Waterfowl Desktop Study

Faro Mine Complex, Yukon

Prepared For:

Denison Environmental Services

Faro Care and Maintenance Project

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1. Introduction

The Faro Mine Complex (FMC) operated near the town of Faro, Yukon from 1969 until 1998, when the mine was placed into receivership. The FMC produced lead, zinc, silver, and gold, during which time two open pits were developed and milled tailings were deposited into a series of tailings ponds. Since 1998, the FMC has been under care and maintenance, with these activities more recently being managed by Denison Environmental Services (DES).

Under the care of DES, waterfowl have been observed occasionally using several of the pits and ponds at the site, some of which are known to contain relatively low pH water (in the range of 2-5), and elevated concentrations of several metals, including aluminum, arsenic, cadmium, copper, iron, nickel, lead, thallium, uranium, and zinc ('elevated' referring to levels above CCME guidelines for the protection of aquatic life; CCME 2007). A summary of water quality data from the FMC is attached to this document as Appendix 1 (DES 2011).

Observations of waterfowl were collected by DES during the fall of 2009 and summer season of 2010, and these observations indicated variable usage through the spring, summer, and fall seasons (from one to 24 ducks), however the absolute length of time spent by ducks, gulls, or other birds around the infrastructure could not always be determined from the data. Additionally, the behavior of waterfowl at the site (whether they may be attempting to feed), the quality of sediments, or existence of life within the ponds/pits are not known. Anecdotal information from mine site workers (provided by DES) indicated that no aquatic life had been observed in the mine facility waters (e.g. fish, invertebrates, or vegetation).

This literature review, prepared on behalf of DES, has been conducted to collect information regarding the effects that low pH and elevated metals (as observed in the FMC ponds) may have on the waterfowl and other birds that use them. The primary effort was to review studies and findings related to occasional use of contaminated water (through external effects or ingestion). Habitat loss was not included within the scope of this review.

2. Literature Review Techniques

An earlier preliminary literature review had revealed little information regarding the aforementioned environmental factors on waterfowl and water birds, and it was the intent of this literature review to use more in-depth techniques to determine whether relevant information could be assembled. This review is based on an approximate total research effort time of 40 hours, and included:

- Database searches within the primary literature, including primarily peer-reviewed scientific articles.
- Searches of secondary literature including government libraries, public libraries and web searches.
- Email contacts to numerous researchers and professional staff.
- Phone interviews with researchers and professional staff.

During this research study, ELR conducted searches directed at mine-related studies, systems, and literature (the most relevant research topics to the current study), but also extended searches to the greater overall interactions in question. In summary, this included acidic or low pH conditions, elevated metals, wildlife usage of similar industrial sites, the ecology of waterfowl and waterbirds in relation to pollutants, as well as a review of relevant study systems (where bodies of literature and research have been produced). These are all summarized herein.

All of the research findings, articles, and communications collected during the research period were reviewed and have been summarized into this summary document. Information has been organized according to major topic areas for ease of reading, with a bibliography, keyword index, and summary of key research sources and contacts attached as Appendices 1 through 4.

3. Overview of Research Findings

3.1 General Usage of Industrial Sites by Waterfowl

Overall, ELR found there to be a moderate body of literature and research related to the interactions of waterfowl, water birds, or wildlife with mine facility waters (pits and tailings ponds of similar characteristics to the FMC). However, much of this literature is not directly related through water quality, but rather focuses on feeding and feeding-related pathways of intake (through sediments or contaminated food sources). It is acknowledged in the literature however that wildlife in general do visit various types of mine infrastructure to rest, to find cover, and to forage for food (Smith et al. 2008, Hudson and Bouwman 2008). Birds tend to be the most documented users of mine facility waters, as usage by mammals tends to be restricted by terrestrial gates and fences (Smith et al. 2008).

Numerous waterfowl species are known to migrate at night and have been documented to land on unsuitable or shiny surfaces such as iron roofs, wet road surfaces or ponds with unsuitable water conditions. When hungry, thirsty or exhausted, waterfowl failing to find suitable habitat and interacting with unsuitable conditions may be killed (Read 1999). Larger water bodies are also generally observed to attract waterfowl at greater rates than do smaller water bodies (Smith et al. 2008).

Birds are indeed the most documented fauna using tailings systems, and it is also unclear whether birds are able to differentiate between water collecting from precipitation and tailings ponds (Smith et al. 2008). Season (in relation to migration), as well as food availability (such as insect hatches), are likely to influence visitation rates and diversity of fauna, and hence the interaction level with contaminated waters.

4. Case Study Systems

The following section summarizes several systems where birds were documented interacting with tailings storage facilities, industrial sites, or pollutants. Conditions, locations and contaminants in question in these specific studies vary from that at the FMC, but are well known and studied cases. These may help to understand the general ecology of tailings storage facilities.

4.1 Eastern Goldfields, Australia

Waterfowl, wading birds and passerines have been observed inhabiting and interacting with mine waste solutions in the Eastern Goldfields in Western Australia. Tailings slurry at that location had 55% solids, pH of 9, was hyper saline (as a result of the use of groundwater), and had elevated levels of some metals such as iron, mercury, zinc, copper, arsenic and reagents such as cyanide . No absolute water quality values were provided in this study. Despite that fact that these tailings ponds are essentially abiotic, water and wet mud at the site have been found to attract avian species. Airborne macro-invertebrates trapped in the solution are targeted as food source and as a result, birds picking insects from the surface expose themselves to contaminants (Smith et al. 2008).

After measuring avian abundance within the tailings storage facility, Smith et al. (2008) found that the guild containing wading birds (e.g. Red-capped Plover (*Charadrius ruficapillus*), non-migratory) comprised 91.7% of the records and only two pairs on ducks were observed resting on the pond. Six species successfully foraged food from the tailings area, although none were observed drinking. Feeding actions primarily consisted in pecking at the surface, sometimes probing and putting their bill into the water, but those attempts seemed unsuccessful. One bird was observed putting its head in the hyper saline tailings water and appeared to be washing itself afterwards. The authors believed that the hyper saline nature of the solution prevented fauna from drinking the waste water.

Read (1999) suggested that the poisoning of waterfowl in Australia as a result of the use of toxic dams from mineral extraction is common, although limited published information is available. In Australia, an average of 1000 birds die in a typical year as a result of gold mining tailings dams, in addition to irregular but occasional incidents likely caused by cyanide (Read 1999).

4.2 Anacostia River, USA

Waterfowl interactions with sediment were studied in the Anacostia River, USA, which is a highly polluted watercourse tributary to Chesapeake Bay (resulting from urban pollution). In a controlled experiment, contaminated sediments from the Anacostia River were fed to a mute swan for 6 weeks, leading to an increase within their bodies of aluminum, iron, lead, and to a lesser extent cadmium, copper and zinc. Because of the lack of accumulation of metals observed in the liver, and a lack of other indicators during necropsies and through haematological indicators and body weights, the authors concluded that the treated swans remained basically healthy and that the elements were not readily bioavailable. However, effects on the immune or reproductive system were not measured (Beyer et al. 2000).

4.3 Tri-State Mining District, USA (Oklahoma, Kansas and Missouri)

The Tri-State Mining District was once the greatest lead-zinc ore producer (Beyer et al. 2004) in the world. Water and sediment are contaminated (lead, cadmium, zinc; water concentrations were not provided in the study) from mining, milling and smelting, and deaths from lead and zinc poisoning were reported for the first time in the 1930's. Five waterfowl suffering from severe zinc poisoning (pancreatitis) were also more recently discovered (Beyer et al. 2004; Sileo et al. 2004).

The landscape of this mining district is characterized with sink holes and mining refuse contaminated with lead, zinc and cadmium, resulting in hazards to birds and wildlife in the area. In February 2001, the tissue of four waterfowl were assessed, from which high levels of lead and zinc were found in addition to reduced motor function and low body fat. These birds are thought be the first free ranging wild birds to be affected by zinc toxicosis (Sileo et al. 2004). Tissue concentrations of zinc in these birds were found to be many times the level commonly found during laboratory toxicity studies, and it was suggested that the source of zinc was through the ingestion of contaminated river sediments (previous samples taken in 1987 contained an average of 23 000 mg/kg of zink and 1 600 mg/kg of lead).

4.4 Mponeng, South Africa

Birds associated with a tailings storage facility (TSF) containing cyanide (< 50 mg /l, weak-acid-dissociable form) in Mponeng were inventoried, and extensive searches were performed for casualties (Hudson and Bouwman 2008). Out of 25 birds species detected in the tailings vicinity, five were using the tailings ponds. Wading birds were observed feeding on macro invertebrates at the surface and on shore, while others actively avoided the water (suggesting avoidance behavior). Waterfowl observation never occurred on the tailings pond. They were only observed at the returned water dam, where sediment has settled out and from where water is recycled. Only two brown-throated martin were observed drinking in flight on the tailings on one occasion. The authors indicate that the habitat at the TSF is not suitable because of the lack of nesting sites and the (presumed) absence of food web.

Granivorous species, which are known to require daily water supply, did not use the tailings storage facility for drinking. These species in fact almost exclusively restricted their activity to areas close to cleaner water. The authors attribute this restriction to the absence of nesting habitat and the potential avoidance of contaminated water. The distinct differences in bird distribution suggest either strong visual cues or learned avoidance behavior, or both.

No casualties were observed during carcass searches, however the authors also mention the presence of scavengers and tall grassland, which may diminish the potential of locating bird carcasses. The study was also undertaken during the winter season. They add that wildlife interaction patterns may potentially vary in relation to the chemical content in weak-acid-dissociables (WAD), as well as in relation to seasons such as spring (migration), summer (nesting) or at night (Hudson and Bouwman 2008).

5. The Effects of Low pH on Waterfowl and Water Birds

The potential effects of low pH on waterfowl were examined from two potential routes, external effects and internal effects.

5.1 External Effects

No information concerning the potential topical effects of moderately acidified water (pH 2-5) on the external on the body was found. Of 31 professionals that were contacted regarding the potential effects, four animal health professionals (CCWH and Veterinary Medicine Colleges) and five wildlife health professionals responded to inquiries on the subject, and none were unable to reference literature or communicate direct research information on the topic. It was the professional opinion of several of these interviewees that water of pH 2 was considered to be dangerously low for most animals, including birds. No published information regarding burns, de-oiling, or other potential external effects were found.

5.2 Internal and Secondary Effects

Literature was also investigated regarding the effects of low pH water in the case of ingestion (internal effects or secondary effects). No published information was found regarding consequences that acidic water ingestion may pose, however Thomas and McGill (2008) state the pH of the gizzard to be 2, similar to valued in question for this study. It is also unclear in the literature as to whether birds are able to differentiate between water collecting from precipitation and potentially contaminated surface waters (Smith et al. 1999).

While the direct literature concerning the direct effects of ingesting water with pH of 2 to 5 on waterfowl is very scarce, secondary potential effects on waterfowl are more abundant within the literature. It is well demonstrated that acidity has an impact on aquatic food webs by reducing the availability of invertebrates (Scheuhammer 1987, 1991, Alvo et al. 1998, McNicol and Wayland 1992). For example, the failure of a holding facility and spill of acidic mine tailings in Spain (April 1998) flooded the Agrio River and land surrounding it, consequently preventing birds from feeding until June 15th of that year, once the acidity had reduced considerably and invertebrate fauna recovered (Gomez et al. 2004).

While food webs can be affected, there are some species tolerant to acidified environments (below pH 5.5), including odonates and various nectonic insects on which duck species have to rely, which indicates a change in feeding behaviour (Scheuhammer 1991). While not directly within the scope of the current review, the literature suggests that very low pH tailings water (< pH 1.5) prevents the establishment of aquatic fauna and flora, and also prevents waterfowl from using these areas to feed or drink (Read 1999). In a similar context, Read and Pickering (1999) attribute the scarcity of birds on an island of the radioactive and acidic tailings of Olympic Dam, Australia to the lack of habitat or drinking water (pH between 0.7 and 1). At this location, only 3 species were observed out of over 160 that occur in the region.

Although the generally documented effect of acidification on aquatic environments is a reduction in species richness, McNicol and Wayland (1992) suggest that the effect of decreasing pH on waterfowl will vary with the severity of acidification. It was the opinion of researchers contacted as part of this study that acidic conditions such as those at the FMC would not prevent the establishment of benthos and a basic food web within aquatic systems, thereby providing potential pathways for metals to be ingested (described in following sections). Various invertebrates are tolerant to and can accumulate metals, thereby posing a risk to wildlife.

6. The Effects of Metals in Relation to Waterfowl and Water Birds

6.1 Potential External and Internal Pathways of Absorption

Very limited information exists on the potential external effects that metals found to be elevated at the FMC could have on waterfowl. Within the literature, the only information found that stated the potential for absorption of metals through the skin were of methyl mercury and cyanide (The Bird Observer 1996). The remainder of the data that was found on the topic of metals was related to the intake and accumulation of those metals through ingestion (indirectly or directly through feeding, and primarily from sediments). Accordingly, the majority of information in this review relates to these pathways of ingestion as outlined in the following sections.

6.2 Factors Affecting Metal-Related Effects

In addition, several studies have demonstrated specific interactions between metals within waterfowl metabolism (Kalisinska et al. 2004). Excesses or deficiencies of essential metals combined with the presence of toxic metals beyond tolerance limits has proven to affect bird's survival rate, behaviour, morphology and reproductive success (Kalisinska et al. 2004). Effects can also be a function of bird species, age and sex (Kalisinska et al. 2004). It is also believed that some bird species may have physiological protection mechanisms that help to reduce or reverse the effect of heavy metal contamination (Norheim 1987).

Gomez et al. (2004) found that the species and trophic level had more influence on organ and tissue contamination than did age, sex, size and residence. It was also found that certain species groups such as geese, swans, coot and gallinules are more at risk, potentially because of their feeding habits and trophic position (Gomez et al. 2004, Beyer et al. 2004). In addition to feeding on large quantities of bulbs where heavy metals concentrate, they incidentally or voluntarily ingest sand and sediment for grinding action in the gizzard (Beyer et al. 1998, Gomez et al. 2004), which may result in death if concentrations are high enough (Beyer et al. 2000). Read (1999) suggests that species such as duck, grebes and coots using toxic water as a defensive refuge (diving) accounted for the majority of casualties.

These reports suggest that is it important to consider detailed information when considering effects. While age, sex, and size of birds at the FMC may not be as critical, knowing behaviors or absolute time of residency in ponds may be important in interpreting potential effects.

6.3 Essential Metals

Essential elements are those that are required for many metabolic pathways in the body, and that have also been found to provide protection from the toxic effects of other non-essential elements. Negative effects from essential elements have also been observed to be caused by their over-exposure as well as under-exposure (CCME 2007). However, other literature sources also suggest that it is not well established as to what element are essential or non-essential (Custer et al. 2009).

Some authors have stated that because of their essential nature, essential elements are more well regulated by the bird's body and do not appear to accumulate to harmful levels unless the exposure is extreme (Custer et al. 2009).

6.3.1 Copper (Cu)

Gomez et al. (2004) suggest that waterfowl may accumulate more copper than other bird species, without showing signs of toxicity (Norheim 1987). The highest observed accumulation of copper in several waterfowl species was observed in the liver (Gomez et al. 2004) and to a much lower rate in kidneys and muscles (Kalisinska et al. 2004).

A severe case of copper toxicity in a 3 week old Canada goose that had ingested water contaminated with copper sulphate was reported (Thomas and McGill 2008). The authors calculated the copper sulphate intake to have been 600 mg copper sulphate/kg body weight; however they only provided dietary values, and did not make comparisons to water or environmental concentrations. Thinning of caecal walls was also observed in a few feeding experiments where supplemental copper was added to diets (Thomas and McGill 2008). Copper toxicity symptoms in waterfowl may include reduced growth, body mass loss, reduction in egg laying rates, thinning in caecal walls and gizzard lining erosion. Additionally, in the small intestine, metabolic interaction between copper, iron, molybdenum and zinc would have potential influence on their bioavailability, toxicity and absorption (Thomas and McGill 2008).

Unlike some elements (whether essential or not) that are known to bioaccumulate, copper has been found to more closely match diet concentrations (Custer et al. 2009). However, some authors also conclude that the species differences in hepatic copper retention is a reflection of difference in excretion rate rather than dietary intake (Beyer et al. 1998).

At the FMC, copper is elevated within several of the area ponds and pits included in the scope of this study, however the existence or extent of potential dietary pathways has not been determined.

6.3.2 Iron (Fe)

In a study conducted on Mallards (Kalisinska et al. 2004), highest iron concentrations were found in liver tissue, followed by kidney, muscles, and more inconsistently in the brain. Kalisinska et al. (2006) reported iron and cadmium to be age-dependant on white-tailed Eagles from Poland. Immature eagles accumulated significantly less metals than did adults. On the other hand, Thomas and McGill (2008) referred to a study that has proven iron to be non-toxic to water birds when continuously present in the form of iron shots in the gizzard. No specific data regarding iron concentrations were found in the literature which may be comparable to conditions at the FMC.

6.3.3 Nickel (Ni)

Nickel contamination in birds has rarely been studied and its content in tissue is generally low (Kalisinska et al. 2004). In a study evaluating the Mallard as a heavy metal biomonitor, nickel was found below detection in some tissue samples. Highest content were found in muscles, and slightly lower levels were also found in liver and kidney, brain and bones (in lower levels).

One case of nickel accumulation was described in the Redknobbed Coot (*Fulica cristat*), where various non-ferrous metals are mined and processed (South Africa) and ambient heavy metals concentrations very high (Kalisinska et al. 2004).

6.3.4 Zinc (Zn)

In Mallards, zinc accumulates primarily in the liver (Gomez et al. 2004) and kidneys, but is also found in muscles, brain and bones (in immature individuals; Kalisinska et al. 2004). However, the measured concentration of zinc in tissue has proven to be an unreliable indicator of actual exposure in birds (Beyer et al. 2004). Pancreatitis has been identified as the best tool with which to diagnose zinc poisoning in pets or captive birds, subsequent to the ingestion of galvanized hardware or other items containing zinc (Beyer et al. 2004). The same authors believe that birds can effectively regulate zinc in their body from a wide range of exposure, even though zinc poisoning may occur.

In another study, a trumpeter swan was observed for four weeks on a millpond in Picher (OK), in February and March of 2003. The bird was taken for treatment where it died after one day and was later diagnosed with zinc toxicosis based on pancreatic lesions and increased tissue concentrations (Beyer et al. 2004). Zinc poisoning was also observed at the Tri-State Mining District in the United States (Case study section). Waterfowl were the primary bird group observed to have increased levels of zinc in liver and kidneys (Beyer et al. 2004).

Aquatic vascular plants are also known to uptake high zinc concentrations and represent an additional route of exposure through the sequestration of zinc into iron plaque deposits on the root system (Beyer et al. 2004).

Generally, no discrete concentrations of zinc were provided in the above studies, only the suggestion that the uptake was through contaminated sediments. Sileo et al. (2004) suggest that zinc exerts its toxicity partially by interfering with copper metabolism, as numerous birds suffering from zinc toxicity have been found to have abnormal hepatic copper levels (both increased and decreased). The applicability to the FMC cannot be determined directly, as sediment concentrations of zinc at the FMC water bodies are not known, nor are the potential pathways for ingestion. Concentrations of zinc in water are known to exceed CCME levels in the Vangorda Pit, Little Creek Dam Pond, and the Intermediate Pond.

6.4 Non-Essential Metals

It is often non-essential elements that are known to be toxic in birds (Custer et al. 2009). Cadmium, lead and mercury are confirmed to be harmful to birds when elevated beyond safe levels for ingestion through food or non-food sources (Custer et al. 2009, Kalisinska et al. 2006).

6.4.1 Aluminum (Al)

The degree of exposure to aluminum is difficult to assess but is primarily related to the disruption of absorption and metabolism of calcium, phosphorus and Vitamin D, which may result in impaired growth and bone abnormalities (Scheuhammer 1987, 1991). Elevated levels of aluminum, when ingested, are primarily excreted in urine (Scheuhammer 1987) without affecting kidney function. Moreover, the absorption in the gastrointestinal tract of all forms of dietary aluminum has been found to be low (Scheuhammer 1991). As a consequence, using elevated concentrations of aluminum in the tissue of organs typically used as biochemical indicators are not useful in this case. Only bone tissue accurately reflects dietary intake of aluminum (Scheuhammer 1987).

Some studies in Sweden reported serious eggshell defects, reduced clutch sizes and mortality in insectivorous passerine species nesting along the shore of an acid-stressed lake (Nyholm and Myhrberg 1977 and Nyholm 1981 *as cited in* Scheuhammer 1991). However, it is suggested that scarce availability of essential calcium in acidified environments may be a more direct explanation. Scheuhammer (1991) found that aluminum levels found in kidney were a function of species rather than water chemistry variables.

Drover et al. (1999) support that aluminum concentrations are inversely correlated to pH and have adverse effects on various organisms, such as amphibians. Aluminum is known to rapidly become more soluble with decreasing pH, and this aluminum can have effects on aquatic life.

6.4.2 Arsenic (As)

Most studies documenting the adverse effects of chronic exposure to arsenic on wildlife are scattered and derived from laboratories, however the toxic potential of arsenic is well known (Moreau et al. 2007). Inorganic arsenic is the prevalent form found in sediment and water which is harmful or toxic when ingested. Over time, this inorganic arsenic is transformed by phytoplankton in organoarsenic, which is less toxic. The compound is metabolized through the food chain to arsenobetaine, the major organic species found in higher trophic levels of the food chain which is relatively non-toxic.

Arsenic levels are elevated in the waters of the Intermediate Pond and Little Creek Dam Pond at the FMC, however the literature reviewed suggests that a pathway of ingestion directly or indirectly through sediments is required if effects are to occur. It is not known whether these pathways exist at the FMC.

Arsenic is known to biomagnify, however it was not found in upper trophic level organisms of the Salton Sea (California) during an effort to determine whether fish-eating birds and humans were at risk from arsenic exposure in Tilapia (Moreau et al 2007). In birds, arsenic primarily concentrates in muscle and liver tissue (Gomez et al. 2004).

6.4.3 Cadmium (Cd)

Cadmium occurring in the environment is generally found to originate from anthropogenic sources, and is considered to be a very toxic trace element (Kalisinska et al. 2004). Cadmium is believed to be dose-dependent, and at high levels is accumulated in vertebrate tissue, most likely through diet (Scheuhammer 1987, 1991). Additionally, the distribution of cadmium in tissue has been found to be related to the uptake of other elements (Norheim 1987). For example, diets depleted in calcium, zinc or iron may also facilitate intake of cadmium in the intestine (Scheuhammer 1991).

Cadmium primarily concentrates in kidneys and to a lesser extent in the brain and bones (Scheuhammer 1987, Kalisinska et al. 2004). After analyzing 14 species of waterfowl contaminated following a mine tailing spill incident, Gomez et al. (2004) and Custer et al. (2009) both found that cadmium accumulated mostly in the kidneys (no water concentrations or sediment concentrations were provided). Scheuhammer (1991) also considers the kidney to be the critical organ for chronic toxicity, and adds that even low levels are able to be harmful if exposure is prolonged (Kalisinska et. al. 2006). In the case of excess dietary cadmium, because of the slow excretion of incorporated cadmium from the body, the element has the tendency to accumulate with age (Norheim 1987). Therefore, long-lived species are more at risk for low and chronic exposure to cadmium (Scheuhammer, 1991). Adult individuals tend to accumulate more cadmium in liver and brain than do immature. (Kalisinska et al. 2004).

Kalisinska et al. (2006) found that high cadmium intake by water or food accumulated in kidney and created damage to the tubules, resulting in calcium metabolism disorders and liver function impairment. Moreover, chronic exposure to cadmium is known to reduce reproductive success in birds and to accumulate in testicles. It also increases the bird's susceptibility to disease and other types of stress (Kalisinska et al. 2004).

Concentrations of cadmium in water at the FMC were documented to be as high as approximately 1,000 times the CCME standards for protection of aquatic life in the Vangorda Pit, Little Creek Dam Pond, and Intermediate Pond. However, literature based documentation of effects of cadmium relate primarily to ingestion through the food web and directly through sediments only, and sediment concentrations or potential pathways for ingestion are not known for the FMC.

6.4.4 Lead (Pb)

Lead poisoning in waterfowl has been extensively studied, and most literature stems from the link between waterfowl ingestion of spent lead shot from hunting or sinkers (Gomez et al. 2004, Beyer et al. 2004, Guitart et al. 2010). Ingestion of contaminated sediments is considered to be the second most important route of exposure to waterfowl (Beyer et al 2004). Lead is not biomagnified in the food chain, and therefore effects are primarily linked to chronic exposure (Beyer et al. 1998).

Critical levels for lead toxicosis vary within literature (Kalisinska et al. 2004). There is some evidence that birds would tolerate higher levels of lead in blood than mammals or humans before developing signs of poisoning (Scheuhammer 1987).

Lead is associated with impaired biological function, as well as external signs of poisoning (Gomez et al. 2004). The element is considered a serious neurotoxin and may alter bird's behaviour and compromise survival, as well as reproductive success. Based on Scheuhammer (1991), major effects are haematological, neurological and renal. Signs of lead toxicity in adult birds (and mammals) include lethargy, loss of appetite, green watery feces, weakness, emaciation, impaired body movement, impaired coordination, tremors, blindness (Scheuhammer et al. 1991) and death, if exposure is long enough (Custer et al. 2009). Reproductive impairments occur at lower levels of exposure in comparison to other effects (Scheuhammer et al. 1991).

Gomez et al. (2004) found that lead accumulation primarily occurred in the kidneys, and consequently that concentrations in the kidneys and liver would best reflect recent exposure. In contrast, lead contained in bones requires a longer period to accumulate (Kalisinska et al. 2004, 2006) and is then considered to be non-mobilisable (Scheuhammer, 1987, 1991).

Absorption of lead is considerably higher in immature individuals, and is more critical to altricial birds than juvenile precocial birds (Scheuhammer 1987, 1991). Moreover, absorption and retention of dietary lead can be dramatically affected by nutritional factors such as a deficiency of calcium or protein.

In a personal communication, Sheuhammer stated the opinion that lead from feeding in sediments contaminated with lead is the most relevant concern for potential toxicity on waterfowl. While the level of lead in FMC pond sediments is not known, lead concentrations in the water of the Vangorda Pit, Little Creek Pond Dam, and Intermediate Pond do exceed CCME guideline levels for the protection of aquatic life (CCME 2007).

6.4.5 Thallium (Tl)

Thallium is toxic to both humans and wildlife, although very little information is available regarding the effects of thallium on wildlife. In a study by Mochizuki et al. (1995), the death of birds of prey and magpies observed near a zinc mine was thought to have occurred as a result of acute thallium poisoning. Most thallium poisoning cases that involve wildlife are generated through the ingestion of rodenticides (which contain thallium).

6.4.6 Uranium (U)

The radioactive heavy metal uranium does not appear to be absorbed in avian tissue although it is detected in insect (prey) samples. This element is either not absorbed or is metabolized once it enters the digestive tract (Custer et al. 2009).

7. Inter-Metal Interactions

Several studies have demonstrated specific interactions or synergy between different metals in waterfowl metabolism (Kalisinska et al. 2004) such as cadmium and lead and lead and iron in the liver (Kalisinska et al. 2006). Toxicity of cadmium is also enhanced by deficiency in calcium, zinc and iron (Scheuhammer 1987). Several studies have found selenium and zinc to help reduce the toxic effects of mercury and cadmium (Norheim 1987). Zinc and copper are also known to protect against cadmium toxicity.

High concentrations of zinc have been found to interfere with cadmium absorption and potentially provide protection to some food chains exposed to cadmium toxicity (Beyer et al. 2004).

8. Interactions between Metals and pH

Environmental mobilization of toxic metals in response to acidification has been demonstrated (Alvo et al. 1998), although their availability to birds and subsequent accumulation is unlikely to be a threat of acute toxicity (Scheuhammer 1991). However, the same author also states that studies that have looked at regional differences between acidified and buffered lake have found higher metal accumulation in wildlife in acidified environments (Scheuhammer 1991).

Studies in Sweden reported serious eggshell defects, reduced clutch sizes and mortality in insectivorous passerine species nesting along the shore of an acid-stressed lake (Nyholm and Myhrberg 1977, Nyholm 1981 *as cited in* Scheuhammer 1991). However, it was suggested that scarce availability of essential calcium in acidified environments may be a more direct explanation. This concept is also put forth by Scheuhammer (1991), who stated that the capacity of insectivorous and omnivorous birds to find food sources rich in calcium is compromised in acidified environments.

As earlier noted, aluminum solubility is stated to increase with decreasing pH, suggesting that the potential update and effects through the food chain could also be increased in some situations.

9. Summary

This document represents and summarizes the most applicable findings of ELR's research into the potential effects of water with low pH and containing elevated metals concentrations at the FMC, Yukon. No published information on the external or internal (ingestion-related) effects that water with pH 2-5 may have on waterfowl was found. However, it was the general opinion of the experts consulted that a pH of 2 is considered dangerously low for birds and wildlife.

Published literature, reports, as well as requests for information to animal experts could not help to conclude whether the external exposure to metals in high concentration in the tailings or pit water may threaten waterfowl. While cyanide and methyl mercury are known to be absorbed through the skin, the presence of those compounds is not known for the FMC. It is also established that low pH increases metal availability for uptake by wildlife. Some metals such as aluminum become rapidly soluble with the decrease of pH, causing concentrations to rise.

Based on the literature findings and the data reviewed, it appears that the primary potential pathway of effects would be through metal ingestion, however determining the occurrence and degree of exposure is essential to assessing those effects. Incidental observations during the nesting period (June through August) may suggest nesting activities somewhere in the vicinity of the FMC in addition to use during migration periods. Additionally, the literature suggests a lack of conclusion as to whether birds can discriminate low water quality from more suitable environments.

The potential for ingestion of metals through the food web or through sediments is a potential path of contamination that should be investigated in the case of further study in this system. Based on the literature, lead, cadmium, arsenic and potentially zinc and aluminum are elements often encountered to be problematic pollutants in birds or wildlife. Those elements are also found in high levels in waters of the tailings ponds and pits of the FMC. In addition, it was the opinion of several professionals consulted that despite the poor water quality at the FMC, a simple food web may be established within certain ponds. They suggested that this may be possible as some invertebrates and plants are tolerant to both low pH and metal pollution.

An important outcome of this study is that effects could potentially occur through the ingestion of metals, however that more detailed information regarding exposure pathways is required. Our knowledge of these potential pathways at the FMC is limited at this point with respect to:

- The species of waterfowl that use the site (some are at greater risk than others).
- The discrete duration of use (exposure and likelihood of feeding attempts can increase with time).
- Behaviour of those waterfowl that do use the site (whether resting or active).
- Feeding types (filter feeders, insectivorous, or herbivorous).
- Bird's status (migratory or resident).
- The presence of food items, and the metal content of those items (if food web is present).
- Metal concentrations in sediment.

Without more information regarding these factors, it is difficult make accurate assessments regarding the potential impacts of usage of the FMC pits and ponds on waterfowl.

Appendix 1 – Summary of FMC Water Quality Data

Pond	Type	Al	As	Cd	Cu	Fe	Ni	Pb	Tl	U	Zn
Intermediate Pond (X4)	Min	6.00	0.20	0.86	0.50	40500.00	50.20	1.88	0.11	0.59	7770.00
	Avg	459.09	2.34	12.936	93.18	68708.33	100.38	999.52	1.59	1.82	32780.83
	Max	847.00	8.50	21.00	191.00	107000.00	157.00	2740.00	3.69	2.68	60900.00
	CCME	5	5	0.114-0.262	13.77	300	274 – 591	19.71 – 68	0.8	33	30
Cross Valley Pond (X5)	Min	1.50	<0.1	0.1	0.31	82.00	11.90	0.14	0.17	0.98	170.00
	Avg	6.46	0.29	0.16	0.64	330.96	31.16	1.75	0.414	2.83	280.26
	Max	28.00	0.90	0.22	1.20	669.00	83.90	13.10	0.69	7.2	411.00
	CCME	5	5	0.253	17.66	300	467 – 748	44.9 – 105	0.8	33	30
Cross Valley Pond (X5P)	Min	<1.0	0.18	0.06	0.40	107.00	3.24	0.40	0.17	1.06	62.80
	Avg	9.69	0.34	0.17	0.80	458.58	28.47	2.06	0.38	3.76	303.82
	Max	31.80	0.50	0.29	1.10	787.00	52.90	4.59	0.73	7.63	453.00
	CCME	5	5	0.259	18.25	300	304 – 733	22 – 88	0.8	33	30
Little Creek Dam Pond (LCD)	Min	3100.00	1.30	156.00	51.40	26100.00	480.00	37.3	0.25	8.10	203000.00
	Avg	13716.67	6.47	570.00	253.23	94266.67	1863.33	409.38	1.26	40.96	853000.00
	Max	18600.00	10.60	791.00	326.00	142000.00	2460.00	545.00	2.01	56.90	1160000.00
	CCME	5	5	0.244 – 0.722	54.02	300	558 - 2360	59 - 684	0.8	33	30
Vangorda Pit (V22)	Min	471.00	0.70	88.90	195.00	23400.00	426.00	37.8	1.60	2.450	111000.00
	Avg	1449.50	2.78	120.48	509.25	54700.00	515.00	196.37	1.93	4.28	157500.00
	Max	3220.00	3.70	151.00	1120.00	98400.00	584.00	345.00	2.19	6.90	181000.00
	CCME	5	5	0.208	17.64	300	486 - 570	52	0.8	33	30

Notes:
- CCME standards provided are approximate guidelines for the protection of aquatic life, provided for water (2007). Many standards vary according to characteristics such as pH and water hardness.
- Water quality data is only provided here for those elements where exceedances were noted in a review of available data.
- All measurements and standards are provided in µg/L.

Appendix 2 – Summary of Personal Communications

Professional	Organisation	Position	Date Contacted	Method of Contact	Response Received Yes	No	Type and Subject Matter of Information Provided
Birgit Braune	Contaminant Monitoring and Surveys, National Wildlife Research Center (EC)	Research Scientist	20/02/11	Email, Phone	X		- Provided some references to articles and other researchers - General background information on contaminants (Hg) - Cited examples of mine related contamination
Glen A. Fox	University of Guelph, National Wildlife Research Center (EC)	Professor and Researcher	20/02/11	Email		X	
Tony Scheuhammer	National Wildlife Research Center (EC)	Research Scientist	20/02/11	Email		X	- No experience on mine related topics or low pH and metal - Opinion on what metal may be a problem in this case (lead) - Refers to Coeur d'Alene (Idaho)
Louise Champoux	Ecotoxicology and Wildlife Health Division (EC)	Ecotoxicologist	20/02/11	Email, Phone	X		- Believes there may a hazard but difficult to establish since very little initial information - Benthic fauna potentially established - Recommended verifying programs (Federal) and other researchers
Yves Couillard	Science & Technology (EC)	Senior Evaluator	20/02/11	Email		X	
Jean-Luc DesGranges	Science & Technology (EC)	Research Scientist	20/02/11	Email	X		- Referred Louise Champoux
Doug Forsyth	Ecotoxicology and Wildlife Health Division (EC)	Research Scientist	20/02/11	Email	X		- Recommended additional researchers - Provided related literature
Philip Spear	UQAM- Research Center on Environmental Toxicology (TOXEN)	Researcher and Teacher	20/02/11	Email		X	
Guy Fitzgerald	Faculty of Veterinary Medicine in Saint-Hyacinthe (Quebec)	Professor, Veterinary	20/02/11	Email	X		- Unable to provide information on the topic
Monique Boily	UQAM- Research Center on Environmental Toxicology (TOXEN)	Associate Professor and Researcher	20/02/11	Email	X		- Provided 5 additional contacts she thought could help
Catherine Jumarie	UQAM- Research Center on Environmental Toxicology (TOXEN)	Professor and Researcher	20/02/11	Email	X		- Responded positively at first and asked for more details, but then never returned further communications
Christy Morrissey	University of Saskatchewan	Assistant Professor Biology	20/02/11	Email	X		- Provided her professional opinion on the situation o Some metals are indeed very high o Birds likely at risk, swans at greater risk from sediment o May be food web despite water quality - Literature and researchers recommended
Ted Leighton	CCWHC University of Saskatchewan	Executive Director (CCWHC), Professor at U of S Western College of Veterinary Medecine	20/02/11	Email	X		- Responded positively but could not answer the questions - Recommended other researchers
John Giesy	University of Saskatchewan	Professor & Canada Research Chair in Environmental Toxicology	20/02/11	Email		X	
Gary Wobeser	University of Saskatchewan, Western College of Veterinary Medicine; CCWHC	Professor Emeritus	03/03/11	Email	X		- Could not add any information on external exposure to acidic water - Did not know of such specific studies
Jim Hawkings	Canadian Wildlife Service	Biologist	21/02/11	Email	X		- Has never dealt with such circumstances
David Hoffman	USGS-Patuxent Wildlife Research Center	Research Physiologist	21/02/11	Email		X	
Barnet Rattner	USGS-Patuxent Wildlife Research Center	Ecotoxicologist	21/02/11	Email, Phone	X		- Never worked with low pH - Suggested and sent one of his article on Vanadium

Professional	Organisation	Position	Date Contacted	Method of Contact	Response Received		Type and Subject Matter of Information Provided
Lynn Miller	Wild Bird Conservation Center	Board of Director, PhD Candidate	21/02/11	Email		X	
Peter Campbell	INRS- Water Earth Environment	Professor and Researcher	21/02/11	Email		X	- Worked with the aquatic environment but never in connection with waterfowl - Recommended other researcher
Claude Fortin	INRS- Water Earth Environment	Professor and Researcher	21/20/11	Email		X	
Donald W. Sparling	Southern Illinois University Carbondale	Associate Professor	02/03/11	Email		X	
Valerie Shearn-Boschler	USGS, National Wildlife Health Center	Veterinary Research Pathologist	02/03/11	Email	X		- Sent one of her publications
Scott McBurney	UPEI Atlantic Veterinary College	Clinical Veterinary Professional-Wildlife Pathologist; Adjunct & Graduate Faculty Member	02/03/11	Email		X	
Maria Forzan	UPEI Atlantic Veterinary College; CCWHC	Wildlife Pathologist	02/03/11	Email		X	
Natacha Hogan	UPEI	Assistant Professor Biology	03/03/11	Email		X	
Mike Van den Heuvel	UPEI Biomedical Sciences	Associate Professor, Canada Research Chair in Watershed Ecological Integrity	03/03/11	Email		X	
Mary Vanderkop	Environment Yukon	Animal Veterinarian	02/03/11	Email	X		- No expertise in this field - Suggested contacting the CCWHC
Todd Powell	Environment Yukon	Manager, Biodiversity Programs	02/03/11	Email	X		- Suggested potential professionals
Karsten Liber	University of Saskatchewan	Executive Director and Professor, School of Environment and Sustainability	07/03/11	Email	X		- pH of 2 may present danger to wildlife and birds - Cannot confirm if metals infiltrates in body through skin (aside from methyl mercury)

Notes: EC – Environment Canada
TOXEN – National Institute of Scientific Research in Québec
CCWHC - Canadian Cooperative Wildlife Health Center
USGS – United States Geological Survey
INRS –National Institute of Scientific Research in Québec
UPEI – University of Prince Edward Island

Appendix 3 – Keyword Index

Keyword	Reference
Abandoned mine tailings	Custer et al. 2009
Aluminum	Drover et al. 1999; Scheuhammer 1987, 1991
Anacostia river	Beyer et al. 2000
Arsenic	Moreau et al. 2007; Gomez et al. 2004; Smith et al. 2008
Avian immunotoxicology	Fairbrother et al. 2004
Avoidance	Hudson and Bouwman 2008
Bioavailability	Beyer et al. 2000
Cadmium	Pillatzki et al. 2010; Kalisinska et al. 2004; Kalisinska et al. 2006; Norheim 1987; Beyer et al. 2004; Scheuhammer 1987, 1991
Coeur D'Alene	Nordwick and Lewis 2008; Hoffman et al. 2000
Chronic toxicity	Scheuhammer 1987
Copper	Pillatzki et al. 2010; Custer et al. 2008; Thomas and McGill 2008; Norheim 1987; Beyer et al. 1998; Kalisinska et al. 2004
Developmental toxicity	Hoffman et al. 2000
Gold mining tailings	Smith et al. 2008
Heavy Metal concentration	Nordwick and Lewis 2008;
Hepatic element concentration	Kalisinska et al. 2004
Ingestion pathway	Smith et al. 2008; Beyer et al. 1998
Insectivorous birds	Custer et al. 2009
Iron	Nordwick & Lewis 2008; Thomas and McGill 2008; Kalisinska et al. 2004
Lead	Fairbrother et al. 2004; Hoffman et al. 2000; Nordwick & Lewis 2008; Kalisinska et al. 2004 ; Kalisinska et al. 2006; Beyer et al. 1998; Beyer et al. 2004; Scheuhammer 1991; Guitart et al. 2010
Invertebrates	Smith et al. 2008; Hudson and Bouwman 2008; Scheuhammer 1987
Metal	Custer et al. 2009; Kalisinska et al. 2006; Beyer et al. 1998; Scheuhammer 1987, 1991
Metal interaction	Kalisinska et al. 2004, 2006; Thomas and McGill 2008; Norheim 1987; Beyer et al. 2004
Micro-invertebrates	Smith et al. 2008
Pancreatitis	Sileo et al. 2004; Beyer et al. 2004
pH	Drover et al. 1999; Nordwick and Lewis 2008; Read 1999; Scheuhammer 1991 ; Alvo et al. 1988; Read and Pickering 1999; Smith et al. 2008
Sediment	Nordwick and Lewis 2008; Hoffman et al. 2000; Beyer et al. 1998, 2000
Swans	Beyer et al. 2000, 2004

Keyword	Reference
Tailings pond	Read and Pickering 1999; Read 1999; Smith et al. 2008
Thallium	Mochizuki et al. 2005
Tri-State Mining District	Beyer et al. 2004; Sileo et al. 2004
Uranium	Custer et al. 2008
Waterfowl	Scheuhammer , 1987, 1991; Read 1999; Norheim 1987; Kalisinska et al. 2004; Smith et al. 2008; Beyer et al. 1998; Beyer et al. 2000
Zinc	Fairbrother et al. 2004; Beyer et al. 2004; Kalisinska et al. 2004; Scheuhammer 1991; Sileo et al. 2004

Appendix 4 – List of Primary Literature Sources Consulted

The following primary literature journals provided useful articles that were included in the desktop study. The overall literature search utilized major research databases, however, and was not restricted to these sources only.

- African Journal of Ecology
- Archive of Environmental Contamination and Toxicology
- Avian Pathology
- Colonial Waterbirds
- Canadian Journal of Zoology
- Canadian Journal of Fisheries and Aquatic Science
- Environmental Health Perspectives
- Environmental Monitoring Assessment
- Environmental Pollution
- Environmental Research
- Environmental Toxicology and Chemistry
- International Journal of Mining, Reclamation and Environment
- Journal of Applied Ecology
- Journal of Toxicology and Environmental Health
- Journal of Wildlife Diseases
- Mineral Council of Australia
- National library of Australia
- Polish Journal of Environmental Studies
- Science of the Total Environment
- The Condor

Appendix 5 – Reference Bibliography

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