Potential Impacts of Woodfibre LNG's Wastewater Discharge Authorization Application on the Receiving Environment

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Overview of Wastewater Discharge Authorization Application and Contaminants of Concern

Woodfibre LNG (WLNG) has submitted a Wastewater Discharge Authorization (WDA) application to the B.C. Energy Regulator (BCER) for the discharge of water associated with the construction of a liquefied natural gas (LNG) export facility near Squamish, B.C. With this application, a Technical Assessment Report (TAR), intended to address the information requirements, was also submitted.

Effluent discharge into Howe Sound is anticipated to occur from October 2023 to December 2027. The effluent source includes water run-off from construction on site that will be collected in two lined sedimentation ponds, referred to as the West Sedimentation Pond (~71 m long and 14 m wide) and the East Sedimentation Pond (~87 m long and 14 m wide). In addition, since this is a site historically contaminated with toxic heavy metals and various organic chemicals (i.e. hydrocarbons, dioxins and furans) from the previous Woodfibre pulp mill in operation from the early 1900’s to 2006, wastewater treatment plants (WWTPs) will also be constructed. The purpose of the WWTPs is to reduce these metal and organic contaminants in construction waters prior to diversion into the sedimentation ponds, which will then be discharged into the foreshore of Howe Sound. Woodfibre LNG has used models described in the TAR[1] to predict the sedimentation ponds’ effluent quality for a base case and an upper case scenario where the contaminants being discharged in the effluent are estimated and compared to federal and BC water quality guidelines.

The Átl'k̲a7tsem / Howe Sound region was designated as Canada’s 19th UNESCO Biosphere Region in 2021. The designation was a recognition of the region’s biodiversity and fragile environmental recovery. The Átl’k̲a7tsem/Howe Sound Biosphere Region has been endorsed by the District of Squamish, the Squamish Lillooet Regional District, Provincial authorities, Fisheries and Oceans Canada, Sk̲wx̱wu7mesh Úxwumixw and other authorities responsible in Átl'k̲a7tsem / Howe Sound. Any degradation of the marine environment will affect the Biosphere Region’s commitment to the highest and best practices for sustainable development.

The WDA application requests the continuous (i.e. 24 h/day) discharge of an average daily rate of 1,600 m^3/day and maximum rate of 30,000 m^3/day of effluent associated with construction at the WLNG facility over four years. Despite the treatment of effluent in WWTPs on site, Woodfibre LNG predicts that, based on mathematical models, most metals, hydrocarbons, and total suspended solids (TSS) will be continuously released at levels below or at water quality

[1] TAR 2023

guidelines aimed to be protective of marine life.[2] However, four heavy metals (copper, lead, zinc and vanadium) and total suspended solids are predicted to be discharged into Howe Sound at concentrations *exceeding* the lowest applicable water quality guideline under the highest effluent discharge scenario predicted by Woodfibre LNG.

In addition, Woodfibre LNG is requesting to discharge effluents into Howe Sound with a pH range from 5.5 to 9.0, which exceeds the lower and upper limits of the long-term water quality guidelines for pH for the protection of marine aquatic life. British Columbia's long-term water quality guidelines are pH 7.0 to 8.7 for marine waters and pH 6.5 to 9.0 for freshwater. This pH range *also* exceeds the less conservative range of pH values allowable in metal or diamond mine effluents discharged into receiving waters as specified in the *Metal and Diamond Mining Effluent Regulations* [MDMER, Part 1, Section 4(1)(b)] under the *Fisheries Act*, which specifies the acceptable pH range of the effluent to be pH 6.0 to 9.5.

These exceedances of four heavy metals, total suspended solids, and low pH are of particular concern due to their known inherent hazards to wildlife and the long duration exposure scenario for local aquatic life (i.e. four years) for each of these parameters individually, in addition to the cumulative effects these multiple stressors will exert.

Critique of Woodfibre LNG's Wastewater Discharge Authorization Application Technical Assessment Report

Weaknesses of the Baseline Data

Contaminated Site as Baseline Environment

Critical for understanding the Project's impact on the local environment is knowledge of the environmental and biological baseline conditions. In the case of Woodfibre LNG's WDA application, this includes a conventional assessment of water quality as well as legacy parameters of concern (POCs) resulting from the operation of the Woodfibre pulp mill, such as heavy metals, dioxins, furans, and other harmful organic compounds.

The Project site is located within portions of three sub-watersheds that discharge into Howe Sound: Mill Creek, Woodfibre Creek, and East Creek. As mentioned earlier, the Woodfibre pulp and paper mill operated on the Project site for almost a century before ceasing operations in

[2] TAR 2023

2006. Operation of the mill resulted in varying degrees of contamination in the soils, sediments, creeks, and adjacent marine waters. No water quality monitoring program was conducted during mill operation; therefore, historical water quality data to describe the conditions of the area before and during mill operations are not available.

Water quality data collection as reported in the TAR began in 2006, after mill closure. Thus only a characterization of the contaminated environment has been obtained. Water quality data collection consisted of intermittent sampling of the site in 2006, 2007, and 2013,[3] and monthly sampling from 2021 to 2022.[4]

These contaminated site data are not representative of baseline conditions in undisturbed waters, sediment, and soil. Background values for POCs derived from these data are likely overestimating background levels typical for undisturbed reference areas. Therefore, using these contaminated site data to guide the minimum water quality objectives of WLNG's WDA will result in the continued degradation of the water quality in and around the Project site. This will in turn result in a reduced capacity of the surrounding aquatic environment to support wildlife and negatively impact Howe Sound's trajectory of ecological recovery.

Lack of Freshwater Reference Sites

Review of the water quality sampling sites from 2006 to 2022 in the TAR indicates that no freshwater reference sites were established. Identification of and continued data collection at reference sites are necessary and required components of any baseline study. WLNG's consultants could have established potential reference sites in creeks situated outside the Certified Project Area (CPA) or reaches in Mill, Woodfibre, and East Creek upstream of the CPA. Without such reference data, shifts in stream water quality attributable to the Project cannot be identified. Such reference sites are needed to ensure that diversion of water affected by construction activities is successful and that construction activities do not result in deteriorating water quality in the streams within the CPA.

Figure 3-15 in the TAR shows that only four of the 139 water quality samples were collected upstream of the CPA between 2006 and 2022 (upstream Mill Creek site CR6-06 [pH of 7.17] and three landfill/laydown/road runoff sites: SW07-15 [pH of 6.78]; SW07-14 [pH of 6.92]; and,

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[3] Keystone Environmental Ltd. (Keystone). 2014a. Report of Findings for Preliminary Site Investigation Stage 1, Preliminary Site Investigation, Stage 2, Detailed Site Investigation and Supplementary Site Investigation, Former Squamish Pulp Mill site, Woodfibre, BC. Report prepared for Western Forest Products Inc. Dated October 30, 2014.

[4] Stantec Consulting Ltd. (Stantec). 2022. Hydrogeochemical Assessment in Support of Effluent Discharge Permitting (EDP). Subsurface Investigation Report: Woodfibre LNG Site, Squamish, British Columbia, Canada, 2022. Project Number 123221624.

SW07-16 [pH of 6.34]). However, sites SW07-15, SW07-14, and SW07-16 must be considered contaminated sites.

Lack of Long-Term Water Quality Data

The TAR claims that long-term estuarine and freshwater baseline data were obtained to inform the proposed water quality objectives. However, review of the estuarine and freshwater quality data presented in Appendix 2-4.1 of the TAR indicates that water quality sampling was conducted only once at many sites.

As mentioned above, fresh and estuarine water quality of the watercourses and runoff within the WLNG site have been infrequently monitored from 2006 to 2022 after the closure of the Woodfibre pulp mill.[5,6] Tables 3.10-3.13 in the TAR show that the numbers of samples assessed for a given water quality parameters of interest vary greatly. This makes it difficult to establish a comprehensive baseline.

These sampling efforts resulted in a total of 133 water quality samples comprised of: 41 creek and runoff samples from Woodfibre Creek, Mill Creek and East Creek catchments collected sporadically in 2006, 2007 and 2013; 20 surface water samples from Woodfibre Creek and Mill Creek collected approximately quarterly from 2018 to 2020; and 72 samples from Woodfibre Creek, Mill Creek and East Creek collected approximately monthly from February 2021 to March 2022.

Based on these samples, the TAR states that all three creeks show pre-construction median pH values within BC long-term water quality guidelines for estuarine and freshwater and are circum-neutral to mildly acidic. However, field pH measurements were only collected for a subset of the 133 water quality samples. Furthermore, evaluation of continuity of field pH collection in Table 2 of the TAR Appendix 3-4.1 shows that data was collected approximately quarterly from 2018 to 2021 and continuous monthly sampling in all three creeks was only conducted from February 2021 to March 2022. The short time-frame of just over one year of continuous monthly sampling is insufficient to adequately capture field pH baseline conditions. This is especially noteworthy because these field pH data inform WLNG's proposed effluent pH compliance limits.

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[5] Keystone Environmental Ltd. (Keystone). 2014a. Report of Findings for Preliminary Site Investigation Stage 1, Preliminary Site Investigation, Stage 2, Detailed Site Investigation and Supplementary Site Investigation, Former Squamish Pulp Mill site, Woodfibre, BC. Report prepared for Western Forest Products Inc. Dated October 30, 2014.

[6] Golder Associates. 2014. Woodfibre LNG Marine Resources Baseline Study. Appendix 5.10 1 of the Woodfibre LNG Application for an Environmental Assessment Certificate.

In summary, contaminated site conditions, lack of reference sites, and lack of a long-term continuous data set prevent the adequate establishment of a comprehensive estuarine and freshwater quality baseline. Ultimately, by relying on the pre-construction/post-industrial conditions for contaminants and pH at this historically contaminated site, an overestimate of the discharge limits for most parameters of concern is derived. This results in a scenario whereby effluents will have a higher potential for harming marine aquatic life in the Howe Sound foreshore, and to some unknown extent beyond this boundary over a four-year period.

Hazards of Individual Contaminants / Parameters of Concern on Aquatic Wildlife

Metals

Heavy metals are naturally occurring elements within the Earth's crust, and are present in air, water, sediments, and soils through the natural weathering of minerals, forest fires, volcanic emissions, and other natural processes. However, several heavy metals have become global pollutants due to various human activities that release metals from the earth's crust at unnaturally elevated levels into the environment. Once released into the environment, heavy metals persist because they do not degrade or break down.[7] Some heavy metals, including copper, iron and zinc (but not cadmium or lead) are essential elements or micronutrients and are required for metabolic activity in living organisms.[8] However, when living organisms are exposed to levels of heavy metals that exceed natural background levels of essential or non-essential metals in water, air or food they can be toxic.[9]

For the base case predictions for the Woodfibre LNG project copper (Cu) and Vanadium (V) will be discharged at rates 1.1 and 1.5 times above the lowest applicable water quality guideline for the protection of marine water aquatic life (MWAL), and if the upper case scenario with higher

[7] Wu, G., H Kank, X Zhang, H Shao, L Chu, and C Ruan. 2010. A critical review on the bio-removal of hazardous heavy metals from contaminated soils: Issues, progress, eco-environmental concerns and opportunities. Journal of Hazardous Materials 174 (1-3): 1-8.

[8] Peralta-Videa, J.R., Lopez, M.L., Narayan, M., Saupe, G. and Gardea-Torresdey, J. (2009) The Biochemistry of Environmental Heavy Metal Uptake by Plants: Implications for the Food Chain. The International Journal of Biochemistry & Cell Biology, 41, 1665-1677.

[9] Peralta-Videa, J.R., Lopez, M.L., Narayan, M., Saupe, G. and Gardea-Torresdey, J. (2009) The Biochemistry of Environmental Heavy Metal Uptake by Plants: Implications for the Food Chain. The International Journal of Biochemistry & Cell Biology, 41, 1665-1677.

discharge rates is reached then it is predicted that **copper, lead, zinc, and vanadium** would exceed the lowest applicable water quality guidelines for the protection of marine water aquatic life by 2.2, 1.6, 1.6 and 1.3 times, respectively. As described in the TAR (2023; Section 5.2), these total metal concentrations in the effluent are predicted to be:

- medium in magnitude (one to ten times the long-term water quality guideline);
- local in spatial extent from discharge point (100 m or less);
- long-term in duration (elevated above water quality guideline >1 year); and
- result in continuous exposure of organisms to the elevated metal.

The conclusions in the TAR (2023) are that all adverse effects from these metal exposures will be reversible in less than four months after the discharge ceases and result in high resiliency with full recovery of marine communities.

There is an alternative assessment of the magnitude offered in the TAR by comparing dissolved (instead of total) metals to water quality guidelines whereby the magnitude of the dissolved metal then equates to or is less than the water quality guideline (i.e. is categorized as low magnitude). This may be close to adoption by BC regulators for copper and zinc, but not for vanadium and lead. Indeed, in the environment, heavy metals speciation is complicated and metals may form complexes with other organic or inorganic compounds or may be present in their pure elemental form as cations in the water column. Importantly, metal speciation in the environment is also influenced by several factors, such as pH, dissolved organic carbon, hardness and temperature.[10] In their pure elemental form as cations, metals are soluble in water, thus may be readily absorbed by living organisms and can concentrate or accumulate in organisms at toxic levels. Regardless of their form, heavy metals are persistent since the metal element itself does not degrade and depending on their form metals can be transported to new locations in the environment.[11]

In light of the long-term duration (years), high frequency or continuous discharge, as well as the low pH of the effluent that typically increases metal solubility in water, it can be argued that these metals may have adverse effects on the marine environment. Furthermore, the resiliency of marine life and re-establishment of communities has been shown to take years based on reports for the recovery of Howe Sound from after decades of multiple industrial activities

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[10] US EPA 2021. Metals: Overview.

[11] Gray, JS. 2002. Biomagnification in marine systems: the perspectives of an ecologist. Marine Pollution Bulletin 45(1-12): 46-52.

discharging wastes. For example, intertidal biodiversity recovery took decades to begin to re-establish after the Britannia Mine closure at several sites that were several kilometers away from the point source of copper and zinc and low pH discharges into Howe Sound.[12] This is also reflected in laboratory toxicity testing of waters on marine species collected from similar sites across Howe Sound in recent years as well as transplantation studies with mussels.[13]

Copper Toxicity Overview

Copper is a metal and an essential micronutrient for all plants and animals and plays an important role in several biological processes. However, elevated concentrations of copper are highly toxic to aquatic life, and it is a metal of high concern globally due to human activities enriching this metal above natural background levels in numerous countries. When copper is released into waters it can bind to suspended particles and remain in the water column bound to this particulate matter and/or can settle into sediments and a fraction of copper will remain in a dissolved form.[14] Various environmental factors influence the fate and form of copper in an aquatic system (i.e. particulate bound, sediment bound, dissolved in water), therefore, the BC water quality guideline is calculated on a site specific basis and requires the input of four water chemistry parameters to calculate the water quality guideline for a site, specifically, temperature, dissolved organic carbon, pH and hardness.[15]

Toxic Effects of Copper in Algae and Aquatic Plants

Specifically in algae, in addition to growth inhibition observed in numerous studies,[16] other harmful effects of elevated copper to algae are changes in cell size,[17] decreased chlorophyll[18]

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[12] Bard, S.M. 1998. A biological index to predict pulp mill pollution levels. Water Environment Research 70(1): 108-122.

[13] Barry, et al., 2000; Grout and Levings, 2001; Levings et al., 1976; Ukah, 2018; Zis et al., 2004)

[14] Georgopoulos, P.G., A Roy, M.J. Yonone-Lioy, R.E. Opiekun, and P.J. Lioy 2001. Environmental copper: its dynamics and human exposure issues. J Toxicol Environ Health B Crit Rev 4(4):341-94.

[15] B.C. Ministry of Environment and Climate Change Strategy. 2021. British Columbia Approved Water Quality Guidelines: Aquatic Life, Wildlife & Agriculture.

[16] Nyholm, 1990; Heijerick et al., 2005; De Schamphelaere and Janssen, 2006; Wilde et al., 2006; Perales-Vela et al., 2007; Stoiber et al., 2010; Bajguz, 2011; Kebeish et al., 2014.

[17] Franklin et al., 2002. Effect of initial cell density on the bioavailability and toxicity of copper in microalgal bioassays. Environmental Toxicology and Chemistry 21(4): 742-751.

[18] Fargašová et al., 1999; Perales-Vela, 2007.

and reduced photosynthesis efficiency.[19] The mechanisms by which copper causes these harmful effects on algae have been reported to be due to the substitution of copper for magnesium in chlorophyll[20] or suppression of mitosis (the process of cell division) via pathways involving oxidation of glutathione.[21] In plants, copper is critical for many biological processes, such as: plant growth hormone signaling; photosynthesis; cellular energy production; formation of cell walls; and, a defense mechanism against pests and pathogens as cofactors of various enzymes in plants.[22] Elevated copper levels in the environment have shown to have toxic effects on aquatic plants by causing impaired growth, chlorosis (loss of green color of leaves), leaf death, decreased root growth and elongation, decreased rates of photosynthesis and respiration and oxidative stress (i.e. increased reactive oxygen species that damage intracellular components).[23] Another key mechanism of copper toxicity discovered in plants is the inhibition of electron transport during photosynthesis leading to the production of reactive oxygen species that interact with and damage cellular components, including membrane lipids.[24]

Toxic Effects of Copper in Aquatic Invertebrates

Aquatic invertebrates are known to be quite sensitive to elevated copper in the aquatic environment. Indeed, elevated copper in the short-term causes increased mortality, and in the long-term reductions in growth and reproduction and increased mortality are prevalent toxic effects. In invertebrates studies have shown that copper acts by various mechanisms, many of which are related to ionoregulatory disturbances (i.e. disturbance of the activities of ion channels and transporters that maintain physiologically appropriate solutes and ions within various components of organisms). For example, in the great pond snail (*Lymnaea stagnalis*) excess copper caused decreased hemolymph (i.e., the circulatory fluid of invertebrates) ionoregulatory disturbance, reduced hemolymph pH, and inhibited calcium uptake.[25] In

[19] Danilov and Ekelund, 2001; Perales-Vela et al., 2007.

[20] Küpper et al., 2003. Copper-induced inhibition of photosynthesis: limiting steps of in vivo copper chlorophyll formation in Scenedesmus quadricauda. Funct Plant Biol 30(12): 1187-1196.

[21] Stauber and Florence, 1987.

[22] McSteen and Zhao, 2008; Rochaix, 2011; Shahbaz et al. 2015; Thomas et al., 2016, 2013; Printz et al., 2016; Tavladoraki et al., 2016; Ghuge et al., 2015; Constabel and Barbehenn, 2008.

[23] Shabbir et al., 2020; Yruela, 2005.

[24] Fernandes and Henriques, 1991. Biochemical, physiological, and structural effects of excess copper in plants. The Botanical Review 57: 246-273.

[25] Brix et al., 2011. The toxicity and physiological effects of copper on the freshwater pulmonate snail, Lymnaea stagnalis. Comp Biochem Physiol C Toxicol Pharmacol 154(3): 261-267.

experiments with the fatmucket clam (*Lampsilis siliquoidea*) the most severe physiological disturbance observed after chronic copper exposure was a decrease in whole-body sodium content that simultaneously occurred.

Toxic Effects of Copper in Fish

The main effect of elevated copper in fish in the short-term is increased mortality,[26] and while chronic effects are also increased, mortality but also several sub-lethal effects ensue, including impaired growth and reproduction and abnormal behaviors.[27] The abnormal behaviors reported due to elevated copper in fish are impaired olfactory-mediated behaviors and swim performance after short- and long-term exposure to relatively low levels of copper concentrations in salmonids.[28] Inhibition of such behaviors translates into impediments to important activities such as locating food, predator avoidance and migratory behavior which is critical for fish that need to travel to feeding and/or spawning grounds. The main mechanism of acute copper toxicity in fish is impaired osmoregulation due to decreased sodium uptake and increased sodium loss causing increased blood viscosity, in turn leading to cardiovascular failure and death.[29] Sub-lethal levels of copper are associated with many disrupted pathways such as abnormal elevations of plasma ammonia/ammonium, acid-base imbalances, oxidative stress and respiratory distress many of which eventually lead to reduced growth and reproduction.[30] In general, several acute and chronic studies show that early, younger life stages of fish appear to be more sensitive to the toxic effects of copper compared to older life stages.[31]

Lead Toxicity Overview

Lead is non-essential to all organisms and has no known biological function. It is highly toxic to plant and animal life and is a pollutant of global concern.[32] In the aquatic environment lead exists in multiple forms that depend on pH, with the water solubility of lead generally

[26] Jones, 1938; Sprague and Ramsay, 1965; Erickson et al., 1996; Grosell, 2012; Vardy et al., 2013; Calfee et al., 2014.

[27] McKim et al., 1978; Pickering et al., 1977; Besser et al., 2007; Wang et al., 2014.

[28] Waiwood and Beamish, 1978; McGeer et al., 2000; Tierney et al., 2010; Meyer and DeForest, 2018.

[29] Grosell et al., 2012.

[30] Ibid.

[31] Vardy et al., 2013; Little et al., 2012.

[32] Landis, W.G., R.M. Sofield, and Ming-Ho Yu. 2018. Introduction to Environmental Toxicology: Molecular Substructures to Ecological Landscapes, 5th Edition, CRC Press, 2018 ISB 1498750427, 9781498750424, pp 258

decreasing with increased alkalinity (i.e. pH>7).[33] In addition to dissolved forms of lead in waters, lead can also form complex compounds by binding to particulate organic or inorganic matter in waters and settling out into sediments. The organic-lead compounds are the most toxic (i.e., alkylated lead compounds) and have been measured in fish tissues, while the inorganic lead forms are less toxic.[34] Lead toxicity is influenced by water quality (e.g., water hardness, pH, presences of anions such as sulphate and phosphate). Indeed, the BC water quality guideline requires the input of water hardness in the form of mg/L of $CaCO_3$ for the calculation of the final lead numerical BC water quality guideline. Typically lead is more toxic to organisms in soft water than in hard water.

Toxic Effects of Lead in Algae and Aquatic Plants

Algae exposed to elevated lead concentrations exhibit reduced growth and inhibition of reproduction in several species.[35] In plants, elevated lead causes reduced growth and development. Although the mechanism(s) of action have not been fully studied in algae, in plants lead has been shown to inhibit cell division at very low concentrations and to inhibit the cellular energy production via inhibition of the electron transport chain.[36] Ultimately, several studies[37] report that elevated lead causes the production of reactive oxygen species that in turn cause toxicity by damaging tissue structure, cellular components and molecules within cells.

Toxic Effects of Lead in Aquatic Invertebrates

In aquatic invertebrates, the short-term toxic effects of elevated lead are increased mortality, while the long-term effects of lead include increased mortality and reduced reproduction.[38] Short-term toxicity studies in aquatic insects and aquatic snails have demonstrated that early

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[33] B.C. Ministry of Environment and Climate Change Strategy. 2021. British Columbia Approved Water Quality Guidelines: Aquatic Life, Wildlife & Agriculture.

[34] Chau, Y. K., and Wong, P. T. S. 1976. Complexation of metals in natural waters. In: Andrew, R.W., Hodson,P.V., and Konasewich, D.E. (Eds.), Toxicity to Biota of Metal forms in Natural water. Proc. Workshop,Duluth, Minnesota, October 7-8, 1975. pp. 187-196.; Chau et al., 1979; Chau et al., 1985.

[35] Monahan, 1976; Chau and Wong, 1976; Steele and Thursby, 1983.

[36] Koeppe and Miller 1970; Landis et al., 2018.

[37] Kumar and Prasad 2018. Plant-lead interactions: Transport, toxicity, tolerance, and detoxification mechanisms. Ecotoxicology and Environmental Safety 166: 401-418.

[38] U.S. EPA, 1985a; Biesinger and Christensen, 1972

life stages (i.e., embryo and larval) are more sensitive than older life stages.[39] The precise mechanisms of action underlying these toxic effects in invertebrates is not fully understood.

Toxic Effects of Lead in Fish

Short-term toxicity of elevated lead exposure to fish causes increased mortality. The long-term toxic effects in several fish species include spinal deformities, significant adverse effects on the circulatory system (i.e., increased red blood cell numbers, reduced red blood cell volumes and iron content), all of which lead ultimately to difficulty swimming, impaired reproduction and survival.[40] The mechanisms of action whereby lead exposure causes toxic effects are known to be disruption of: ion regulation, in particular appropriate levels of calcium, sodium and potassium; increased generation of reactive oxygen species that damage cellular components and biomolecules; and disruption of nerve cell signaling.[41]

Zinc Toxicity Overview

Zinc is an essential micronutrient that is incorporated into numerous enzymes in plants and animals and is involved in a wide array of biological processes such as cellular metabolism, signal transduction, cellular proliferation, cellular differentiation, apoptosis (programmed cell death) and antioxidant production.[42] Consequently, abnormally high levels of zinc have toxic effects on multiple biological processes in organisms, such as blood cell and plasma formation, lipid metabolism and immune system function.[43] In aquatic systems zinc may be dissolved in the water in various forms or bind particulate matter within the water column or partition into bottom sediments.[44] Water hardness measured as $CaCO_3$ is a key environmental factor that influences the toxicity of zinc, therefore, the BC water quality guideline requires the input of

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[39] Cairns et al., 1976; Anderson et al., 1980

[40] Hodson, 1976; Hodson et al., 1978; Holcombe et al. 1976; Burden et al., 1998.

[41] Lee et al., 2019. Toxic effects of lead exposure on bioaccumulation, oxidative stress, neurotoxicity, and immune responses in fish: A review. Environ Toxicol Pharmacol 68:101-108.

[42] Hogstrand C, 2011. Zinc. In: Wood CM, Farrel AP, Brauner CJ (eds) Homeostasis and toxicology of essential metals. Academic Press, London, p 135–200; Maret W, 2013. Zinc biochemistry: from a single zinc enzyme to a key element of life. Adv Nutr 4(1):82–91.

[43] Butrimavičienė et al., 2021. Impact of copper and zinc mixture on haematological parameters of rainbow trout (Oncorhynchus mykiss): acute exposure and recovery. Ecotoxicology 30: 873-884.

[44] Florence, 1977; Stumm, W., and Morgan, J.J. 1981. Aquatic chemistry: An introduction emphasizing chemical equilibria in natural waters. John Wiley & Sons, Inc., New York, NY.

water hardness to calculate the water quality guideline for a site.[45] Typically, increasing water hardness reduces the toxicity of zinc.[46]

Toxic Effects of Zinc in Algae and Plants

In algae, elevated zinc has been shown to cause cytoplasmic abnormalities, inhibit photosynthesis and growth and increase mortality.[47] Although the toxicity of zinc varies with algal species, algae appear to be more sensitive than aquatic plants. Nonetheless, aquatic plants have been shown to accumulate zinc in their tissues with toxic effects manifesting as increased mortality and impaired growth. For example, increased mortality after elevated zinc ensued in three aquatic plant species (*Lemna minor* and *Elodea canadensis*, and *Leptodictyum riparium*), while sublethal concentrations of the heavy metals tested induced cell plasmolysis (or abnormal water loss) and caused abnormal alterations of the chloroplast arrangement.[48]

Toxic Effects of Zinc in Aquatic Invertebrates

Elevated zinc has been shown to cause increased mortality and reduced growth in several aquatic invertebrate species. Studies of aquatic invertebrates show that daphnids (e.g. *Daphnia magna*) appear to be the most sensitive to the short-term lethal effects of zinc.[49] The long-term toxic effects reported for elevated zinc in other invertebrates such as adult Asiatic clams (*Corbicula sp.)* were reduced shell growth and weight in juveniles during chronic exposure,[50] and tissue deterioration and death during chronic zinc exposures with *Ephydatia fluviatilis*, a freshwater sponge.[51]

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[45] B.C. Ministry of Environment and Climate Change Strategy. 2021. British Columbia Approved Water Quality Guidelines: Aquatic Life, Wildlife & Agriculture.

[46] Ibid.

[47] McHardy and George, 1990; US EPA, 1980; Huebert and Shay, 1992.

[48] Basile et al., 2012.

[49] B.C. Ministry of Environment and Climate Change Strategy. 2021. British Columbia Approved Water Quality Guidelines: Aquatic Life, Wildlife & Agriculture.

[50] Farris et al., 1999.

[51] Francis, J. C., and Harrison, F. W. 1988. Copper and zinc toxicity in Ephydatia fluviatilis (porifera: spongillidae). Transactions of the American Microscopical Society, 107: 67-78.

Toxic Effects of Zinc in Fish

At elevated concentrations of zinc short- and long-term toxic effects in fish on survival, growth, reproduction, and behavior occur.[52] In fish the mechanism of action of elevated zinc is disruption of the uptake of calcium at the gill and calcium deficiency.[53] This can also cause lethality due to the irreversible destruction of the gills at the cellular level (i.e. gill epithelium destruction) which in turn causes tissue level hypoxia (i.e. low oxygen levels), osmoregulatory failure, acidosis and low oxygen in the blood.[54] Salmonids appear to be more sensitive to short-term toxic effects of zinc compared to other fishes.

Vanadium Toxicity Overview

Vanadium is considered an essential trace metal in enzyme systems in bacteria, algae and marine invertebrates[55] and can be found in various states (i.e. oxidized anionic forms and reduced cationic forms) in ambient air, surface water, sediments and soils. The freshwater long-term Federal Environmental Quality Guideline in Canada was derived based on laboratory chronic toxicity data for three fish, one invertebrate and four algal species (all freshwater species). Tulcan et al. (2021) reviewed the toxicity of vanadium in plants and animals and reported that invertebrates, e.g., crustaceans, echinoderms, mollusks, showed the highest sensitivity to vanadium among taxonomic groups. It was also revealed that invertebrates were the taxonomic groups with higher vanadium concentrations when reviewing the global peer-reviewed data available.[56] Compared to other metals (i.e. copper, lead, zinc, arsenic) considerably less toxicity data exists for vanadium.[57]

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[52] World Health Organization (WHO). 2001. Environmental health criteria 221: Zinc. World Health Organization, Geneva, Switzerland.

[53] Hogstrand et al. 1994; Spry and Wood, 1985.

[54] Hiltibran, 1971; Skidmore, 1970; Skidmore and Tovell, 1972.

[55] IPCS 2001. Costigan, M, Cary, Richard, Dobson, Stuart, World Health Organization & International Programme on Chemical Safety. (2001). Vanadium pentoxide and other inorganic vanadium compounds. World Health Organization.

[56] Tulcan et al. 2021. Vanadium pollution and health risks in marine ecosystems: Anthropogenic sources over natural contributions. Water Research 207.

[57] Schiffer and Liber, 2017. Toxicity of aqueous vanadium to zooplankton and phytoplankton species of relevance to the athabasca oil sands region. Ecotoxicol Environ Saf 137:1-11.

Toxic Effects of Vanadium in Algae and Plants

Limited data exist on the impacts of vanadium on plants and algae and the sensitivity appears to vary widely dependent on the species. However, inhibition of growth has been documented for several species during chronic exposure to high levels of vanadium.[58]

Toxic Effects of Vanadium in Aquatic Invertebrates

Studies have reported the inhibition of Na-K-ATPase activity in the gills of crab,[59,60] although little data on the toxic mode of action in other invertebrates is available. The Federal water quality guideline in Canada was derived based on the acute exposure inhibiting development in the *Crassostrea gigas* (oyster) larvae and the lowest chronic exposure causing mortality in *Artemia salina* (brine shrimp).[61] [62] GC, 2010). Indeed, the lowest acute value inhibiting development in the oyster larvae was selected as a critical toxicity value and an application factor of ten was applied to obtain the predicted no effect concentration and Federal water quality guideline for marine aquatic life of 5 µg/L.

Toxic Effects of Vanadium in Fish

It has been established that the vanadium anions (i.e., $H_2VO_4^-$ and HVO_42^-) are bioavailable and taken up thorough phosphate anion-exchange systems and interfere with phosphate uptake, and as such, are potent inhibitors of certain enzymes involved in phosphate metabolism (i.e., phosphatases such as ATPase, phosphotransferase, nuclease and kinase) in vertebrates, including fish. In freshwater species exposed to vanadium under chronic conditions summarized in ECCC (2015; fathead minnow, brook trout and American flagfish) reduced growth and survival have been documented, with the American flagfish the most sensitive. There is a lack of studies on marine fish, thus there is considerable uncertainty regarding the sensitivity of these taxa to vanadium.

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[58] ECCC 2016. Biomonitoring-based Approach 1 for Beryllium Vanadium, trichlorooxo Vanadium oxide.

[59] Bell and Sargent 1979. The partial purification of sodium-plus-potassium ion-dependent adenosine triphosphatase from the gills of Anguilla anguilla and its inhibition by orthovanadate. Biochemical Journal 179: 43l-438.; Holleland and Towle 1990

[60] Holleland, T. and D.W. Towle. 1990. Vanadate but not ouabain inhibits Na+K-ATPase and sodium transport in tight inside-out native membrane vesicles from crab gill (Carcinus maenas). Comp Biochem. Physiol. 96B: 177-181.

[61] ECCC 2016. Biomonitoring-based Approach 1 for Beryllium Vanadium, trichlorooxo Vanadium oxide.

[62] Government of Canada. 2010. Screening Assessment for the Challenge: Vanadium oxide (vanadium pentoxide). Available from: http://www.ec.gc.ca/ese-ees/default.asp?lang=En&n=62A2DBA9-1

Total Suspended Solids

The definition of total suspended solids in the *Metal and Diamond Mining Effluent Regulations* (MDMER) under the Fisheries Act refers to matter contained in an effluent that is retained on a 1.5 micron pore filter paper, and is one of the nine deleterious substances with prescribed limits in the MDMER under the Fisheries Act (22.5 mg/L for a composite sample and 30 mg/L for a grab sample). Elevations in total suspended solids are known to reduce biological productivity in aquatic systems. Excess total suspended solids reduce light penetration required for plant and algal growth that may, in turn, have consequences on secondary productivity (organisms that feed on plant/algae), which are in turn fed upon by tertiary consumers.[63] In addition, direct lethal effects in fish and smothering of invertebrates during short term exposure in the range of hundreds to thousands of mg/L total suspended solids are typical, while sublethal effects in tens to hundreds of mg/L impair feeding and behavior and result in lower habitat quality for developing fish and invertebrates.[64, 65, 66]

According to Woodfibre LNG's TAR (2023), the levels of total suspended solids discharged into Howe Sound foreshores are predicted to range from 25 to 75 mg/L. The latter concentration is above the lowest applicable water quality guideline, and both values exceed the allowable discharge limits for metal and diamond mine effluents discharged into receiving waters as specified in the MDMER [Part 1, Section 4(1)(b)] under the *Fisheries Act.* It is proposed by the applicant that despite this exceedance of total suspended solids it is expected to be low risk to aquatic life, including to rockweed areas (known potential herring spawning substrate) 500 meters southeast of the West pond outfall, due to the dilution of total suspended solids upon release into Howe Sound foreshore. However, it is noted in the TAR (2023) that this must be monitored in order to conclude that sufficient dilution of total suspended solids is not harming aquatic wildlife. Therefore, whether the levels of total suspended solids will remain within this chronic sublethal range and the spatial extent of this parameter from the discharge sites is not clear. Therefore, the extent that aquatic wildlife will be harmed or not cannot be determined at this time and will be evaluated in real-time during the four-year period of continuous effluent

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[63] DFO, 2000. Effects of sediment on fish and their habitat. DFO Pacific Region Habitat Status Report 2000/01.

[64] Ibid.

[65] Rubin SP, Miller IM, Foley MM, Berry HD, Duda JJ, Hudson B, Elder NE, Beirne MM, Warrick JA, McHenry ML, Stevens AW, Eidam EF, Ogston AS, Gelfenbaum G, Pedersen R. 2017. Increased sediment load during a large-scale dam removal changes nearshore subtidal communities. PLoS One 12(12).

[66] Farrow, George E., James P. M. Syvitski, and V. Tunnicliffe. 1983. Suspended Particulate Loading on the Macrobenthos in a Highly Turbid Fjord: Knight Inlet, British Columbia. Canadian Journal of Fisheries and Aquatic Sciences. 40(S1): s273-s288. https://doi.org/10.1139/f83-289

release. Nonetheless, based on chronic exposure to a range of total suspended solids between 25 to 75 mg/L over the four-year duration of this discharge permit, sublethal effects are expected on marine wildlife to some spatial extent within the foreshore of Howe Sound near these discharge sites.

pH

High environmental acidity reduces biodiversity and the general quality of the ecosystem,[67,68] hence specified ranges exist for both fresh and marine waters delineating levels supportive of aquatic life. The pH of marine waters is usually quite stable with extreme fluctuations typically due to industrial activities.[69] This can be exacerbated seasonally when $S0_2$ and NO_x emissions from industry reduce the pH of surface waters after spring snowmelt as accumulated acid deposition flows into marine and estuarine waters. A wide array of adverse effects due to pH fluctuations have been documented for estuarine and marine organisms. For example, studies have shown decreased maximum oxygen saturation in hemocyanin in a marine octopus at pH below 7.2 (*Octopus dofleini*)[70] and decreased growth, shell size, and feeding and shell dissolution and death at pH below 7 in four species of bivalves.[71, 72] The pH of water can also alter the solubility, chemical forms, and toxicity of other substances. For example, at lower pH the solubility of metals tends to increase, which increases the bioavailability of metals to biota and thus presents a more toxic exposure scenario.[73]

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[67] Driscoll, C.T., Lawrence, G.B., Bulger, A.J., Butler, T.J., Cronan, C.S., Eagar, C., Lambert, K.F., Likens, G.E., Stoddard, J.L., Weathers, K.C., 2001. Acidic deposition in the northeastern United States: sources and inputs, ecosystem effects, and management strategies. Bioscience 51 (3), 180–198.

[68] Watras, C., Hudson, R.J.M., Wente, S., States, U., Protection, E., 1998. Bioaccumulation of mercury in pelagic freshwater food webs bioaccumulation of mercury in pelagic freshwaterfood webs. Sci. Total Environ. 219, 183–208.

[69] [CCME] Canadian Council of Ministers of the Environment, 1999. Canadian Water Quality Guidelines for the Protection of Aquatic Life: pH (Marine). In: Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment, Winnipeg.

[70] Miller, K.I., and C.P. Magnum. 1988. An investigation of the nature of Bohr, Root, and Haldane effects in Octopus dofleini hemocyanin. J. Comp. Physiol. B. 158:547-552

[71] Bamber, R.N. 1987. The effects of acidic sea water on young carpetshell clams Venerupis decussata (L.) (Mollusca: Veneracea). J. Exp. Mar. Biol. Ecol. 108:241-260.

[72] Bamber, R.N.. 1990. The effects of acidic seawater on three species of lamellibranch mollusc. J. Exp. Mar. Biol. Ecol. 143:181-191.

[73] Saalidong BM, Aram SA, Otu S, Lartey PO. 2022. Examining the dynamics of the relationship between water pH and other water quality parameters in ground and surface water systems. PLoS One.

Woodfibre LNG is requesting to discharge effluents into Howe Sound ranging from pH 5.5 to 9.0, which exceeds the lower and upper limits of the long-term water quality guidelines for pH for the protection of marine aquatic life (BC long-term water quality guideline for marine waters is 7.0 to 8.7, and for freshwater is 6.5 to 9.0). This pH range also exceeds the less conservative lower range pH value allowable in metal or diamond mine effluents discharged into receiving waters as specified in the MDMER [Part 1, Section 4(1)(b)] under the *Fisheries Act* (i.e. specifies the acceptable pH range of the effluent is 6.0 to 9.5). In light of these stricter standards even for metal mines in Canada tasked with treating high metal waste products and maintaining a pH of 6 in effluents, it does not seem reasonable that a construction site discharge wastes at lower pH levels known to be harmful to many species in the aquatic environment.

Organic Pollutants

Low concentrations of several organic contaminants present in some areas of the Project Site Area soil, water, sediment and groundwater are likely to be mobilized and released into Howe Sound. The specific organic contaminants are listed in Table 4-2 in the WLNG TAR and include dioxins, furans, and hydrocarbons. Although it is predicted that these organic contaminants will not exceed available water quality guidelines, these compounds are of concern because of their persistent and toxic nature and because they are known to bioaccumulate and biomagnify in animals. These contaminants may be released from the WWTP at the Project Site Area, most likely adsorbed to particulate matter in the water or dissolved at low levels in the water prior to discharge due to their hydrophobic nature.

There are 210 different dioxins and furans, and these substances vary widely in toxicity.[74] The most toxic dioxin is referred to as 2,3,7,8-tetrachlorodibenzo-p-dioxin, or simply TCDD.[75] The harmful effects of dioxins in humans have been well studied and examples include: skin disorders (i.e. chloracne); liver damage; impairment of the immune system and the endocrine system (i.e. reproductive functions); effects on development (i.e. malformation of nervous system); and certain types of cancers.[76] Similar effects in non-human animals have been observed, including effects on early life stages of fish such as: developmental deformities (e.g.

[74] Health Canada. 2005. DIOXINS AND FURANS It's Your Health. Catalogue# H50-3/26-2004E-PDF, ISBN# 0-662-35892-9

[75] Ibid.

[76] Ibid.

skeletal, craniofacial, edemas); reproductive dysfunction; and, tumors.[77, 78] In general, if released into water dioxins and furans typically adsorb onto particles, and although these compounds may undergo photochemical degradation or biodegradation, they are generally very stable and hardly degrade.[79] Ultimately, in the aquatic environment these persistent organic contaminants accumulate in lipid-rich tissues of aquatic organisms, and cause adverse effects when they reach toxic thresholds. Dietary exposure is presumed to be the most significant route of exposure for humans, and Canada refers to the World Health Organization's tolerable monthly intake recommendation as the safe level not to exceed in order to avoid adverse health effects in humans.[80]

Hydrocarbon compounds are composed of hydrogen and carbon, are classified as either aromatic (cyclic) or aliphatic (straight-chained), and are the main components in many types of fuels.[81] Their persistence and toxicity varies due to the range of types and sizes of the thousands of hydrocarbons present in petroleum products.[82] However, as evidenced by various historical oil spills, many are resistant to degradation, persist for years, and exert a range of adverse effects in animals after low-level, long-term exposures. Particularly well-studied are the polycyclic aromatic hydrocarbons (PAHs), of which 16 have been identified as priority pollutants by the United States Environmental Protection Agency (US EPA) also listed under Schedule 1 of the Canadian Environmental Protection Act. One of the most well studied PAH, benzene, is a known human carcinogen, and benzene as well as several other PAHs have been shown to cause developmental abnormalities and impair reproduction in animals.[83]

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[77] Boulanger E, Barst BD, Alloy MM, Blais S, Houde M, Head JA. 2019. Assessment of environmentally contaminated sediment using a contact assay with early life stage zebrafish (Danio rerio). Sci Total Environ. 659:950-962.

[78] Hoffman JC, Blazer VS, Walsh HH, Shaw CH, Braham R, Mazik PM. 2020. Influence of demographics, exposure, and habitat use in an urban, coastal river on tumor prevalence in a demersal fish. Sci Total Environ. 712.

[79] Government of Canada, Version 1.2.2. Public Services and Procurement Canada. https://gost.tpsgcpwgsc.gc.ca/Contfs.aspx?ID=66&lang=eng

[80] Health Canada. 2005. DIOXINS AND FURANS It's Your Health. Catalogue# H50-3/26-2004E-PDF, ISBN# 0-662-35892-9

[81] Canadian Council of Ministers of the Environment. 1999. Canadian water quality guidelines for the protection of aquatic life: Polycyclic aromatic hydrocarbons (PAHs). In: Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment, Winnipeg.

[82] Canadian Council of Ministers of the Environment. 1999. Canadian water quality guidelines for the protection of aquatic life: Polycyclic aromatic hydrocarbons (PAHs). In: Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment, Winnipeg.

[83] Canadian Council of Ministers of the Environment. 1999. Canadian water quality guidelines for the protection of aquatic life: Polycyclic aromatic hydrocarbons (PAHs). In: Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment, Winnipeg.

Impacts of Parameters of Concern on Human Health

With respect to the potential human health impacts of WLNG's effluent discharge into Howe Sound, there is potential for direct dermal and oral exposure via recreational activities, and oral exposure via consumption of shellfish and fish harvested within the WLNG contaminated receiving waters. These human exposure scenarios are likely to be low-level based on mathematical models predicted by WLNG for most metals, hydrocarbons, dioxins, furans and other organics associated with total suspended solids (TSS) that will be continuously released at levels below or at water quality guidelines aimed to be protective of marine life.[84] Therefore, concentrations causing any acute human poisoning scenarios will not be reached for these contaminants based on the predicted waste effluent discharge rates.

However, for the four heavy metals (copper, lead, zinc and vanadium) predicted to be discharged into Howe Sound at concentrations *exceeding* the lowest applicable water quality guideline under the highest effluent discharge scenario predicted by Woodfibre LNG, there are potential concerns for chronic/long-term human exposure to toxic levels of these metals. This will depend on the frequency of human exposure and effluent dilution in Howe Sound receiving waters and the resultant human exposure concentrations. Ultimately, this may result in low level chronic exposure through repeated recreational use and/or ingestion of fish and shellfish. Due to their water solubility and because they do not degrade, metals persist once released into the environment, can be transported via the water, and bioconcentrate and bioaccumulate in animals (i.e. fish and shellfish).[85,86]

Harvesting of crabs and bivalves was restricted in most of Átl'ḵa7tsem / Howe Sound in the 1980s due to high levels of dioxins and furans from two pulp mills, which made them unsafe for human consumption.[87] In recent years, some of these restrictions have been lifted as the levels of dioxins and furans present in crabs and sediments have declined, however restrictions are still in place near the Woodfibre site.[88] Thus, it is likely that continued impairment of fish and

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[84] TAR 2023

[85] Eroglu, A., Dogan, Z., Kanak, E.G., Atli, G., Canli, M., 2015. [Effects of heavy metals (Cd, Cu, Cr, Pb, Zn) on fish glutathione metabolism](). Environ. Sci. Pollut. Res. 22, 3229–3237.

[86] Landis, W.G., R.M. Sofield, and Ming-Ho Yu. 2018. Introduction to Environmental Toxicology: Molecular Substructures to Ecological Landscapes, 5th Edition, CRC Press, 2018 ISB 1498750427, 9781498750424, pp 258

[87] Alava JJ 2017 Dioxin and furan contamination from pulp mills: A successful history of source control and regulations. In Bodtker K et al (Ed.) Ocean Watch: Howe Sound Edition 2017. Ocean Wise. 364 pp.

[88] Chapman J 2020 Pulp Mill: marine effluent. In Miller A et al (Ed.) 2020. [Ocean Watch: Átl'ḵa7tsem/Txwnéwu7ts/Howe Sound Edition 2020](). Ocean Wise. 388 pp.

shellfish harvesting will ensue due to the accumulation of metals and persistent organic pollutants (e.g. dioxins, furans) in these marine animals within the effluent plume of the WLNG wastewater discharge.

Ongoing monitoring of fish and shellfish concentrations for contaminants specified by Health Canada is recommended to determine if these wildlife are safe for human consumption. Health Canada (Bureau of Chemical Food Safety) provides a list of chemical contaminants prohibited or acceptable dietary doses and this includes limits for some metals (arsenic, lead, tin, mercury), some hydrocarbons (polycyclic aromatic hydrocarbons) and some dioxins (chlorinated dibenzo-p-dioxins, 2,3,7,8-tetrachlorodibenzoparadioxin). However, no safe human consumption limits are available for copper, zinc or vanadium. B.C. has Recreational Water Quality Guidelines (RWQGs) that are used to specifically help manage recreational water quality and assess the risks to human health, however, no metal, hydrocarbon or dioxin limits exist.

In general, most non-essential and excessive levels of essential metals are systemic poisons and have toxic effects on many organs once taken up and absorbed into the circulatory system in animals, including humans. Copper and zinc are essential micronutrients for all plants and animals and play important roles in several biological processes. Thus, copper and zinc are beneficial at appropriate concentrations, but deficiencies and toxic overloads occur at low and high concentrations, respectively. Lead is non-essential to all organisms and has no known biological function and is a well characterized poison in humans.

Although lead can be absorbed dermally, it is most efficiently taken up via respiratory and digestive systems. In humans, it can cause neurological, respiratory, urinary, and cardiovascular disorders due to immune-modulation, oxidative and inflammatory mechanisms. Children are especially susceptible to the neurotoxic effects of lead as this is a critical period of brain development, and several studies have demonstrated low level lead exposure is associated with numerous irreversible neurotoxic adverse effects, such as: reduced intellectual abilities; and, impaired learning, memory, speech and language, hearing, visual-spatial skills, social behavior, motor skills, etc.[89] Vanadium is considered an essential trace metal in enzyme systems in bacteria, algae and marine invertebrates, but has no known functions in humans. Vanadium toxicity in humans has been shown to cause decreases in the number of red blood cells, increased blood pressure, and mild neurological effects, as well as increased birth defects and reduced birth weight after in utero exposure.[90]

[89] Ibid.

[90] Agency for Toxic Substances and Disease Registry (ATSDR). 2012. Toxicological Profile for Vanadium. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service.

Evaluating Effects of the Geographic Extent of Contaminants and their Impacts on Aquatic Life

In the TAR (2023) it is stated that Howe Sound has a stratified water column with the shallow freshwater influenced surface layer up to 10 m depth with limited mixing of the surface layer with deeper water layers. It is further stated in the TAR (2023) that due to the water column stratification, the discharges from the sediment ponds will not mix with deeper water layers and will not mix with the treated domestic wastewater and treated leachate effluent already being discharged into deeper layers. Two concerns are noted: 1) these are predictions and no monitoring stations appear to be included to verify these predictions and confirm contaminants are not dispersing into deeper waters (Section 4.4.3, TAR, 2023); and, 2) this suggests that the contaminants will be released and concentrate within the first 10 m depth of waters, yet no intertidal and subtidal biota health monitoring (i.e. fish and fish spawning surveys especially herring surveys, upmigrating salmonid surveys or intertidal biodiversity surveys, etc.) is included in the monitoring plan for the receiving environment (Table 4-17, TAR, 2023). Regarding this latter point, metal mines in Canada are required to conduct environmental effects monitoring studies to determine the potential effects of metal mine effluent discharge on the aquatic environment. In light of the similarity between the effluents predicted from the Woodfibre LNG project to those of metal mines, there is considerable rationale for conducting environmental effects monitoring at the Woodfibre LNG intertidal and subtidal areas to monitor fish health and habitat prior to and during this project.

Combined Hazards of Multiple Contaminants on Aquatic Life

Although there is less data assessing the risks of contaminant mixtures on wildlife, some examples for metals (e.g. metal mine environmental effects monitoring data across Canada, intertidal biodiversity in Howe Sound) and hydrocarbons (e.g. Puget Sound studies in fish) are discussed below that provide strong lines of evidence for additive harmful effects of mixtures at the organismal and community level with long-term exposures. Based on several studies to date it is highly probable that exposure to multiple heavy metals, reduced pH and elevated total suspended solids and other organic contaminants released from the Woodfibre LNG project area simultaneously will cause combined toxic effects on intertidal and subtidal communities to some spatial extent (i.e. within 100 m or > from the discharge point). It is also important to note that the levels of contaminants and effluent quality discharged from this facility are only predictions, and future monitoring will be needed to verify these predictions.

Heavy metals are of particular concern because of their persistence, bioaccumulation and harmful impacts on growth, survival and reproduction in aquatic organisms. Indeed, copper, zinc and lead are three of the nine deleterious substances with prescribed limits in the *MDMER* under the Canadian *Fisheries Act*, but less is known regarding the toxic effects of vanadium. Ultimately when aquatic organisms are exposed to multiple metals, this presents an exposure scenario whereby the toxic effects of multiple metals may be additive, more than additive (synergistic) or less than additive (antagonistic) relative to the effects/responses measured for a single-metal. Although, there are some knowledge gaps regarding the toxic effects of all combinations of heavy metals on aquatic organisms, there are several reports of additive and synergistic toxic effects metals. Two case studies of relevance to natural aquatic ecosystems are discussed below that provide strong evidence that exposure to more than one toxic heavy metal: is approximately additive; that single metal exposures at concentrations that do not cause toxic effects when combined at these same low concentrations do cause toxic effects; and, multiple years of field studies show harmful effects of mixtures of metals on aquatic life.

Mebane et al. (2020) describes long-term experiments conducted in a controlled laboratory setting exposing aquatic insect communities to zinc, copper, cadmium and nickel individually and in mixtures in artificial streams, and measured effects on organism abundance as an indicator of survival.[91] These experiments demonstrated that metals strongly accumulated in sediments, periphyton and the one insect measured (caddisfly), with periphyton exhibiting the highest accumulation of metals. In natural streams and in this artificial stream experiment, periphyton refers to the material accumulating on submerged surfaces and typically includes algae, bacteria, dead organisms as well as previously suspended organic and inorganic materials. Periphyton is a food source for many aquatic insects, including many caddisfly species. This artificial stream exposure experiment reflects a natural environmental exposure scenario whereby metal exposure occurs via dissolved metals in the water column, but also via sediment and dietary exposure for aquatic insects. A key finding from this study was that relative to the single metal exposure responses in survival of aquatic insects, the toxicity of the mixtures of metals was either approximately additive or slightly less than additive. This indicated that multiple toxic metals when combined are more toxic than a single metal exposure. In addition, although some single-metal exposures caused no significant reductions in mayfly abundance, exposure to mixtures of metals caused significant declines in abundance.

[91] Mebane, C.A., T.S. Schmidt, J.L. Miller, and L.S. Balistrieri. 2020. Bioaccumulation and Toxicity of Cadmium, Copper, Nickel, and Zinc and Their Mixtures to Aquatic Insect Communities. Environmental Toxicology 39(4): 812-833.

These data indicate that a given metal concentration was usually more toxic in the presence of other metals than in individual metal exposure experiments. Mebane et al. (2020) concluded that metal mixture toxicity should be considered in risk assessments.[92] Indeed, in light of these data showing that even if less than additive effects of metals occur, low concentrations of metals can be toxic when combined even when none of the individual metal component concentrations are toxic.

Under the Fisheries Act as of 2002, metal mines in Canada are required to conduct environmental effects monitoring studies to determine the potential effects of metal mine effluent discharge on the aquatic environment. This monitoring program has provided nationally consistent methods and data interpretation for assessing the effects of metal mine effluents using field studies on fish and fish habitat in sites downstream of discharge sites (i.e., with elevated metals) compared to upstream reference sites (i.e., with natural background levels of metals). Metal mines are required to conduct these environmental effects monitoring field studies every three years by: conducting a fish population survey to assess fish health; a benthic invertebrate community survey to assess effects on fish habitat; and, a study of mercury levels in fish tissue to assess the effects of the usability of fisheries resources. Therefore, the data and main findings from these multi-year, Canada-wide, field-based studies comparing wild fish and benthic invertebrates in natural settings under metal mixture exposure scenarios to upstream non-exposed sites lends well to understanding long-term toxic effects of metal mixtures on fish and aquatic invertebrates in Canada.

The key findings in the second and third national assessments of metal mines in Canada were similar.[93, 94] Specifically, these assessments report significant differences in several measures in fish between the exposure areas downstream of metal mine discharge sites compared to reference (upstream) sites, such as: body condition; liver condition; reproduction; growth; and, survival. Similarly, significant differences between downstream metal mine exposure areas and reference sites were also observed in benthic invertebrate communities based on several measures, such as: community structure; number of species present; and, total abundance of animals. The substances in effluent identified as the potential causes of these effects were major ions, metals, nitrogen, total suspended solids, phosphorus and selenium. Metals and

[92] Ibid.

[93] Environment Canada. 2012. Second National Assessment of Environmental Effects Monitoring Data from Metal Mines Subjected to the Metal Mining Effluent Regulations. National Environmental Effects Monitoring Office, Forestry, Agriculture and Aquaculture Division, ISBN: 978-1-100-20588-5

[94] Environment and Climate Change Canada. 2015. Third National Assessment of Environmental Effects Monitoring Information from Metal Mines Subject to the Metal Mining Effluent Regulations Industrial Sectors, Chemicals and Waste and Environmental Protection Operations Directorates, ISBN: 978-0-660-04509-2

selenium were most often associated with inhibitory effects, while major ions and phosphorous were associated with stimulatory effects and nitrogen compounds were associated with stimulatory and inhibitory effects. Collectively, these field-based environmental effects monitoring studies support numerous controlled laboratory studies on multiple species demonstrating the toxic effects of metals and mixtures of metals in fish and invertebrates that cause reductions in survival, growth and reproductive success.

Cumulative Effects of Historical, Current, and Proposed Pollution Inputs on Howe Sound Ecosystem

Due to a legacy of industrial activity in Howe Sound, industrial pollution, including metals, organic persistent pollutants, and acids remain today. The large scale point source pollution inputs began in the early 1900's from two pulp mills located in Woodfibre and Port Mellon, and the Britannia Copper Mine whereby decades of water effluents were discharged into Howe Sound containing metals (mainly copper and zinc) and organic persistent chlorinated compounds (mainly dioxins and furans). In addition, a mercury cell chlor-alkali plant was operational during 1964-1991 in the Squamish delta area, producing caustic soda (NaOH) and hydrochloric acid for pulp mills. This caused substantially high levels of mercury in Howe Sound biota and alkalis, acids, sulphates and chlorine in receiving waters in the 1970's.[95] Collectively, this resulted in severe degradation of intertidal and subtidal marine organism health that has been slowly demonstrating recovery based on increased biodiversity and reduced mercury levels in biota within Howe Sound. For example, once mercury scrubbers were implemented at the chlor-alkali plant, mercury biota levels decreased in biota to levels safe for human consumption (i.e. 0.5 mg/kg). Furthermore, intertidal biodiversity recovery took decades to begin to re-establish after the Britannia Mine closure at several sites that were several kilometers away from the point source of copper and zinc and low pH discharges into Howe Sound.[96, 97]

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[95] Hoos, L.M. and C.L. Vold 1975. The Squamish River Estuary. Status of environmental knowledge to 1974. Report of the Estuary Working Group, Dept. Environment, Regional Board Pacific Region. Special Estuary Series No. 2: 261 pp.

[96] Willems, W. 2004. A GIS-approach to assess the impact of two pulp mills (Woodfibre and Port Mellon) on intertidal biodiversity in the Howe Sound region (British Columbia, Canada). Master of Science Thesis. Advanced Studies in Marine and Lacustrine Sciences, Dalhousie University.

[97] Bard, S.M. 1998. A biological index to predict pulp mill pollution levels. Water Environment Research 70(1): 108-122.

In addition to the industrial legacy point sources of pollution into Howe Sound, current significant point source pollution inputs into Howe Sound include community wastewater treatment plant effluent discharge, urban run-off, log sorts, and a proposed Fortis B.C. WDA application related to land-based construction and a tunnel under Howe Sound. The Mamquam wastewater treatment plant discharges primary and secondary sewage effluent into the Squamish River (up to 17,850 m^3/day) which then flows into Howe Sound.[98] Hundreds of chemicals released from municipal wastewater treatment plants (WWTPs) which include contaminants such as metals, salts, nutrients, polycyclic aromatic hydrocarbons (PAHs), polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans, surfactants (i.e., alkylphenol ethoxylates), pesticides, polybrominated diphenyl ethers (PBDEs), polychlorinated biphenyls (PCBs), human hormones, pharmaceuticals and personal care products (PPCPs; i.e., prescription, over the counter, and veterinary therapeutic drugs for human and animal ailments/diseases, and PCPs such as soaps, deodorants, and cosmetics).[99] Urban run-off provides a similarly complex contaminant milieu such as tire degradation products, metals, pesticides gas and oil products.

FortisBC has applied to discharge effluent from construction activities for the Eagle Mountain to Woodfibre Pipeline project as outlined in FortisBC's application for Waste Discharge Authorization under the Environmental Management Act under permit PE 110163 (Application Number 388398). This effluent would be released into the Squamish River ~4km upstream of Howe Sound, and would contain metals, persistent organic pollutants and water quality parameters (i.e. pH, temperature, dissolved oxygen) at or below B.C. Water Quality Guidelines. However, part of the proposal entails monitoring at weekly or monthly intervals to verify B.C. Water Quality Guidelines are met for these contaminants and water quality parameters. Therefore, some uncertainty in the levels of contaminants/quality of water discharged and the potential for exceedances of guidelines in discharged water may occur from one week up to one month in duration between monitoring prior to mitigation measures.

Collectively, this multi-chemical stressor environment contributes to adverse effects on aquatic biota including negative metabolic changes in fish, endocrine disruption (for example, reduced fertility), increased antibiotic resistant bacteria, physical injury, and even death.

Although the toxic effects of various chemical mixtures that reflect environmentally relevant exposure scenarios has not been documented for all possible combinations and risk

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[98] Opus. 2016. District of Squamish, Sanitary Sewer Master Plan.

[99] Khan, U., Bloom, R.A., Nicell, J.A., Laurenson, J.P., 2017. Risks associated with the environmental release of pharmaceuticals on the U.S. Food and Drug Administration "flush list." Science of The Total Environment 609, 1023–1040.

assessments of mixtures are complicated, contaminants have been identified as one of Earth's greatest threats to human and environmental health.[100] This is in large part a result of decades of industrial, agricultural, and urban anthropogenic activities deliberately or accidentally releasing numerous chemical pollutants into waterways.[101] Howe Sound is a prime example of an aquatic ecosystem with documented historical pollution, and ongoing current point source pollution that has shown considerable recovery in the last two decades. However, adding another point source of non-degradable and persistent toxic pollutants will hamper the recovery of this aquatic ecosystem to some unknown geographic extent. Indeed, the surface flows presented in Willems (2004) of the WLNG site foreshore and other areas of Howe Sound suggest a more complex and unpredictable water mixing scenario that will be influenced by seasons, storm events, barge traffic, etc., and there is a lack of empirical data delineating the transit distance of the WLNG effluent discharge.[102] Together, it is clear that a toxic effluent plume will carry pollutants into the foreshore of Howe Sound. However, the geographic extent of this contamination and how this will culminate in additive or synergistic effects at various Howe Sound sites previously or currently impacted by pollution is unknown. This uncertainty makes it difficult to understand the risk for both aquatic wildlife and humans utilizing Howe Sound beyond the project area identified in the WLNG WDA application.

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[100] Landrigan, P.J., Fuller, R., Acosta, N.J.R., Adeyi, O., Arnold, R., Basu, N. (Nil), Baldé, A.B., Bertollini, R., Bose-O'Reilly, S., Boufford, J.I., Breysse, P.N., Chiles, T., Mahidol, C., Coll-Seck, A.M., Cropper, M.L., Fobil, J., Fuster, V., Greenstone, M., Haines, A., Hanrahan, D., Hunter, D., Khare, M., Krupnick, A., Lanphear, B., Lohani, B., Martin, K., Mathiasen, K. v, McTeer, M.A., Murray, C.J.L., Ndahimananjara, J.D., Perera, F., Potočnik, J., Preker, A.S., Ramesh, J., Rockström, J., Salinas, C., Samson, L.D., Sandilya, K., Sly, P.D., Smith, K.R., Steiner, A., Stewart, R.B., Suk, W.A., van Schayck, O.C.P., Yadama, G.N., Yumkella, K., Zhong, M., 2018. The Lancet Commission on pollution and health. The Lancet 391, 462–512.

[101] Rehman, M.S.U., Rashid, N., Ashfaq, M., Saif, A., Ahmad, N., Han, J.-I., 2015. Global risk of pharmaceutical contamination from highly populated developing countries. Chemosphere 138, 1045–1055.

[102] Willems, W. 2004. A GIS-approach to assess the impact of two pulp mills (Woodfibre and Port Mellon) on intertidal biodiversity in the Howe Sound region (British Columbia, Canada). Master of Science Thesis. Advanced Studies in Marine and Lacustrine Sciences, Dalhousie University.

Conclusions

Effluent exposure will be continuous and of long duration especially for sessile organisms or organisms with high site fidelity (i.e. plants, algae, echinoderms, crustaceans, mollusks, etc.) and for organisms using this site seasonally (i.e. salmonids, herring, etc.) in the intertidal and subtidal areas for all contaminants discharged from the sedimentation ponds.

In the TAR (2023) it is stated that reduced growth rates and reduced reproduction are likely effects for sessile organisms, but that these will be reversible when the discharge stops. However, the metals and persistent organic pollutants present in this effluent are also likely to partition into sediments and be taken up by biota to some extent, and ultimately, cycle between residing in the sediments, biota and the water column in the exposed area. This may not allow for reversal of adverse effects upon cessation of discharge of effluents for years since metals do not degrade and the organic contaminants are known to persist for years.

Therefore, based on several studies to date, it is highly probable that exposure to multiple heavy metals, reduced pH, elevated total suspended solids and other organic contaminants released from the Woodfibre LNG project area simultaneously will cause cumulative, long-term toxic effects on intertidal and subtidal ecosystems to some yet to be determined spatial extent.

Recommendations

To balance the economic benefits with the environmental impacts the proponent would need to employ <u>the highest environmental standards and apply the precautionary principle to its total project impacts on the marine ecosystem</u>. Therefore, we would not support effluent discharge that compromises healthy levels of water quality and urge Woodfibre LNG to seek alternative solutions for containing and removing their wastewater so it can be disposed of through regulated treatment systems.

We make the following recommendations:

- Additional water quality sampling should be conducted. Specifically:
    - Due to historical industrial contamination at the project site, background values for Parameters of Concern (POC) derived from water quality data are likely overestimating background levels typical for undisturbed reference areas. Therefore, we recommend that the applicant be required to conduct water

quality sampling from an uncontaminated geologically and ecologically similar site in order to establish baseline conditions.

- No freshwater reference sites were established by the applicant. Without such reference data, shifts in stream water quality attributable to the Project cannot be identified. We recommend that Woodfibre LNG be required to establish potential reference sites in creeks situated outside the Certified Project Area (CPA) or reaches in Mill, Woodfibre, and East Creek upstream of the CPA.

- Long-term surface water quality data collection was not thoroughly conducted by the applicant. A little over one year of continuous monthly sampling is essentially the minimum length of time suggested by the B.C. Ministry of Environment to capture field baseline conditions. Since the pH field data inform WLNG's proposed effluent pH compliance limits and are highly influenced by various abiotic factors (i.e. surface water flows which require a 2-year minimum baseline data collection), we recommend that the applicant conduct an additional 1 to 2 years of continuous monthly sampling in order to more accurately capture pH baseline conditions.

- Require environmental effects monitoring of intertidal and subtidal biota to monitor fish and ecosystem health prior to and during the project, including fish and fish spawning surveys (especially herring surveys), upmigrating salmonid surveys, and intertidal biodiversity surveys.

- Contaminant concentrations should not exceed BC long-term water quality guidelines for metals, organic pollutants, total suspended solids (TSS), and pH for marine waters. Specifically:

  - If the upper case scenario with higher discharge rates is reached, copper is predicted to exceed the lowest water quality guidelines by 2.2 times. Copper is highly toxic to aquatic life, and it is a metal of high concern globally due to human activities enriching this metal above natural background levels in numerous countries. We recommend that copper concentrations not be permitted to exceed water quality guidelines.

  - Lead is predicted to exceed water quality guidelines by 1.6 times. Lead is highly toxic to plant and animal life and is a pollutant of global concern.[103] We

[103] Landis, W.G., R.M. Sofield, and Ming-Ho Yu. 2018. Introduction to Environmental Toxicology: Molecular Substructures to Ecological Landscapes, 5th Edition, CRC Press, 2018 ISB 1498750427, 9781498750424, pp 258

recommend that lead concentrations not be permitted to exceed water quality guidelines.

- Zinc is predicted to exceed water quality guidelines by 1.6 times. High levels of zinc have toxic effects on multiple biological processes in organisms, such as blood cell and plasma formation, lipid metabolism and immune system function.[104] We recommend that zinc concentrations not be permitted to exceed water quality guidelines.

- Vanadium is predicted to exceed water quality guidelines by 1.3 times. Vanadium has been shown to cause inhibition of growth, development, and survival in plants, invertebrates, and fish, respectively. We recommend that lead concentrations not be permitted to exceed water quality guidelines.

- TSS discharged into Howe Sound foreshores are predicted to range from 25 to 75 mg/L. The latter concentration is above the lowest applicable water quality guideline, and both values exceed the allowable discharge limits for metal and diamond mine effluents discharged into receiving waters as specified in the MDMER [Part 1, Section 4(1)(b)] under the *Fisheries Act.* Excess TSS have consequences on secondary productivity.[105] Sublethal effects in tens to hundreds of mg/L impair feeding and behavior and result in lower habitat quality for developing fish and invertebrates.[106] We recommend that TSS concentrations not be permitted to exceed water quality guidelines.

- Woodfibre LNG is requesting to discharge effluents into Howe Sound ranging from pH 5.5 to 9.0, which exceeds the lower and upper limits of the long-term water quality guidelines for pH for the protection of marine aquatic life (BC long-term water quality guideline for marine waters is 7.0 to 8.7, and for freshwater is 6.5 to 9.0). High environmental acidity reduces biodiversity and the

[104] Butrimavičienė et al., 2021. Impact of copper and zinc mixture on haematological parameters of rainbow trout (Oncorhynchus mykiss): acute exposure and recovery. Ecotoxicology 30: 873-884.

[105] DFO, 2000. Effects of sediment on fish and their habitat. DFO Pacific Region Habitat Status Report 2000/01.

[106] Ibid.

general quality of the ecosystem.[107, 108] We recommend that the pH of effluents discharged into Howe Sound be limited to long-term water quality guidelines.

  - Given that the pH of water can also alter the solubility, chemical forms, and toxicity of other substances, we recommend that cumulative effects of predicted pH and proposed contaminant releases be determined.

- An effluent plume study should be conducted to examine the distance discharged contaminants will travel from the discharge pipes across seasons in order to verify the geographic extent of contamination (of relevance for both human recreational exposure, fish and shellfish and other aquatic life exposure).

- Require ongoing monitoring of fish and shellfish concentrations for contaminants specified by Health Canada to determine if these wildlife are safe for human consumption.

- Conduct a cumulative effects assessment to determine the risk of combined hazards of multiple contaminants (heavy metals, organic pollutants, total supended solids, and pH) on aquatic life.

- Conduct a cumulative effects assessment to evaluate the combined impacts of historic, current, and proposed pollution on Howe Sound's ecosystems, including FortisBC's application to discharge effluent from construction activities for the Eagle Mountain to Woodfibre Pipeline project as outlined in FortisBC's application for Waste Discharge Authorization under the Environmental Management Act under permit PE 110163 (Application Number 388398).

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Acronyms

BCER	B.C. Energy Regulator
CPA	Certified Project Area
DFO	Fisheries and Oceans Canada
ECCC	Environment and Climate Change Canada
MDMER	Metal and Diamond Mining Effluent Regulations
MWAL	Marine water aquatic life
LNG	Liquefied natural gas
POC	Parameter of Concern
TAR	Technical Assessment Report
TSS	Total suspended solids
UNESCO	United Nations Educational, Scientific and Cultural Organization
US EPA	United States Environmental Protection Agency
WDA	Wastewater Discharge Authorization
WLNG	Woodfibre LNG
WWTP	Wastewater treatment plant