Assessment of a Quarter Century Dataset of Pulp Effluent Metal(loid) Contaminated Sediment to Inform Remediation Decisions

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BACKGROUND

A bleached kraft pulp mill in Nova Scotia has discharged effluent wastewater into *Boat Harbour* (BH), a former tidal lagoon within *Pictou Landing First Nation* (PLFN) since 1967 (**Fig.1**). BH has been used as the treatment facility for pulp mill effluent (Hoffman et al., 2015; Walker et al., 2016) (**Fig.2**).

Effluent discharge to BH has created >170,000 m^3 of unconsolidated sediment, impacted by inorganic and organic contaminants (metal[loid]s, polycyclic aromatic hydrocarbons [PAHs], dioxins and furans).

This study aimed to spatio-temporally characterize impacted sediments from 1992-2015 to help inform decisions for a $89 million (CAD) remediation program, designed to return this contaminated site back to a tidal lagoon beginning in 2020.

Fig 1. Location of BH in Pictou County, Nova Scotia relative to communities (e.g., Pictou, and PLFN) (©Google Earth).

Fig 2. Components of the Boat Harbor Treatment Facility (BHTF), relative to the neighboring PLFN community (©Google Earth).

METHODS

Spatio-temporal variation of metal(loid) sediment concentrations across BH (103 samples from 81 stations), and reference locations were assessed with secondary data from 1992-2015 using GIS techniques (**Fig. 3**). Of >200 reports reviewed, only eight contained relevant data (i.e., metal(loid) sediment concentrations; georeferenced locations; sediment depth and collection methods; and consistent laboratory analytical methods).

Based on sampling methods, 'sample types' were categorized as 'grab' or 'core'. Additionally, samples were categorized as composite or discrete. Vertical composites represent horizontal layer mixing, and horizontal composites represent aggregates of sub-samples from an area. Discrete samples were collected from a specific horizontal location, or vertical interval.

Metal(loid) parameters were compared to current freshwater and marine *Canadian Council of Ministers of the Environment* (CCME) sediment quality guidelines (SQGs) (CCME, 2016). BH currently operates as a freshwater treatment lagoon, but will be returned to tidal influences following sediment remediation. CCME *interim sediment quality guidelines* (ISQGs) and *probable effect levels* (PELs) were used for comparison. Spatio-temporal analyses focused on six metal(loid)s (*Cd, Cr, Cu, Pb, Hg, Zn*), based on frequent SQG exceedances.

RESULTS & DISCUSSION

Spatio-temporal analysis of a quarter century of sediment metal(loid) concentrations inadequate spatial coverage, presenting challenges for remediation decisions regarding vertical and horizontal delineation of contaminants. The western half of BH had limited coverage, compared to the eastern tidal channel (**Fig. 3**). Most BH sediment samples (69%) were from shallow horizons (0-15 cm); leaving deeper horizons under-characterized (**Fig.4**). Seven metal(loid)s (As, Cd, Cr, Cu, Pb, Hg, Zn) exceeded freshwater and marine ISQGs; six (As, Cd, Cr, Pb, Hg, Zn) exceeded freshwater PELs; and four (Cd, Cu, Hg, Zn) exceeded marine PELs (**Figs. 4, 5, 6**). Most samples (75%) exceeded ISQGs. Cd, Hg and Zn were frequently higher (52%) than PELs. Significantly higher Cd, Cu, Pb, Hg and Zn concentrations were measured between 1998 and 2000, compared to earlier (1992-1996) and more recent (2003-2015) data (**Fig.5**). Results were mirrored in geo-spatial data (e.g., Cd) (**Fig.6**).

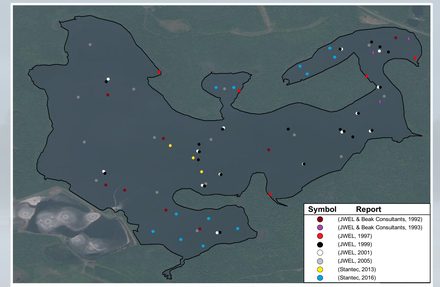
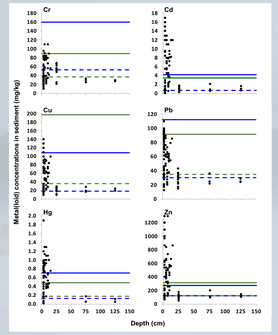


Fig 3. Spatio-temporal coverage (1992-2015) of sediment sampling in BH indicated by coloured circles.



Most historical sediment sampling was conducted *a priori* of remediation.

Gaps exist in our understanding of sediment characteristics, including spatial (vertical and horizontal), and temporal variation of sediment contamination.

Fig 4. Spatial (vertical) variation of metal(loid) concentrations with sediment depth (cm). CCME freshwater (dark green) and marine (blue) sediment quality guidelines are indicated using *solid horizontal lines* for PEL and *dashed lines* for ISQG values (CCME 2016).

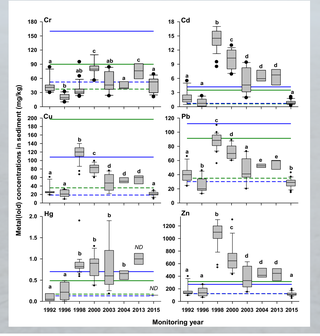


Fig 5. Temporal variation (~25 years) of metal(loid) concentrations in sediment. CCME freshwater (dark green) and marine (blue) sediment quality guidelines are indicated using *solid horizontal lines* for PEL and *dashed lines* for ISQG values (CCME 2016). Significant temporal differences were determined by one-way ANOVA followed by Tukey's test; years attributed with same letters were not significant and those with different letters were significantly different ($p < 0.05$ level). Number of sediment samples analysed in any given year varied widely (2-26, depending on analyte). *ND* – not determined (too few samples for one-way ANOVA).

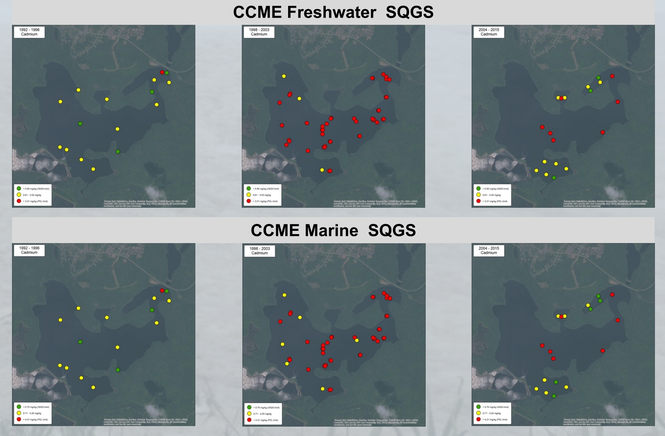


Fig 6. Spatial-temporal variation of Cd concentrations compared to CCME freshwater (*green*, <0.60 [ISQG]; *yellow*, 0.61-3.50; *red*, >3.51 [PEL] mg/kg) and marine (*green*, <0.70 [ISQG]; *yellow*, 0.71-4.20; *red*, >4.21 [PEL] mg/kg) SQGs in BH sediment over three periods: top 1992-1996; middle 1998-2003; bottom 2004-2015.

RECOMMENDATIONS

- More *detailed sediment sampling* (e.g., piston coring, discrete sampling across vertical horizons, dating and greater spatial coverage), are required prior to remediation to enable cost-effective approach to a decades-old problem.
- *Baseline monitoring* (over several years) using a reference site is critical to establish a benchmark for comparing contaminated sediment sites before and after remediation.
- A *follow-up study* to assess and compare measurable changes of conditions in BH post remediation.

CONCLUSIONS

Decades of pulp mill effluent releases into BH have resulted in deposition of large quantities of unconsolidated sludge and sediment that require remediation in the near future. Metal(loid) concentrations in sediment using a variety of sampling techniques showed wide temporal variation between 1992-2015, with concentrations peaking between 1998-2000. Despite variation of sampling techniques, Cd, Cr, Cu, Pb, Hg, Zn frequently exceeded Canadian SQGs, posing significant risks to aquatic ecosystems.

Results suggest the mill's effluent as the primary source of metal(loid) loadings. A critical review of this historical dataset revealed inherent gaps in sediment characteristics (vertical and spatial coverage), which suggests that more detailed sediment sampling is required in BH and nearby reference sites prior to costly remediation.

REFERENCES

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