the past 3 decades, from niche applications to a more systematic and robust framework for project management and systems evaluation. Examples of less traditional areas now using LCA include the food industry, construction activities, and the service sector.

Life Cycle Impacts for Sediment Remediation

Even though life cycle impacts of environmental management in aquatic ecosystems are gaining interest in both academia and industry, LCA has rarely been used for sediment management. However, in the related field of soil and groundwater contamination, an LCA framework has been developed to address environmental impact from different remedial technologies (Lesage et al. 2007). An adaptation of the LCA framework for sediment remediation is given in Figure 1. The LCA impacts have normally been referred to as primary, secondary, and tertiary effects. Primary effects originate from the contamination source and site specific impacts, for example, effects from contaminant uptake in seafood, local ecotoxicological effects on the benthic fauna, and physical local impacts of the remediation operation. Secondary impacts are the effects related to the use of resources and energy during the remedial implementation. Tertiary impacts could include additional postremedial effects, such as increased recreational use of the area after remediation.

The Grenland Fjord Capping Case

Sparrevik et al. (2011) applied LCA to assess possible future remediation alternatives for the Grenland Fjord in Norway, which is contaminated by polychlorinated dibenzo-*p*-dioxins and -furans (PCDD/Fs). Capping the contaminated sediments has been proposed as a viable option to mitigate risk, based on ERA for fish and shellfish. The risk-reduction effectiveness of different capping alternatives has previously been assessed based on the ability to reduce the flux of PCDD/F from sediments to the food chain below threshold levels (Saloranta 2008).