GEOSCIENCE AND MINES BRANCH

Review of the Environmental Impacts of Historic Gold Mine Tailings in Nova Scotia

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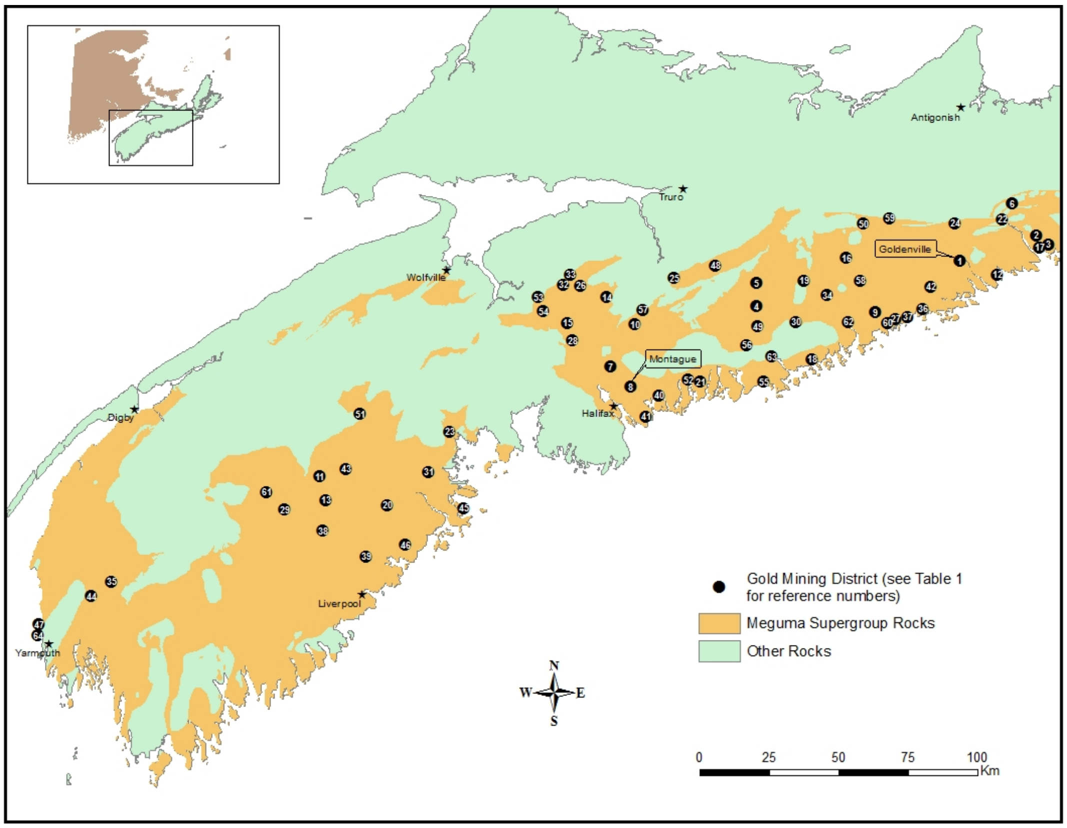

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Introduction

Historic gold mining in Nova Scotia produced over 3 million tonnes (t) of tailings (Parsons et al., 2012). During this period, no environmental regulations were in place and tailings were commonly discharged into streams, ponds, rivers, wetlands and surface depressions. This resulted in the formation of tailings flats that can measure up to 1 km^2 in surface area and several metres in thickness. In some cases, tailings have migrated downstream in rivers and streams for more than 2 km from the mine site.

The tailings contain high concentrations of arsenic and other metals. Arsenic has been measured at concentrations up to 312,000 mg/kg (Parsons et al., 2012), which is approximately 10,000 times the current Nova Scotia guideline for arsenic in soil (31 mg/kg; NSE, 2013). Other chemicals in the tailings that exceed environmental guidelines include mercury, nickel, lead and antimony. Recent land-use changes in the vicinity of historic mine sites, such as residential development, recreational development and shellfish harvesting, have raised concerns about the potential risks that the tailings pose to human health and the environment.

The first environmental investigation associated with historic gold mine tailings in Nova Scotia occurred in 1976, when a resident of Waverley suffered chronic arsenic intoxication after drinking water from a dug well with high arsenic levels. The arsenic concentration in this well was reported to be 5,000 µg/L (Grantham and Jones, 1977), which is 500 times higher than the current Canadian drinking water guideline of 10 µg/L (Health Canada, 2012). Subsequent investigations found that arsenic can occur in wells located inside or outside of historic gold districts, and can be caused by naturally occurring arsenic in bedrock and historic mining activities.

Since the discovery of arsenic in well water in 1976, there has been extensive environmental work completed on the historic gold mine tailings in Nova Scotia. The purpose of this report is to provide a summary of the environmental work that has been completed to date. The report begins with a brief history of gold mining in Nova Scotia and then discusses the environmental issues associated with the tailings. The standard approach to environmental site management involves a multi-step process that starts with site investigation, and follows with risk assessment and risk management. This report follows a similar format, by discussing the environmental work in terms of environmental investigations, followed by risk assessment and risk management activities.

History of Gold Mining in Nova Scotia

Gold mining began in Nova Scotia in the 1860s and there were three distinct gold rushes, which occurred from 1861-1874, 1896-1893 and 1932-1942 (Art Gallery of Nova Scotia, 2013). Prior to the 1860s, there had been several reports of gold occurrences in the province, but it was the news of gold rushes in California in 1849 and Australia in 1851 that prompted the first systematic gold exploration programs in Nova Scotia.

The first officially documented discovery of gold in Nova Scotia was in 1857, when it was found in sand on the shores of Halifax Harbour (Heatherington, 1868). Based on this discovery, a prospecting license was issued to explore for gold on Sable Island, but the work was never carried out. It was not until the discovery of gold-bearing quartz veins that Nova Scotia's first gold rush began. In 1858 gold-bearing quartz was found in Mooseland along the Tangier River, and in 1861 Mooseland became the first officially designated gold district in the province (Heatherington, 1868). Subsequent geological investigations in 1861 and 1862 identified gold-bearing metasedimentary rocks (i.e. Meguma Supergroup) that stretched along the Atlantic coast for over 400 km. In the years that followed, 64 gold mine districts were established on mainland Nova Scotia. Figure 1 shows the locations of the gold districts and Table 1 provides additional information about each district. Note that the exact number of historical gold mining districts reported in Nova Scotia varies in the literature, depending on how the term 'district' is defined and which areas of the province are included.

There have been no other periods of comparable gold production in Nova Scotia since the end of the third gold rush in the 1940s. Limited production has occurred, however, primarily in the 1950s and 1980s. Increased gold exploration and development is usually associated with spikes in the price of gold. For example, gold exploration and production occurred in Nova Scotia in the early 1980s when the price hit $600 US (i.e. $1800 in 2015 dollars). More recently, rising gold prices ($1700 US in 2012) have renewed interest in gold, and the first gold bar to be produced in the province in over a decade was poured at the Dufferin gold mine in 2014.

Environmental Investigations

There have been numerous investigations into the environmental implications of historic gold mine tailings in Nova Scotia. The work has covered a broad range of issues, including: the nature and extent of the tailings; chemical composition and mineralogy of the tailings; fate and transport of the tailings in surface water, groundwater and air; effects on biota; and the bio-accessibility of arsenic. Investigations began in the 1970s and continue through to the present day (see Table 2). Parsons et al. (2012) published the most comprehensive environmental study of the tailings to date, and this review draws heavily from the information presented in the Parsons et al. (2012) report.

Mapping

The distribution of historic gold mine tailings has been partially mapped by several investigators using a combination of visual observations and chemical sampling. A series of historical gold mining area maps (64 map sheets), which includes the locations of tailings, has been published by DNR and is available on-line (Smith and Goodwin, 2009). These maps include detailed gold district mapping by E. R. Faribault of the Geological Survey of Canada in the late 1800s and early 1900s.

Tailings maps have also been prepared as part of resource evaluations associated with more recent proposals to recover residual gold from the tailings. The most extensive mapping effort of this type was completed for Seabright Resources Inc. in the 1980s, which evaluated tailings deposits in 28 historic gold mining districts (Jacques Whitford and Associates Ltd., 1984, 1985).

Detailed maps of the tailings in 14 gold mine districts are also published in Parsons et al. (2012). These maps are likely to represent the minimum extent of the tailings distribution because the investigations were restricted to Crown land and did not include sampling or mapping on private property.

Tailings Soil Chemistry

Table 3 presents a summary of the geochemistry of the tailings at 14 gold mining districts. The results show that the tailings can exceed soil quality guidelines for arsenic (As), mercury (Hg), nickel (Ni), lead

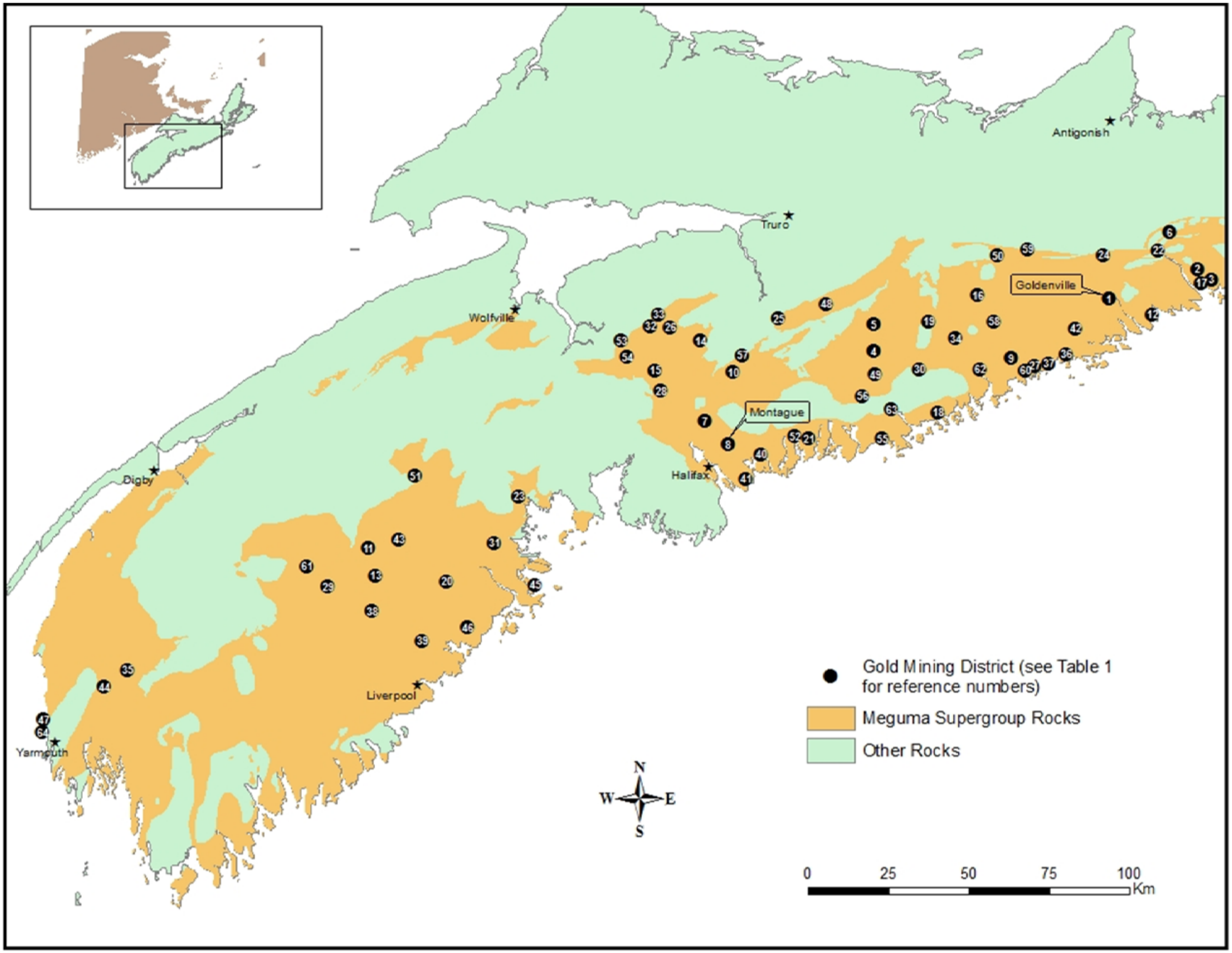

Figure 1. Map of historic gold districts in Nova Scotia.

Table 1. Data from historic gold districts in Nova Scotia (modified after Parsons et al., 2012). See Figure 1 for locations.

No.	Gold Mining District	Dates of Operation	Tailings Mass (tonnes)[a]	Gold Produced (ounces)	Avg. As Level in Tailings (mg/kg)	Max. As Level in Tailings (mg/kg)
1	Goldenville	1862-1941	540,617	210,153	19,181	209,000
2	Upper Seal Harbour	1893-1958	400,516	57,846	12,284	71,961
3	Lower Seal Harbour	1904-1949	394,905	34,295	20,525	312,300
4	Moose River	1888-1989[b]	195,720	28,551	-	-
5	Caribou	1869-1968	168,411	91,359	75,669	250,400
6	Forest Hill	1895-1989[b]	156,502	46,718	-	-
7	Waverley	1862-1940	152,496	73,105	-	-
8	Montague	1863-1940	121,816	68,139	13,651	41,299
9	Salmon River (Dufferin)	1881-2001	107,084	49,216	11,871	149,800
10	Oldham	1862-1946	107,080	85,295	-	-
11	Brookfield	1887-1936	96,756	43,041	2,211	36,776
12	Wine Harbour	1862-1939	75,581	42,727	17,690[d]	196,000[d]
13	Molega	1888-1950	63,926	34,876	-	-
14	Renfrew	1862-1958	60,389	51,986	-	-
15	Mount Uniacke	1867-1941	54,256	27,740	4,418	45,832
16	Fifteen Mile Stream	1878-1988[b]	51,052	19,741	-	-
17	Isaacs Harbour	1862-1958	48,566	39,654	-	-
18	Tangier	1862-1999	45,584	26,135	-	-
19	Beaver Dam	1889-1989[b]	44,345	2,908	-	-
20	Leipsigate	1884-1949	32,456	12,084	55[c]	189[c]
21	Lake Catcha	1882-1961	29,462	26,118	2,813	10,137
22	Country Harbour	1871-1951	26,301	9,960	-	-
23	Gold River	1889-1940	26,223	7,751	-	-
24	Cochrane Hill	1868-1990	24,166	2,081	9,395	178,200
25	Gays River	1870-1968	13,729	2,268	-	-
26	East Rawdon	1884-1932	13,415	13,494	2,111	10,858
27	Harrigan Cove	1874-1961	12,499	8,071	-	-
28	South Uniacke	1888-1948	11,070	20,762	-	-
29	Whiteburn	1887-1955	9,666	11,890	11,865	146,400
30	Mooseland	1861-1934	8,217	3,865	11,128	42,330
31	Blockhouse	1896-1938	5,634	3,588	-	-
32	Central Rawdon	1888-1939	4,840	6,745	-	-
33	West Gore	1905-1939	4,713	7,149	-	-
34	Killag	1889-1951	3,415	3,585	-	-
35	Kemptville	1885-1939	3,110	1,852	-	-
36	Ecum Secum	1893-1935	2,707	1,276	-	-
37	Moosehead	1899-1935	2,576	471	-	-
38	Fifteen Mile Brook	1902-1934	2,518	881	-	-
39	Mill Village	1901-1951	2,071	910	-	-
40	Lawrencetown	1862-1912	1,534	867	-	-
41	Cow Bay	1896-1937	1,326	1,243	-	-
42	Miller Lake	1902-1951	1,164	539	-	-
43	Pleasant River Barrens	1890-1913	464	112	-	-
44	Carleton	1879-1940	431	190	-	-

Table 1. Continued.

45	Ovens	1862-1958	320	544	-	-
46	Vogler's Cove	1905	181	43	-	-
47	Cranberry Head	1870-1900	175	119	-	-
48	Upper Stewiacke	1906-1907	164	44	-	-
49	Gold Lake	1890-1899	91	39	-	-
50	Little Liscomb Lake	1893-1935	86	52	-	-
51	Stanburn	1933-1936	78	13	-	-
52	Chezzetcook	1883-1944	73	11	-	-
53	McKay Settlement	1904-1910	68	14	-	-
54	Ardoise	1890-1904	58	6.8	-	-
55	Clam Harbour	1904	52	54	-	-
56	Lake Charlotte	1938-1964	42	78	-	-
57	Elmsdale	1890	9	1.4	-	-
58	Lochaber Mines	1883	4.5	2.3	-	-
59	Lower Caledonia	1934-1956	1.0	3.6	-	-
60	Quoddy	1906	0.9	1.0	-	-
61	West Caledonia	1925	0.9	1.7	-	-
62	Sheet Harbour	1898-1935	NA	431	-	-
63	Ship Harbour	1935-1937	NA	7.4	-	-
64	Chegoggin	1883	NA	NA	-	-

[a] Tailings mass assumed to be equal to the mass of ore crushed.
[b] Ore from 1980s mining was milled at Gays River, thus tailings associated with this period are located at the Gays River site.
[c] The relatively low As levels at Leipsigate are attributed to reprocessing of the tailings in a cyanide plant.
[d] Arsenic results from 14 tailings samples collected at Wine Harbour (Little et al., in press).

(Pb) and antimony (Sb). Arsenic is by far the most important chemical of concern in the tailings, with 97% of the samples from the 14 gold mining districts exceeding the soil quality guideline. The maximum and mean arsenic concentrations reported in Table 2 exceeded the soil quality guideline by a factor of approximately 10,000 and 400, respectively. Note that the guidelines shown in Table 3 are applicable to soil, but sediment quality guidelines are applicable where the tailings exist as sediment in surface water bodies. In some cases, such as for arsenic, the applicable sediment quality guideline is lower (5.9 mg/kg; CCME, 2001) than the soil quality guideline (31 mg/kg; NSE, 2013).

Groundwater and Water Wells

Groundwater

The migration of arsenic in groundwater, and subsequent discharge to streams, is one of the primary mechanisms for arsenic transport at tailings sites and, therefore, will be an important consideration in any future remediation plans. Although there have been investigations into arsenic in groundwater in Nova Scotia (Meranger et al., 1984; Bottomley, 1984), there has been relatively little investigation of groundwater in the immediate vicinity of the tailings. The main reports that have collected groundwater data directly within the footprints of the tailings include: two Phase II Environmental Site Assessments (ESA) at Montague (Maritime Testing Ltd., 2009) and Goldenville (C. J. MacLellan &

Table 2. Environmental events and investigations associated with historic gold mine tailings in Nova Scotia (modified after Parsons et al., 2012).

Date	Environmental Event/Investigation
1976	Waverley resident diagnosed with chronic As poising from well water. Provincial Arsenic Task Force appointed to study As in well water in Waverley area and in other historical gold districts (Grantham and Jones, 1977).
1977	Clinical study of As exposure in 92 Waverley residents (Hindmarsh *et al*., 1977). Grantham and Jones (1977) identify gold mine tailings and naturally occurring As in Meguma Supergroup as sources of As in well water. Environment Canada study of Hg at abandoned amalgamation sites.
1978	Mudroch and Sandilands (1978) document elevated As and Hg levels in Waverley area lake sediments. The Hg is attributed to both gold amalgamation and historical production of Hg fulminate explosives.
1982	Published studies of As in tailings, sediment, water, and biota at Montague Gold Mines (Brooks et al., 1982; Dale and Freedman, 1982). Formation of Federal-Provincial study group to investigate the impact of past gold mining activities on the Shubenacadie Headwater Lakes.
1984	Published studies of As in Nova Scotian groundwater (Meranger et al., 1984; Bottomley, 1984).
1985	Environment Canada / N.S. Dept. of the Environment report (Mudroch and Clair, 1985, 1986) demonstrates significant contamination of sediment, water, and fish with As and/or Hg in the Waverley and Montague areas.
1988	Investigation of As and Hg concentrations in tailings, waters, and plants at the Oldham Gold District (Lane et al., 1988, 1989).
1999	Wong et al. (1999) publish results from an Environment Canada study of the dispersion and toxicity of metals derived from mine tailings at Goldenville. Tetford (1999) reports high levels of Hg in white perch near the Caribou gold mine.
2002	Wong et al. (2002) publish results from an Environment Canada study of the Caribou Gold District, showing high metal levels in tailings and lake sediments, high gaseous Hg fluxes, and stream water and sediment toxic to benthic biota. Beauchamp et al. (2002) report high Hg fluxes in air over gold mine tailings at Caribou and Goldenville.
2007	Research initiated to assess the bioaccessibility of As in tailings in NS (Koch et al., 2007; Laird et al., 2007; Meunier et al., 2010, 2011).
2009	Phase II Environmental Site Assessments completed at Montague (Maritime Testing (1985) Ltd., 2009) and Goldenville (C. J. MacLellan & Associates Inc., 2009).
2010	Research initiated to investigate the performance of various tailings cover designs and how the tailings geochemistry and As leachability may be affected by covers (DeSisto et al., 2010, 2011; Kavalench and Jamieson, 2012; Hosney and Rowe, 2013)
2011	Ecological risk assessments completed for Montague, Upper Seal Harbour and Lower Seal Harbour (Saunders et al., 2011)
2012	Report on the geochemistry of tailings, sediments and surface waters at 14 gold mining districts in NS (Parsons et al., 2012).
2014	Research initiated to optimize waste by-products as mine soil amendments for re-vegetating gold mine tailings (Piorkowski, 2014).
2015	Little et al. (in press) publish results from a study on the marine impacts of historical gold mining activities at Wine Harbour. The study included testing of marine sediments, tailings and fresh surface water for As and Hg.

Table 3. Tailings chemistry results from 14 gold mining districts (modified after Parsons et al., 2012).

Chemical	Soil Guideline (mg/kg)*	Max. (mg/kg)	Mean (mg/kg)	No. of Samples	% of Samples Exceeding Soil Guideline
As	31	312,000	11,900	482	97%
Hg	6.6	350	6.8	482	20%
Cu	1,100	796	42	481	0%
Ni	330	746	29	482	10%
Pb	140	6,780	137	482	17%
Sb	7.5	1,840	25	482	28%
Zn	5,600	1,000	97	482	0%

* Nova Scotia Tier 1 Environmental Quality Guideline for Soil at a Non-Potable Residential/Parkland Site (NSE, 2013).

Associates Inc., 2009); and a Ph.D. thesis that looked at the hydro-geochemical influences on arsenic mobility for remedial design purposes (DeSisto, 2014).

The ESAs completed at the Montague and Goldenville sites involved the installation of three shallow monitoring wells (i.e. < 6 m deep) at each site. The maximum arsenic concentrations measured at the wells were reported to be 3100 µg/L and 450 µg/L for Montague and Goldenville, respectively. Note that there are no Nova Scotia guidelines for arsenic in non-potable groundwater; however, for comparison purposes the provincial guideline for potable groundwater is 10 µg/L (NSE, 2013) and the freshwater aquatic guideline is 5 µg/L (CCME, 1997).

The investigation completed by DeSisto (2014) looked at groundwater conditions at Montague and Goldenville using piezometers, seepage meters, hydraulic conductivity measurements (slug tests), and pore water chemistry analyses. The investigation found high concentrations of dissolved arsenic in the tailing's pore water. A total of 29 pore water samples were collected and the maximum and median arsenic concentrations in the saturated zone were reported to be 45 000 µg/L and 620 µg/L, respectively (DeSisto, 2014).

Water Wells

There have been several investigations into arsenic levels in well water in Nova Scotia. The Nova Scotia Arsenic Task Force initiated the first large sampling program in 1976 after a case of chronic arsenic intoxication was linked to arsenic in well water (Province of Nova Scotia, 1976; Grantham and Jones, 1977). The water in this well contained 5000 µg/L arsenic, which is 500 times the current drinking water guideline of 10 µg/L and remains the highest reported arsenic level in provincial well water to date.

A subsequent study of 642 wells in gold districts throughout Nova Scotia revealed that 13% exceeded the 1976 drinking water guideline (50 µg/L) for arsenic (Grantham and Jones, 1977). Several dug wells and some drilled wells with high arsenic were found to be receiving groundwater from tailings areas and waste rock deposits. The investigators concluded that there was a higher incidence of arsenic contamination in dug wells located close to, or down-gradient of, tailings and waste rock deposits (Province of Nova Scotia, 1976). They also concluded that high arsenic levels in well water could occur outside of gold mining districts, due to naturally occurring arsenic levels in bedrock that is not related to historical mining activities. Water wells were also tested for mercury and cyanide during these investigations. No significant concentrations of mercury were detected, and cyanide was not detected (Grantham and Jones, 1977).

Surface Water

Several studies have investigated surface water quality in the vicinity of tailings deposits in Nova Scotia (Mudroch and Sandilands, 1978; Brooks et al., 1982; Mudroch and Clair, 1985, 1986; Lane et al., 1988, 1989; Wong et al., 2002). In the most recent study, Parsons et al. (2012) collected 176 surface water samples (pore water samples excluded) from nine gold mining districts. The results indicated that dissolved arsenic levels were high, and accounted for more than 85% of the metalloid sum in tailings-impacted waters. The maximum concentration of the unfiltered samples was 9500 µg/L and the mean was 460 µg/L, compared to the fresh water aquatic guideline of 5 µg/L (CCME, 1997).

Air Quality

Air quality investigations have been carried out at several gold districts, including Caribou, Montague, Goldenville and Lower Seal Harbour. The studies have focused on arsenic levels in airborne dust and mercury vapour fluxes.

Corriveau et al. (2011) reported results for airborne dust samples collected in 2004 at Montague, Goldenville and Lower Seal Harbour. These sites are used for recreational activities, and off-road vehicle racing was taking place at two of the sites when the dust samples were collected. Samples were analyzed for arsenic and nine other chemicals across ten particle size ranges. The results indicated that the total arsenic concentrations ranged from 637 ng/m^3 to 11 260 ng/m^3. The results for Montague exceeded the Ontario Ambient Air Quality Guideline for arsenic of 3000 ng/m^3 (Corriveau et al., 2011).

Mercury concentrations in air above the tailings, and associated surface-to-air flux rates, have been investigated at the Caribou and Goldenville tailings sites (Beauchamp et al., 2002; Wong et al., 2002) and Seal Harbour (Dalziel and Tordon, 2013). The average mercury concentrations in air were reported to be 8.4 ng/m^3 and 3.5 ng/m^3 at Caribou and Goldenville, respectively. The mercury flux rates at these sites were two orders of magnitude higher than those observed over undisturbed soils of similar parent material. Mercury concentrations in air above the tailings were up to ten times higher than background levels (Beauchamp et al., 2002).

Ecological Receptors

Several studies have investigated the effects of the tailings on ecological receptors, including plants and aquatic organisms (Brooks et al., 1982), plants and fish (Dale and Freedman, 1982), plants (Lane et al., 1988), benthic communities (Wong et al., 2002), clams and seaweed (Koch et al., 2007), terrestrial invertebrates (Moriarty et al., 2009) and meadow voles (Saunders et al., 2010). The principal focus of these studies has been on arsenic, but other substances, such as mercury, have also been investigated. The studies found elevated levels of arsenic and mercury in ecological receptors in the tailings areas compared to background sites. In some cases, the studies concluded that the observed arsenic levels were toxic to ecological receptors.

A study of mercury in plants in the tailings areas of the Oldham Gold District (Lane et al., 1988) found mercury concentrations in plant leaves ranging from 0.18 mg/kg to 0.55 mg/kg, and in roots up to 6.1 mg/kg. The authors concluded that arsenic bio-accumulation was occurring in the plants.

Arsenic levels in clams and seaweed were measured in a tailings-impacted area in Seal Harbour (Koch et al., 2007). Arsenic concentrations in clams ranged from 218 mg/kg to 228 mg/kg, and in seaweed ranged from 27 mg/kg to 43 mg/kg. The authors concluded that the clams should not be consumed by humans.

A study of arsenic levels in meadow voles at Montague found that voles living near tailings had higher arsenic levels compared to those living at background sites. Sub-cellular effects were observed in the voles with higher arsenic exposures. The authors concluded that arsenic was being transported up the food chain at the Montague site.

Risk Assessment and Risk Management

Risk Assessment

An inter-departmental Historic Gold Mines Advisory Committee was established in 2005 to evaluate the potential ecological and human health risks associated with tailings and to develop risk management recommendations. The committee was chaired by NS Environment and included five provincial and five federal departments. To date, extensive work has been completed to characterize the nature and extent of the tailings, and this information is available to support risk assessments.

In addition to site characterization work, several studies have been carried out to determine the bio-accessibility of arsenic in the tailings (Koch et al., 2007; Laird et al., 2007; Meunier et al., 2010, 2011). Bio-accessibility information is important for risk calculations because not all arsenic present in the tailings is biologically available and, therefore, does not contribute to risk. Results indicate that the bio-accessibility of arsenic in the tailings ranges from 0.1% to 49%, with a mean of 13% (Meunier et al., 2010). These results are based on 29 samples collected from six different gold mining districts. Although the estimated bio-accessibility values are low, there is still potential for the tailings to pose a risk because of the very high arsenic concentrations present. Based on the mean arsenic level from Table 2 (11 900 mg/kg) and the mean bio-accessibility value referenced above (13%), the mean bio-accessible arsenic concentration would be approximately 1500 mg/kg. This value exceeds the Nova Scotia soil guideline (31 mg/kg) by a factor of 50.

Background metal levels in soil and water are an important consideration in risk assessment because metals can occur naturally at elevated levels in the environment (i.e. above NS soil guidelines). An understanding of natural background concentrations allows the risk associated with natural levels of metals to be distinguished from the risk associated with metals that have been concentrated by anthropogenic activity. Parsons et al. (2012) investigated background levels of arsenic and mercury in streambank sediment and water by collecting samples at 60 sites within a 20 km radius of the Upper and Lower Seal Habour gold districts. The background concentrations of arsenic in streambank sediment and water were reported to range from 2.5 to 70 mg/kg and 0.3 to 14 µg/L, respectively. The background concentrations of mercury in streambank sediment and water were reported to range from 19 to 300 ug/kg and 1.6 to 10 ng/L, respectively.

There have been no human health risk assessments published for historic gold mining sites in Nova Scotia. An ecological risk assessment has been completed, however, for meadow voles at Montague, Upper Seal Harbour and Lower Seal Harbour (Saunders et al., 2011). The risk assessment took into account both natural background conditions and bio-accessibility. The results indicated that meadow vole populations living at all three sites have an unacceptable risk of having adverse health effects as a result of arsenic exposure.

Although there have been no human health risk assessments published for the tailings sites, Health Canada completed a human health risk assessment for consumption of clams and mussels with high arsenic levels in Seal Harbour (Environment Canada, 2007). Based on the results of the risk assessment, it was recommended that the harbour and surrounding waters be closed to harvesting. Signs were posted to alert shellfishers and the public to the closure.

Risk Management

Environmental risk management typically involves managing risks by removing contaminant sources and limiting exposure pathways. Several risk management initiatives have been carried out since the 1970s to limit direct exposure to the tailings, and to limit exposure to arsenic that has been transported from the tailings by water or air (Table 4). Specific risk management initiatives have included (NRCan, 2007): raising public awareness (e.g. press releases, warning signs), reducing human interaction with the tailings (e.g. cancellation of off-highway racing events) and eliminating off-site exposure pathways (e.g. providing central water in Waverley, bivalve and shellfish closures).

Remediation strategies for mine tailings commonly involve clean soil covers to reduce direct human and ecological exposure, dust generation, water infiltration, and sediment erosion and transport. A significant amount of research into the design of soil covers for capping the tailings has been completed for the gold mine tailings in Nova Scotia. The majority of work has been completed at the Montague site. The research has focused on whether or not covers will alter geochemical conditions and promote arsenic leaching (DeSisto et al., 2010, 2011), the performance of various cover designs (Kavalench and Jamieson, 2012; Hosney and Rowe, 2013), and the optimization of soil amendments for re-vegetating the tailings (Piorkowski, 2014).

Table 4. Risk management initiatives associated with gold mine tailings in Nova Scotia.

Year	Environment Risk Management Activity
1976	Establishment of the Provincial Arsenic Task Force, which recommended that groundwater not be used as a source of drinking water in Waverley. A central water supply was subsequently commissioned in Waverley.
2004	Cover and re-vegetation of re-worked tailings at Cochrane Hill.
2005	Establishment of Historic Gold Mines Advisory Committee to assess risks and develop recommendations for managing gold mine tailings in NS.
2005	Two press releases issued by NS Environment to advise the public about tailings, and development of a provincial website with tailings information.
2005	Letters regarding arsenic risks sent to residents living near Montague and Goldenville sites.
2005	Bivalve and shellfish closure of Seal Harbour and Isaacs Harbour due to high arsenic levels in clams and marine sediments.
2006	Health warning signs posted at Montague and Goldenville sites.
2006	Cancellation of off-highway vehicle racing event at Goldenville site.

The studies concluded that secondary arsenic minerals in the tailings (scorodite, amorphous iron arsenates) are stable under oxidizing conditions, but covering the tailings may cause reducing conditions that release arsenic. Conversely, the primary arsenic mineral found in the tailings (arsenopyrite) is stable under reducing conditions and, therefore, excavation of tailings may introduce oxygen and cause arsenic to be released. Investigations of various cover types indicated that low permeability covers (i.e. geosynthetic clay liners) were effective at reducing arsenic leaching. Cover designs with different pH conditions (i.e. vegetative cover with low pH versus crushed limestone cover with high pH), found that pH had no significant effect on arsenic migration compared to regular rainwater.

Conclusions

The environmental investigations that have been completed to date on historic gold mine tailings in Nova Scotia have identified high levels of arsenic and other contaminants that exceed environmental guidelines in soil, sediment, surface water and groundwater. As land development increases in the vicinity of these sites, it will become increasingly important to manage the potential risks they pose. Additional work is needed to select the most appropriate risk management strategies.

For further information on historic gold mine tailings in Nova Scotia please visit: http://www.novascotia.ca/nse/contaminatedsites/goldmines.asp.

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