Alaska Department of Environmental Conservation
555 Cordova Street
Anchorage, Alaska 99501

Total Maximum Daily Load for Metals in the Marine Sediments of Hawk Inlet near Juneau, Alaska

September 2016 DRAFT

(This page is intentionally left blank.)

CONTENTS

TABLES

FIGURES

ACRONYMS

AAC	Alaska Administrative Code
ADEC	Alaska Department of Environmental Conservation
ADF&G	Alaska Department of Fish and Game
APDES	Alaska Pollutant Discharge Elimination System
BMP	Best management practice
CCC	Criterion Continuous Concentration
CFR	Code of Federal Regulations
CMC	Criterion Maximum Concentration
CWA	Clean Water Act
DHSS	Department of Health and Social Services
DMR	Discharge monitoring report
EPA	United States Environmental Protection Agency
ERL	Effects Range Low
°F	Degrees Fahrenheit
FOA	Friends of Admiralty
ft	Feet
ft^2	Square feet
HGCMC	Hecla Greens Creek Mining Company
HUC	Hydrologic unit code
in	Inches
km	Kilometers
km^2	Square kilometers
LA	Load allocation
LEL	Lowest effect level
µg/L	Micrograms per liter
MGD	Million gallons per day
mg/kg	Milligrams per kilogram
MNR	Monitored natural recovery
MOS	Margin of safety
MRLCC	Multi-Resolution Land Characteristics Consortium
NLCD	National Land Cover Database
NOAA	National Oceanic and Atmospheric Administration
NPDES	EPA’s National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
PEL	Probable effects level
SQuiRT	Screening Quick Reference Tables
STATSGO	State Soil Geographic
TDF	Tailings disposal facility
TEL	Threshold effects level

TMDL	Total Maximum Daily Load
USFS	United States Forest Service
WLA	Wasteload allocation
WQS	Water quality standards

(This page is intentionally left blank.)

Total Maximum Daily Load (TMDL) for
Metals in Marine Sediment in
Hawk Inlet, Alaska

TMDL at a Glance:

Water Quality Limited?	Yes
Alaska ID Number:	10204-501
Criteria of Concern:	Toxic and other deleterious organic and inorganic substances – Metals (Cadmium, Copper, Lead, Mercury, and Zinc)
Designated Uses Affected:	(1) Water supply, (2) water recreation, (3) growth and propagation of fish, shellfish, other aquatic life, and wildlife, and (4) harvesting for consumption of raw mollusks or other raw aquatic life
Environmental Indicator:	Metals concentrations in marine sediment
Major Source(s):	Ore concentrate spill, Ore transfer facility
Loading Capacity:	NOAA SQuiRT Effects Range Low, see tables below
Wasteload Allocation:	Not applicable
Loading Capacity:	Cadmium = 1.2 milligrams per kilogram (mg/kg); Copper = 34 mg/kg; Lead = 46.7 mg/kg; Mercury = 0.15 mg/kg; Zinc = 150 mg/kg
Load Allocation:	Cadmium = 1.08 mg/kg; Copper = 30.6 mg/kg; Lead = 42.03 mg/kg; Mercury = 0.135 mg/kg; Zinc = 135 mg/kg
Margin of Safety:	Explicit (10 percent); see tables below
Future Wasteload Allocation:	No allocation is provided for future growth
Necessary Reductions:	Source dependent; see tables below

TMDL allocation summary for metals in sediment in the delineated area of concern (stations S-5S and S-5N)

Metal	Loading capacity (mg/kg)	WLA (mg/kg)	LA (mg/kg)	MOS (mg/kg)	Future growth	Existing maximum concentration (1995–2015) (mg/kg)[a]	Percent reduction to meet TMDL (1995–2015) (%)	Existing maximum concentration (2011–2015) (mg/kg)[b]	Percent reduction to meet TMDL (2011–2015) (%)
Cadmium	1.2	n/a	1.08	0.12	n/a	17.8	93.3	15.6	92.3
Copper	34	n/a	30.6	3.4	n/a	625	94.6	506	93.3
Lead	46.7	n/a	42.03	4.67	n/a	3,680	98.7	2,180	97.9
Mercury	0.15	n/a	0.135	0.015	n/a	26	99.4	2.2	93.2
Zinc	150	n/a	135	15	n/a	3,770	96.0	3,390	95.6

n/a = not applicable; MOS = 10% of the loading capacity

[a] Existing concentration (mg/kg) = maximum observed concentration post-1995 cleanup efforts

[b] Existing concentration (mg/kg) = maximum observed concentration in last 5 years (2011–2015)

TMDL allocation summary for metals in sediment in the area outside of the delineated area of concern (station S-4)

Metal	Loading capacity (mg/kg)	WLA (mg/kg)	LA (mg/kg)	MOS (mg/kg)	Future growth	Existing maximum concentration (1995–2015) (mg/kg)[a]	Percent reduction to meet TMDL (1995–2015) (%)	Existing maximum concentration (2011–2015) (mg/kg)[b]	Percent reduction to meet TMDL (2011–2015) (%)
Cadmium	1.2	n/a	1.08	0.12	n/a	4.23	71.6	0.38	0.0
Copper	34	n/a	30.6	3.4	n/a	110	69.1	110	69.1
Lead	46.7	n/a	42.03	4.67	n/a	378	87.6	49.7	6.0
Mercury	0.15	n/a	0.135	0.015	n/a	3.7	95.9	0.04	0.0
Zinc	150	n/a	135	15	n/a	920	83.7	81	0.0

n/a = not applicable; MOS = 10% of the loading capacity

[a] Existing concentration (mg/kg) = maximum observed concentration post-1995 cleanup efforts

[b] Existing concentration (mg/kg) = maximum observed concentration in last 5 years (2011–2015)

TMDL allocation summary for metals in sediment in the north end of Hawk Inlet (station S-3)

Metal	Loading capacity (mg/kg)	WLA (mg/kg)	LA (mg/kg)	MOS (mg/kg)	Future growth	Existing maximum concentration (1995–2014) (mg/kg)[a]	Percent reduction to meet TMDL (1995–2015) (%)	Existing maximum concentration (2011–2015) (mg/kg)[b]	Percent reduction to meet TMDL (2011–2015) (%)
Cadmium	1.2	n/a	1.08	0.12	n/a	2.76	56.5	1.67	28.1
Copper	34	n/a	30.6	3.4	n/a	105	67.6	64.1	47.0
Mercury	0.15	n/a	0.135	0.015	n/a	0.21	28.6	0.13	0.0
Zinc	150	n/a	135	15	n/a	310	51.6	210	28.6

n/a = not applicable; MOS = 10% of the loading capacity

[a] Existing concentration (mg/kg) = maximum observed concentration post-1995 cleanup efforts

[b] Existing concentration (mg/kg) = maximum observed concentration in last 5 years (2011–2015)

Executive Summary

Hawk Inlet is an approximately 7-mile-long marine waterway extending north from Chatham Strait, located on northern Admiralty Island along the border of the borough of Juneau and the unorganized borough of Hoonah-Angoon. The Clean Water Act (CWA) section 303(d)-listed area near the Greens Creek Mine Ore Concentrate Loading Dock is approximately 2 miles north of the connection to Chatham Strait near an unnamed tributary delta. This area was contaminated by spill of ore concentrate in 1989. The area was cleaned up in 1995; however, cleanup was complicated by debris from a 1974 cannery fire and pockets of ore concentrate remained in various locations (KGCMC 1990 and ADEC 2013a). Dive inspections following the cleanup observed no physical signs of ore concentration on the seafloor at the loading facility (MTS 2016). The 303(d)-listed area is 350 feet in length by 140 feet in width (equivalent to 49,000 square feet [ft^2] or 1.12 acres using the equation: length x width). This area was determined by establishing a perimeter around the loading dock that encompasses the two primary sampling locations. Hawk Inlet is in the 12-digit hydrologic unit code (HUC) subwatershed 190102040802.

Alaska's Department of Environmental Conservation (ADEC) first included the area in Hawk Inlet immediately around the Greens Creek Mine Ore Concentrate Loading Dock on its 2012 CWA section 303(d) list for nonattainment of the toxic and other deleterious organic and inorganic substances water quality standard (WQS). Alaska's process for listing an individual waterbody for failure to meet WQS (impairment), as required in the CWA Section 303(d), begins with an internal review of existing and new information to determine (1) the presence of pollutants, (2) whether persistent exceedances of WQS are occurring, (3) whether impacts on the designated uses are occurring, and (4) the degree to which WQS and the other criteria are attained. The NOAA SQuiRT benchmarks were used to determine whether the WQS narrative criteria were being met. Marine sediment did not meet the National Oceanic and Atmospheric Administration (NOAA) Screening Quick Reference Tables (SQuiRT) Effects Range Low (ERL) screening benchmarks for cadmium, copper, lead, mercury and zinc.

A Total Maximum Daily Load (TMDL) is established in this document to meet the requirements of section 303(d)(1)(C) of the CWA and the U.S. Environmental Protection Agency's (EPA) implementing regulations (40 Code of Federal Regulations Part 130), which require the establishment of a TMDL for the achievement of WQS when a waterbody is water quality-limited. A TMDL is composed of the sum of individual wasteload allocations (WLA) for point sources of pollution and load allocations (LA) for nonpoint sources of pollution and natural background loads. In addition, the TMDL must include a margin of safety (MOS), either implicitly or explicitly, that accounts for the uncertainty in the relationship between pollutant loads and the quality of the receiving waterbody. A TMDL represents the amount of a pollutant the waterbody can assimilate while maintaining compliance with applicable WQS.

Two specific areas of concern in Hawk Inlet (see Section 1) do not fully support the designated uses because of cadmium, copper, lead, mercury and zinc in the bottom sediment. Applicable WQS for toxic and other deleterious organic and inorganic substances in Hawk Inlet establish water quality criteria for the protection of designated uses for water supply, water recreation, and growth and propagation of fish, shellfish, other aquatic life, and wildlife. Alaska WQS include only narrative criteria related to sediment quality; therefore, an appropriate numeric sediment quality target that meets WQS and supports designated uses was identified. The NOAA SQuiRT screening benchmark ERLs (Buchman 2008) were selected as the TMDL numeric targets because they represent sediment quality concentrations below which minimal effects on aquatic life are expected (1.2 milligrams/kilogram [mg/kg] for cadmium, 34 mg/kg for copper, 46.7 mg/kg for lead, 0.15 mg/kg for mercury, and 150 mg/kg for zinc).

The TMDL approach involved extensive data analyses to identify potential sources to Hawk Inlet and to evaluate spatial or temporal trends. These analyses confirmed that there are no water quality impairments in the inlet associated with cadmium, copper, lead, mercury, and zinc. Data analyses of fish and shellfish tissue did show some metals concentrations above EPA recreational and subsistence cadmium and mercury recommended values (USEPA 2000, 2001). However, TMDLs were not developed for tissue because the recent concentrations of metal in tissue are similar to pre-mining conditions in Hawk Inlet, indicating that the tissue levels may be due to naturally high background metals, which is consistent with the natural conditions provision in 18 AAC 70.235(b) (ADEC 2003). Additional monitoring is recommended to determine whether or not there is a tissue impairment. Metals concentrations were observed in the marine sediment at stations S-3 (near the head of Hawk Inlet) and S-4, S-5S, and S-5N (near the historic ore concentrate spill location) above screening marine sediment benchmarks; therefore, TMDLs were developed for these areas.

The TMDLs in Hawk Inlet are expressed as concentrations, equivalent to the NOAA SQuiRT screening benchmark ERLs. No long-term water column data are available for the 303(d)-listed area and no water quality impairments exist in other portions of the Hawk Inlet; therefore, the TMDL only consists of reductions of metals in the marine sediment. A concentration-based TMDL is directly comparable to the applicable sediment quality targets (based on a numeric interpretation of the narrative water quality criteria) and, as such, is easily communicated. Although this TMDL only addresses marine sediment, additional media (i.e., surface water and fish tissue) were assessed throughout the entire waterbody, not just the 303(d)-listed area, and compared to applicable criteria. It is also important to note that the focus of the TMDL is on the marine waterway (Hawk Inlet). Evaluation of freshwater water, sediment, and tissue quality is provided for background and discussion of sources. More data collection and evaluation is needed to characterize potential freshwater impairments.

TMDLs for cadmium, copper, lead, mercury and zinc in marine sediment were developed for two areas in Hawk Inlet (the 303(d)-listed area of concern [stations S-5S and S-5N] and station S-4) and TMDLs for cadmium, copper, mercury, and zinc in marine sediment were developed for station S-3. The percent reduction in cadmium necessary to meet the TMDL in Hawk Inlet ranges from 28.1 percent at station S-3 to 92.3 percent at the 303(d)-listed area of concern (stations S-5S and S-5N); station S-4 meets the TMDL for cadmium based on recent data. Required reductions for copper range from 47.0 percent at station S-3 to 93.3 percent at the 303(d)-listed area of concern. Required reductions for lead range from 6 percent at station S-4 to 97.9 percent at the 303(d)-listed area of concern (a TMDL was not needed for lead at station S-3). The required reduction for mercury is 93.2 percent at the 303(d)-listed area of concern; stations S-4 and S-3 meet the TMDL for mercury based on data collected from 2011-2015. Required reductions for zinc range from 28.6 percent at station S-3 to 95.6 percent at the 303(d)-listed area of concern; station S-4 has been meeting the TMDL for zinc for the past five years.

Potential sources of metal contamination to Hawk Inlet vary by area in the inlet. Specifically, the historic ore concentrate spill is the only known source to stations S-5S, S-5N, and S-4. Exact sources contributing to the metals concentrations at station S-3 are unknown, but potential sources include nonpoint sources such as historic runoff from abandoned mines, fugitive ore dust, natural sources, and internal loading. The Hecla Greens Creek Mining Company (HGCMC) has a permit to discharge metals to Hawk Inlet, but is not considered to be a current source of metals to the impaired areas of the inlet because the mine outfalls do not discharge directly to either of the impaired areas and water quality and sediment monitoring near the outfalls do not indicate exceedances of the applicable water quality or sediment quality targets (see Section 5.2). ADEC plans to reduce metals in Hawk Inlet through natural recovery, as contaminated sediments are buried by “clean” sediment. In addition, ADEC encourages control of any future inputs of metals-laden sediment by focusing on the continued management of shipping and docking operations in Hawk Inlet at the Greens Creek Mine to prevent future spills.

Given that metals in Hawk Inlet will persist for a substantial but unknown period, it is not feasible to establish an exact time frame in which Hawk Inlet will achieve recovery to a "natural condition"; therefore, monitored natural recovery (MNR) is the recommended alternative. If, natural recovery does not result in decreased concentrations of the metals and compliance with the TMDL targets, then other options such as targeted removal should be explored.

The HGCMC Alaska Pollutant Discharge Elimination System (APDES) Permit (AK0043206) currently requires the mine to monitor water quality, sediment, and biological conditions in receiving waters and marine environments that might be affected by the mine's operations. Sea water is sampled quarterly at three locations in Hawk Inlet (stations 106, 107 and 108), and sediment and invertebrate samples are taken annually at three locations (stations S-1, S-2 and S-4) and seven locations (stations S-1, S-2, S-4, STN-1, STN-2, STN-3 and ESL), respectively (see Section 3.2.3). Sediment sampling is also required every five years at station S-5N and S-5S. It is recommended that future discharge permit monitoring include water column sampling in the area of concern (near station S-5S, S-5N, and S-4) to determine whether there is a water quality impairment, and if so whether natural recovery is occurring and metals concentrations are continuing to decrease over time. It is also recommended that cadmium, copper, lead, mercury, and zinc water column and sediment monitoring near the 303(d)-listed area at Greens Creek Mine be expanded outside of stations S-4, S-5N, and S-5S to be sure the entire area is continuing to recover. It is also recommended that future monitoring include tissue sampling in the area of concern (near station S-5S, S-5N, and S-4) and that tissue sampling continues at the current locations to determine whether or not there is a tissue impairment in Hawk Inlet.

In addition to expanding monitoring at the 303(d)-listed area by HGCMC, it is also recommended that cadmium, copper, mercury, and zinc sediment and water quality monitoring continue at station S-3 to ensure that the decreasing trends that have been observed at that station over the past five years continue. See Section 6.2 for more details on monitoring recommendations.

1 Overview

Section 303(d)(1)(C) of the Clean Water Act (CWA) and the U.S. Environmental Protection Agency's (EPA) implementing regulations (40 CFR Part 130 [note: CFR is the Code of Federal Regulations]) require the establishment of a Total Maximum Daily Load (TMDL) to achieve state water quality standards (WQS) when a waterbody is water quality-limited. A TMDL identifies the amount of a pollutant that a waterbody can assimilate and still comply with applicable WQS. TMDLs quantify the amount a pollutant must be reduced to achieve a level (or "load") that allows a given waterbody to fully support its designated uses. TMDLs also include an appropriate margin of safety (MOS) to account for uncertainty or lack of knowledge regarding the pollutant loads and the response of the receiving water. The mechanisms used to address water quality problems after the TMDL is developed can include a combination of best management practices (BMPs) for nonpoint sources and/or effluent limits and monitoring required through EPA's National Pollutant Discharge Elimination System (NPDES) permits (or in Alaska, the Alaska Pollutant Discharge Elimination System [APDES] permits) for point sources.

Alaska's Department of Environmental Conservation (ADEC) first included the area in Hawk Inlet immediately around the Greens Creek Mine Ore Concentrate Loading Area on the 2012 CWA section 303(d) list for nonattainment of the toxic and other deleterious organic and inorganic substances water quality standard due to metals in the marine sediment. Table 1-1 summarizes the information included in the Alaska 2012 section 303(d) list for Hawk Inlet (ADEC 2013a; please note that the area of concern has been updated from this version for consistency with the listing determination documentation).

Table 1-1. Hawk Inlet section 303(d) listing information from ADEC's 2012 Integrated Report

Alaska ID number	Waterbody	Area of concern	Water quality standard	Pollutant parameters	Pollutant sources
10204-501	Hawk Inlet	1.12 Acres	Toxic and Other Deleterious Organic and Inorganic Substances	Metals – Cadmium, Copper, Lead, Mercury, and Zinc	Mine, Ore Transfer Facility
The area in Hawk Inlet immediately around the Greens Creek Mine Ore Concentrate Loading Area is proposed for the 2012 Section 303(d) list for nonattainment of toxic and other deleterious organic and inorganic substances (Metals; Cadmium, Copper, Lead, Mercury, and Zinc) for marine water uses. In 1989 the first attempt to load a barge with ore concentrate resulted in a spill of this concentrate into Hawk Inlet. In 1995 a suction dredge was used to remove as much of the spilled ore concentrate as possible. Prior to Greens Creek operations, a fire in 1974 at the cannery dock left debris on the floor of the inlet at the ore concentrate loading site. This debris complicated cleanup efforts and liter-sized pockets of concentrate now remain in various locations. Prop-wash from tug boats maneuvering barges and ore ships during loading operations continues to re-suspend and mix concentrate with natural sediment in the vicinity of the spill, best management practices, including an enclosed conveyor, now minimize the potential for another spill to take place. Marine sediment sample locations in the immediate vicinity of the Ore Concentrate Loading Area exceed NOAA SQuiRT Effects Range Low (ERL) screening benchmarks for marine sediment for cadmium, copper, lead, mercury, and zinc. Marine water sampling indicates that the water column meets state water quality standards. The area of concern is 350' in length by 140' in width. The total area of concern is 49,000ft^2 in size (L*W) or 1.12 acres. This was determined by establishing a perimeter around the loading dock that is ½ the distance between stations S-5N and S-5S.					

Source: ADEC 2013a

The source of the metals is spilled ore concentrate. In 1989 the first attempt to load a barge at the Greens Creek Mine Ore Concentrate Loading Area resulted in a spill of ore concentrate into Hawk Inlet. Cleanup efforts in the 1990s were complicated by debris from a 1974 cannery fire, resulting in liter-sized pockets of ore concentrate remaining in various locations (Oceanus Alaska 2003; Hecla Greens Creek Mining Company [HGCMC] 2013a, ADEC 2013a, KGCMC 1990). However, based on dive inspections following the cleanup, no physical signs of ore concentration were observed on the seafloor at the loading facility (Marine Taxonomic Services [MTS] 2016). The National Oceanic and

Atmospheric Administration (NOAA) Screening Quick Reference Tables (SQuiRT) screening benchmarks were used to determine whether the WQS narrative criteria were being met within marine sediments. HGCMC marine sample locations S-5N and S-5S, near the Greens Creek Mine Ore Concentrate Loading Area, did not meet the NOAA SQuiRT Effects Range Low (ERL) screening benchmarks for cadmium, copper, lead, mercury and zinc; therefore, this waterbody is in need of a TMDL.

1.1 Location and Identification of TMDL Study Area

Hawk Inlet is an approximately 7-mile-long marine waterway extending north from Chatham Strait and ending in a 0.6-mile-diameter tidal mudflat estuary (Figure 1-1). The inlet is on northern Admiralty Island along the border of the City and Borough of Juneau and the unorganized borough of Hoonah-Angoon. The inlet supports a rich marine life ecosystem because of seawater exchange and input of freshwater nutrients from several freshwater streams.

The 303(d)-listed area near the Greens Creek Mine Ore Concentrate Loading Dock is approximately 2 miles north of the connection to Chatham Strait near an unnamed tributary delta, illustrated in Figure 1-2. The area of concern described in the 303(d) listing is 350 feet in length by 140 feet in width (49,000 square feet [ft^2; length x width] or 1.12 acres) (Figure 1-2). This was determined by establishing a perimeter around the loading dock that is half the distance between monitoring stations S-5N and S-5S. Although impairment in this area has been documented through data analyses, the TMDL evaluates Hawk Inlet in its entirety and addresses the full marine waterbody. Through the results of the data analysis, station S-4 located just outside of the 303(d) list impaired area surrounding stations S-5S and S-5N has also been included in the area of concern near the loading dock (Figure 1-2). All sources of metals to Hawk Inlet, including freshwater inputs, were included in the analyses. Additional data collection and analysis of natural conditions is needed to fully evaluate potential freshwater impairments. Evaluation of the entire inlet resulted in including an additional area of concern in the TMDL that was not included on the 303(d) list. This additional area of concern is located near a single point sampling station S-3 (Figure 1-3), where cadmium, copper, mercury, and zinc exceeded NOAA SQuiRT screening levels for marine sediment.

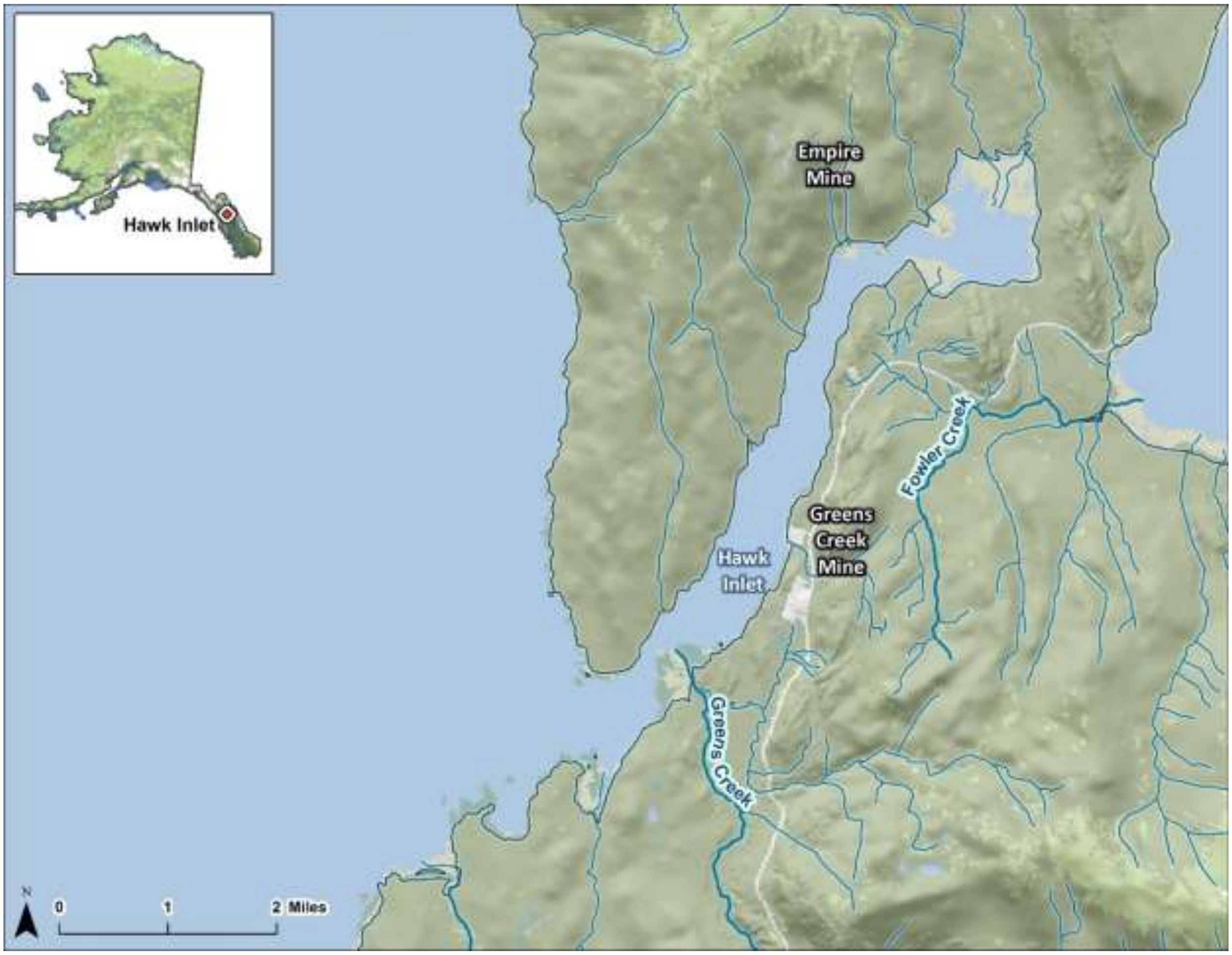


Figure 1-1. Location of Hawk Inlet

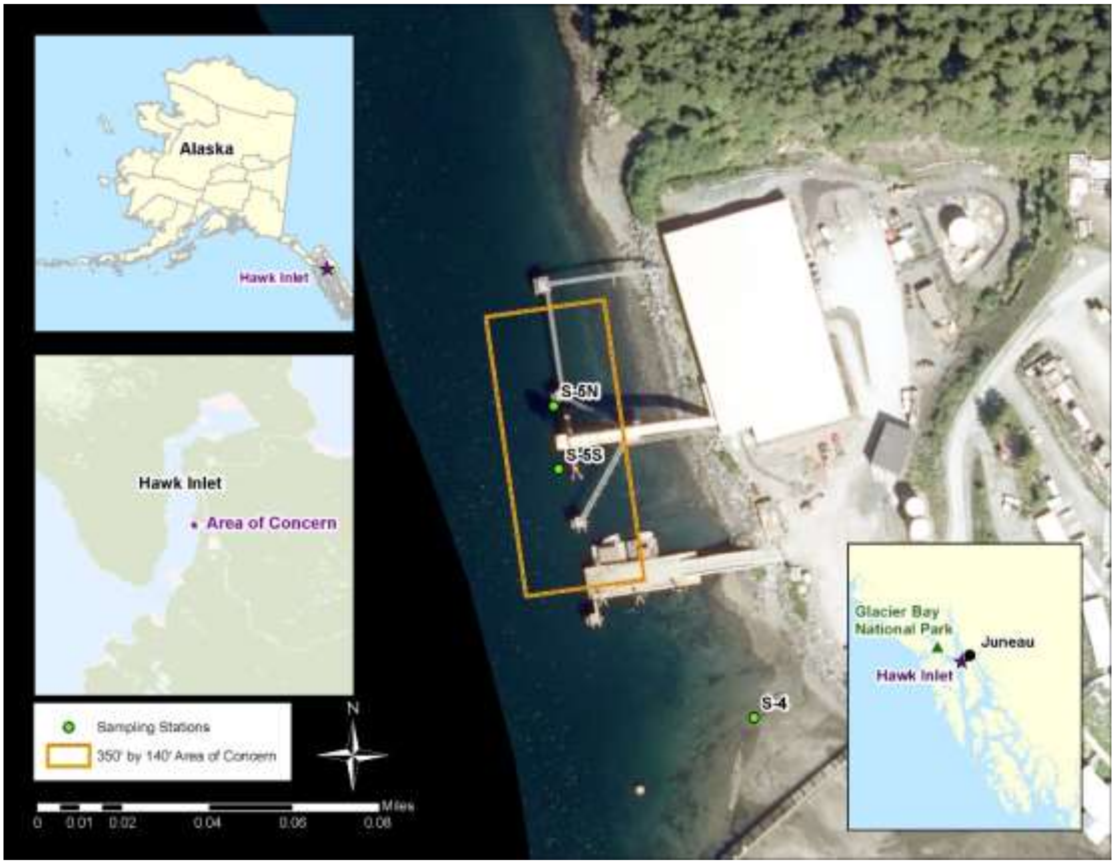


Figure 1-2. Hawk Inlet TMDL 303(d)-listed area of concern

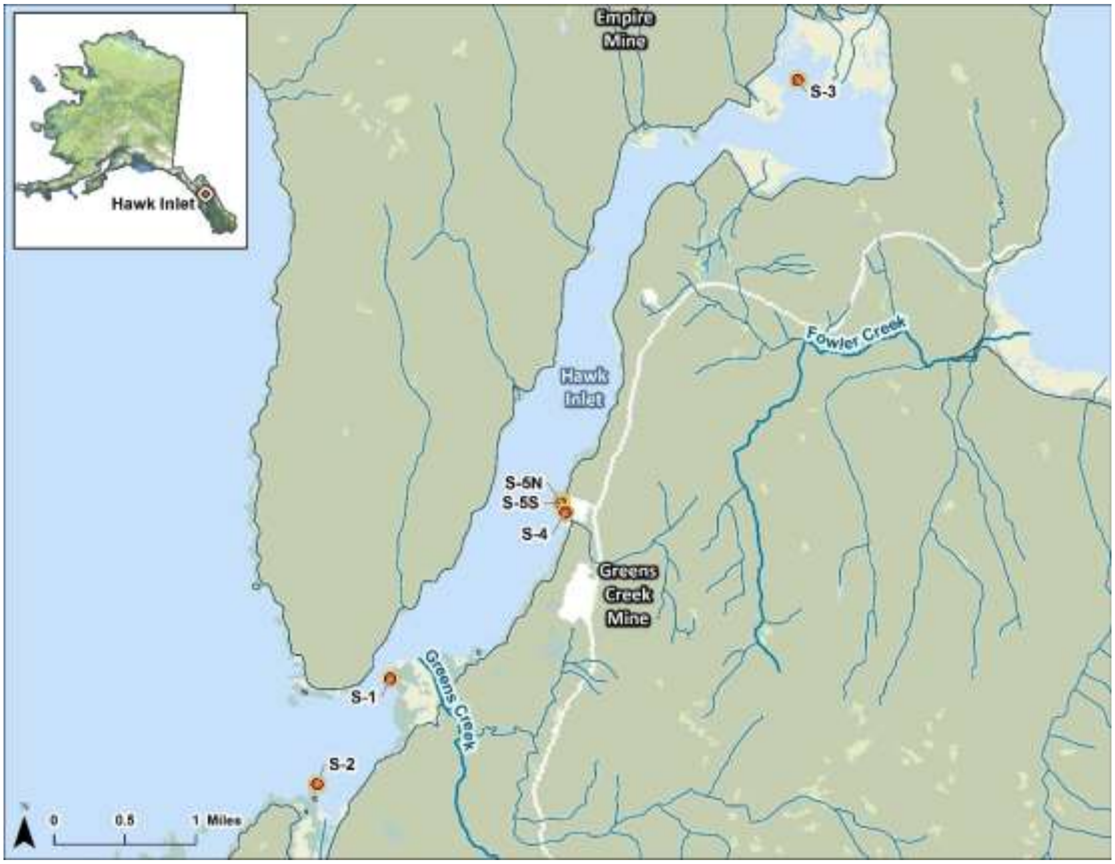


Figure 1-3. Hawk Inlet TMDL sampling station S-3

1.2 Population

Population on Admiralty Island is low. It has only one permanent community, Angoon, with a population of about 570 (National Park Service 2015; SEAtrails 2015). Angoon is approximately 45 miles south of Hawk Inlet at the entrance to Mitchell Bay on Chatham Strait. Its residents are mostly Tlingit Indians. Access to Angoon is limited to float planes and the Alaska Marine Highway ferry. The City of Hoonah is also located approximately 25 miles west of Hawk Inlet. Like Angoon, Hoonah is a largely Tlingit community on Chichagof Island. The population of Hoonah is about 760 people (USDA 2013). The closest large cities to Admiralty Island are Juneau and Sitka. The community of Angoon is about 55 miles southwest of Juneau and 41 miles from Sitka. Juneau's population in 2010 was 31,275. Between 2010 and 2013, Juneau's population increased 4.4 percent (U.S. Census Bureau 2015). Sitka's population in 2010 was 9,020 with a population increase of 1.6 percent between 2010 and 2013. Hecla also houses up to 200 workers at times on the HGCMC's property.

1.3 Topography

Hawk Inlet has a drainage area of approximately 31,000 acres. The minimum elevation of the watershed is 0 meters (sea level). The maximum elevation is 1,318 meters, which occurs near the headwaters of Greens Creek. Figure 1-1 illustrates the topographic variability of the area.

1.4 Land Cover and Land Use

Land cover data were obtained from the 2001 Multi-Resolution Land Characteristics Consortium (MRLCC) National Land Cover Database (NLCD). The NLCD data are based on satellite imagery from 2001. Land in the Hawk Inlet watershed is predominantly forest (72 percent), while 20 percent is scrub/shrub, and only one percent of the watershed is developed (Figure 1-4 and Table 1-2). The majority of land surrounding Hawk Inlet is owned by the federal government and is part of the Tongass National Forest. A portion of the watershed contains a polymetallic (zinc, lead, silver, and gold) underground mine that is owned by HGCMC (HGCMC 2015a). In addition to the Greens Creek Mine land owned by HGCMC, the company also has title to mineral rights on 7,301 acres of federal land acquired through a land exchange with the USFS. The entire mining area consists of 27 square miles.

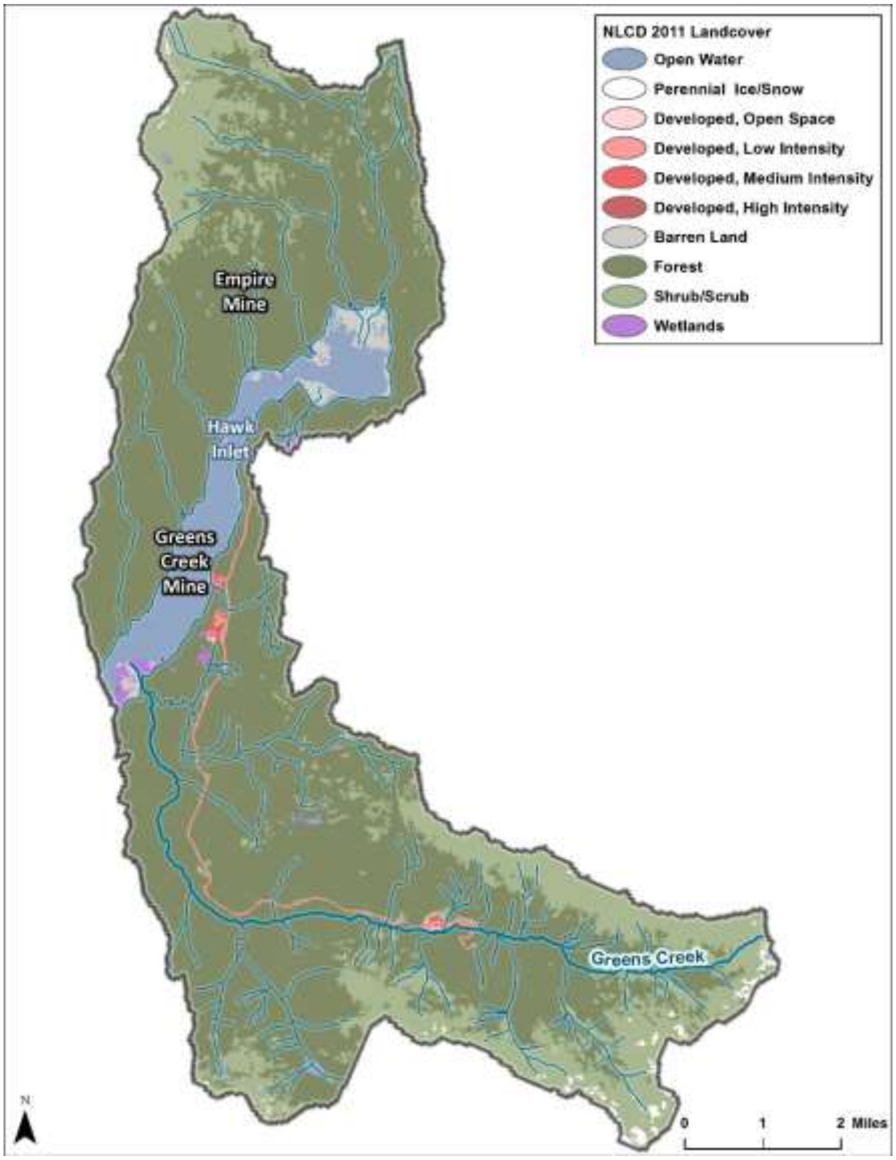


Figure 1-4. Land cover near Hawk Inlet (Source: MRLCC 2001)

Table 1-2. Land cover distribution in the Hawk Inlet watershed

Land cover	Area (acres)	Percent of watershed
Open water	1,926	5.7%
Perennial Ice/Snow	178	0.5%
Developed	256	0.8%
Barren	392	1.2%
Forest	24,132	71.5%
Scrub/shrub	6,673	19.8%
Wetlands	172	0.5%
Total	**33,729**	**100.0%**

1.5 Soils and Geology

Data from the Natural Resources Conservation Service (NRCS) were used to characterize soils in the watershed. General soils data and map unit delineations are available through the State Soil Geographic database (STATSGO).

The hydrologic soil group classification is a means for grouping soils by similar infiltration and runoff characteristics during periods of prolonged wetting. Typically, clay soils that are poorly drained have lower infiltration rates, while sandy soils that are well drained have the greatest infiltration rates. NRCS has defined four hydrologic groups for soils (Table 1-3). The majority of the soils in the higher elevations of the Hawk Inlet watershed are considered to be rough mountainous land and belong to Hydrologic Soil Group D (26 percent of the drainage area), while the rest of the watershed (74 percent) is Hydrologic Soil Group C. Group C soils are moderately well drained, while Group D soils have high runoff potential and very low infiltration rates with a clay layer at or near the surface. Table 1-4 and Figure 1-5 summarize the Hawk Inlet watershed soil information.

Table 1-3. Characteristics of hydrologic soil groups

Soil group	Characteristics	Minimum infiltration capacity (inches/hour)
A	Sandy, deep, well-drained soils; deep loess; aggregated silty soils	0.30 to 0.45
B	Sandy loams, shallow loess, moderately deep and moderately well-drained soils	0.15 to 0.30
C	Clay loam soils, shallow sandy loams with a low permeability horizon impeding drainage (soils with a high clay content), soils low in organic content	0.05 to 0.15
D	Heavy clay soils with swelling potential (heavy plastic clays), water-logged soils, certain saline soils, or shallow soils over an impermeable layer	0.00 to 0.05

Source: NRCS 1972

Table 1-4. Soil distribution in the Hawk Inlet watershed

Hydrologic soil group	Area (acres)	Percent area
C	23,251	74%
D	8,124	26%

Figure 1-5. Soil classification in the Hawk Inlet watershed (Source: NRCS, n.d.)

Note: Andic Haplocryods is Hydrologic Soil Group C and Rough Mountainous Land is Hydrologic Soil Group D.

The rocks and sediments in the Hawk Inlet area were formed through volcanic action (USDA 2003). The bedrock consists of Paleozoic age rocks that have been metamorphosed, folded and faulted. The primary rock types include quartz schist, carbon rich argillite, and phyllite, each of which contains traces of pyrite.

The topography, landforms, and shallow sediments in the area were formed in the more recent geologic past through glacial and marine processes. During the last period of glaciation, an extensive ice sheet flowed outward from higher elevations east of Admiralty Island and buried all but the highest peaks on the Island. As the ice and water retreated, it carved marine beach terraces around the edges of Admiralty Island.

The foundation for these more recent sediments is bedrock that consists of argillites and phyllites. Water in contact with argillite rocks typically has a neutral pH and contains soluble calcium, magnesium, bicarbonate, and sulfate ions. Argillite has proportionately more carbonate minerals than pyrite and should remain neutral in pH. Argillite rocks are also known to be somewhat enriched in zinc (though at lesser concentrations than in ore) possibly resulting in increased zinc levels in water that contacts these rocks.

Like argillite, phyllite contains both pyrite and dolomite, but has proportionately more pyrite than dolomite. Geochemical tests on samples of phyllite from the Greens Creek Mine area indicate that these rocks (unlike the argillite) might become acidic after several years of weathering.

The geology of the Hawk Inlet watershed makes it a desirable location for mining, as indicated by the current underground mining operation along Greens Creek (see Section 4.1.1). Zinc, lead, silver, and gold are the target recovery metals at HGCMC's Greens Creek Mine (HGCMC 2015b).

1.6 Climate

Hawk Inlet is characterized as a temperate rain forest with a maritime climate. Hourly average temperatures ranged from 70 degrees Fahrenheit (°F) to 9 °F during 2000. Average annual precipitation, both in the form of rain and snow, was 53.0 inches (in) for the period of record (1997–2000) at the tailings site just east of Hawk Inlet (USDA 2003). Although precipitation levels in Southeast Alaska are generally high, some areas get more precipitation than others, and the amounts vary widely depending on the particular features of the terrain. The regional annual precipitation at sites near sea level is between 40 inches (Angoon) and 225 inches (Port Walter) (EDE 2002).

1.7 Hydrology and Waterbody Characteristics

Hawk Inlet consists of a narrow basin, partially separated from Chatham Strait by a relatively shallow sill located between the top of the Greens Creek delta and the western shore of Hawk Inlet. The midchannel depth ranges from 35 feet at the sill to 250 feet in the midportion of the inlet. Hawk Inlet has regular, twice-daily tides that flush the entire system approximately every five tidal cycles. The circulation patterns in Hawk Inlet are influenced by the large tidal variation of about 25 feet, the shallow Greens Creek delta, and irregularities in the rocky shoreline. In addition, water flow speed and vertical mixing in the inlet are influenced by wind and fresh water inflow from tributaries (Oceanus Alaska 2003).

There are six small tributaries to Hawk Inlet on the western shore. Greens Creek, on the eastern shore, is the largest tributary to Hawk Inlet. Flows from tributaries peak in September and October (precipitation-driven) and again in May and June (driven by melting snow) (Oceanus Alaska 2003). A large delta was formed near the mouth of the inlet by glacial activity and river-borne sediments from Greens Creek (USDA 2003). Data from Greens, Zinc and Tributary creeks are included in this report. Greens Creek has a watershed area of 14,429 acres (Tetra Tech 2012). Greens Creek starts at an elevation of about 4,600 feet and flows about 10 miles before it empties into Hawk Inlet at a large river delta shared with Zinc Creek. Zinc Creek is located just north of Greens Creek with a watershed of 3,556 acres (Tetra Tech 2012). The lower reaches of Zinc Creek meander in a flat meadow area with a low gradient (< 2 percent). Tributary Creek is a small tributary to Zinc Creek that flows for about 7,400 feet and has a watershed of about 482 acres (Tetra Tech 2012). The headwaters of Tributary Creek start near the tailings disposal facility (TDF) and flow south until its confluence with Zinc Creek. Tributary Creek is narrow, low gradient (<2 percent), and deeply incised with few pools. Flow is sometimes intermittent near the headwaters. The substrate is organic in the upstream portions, with gravel and sand in the lower portion.

The 303(d)-listed area of concern is located on a narrow (20 to 30 feet [ft] wide) inclined shelf at the end of the ore loading facility (KGCMC 1990). The depth of the inlet where vessels dock is approximately 37 ft (NOAA 2016) and drops off steeply to a bottom depth of about 200 ft (KGCMC 1990).

2 Water Quality Standards and TMDL Target

WQS designate the "uses" to be protected (e.g., water supply; recreation; growth and propagation of fish, shellfish, other aquatic life and wildlife) and the "criteria" for their protection (e.g., how much of a pollutant can be present in a waterbody without impairing its designated uses). TMDLs are developed to meet applicable WQS, which may be expressed as numeric water quality criteria or narrative criteria for the support of designated uses. The TMDL target identifies the numeric goals or endpoints for the TMDL that equate to attainment of the WQS. When a numeric water quality criterion is available, the TMDL target is set equal to this value. Alternatively, the TMDL target may represent a quantitative interpretation of a narrative (or qualitative) water quality criterion. This section reviews the applicable WQS and identifies appropriate targets for calculation of the metals TMDLs for Hawk Inlet.

2.1 Applicable Water Quality Standards

Title 18, Chapter 70 of the Alaska Administrative Code (AAC) establishes WQS for the waters of Alaska (ADEC 2012). These include both the designated uses to be protected and the water quality criteria necessary to protect the uses, as described below. State water quality criteria are defined for both marine and fresh waterbodies. The marine water criteria apply to Hawk Inlet and are described below (note: some freshwater WQC were used in the data analyses [Section 3.2.1 and 3.2.2] to characterize freshwater conditions and inputs). In addition, it is important to note that the AAC includes a clause considering the natural condition of a waterway. Specifically, Section 18 AAC 70.235(b) states, "If the department finds that the natural condition of a waterbody is demonstrated to be of lower quality than a water quality criterion set out in 18 AAC 70.020(b), the natural condition constitutes the applicable water quality criterion." (ADEC 2003).

2.1.1 Designated Uses

Designated uses for Alaska's waters are established by regulation and are specified in the State of Alaska Water Quality Standards (18 AAC 70). For marine waters of the state, these designated uses include (1) water supply, (2) water recreation, (3) growth and propagation of fish, shellfish, other aquatic life, and wildlife, and (4) harvesting for consumption of raw mollusks or other raw aquatic life. All designated uses must be addressed unless specifically exempted in Alaska. Therefore, the TMDL must use the most stringent of the criteria among all of the uses. In this case, the most stringent criteria are for growth and propagation of fish, shellfish, other aquatic life, and wildlife and harvesting for consumption of raw mollusks or other raw aquatic life (see Section 2.1.2).

2.1.2 Water Quality Criteria

Hawk Inlet does not fully support its designated uses because of metals in the bottom sediment in two specific areas of concern, one near stations S-4, S-5S, and S-5N and another near station S-3. Stations S-5S and S-5N near the loading dock were included in the original section 303(d) listing as the impaired area of Hawk Inlet; however, data analysis evaluated Hawk Inlet in its entirety resulting in the additional inclusion of station S-4 located just outside of the 303(d) list impaired area surrounding stations S-5S and S-5N as well as station S-3 (see Section 1.1). The metals in marine sediment impairments are specifically: cadmium and zinc at stations S-5S and S-5N, and S-3; copper at stations S-4, S-5S, S-5N and S-3; lead at stations S-5S and S-5N, and S-4; and mercury at stations S-5S and S-5N. Although this TMDL only addresses reductions to metals concentrations in the marine sediment (not metals in the water column), water quality criteria for all designated uses are applicable to Hawk Inlet.

Table 2-1 lists the marine water quality criteria for toxic and other deleterious organic and inorganic substances, on which the section 303(d) listing for Hawk Inlet is based.

Table 2-1. Alaska water quality criteria for toxic and other deleterious organic and inorganic substances in marine waters

Designated use	Description of criteria
(23) Toxic and Other Deleterious Organic and Inorganic Substances, For Marine Water Uses	
(A) Water Supply	
(i) aquaculture	Same as (23)(C).
(ii) seafood processing	The concentration of substances in water may not exceed the numeric criteria for aquatic life for marine water shown in the Alaska Water Quality Criteria Manual (see note 5). Substances may not be introduced that cause, or can reasonably be expected to cause, either singly or in combination, odor, taste, or other adverse effects on the use.
(iii) industrial	Concentrations of substances that pose hazards to worker contact may not be present.
(B) Water Recreation	
(i) contact recreation	There may be no concentrations of substances in water, that alone or in combination with other substances, make the water unfit or unsafe for the use.
(ii) secondary recreation	Concentrations of substances that pose hazards to incidental human contact may not be present.
(C) Growth and Propagation of Fish, Shellfish, Other Aquatic Life, and Wildlife	The concentration of substances in water may not exceed the numeric criteria for aquatic life for marine water and human health for consumption of aquatic organisms only shown in the Alaska Water Quality Criteria Manual (see note 5), or any chronic and acute criteria established in this chapter, for a toxic pollutant of concern, to protect sensitive and biologically important life stages of resident species of this state. There may be no concentrations of toxic substances in water or in shoreline or bottom sediments, that, singly or in combination, cause, or reasonably can be expected to cause, adverse effects on aquatic life or produce undesirable or nuisance aquatic life, except as authorized by this chapter. Substances may not be present in concentrations that individually or in combination impart undesirable odor or taste to fish or other aquatic organisms, as determined by either bioassay or organoleptic tests.
(D) Harvesting for Consumption of Raw Mollusks or Other Raw Aquatic Life	Same as (23)(C).

Source: 18 AAC 70.020 (ADEC 2012)
Note 5: Wherever cited in this subsection, the Alaska Water Quality Criteria Manual *means the* Alaska Water Quality Criteria for Toxic and Other Deleterious Organic and Inorganic Substances*, dated December 12, 2008, adopted by reference in this subsection.*

The State of Alaska has adopted EPA’s water quality criteria for priority and nonpriority pollutants in *Alaska Water Quality Criteria for Toxic and Other Deleterious Organic and Inorganic Substances* (ADEC 2008). Marine water criteria relevant to Hawk Inlet are developed to protect aquatic life and human health, as described below (ADEC 2008).

- **Aquatic life:** Protection of aquatic life is associated with marine water uses of aquaculture and growth and propagation of fish, shellfish, other aquatic life, and wildlife. These uses consist of two classifications: Criteria Maximum Concentration (CMC) and Criterion Continuous Concentration (CCC). The CMC is an estimate of the highest concentration of a material in surface water to which an aquatic community can be exposed briefly without resulting in an

unacceptable effect, representing an acute criterion. The CCC is an estimate of the highest concentration of a material in surface water to which an aquatic community can be exposed indefinitely without resulting in an unacceptable effect, representing a chronic criterion.
- **Human health:** Water quality standards for marine water uses of growth and propagation of fish, shellfish, other aquatic life, and wildlife. Criteria are based on the consumption of aquatic organisms only and both water and aquatic organisms.

Table 2-2 presents the applicable water quality criteria (in micrograms per liter [µg/L]) for metals of concern in Hawk Inlet (ADEC 2008); natural condition of a waterway, Section 18 AAC 70.235(b) has not been applied to the criteria in Table 2-2. For cadmium, copper, lead, and zinc, the chronic aquatic life criterion is the lowest and, therefore, most protective of the water quality criteria. This criterion protects all designated uses, including the human health and acute aquatic life designated uses where applicable, and is based on the dissolved (biologically active) fraction of metal concentration in ambient water. For mercury, the human health for consumption of water and aquatic organisms criterion is the lowest and, therefore, most protective of water quality criterion.

Hawk Inlet was not included on the section 303(d) list because of water column exceedances, but was listed because of concentrations of metals above marine sediment screening benchmarks in bottom sediment at two stations near the Greens Creek Mine Ore Concentrate Loading Dock (see Section 2.1.3). Although no long-term water quality data are available at the Greens Creek Mine Ore Concentrate Loading Dock (stations S-5S, S-5N, and S-4) or at the additional area of concern (station S-3), the criteria in Table 2-2 are included for future reference and comparison.

Table 2-2. Marine water quality criteria for metals of concern in Hawk Inlet

Metal	Use	Criterion value (µg/L)
Cadmium	Acute Aquatic Life (CMC) – (1-hour average)[1](dissolved) [2,3,4]	40
	Chronic Aquatic Life (CCC) – (4-day average)[5](dissolved)[6,4]	8.8
Copper	Acute Aquatic Life (CMC) – (24-hour average)[7](dissolved) [8,9]	4.8
	Chronic Aquatic Life (CCC) – (4-day average)[5](dissolved) [8,9]	3.1
	Human Health for Consumption of Water & Aquatic Organisms	1,300
Lead	Acute Aquatic Life (CMC) – (1-hour average)[1](dissolved) [4, 10]	210
	Chronic Aquatic Life (CCC) – (4-day average)[5](dissolved) [4, 11]	8.1
Mercury	Acute Aquatic Life (CMC) – (1-hour average)[1](dissolved) [12, 13, 14]	1.8
	Chronic Aquatic Life (CCC) – (4-day average)(dissolved)[12, 14, 15]	0.94
	Human Health for Consumption of Water & Aquatic Organisms	0.050[16]
	Human Health for Consumption of Aquatic Organisms Only	0.051[16]
Zinc	Acute Aquatic Life (CMC) – (1-hour average)[1] (dissolved) [4, 17]	90
	Chronic Aquatic Life (CCC) – (4-day average)[5] (dissolved) [4, 18]	81

Metal	Use	Criterion value (µg/L)
	Human Health for Consumption of Water & Aquatic Organisms	9,100
	Human Health for Consumption of Aquatic Organisms Only	69,000

Source: ADEC 2008

[1] Acute criteria are based on the average concentration of chemical pollutants during a 1-hour period. One hour was chosen because it is a substantially shorter period than the length of most acute toxicity tests. Acute and chronic criteria are used together to develop water quality-based effluent limits.

[2] The limited data suggest that the acute toxicity of cadmium is salinity-dependent; therefore, the 24-hour average concentration might be underprotective at low salinities and overprotective at high salinities.

[3] To calculate the dissolved criterion, multiply the total recoverable criterion by the conversion factor (40.28)(0.994) = 40.04 ~ 40.

[4] This water quality criterion is based on a 304(a) aquatic life criterion that was derived using the 1985 Guidelines (Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses, PB85-227049, January 1985) and was issued in one of the following criteria documents: Arsenic (EPA 440/5-84-033), Cadmium (EPA-822-R-01-001), Chromium (EPA 440/5-84-029), Copper (EPA 440/5-84-031), Cyanide (EPA 440/5-84-028), Lead (EPA 440/5-84-027), Nickel (EPA 440/5-86-004), Pentachlorophenol (EPA 440/5-86-009), Toxaphene, (EPA 440/5-86-006), Zinc (EPA 440/5-87- 003).

[5] Chronic criteria are based on the average concentration of chemical pollutants during a 4-day period. A 4-day averaging period was chosen because it is substantially shorter than most chronic toxicity tests. Chronic criteria are typically stricter than the acute criteria and are therefore used to protect ambient waters.

[6] To calculate the dissolved criterion, multiply the total recoverable criterion by the conversion factor (8.846)(0.994) = 8.793 ~ 8.8.

[7] The 24-hour average is to be applied as an average concentration and not as a criterion to be met instantaneously at any point in the surface water.

[8] When the concentration of dissolved organic carbon is elevated, copper is substantially less toxic and use of site-specific criteria might be appropriate.

[9] Conversion factors for saltwater chronic criterion are not currently available. The conversion factor of 0.83 derived for the saltwater acute criterion has been used for both saltwater acute and chronic criteria.

[10] To calculate the dissolved criterion, multiply the total recoverable criterion by the conversion factor (217.16)(0.951) = 206.519 ~ 210.

[11] To calculate the dissolved criterion, multiply the total recoverable criterion by the conversion factor (8.468)(0.951) = 8.053 ~ 8.1.

[12] The recommended criteria were derived from data for inorganic mercury (II), but are applied here to total mercury. If a substantial portion of the mercury in the water column is methylmercury, the criteria will probably be underprotective. In addition, even though inorganic mercury is converted to methylmercury and methylmercury bioaccumulates to a great extent, these criteria do not account for uptake via the food chain because sufficient data were not available when the criteria were derived.

[13] To calculate the dissolved criterion, multiply the total recoverable criterion by the conversion factor (2.062)(0.85) = 1.752 ~ 1.8.

[14] This recommended water quality criterion was derived on page 43 of the mercury criteria document (EPA 440/5-84-026, January 1985). The saltwater CCC of 0.025 µg/L given on page 23 of the criteria document is based on the Final Residue Value procedure in the 1985 Guidelines. Since the publication of the Great Lakes Aquatic Life Criteria Guidelines in 1995 (60FR15393-15399, March 23, 1995), the EPA no longer uses the Final Residue Value procedure for deriving CCCs for new or revised 304(a) aquatic life criteria.

[15] To calculate the dissolved criterion, multiply the total recoverable criterion by the conversion factor (1.106)(0.85) = 0.9401 ~ 0.94.

[16] This criterion has been revised to reflect the Environmental Protection Agency's q1* or RfD, as contained in the Integrated Risk Information System (IRIS) as of April 8, 1998. The fish tissue bioconcentration factor (BCF) from the 1980 Ambient Water Quality Criteria document was retained in each case.

[17] To calculate the dissolved criterion, multiply the total recoverable criterion by the conversion factor (95.10)(0.946) = 89.96 ~ 90.

[18] To calculate the dissolved criterion, multiply the total recoverable criterion by the conversion factor (86.14)(0.946) = 81.49 ~ 81.

2.1.3 Sediment Quality Guidelines

Hawk Inlet is currently listed as impaired due to concentrations of metals above marine sediment screening benchmarks in bottom sediment at two stations near the Greens Creek Mine Ore Concentrate Loading Dock (Figure 1-2). Metal concentrations in bottom sediment can contribute to surface water impairment and monitoring studies have indicated high concentrations of cadmium, copper, lead, mercury, and zinc above marine sediment screening benchmarks in inlet bottom sediments (Oceanus Alaska 2003; HGCMC 2013a).

To date, ADEC has not adopted numeric sediment quality standards for the evaluation of impacts to aquatic life; therefore, several values were considered. The ADEC Contaminated Sites Program has issued the technical memorandum *Sediment Quality Guidelines* (ADEC 2013b), which recommends using the Threshold Effects Levels (TELs) and Probable Effects Levels (PELs) for evaluating sediment quality. TELs define chemical sediment concentrations below which toxic effects are rarely observed in sensitive species, while PELs define concentrations above which effects are frequently or always observed. Hawk Inlet was listed because marine sediment metals samples exceeded the Effects Range Low values (ERLs), which is a different NOAA SQuiRT sediment quality benchmark (Buchman 2008). The ERL is the low end of a range of levels at which effects are observed. It represents the value at which toxicity might begin to be observed in sensitive species (Buchman 1999). The TEL, ERL, and PEL concentrations in milligrams per kilogram (mg/kg) are presented in Table 2-3 (Buchman 2008).

Table 2-3. Marine sediment screening levels for metals of concern in Hawk Inlet

Metal	TEL (mg/kg)	ERL (mg/kg)	PEL (mg/kg)
Cadmium	0.68	1.2	4.21
Copper	18.7	34	108
Lead	30.24	46.7	112
Mercury	0.13	0.15	0.7
Zinc	124	150	271

Source: Buchman 2008

2.1.4 EPA Recommended Tissue Values

As stated above, Hawk Inlet is currently listed as impaired due to concentrations of metals above marine sediment screening benchmarks in bottom sediment at two stations near the Greens Creek Mine Ore Concentrate Loading Dock (Figure 1-2). Two additional stations (S-4 and S-3) have also been found to have metals concentrations above marine sediment screening benchmarks and have been assigned TMDLs as well. Metal concentrations in bottom sediment can contribute to surface water impairment as well as increased metals concentrations in fish and shellfish. Monitoring studies have indicated concentrations of cadmium and/or mercury in tissue above EPA recommended values in Hawk Inlet and its inputs (HGCMC 2005-2015; ADEC 2014; ADF&G 2015; and KGCMC 1990).

To date, ADEC has not adopted tissue quality standards for the evaluation of impacts to harvesting for consumption of raw mollusks or other raw aquatic life. Alaska typically determines site-specific tissue screening values when necessary; however, no site-specific screening values currently exist for Hawk Inlet. Therefore, EPA's tissue quality guidelines for recreational and subsistence fishing were used for comparison with all available tissue data, as described in Section 3 below (USEPA 2000, 2001). There are currently no established fish consumption rates for subsistence fishers; however, ADEC has estimated a consumption rate of 10 times the recreational fisher's consumption rate to provide the 0.03 mg/kg recommended value. The EPA tissue recommended values are presented in Table 2-4.

Table 2-4. Wet weight tissue quality guidelines (EPA recommended values) for fish and shellfish

Contaminant	EPA recommended value for recreational fishers[a]	EPA recommended value for subsistence fishers[a]
	Non-carcinogenic	Non-carcinogenic
Cadmium (mg/kg)	4[b]	0.491[b]
Mercury (mg/kg) – methylmercury (unless otherwise noted)[d]	0.3[c]	0.03[c]

[a] EPA recommended values for recreational fishers are based on a consumption rate of 17.5 grams/day and a body weight of 70 kilograms, while recommended values for subsistence fishers are based on a consumption rate of 142.4 grams per day and a body weight of 70 kilograms.

[b] EPA recommended values are associated with both finfish and shellfish (USEPA 2000).

[c] EPA recommended values for methylmercury Water Quality Criterion (USEPA 2001).

.

[d] As noted by USEPA, "because most mercury in fish and shellfish is present primarily as methylmercury and because of the relatively high cost of analyzing for methylmercury, it is recommended that total mercury be analyzed and the conservative assumption be made that all mercury is present as methylmercury" (USEPA 2000).

N/A = Mercury and cadmium are not known carcinogens.

2.1.5 Department of Health and Social Services Recommended Tissue Values

In addition to the EPA recommended values for tissue, Alaska's Department of Health and Social Services (DHSS) calculated maximum recommended values of cadmium, copper, mercury and zinc for several marine species that were analyzed in Hawk Inlet. There are no recommended lead values because there is no level of exposure to lead that has been shown to be safe (ADEC and DHSS 2016). The values for cadmium, copper, mercury and zinc were calculated based on the 95th percentile harvest data (that served as a proxy for consumption rates) from Angoon in 2012 and from the comparison values that DHSS used in the analysis of the Hawk Inlet data in the response letter to the community of Angoon's concerns (ADEC and DHSS 2016). The 2012 Angoon harvest data were obtained from the Alaska Department of Fish & Game's (ADF&G) Community Subsistence Information System and represent the usable harvest weight (i.e., parts of marine species residents would actually consume) (ADEC and DHSS 2016). These DHSS maximum recommended values provide the concentrations for each metal in each species that are not likely to cause adverse health effects if these species are consumed at the 95th percentile harvest rates.

While both the EPA recommended tissue values (see Section 2.1.4) and DHSS recommended values are compared to the data in this report (see Section 3.2), there are differences between the two recommended values. The DHSS recommended values are based on local harvest information and incorporate both health benefits from consuming fish and risk from contamination in the fish. EPA's recommended values consider only risk, but are based on national consumption estimates when actual subsistence consumption varies with location. The DHSS recommended values are presented in Table 2-5.

Table 2-5. Maximum safe tissue concentrations in marine species (mg/kg)

	Cadmium (mg/kg)	Copper (mg/kg)	Mercury (mg/kg)	Zinc (mg/kg)
Clams	33.2	1,635	4.89	4,891
Cockles	41.5	2,046	6.12	6,122
Mussels	137	6,770	20.2	20,258
Crab	25.1	1,239	3.70	3,708
Shrimp	103	5,072	15.2	15,177
Seaweed	49.5	2,442	7.30	7,307

Source: DHSS (2016)

2.2 Antidegradation

Alaska's WQS (18 AAC 70.015) also include an antidegradation policy, which states that existing water uses and the level of water quality necessary to protect the existing uses must be maintained and protected. The policy also states that high quality waters must be maintained and protected unless the state finds that allowing lower water quality is necessary to accommodate important economic or social development in the area in which the water is located. In allowing permitted discharges that degrade water quality, the state must ensure water quality adequate to fully protect existing uses of the water.

The methods of pollution prevention, control, and treatment found to be the most effective and reasonable will be applied to all discharges. All discharges will be treated and controlled to achieve the highest statutory and regulatory requirements for point sources and all cost-effective and reasonable BMPs for nonpoint sources.

The antidegradation policy also requires that state waters that are designated as an outstanding national resource must be maintained and protected. In such waters, no degradation of water quality is allowed. To date, Hawk Inlet is not designated as an outstanding national resource.

2.3 Designated Use Impacts

The area of concern in Hawk Inlet was placed on the 2012 CWA section 303(d) list for nonattainment of the water quality standards for toxic and other deleterious organic and inorganic substances in marine waters, specifically for cadmium, copper, lead, mercury, and zinc in marine sediment (ADEC 2013a). All designated uses must be addressed unless specifically exempted in Alaska; none of the designated uses have been exempted in Hawk Inlet, therefore, the nonattainment affects the designated uses of (1) water supply, (2) water recreation, (3) growth and propagation of fish, shellfish, other aquatic life, and wildlife, and (4) harvesting for consumption of raw mollusks or other raw aquatic life. Hawk Inlet is used for commercial, sport, and subsistence fishing.

2.4 TMDL Target

The TMDL target is the numeric endpoint that represents attainment of applicable WQS. This value is used to calculate the loading capacity and necessary load reductions. Because all designated uses must be addressed unless specifically exempted in Alaska, the TMDL must use the most stringent criteria among all of the uses. In this case, the most stringent water quality criterion is for cadmium, copper, lead, and zinc is associated with the growth and propagation of fish, shellfish, other aquatic life, and wildlife; the most stringent water quality criterion for mercury is for human health consumption (see Section 2.1.2). The marine water column TMDL numeric targets are equivalent to the CCC water quality criteria of 8.8 μg/L for cadmium, 3.1 μg/L for copper, 8.1 μg/L for lead, and 81 μg/L for zinc, and the human health criteria of 0.05 μg/L for mercury. As documented in Section 2.1.2, these criteria represent the most protective criteria, addressing all designated uses. Although these water quality criteria are applicable to water column data in Hawk Inlet, they were used only to evaluate the waterbody and were not used as the final TMDL targets. There were no long-term water column data showing exceedances of these criteria in Hawk Inlet; therefore, the TMDL was based on the targets for bottom marine sediments discussed below.

As shown in Table 2-1, to establish a numeric TMDL target based on growth and propagation of fish, shellfish, other aquatic life, and wildlife criterion, one must ensure that no concentrations of toxic substances in the water column *or bottom sediments*, singly or in combination, cause, or reasonably can be expected to cause, adverse effects on aquatic life or produce undesirable or nuisance aquatic life. Known exceedances of the marine sediment ERL screening benchmarks have been documented in Hawk Inlet (ADEC 2013a); therefore, it is important to identify sediment numeric targets for these TMDLs to ensure the designated uses are met.

Alaska WQS include only narrative criteria related to sediment quality; therefore, an appropriate numeric sediment quality target that meets WQS and supports designated uses must be identified. The ERLs have been selected as the TMDL numeric targets because they represent sediment quality concentrations below which minimal effects on aquatic life are expected. In addition, the ERLs were used for the original listing and are consistent with previous Alaska TMDLs (Skagway Harbor [ADEC 2011] and Klag Bay [ADEC 2009]). The ERLs were used to set the marine sediment TMDL numeric target concentration for Hawk Inlet (1.2 mg/kg for cadmium, 34 mg/kg for copper, 46.7 mg/kg for lead, 0.15 mg/kg for mercury, and 150 mg/kg for zinc).

Alaska’s waterbodies must also support harvesting for consumption of raw mollusks or other raw aquatic life. As stated above, ADEC has not adopted tissue quality standards for the evaluation of impacts to fish tissue, therefore, EPA’s tissue quality guidelines for cadmium and mercury for recreational and subsistence fishing (USEPA 2000, 2001) and DHSS’s maximum safe tissue concentrations for cadmium, copper, mercury and zinc (DHSS 2016) were applied. There are no available EPA recommended screening values for copper, lead, or zinc and no DHSS recommended maximum concentrations for lead. Data analyses of tissue did show some metals concentrations in the marine tissue samples above EPA recreational and subsistence cadmium recommended values (USEPA 2000, 2001). However, TMDLs were not developed for tissue because the recent concentrations of metals in tissue are similar to conditions in the 1980s before mining began in Hawk Inlet (Oceanus Alaska 2003). Therefore, consistent with the natural conditions provision in the Alaska WQS (18 AAC 70.235(b)), tissue samples at these stations were not characterized as impaired as the concentrations above EPA recommended values may be due to naturally high background metals. Please note that a natural conditions provision has not been determined or approved for Hawk Inlet. Additional monitoring is recommended to support the determination of site-specific tissue screening values and any potential tissue impairment in the Hawk Inlet area, including in freshwater tributaries.

3 Data Review

Compiling and analyzing data and information is an essential step in understanding the general water quality conditions and trends in an impaired water. This section outlines and summarizes all of the data reviewed, including impairment analyses and temporal and spatial trends.

3.1 Data Inventory

Monitoring has been conducted in and around the 303(d)-listed area before and after HGCMC operations began in 1989. All available data at the time of TMDL development within and outside of the 303(d)-listed area were evaluated to characterize trends in Hawk Inlet, which helped identify sources and critical conditions. The TMDL specifically addresses confirmed impairments in the marine waterbody, while freshwater data were evaluated to characterize sources and inform the TMDL. Data include water column, sediment, and biological samples collected in Hawk Inlet (marine) and its tributaries (freshwater) as described below and listed in Table 3-1.

- **Water Quality Data**: Water column sampling is performed at ambient stations 106, 107, and 108 in Hawk Inlet; outfall and stormwater monitoring stations; several stations along tributaries to Hawk Inlet; and several stations near Empire Mine at the head of the inlet. All these stations are outside of the 303(d)-listed area (Figure 3-1, Figure 3-2, Figure 3-3, and Figure 3-4). Water quality data at stations 106 and 107 represent 1985 through 2015; station 108 represents 1987 through 2015. Two additional stations (104 and 105) are also located in Hawk Inlet (Figure 3-1). These stations are no longer sampled. Data at station 104 were collected from 1985 through 2005 and data at station 105 were collected from 1985 through 1998. Additional water quality data were collected from four locations in Hawk Inlet in May 2015 as part of an ongoing marine ecology study (Ridgway 2016). The locations of these figures are shown in Section 3.2.3.1.

- **Sediment Quality Data**: Sediment sampling was performed at stations S-1, S-2, S-3, S-4, S-5N, and S-5S in Hawk Inlet (note: stations S-5N, S-5S, and S-4 are located within or near the 303(d)-listed area and station S-3 is located in the additional area of concern identified through data analysis) (Figure 3-1); stations 48 and 54 along Greens Creek; station 9 in Tributary Creek (Figure 3-3); and stations 1, 6, 11, 14, US001S, US003S, US002S, LS002S, LS001S, LS003S, and US004S at Empire Mine (Figure 3-4). Additional sediment data were collected in 1981, 1997, 2015, and 2016 at stations throughout Hawk Inlet. Only approximate locations of the 1981 and 1997 sampling stations are available so they are not shown on a map, but the data are presented in this section of the report. The locations of the data collected in 2015 and 2016 are shown in Section 3.2.3.3.

- **Biological Data**: Biological data have been collected at stations S-1, S-2, S-3, S-4, STN-1, STN-2, STN-4, and ESL (Figure 3-1) in Hawk Inlet as well as stations 48, 54, and 6 on Greens Creek, station 9 on Tributary Creek (Figure 3-3), and stations 4, 5, and 6 at Empire Mine (Figure 3-4). ADF&G collected 10 fish tissue samples in the anadromous section of Empire Creek (Figure 3-4). In addition, shellfish were sampled throughout Hawk Inlet in May 2015 (Oceanus Alaska 2015a); however, the specific sampling locations are unknown at this time. Additional tissue data were collected in 1980, 1981, 1997, 2015, and 2016 at stations throughout Hawk Inlet; however, only approximate locations of the 1981 and 1997 sampling stations are available so they are not shown on a map, but the data are presented below. The locations of the data collected in 2015 and 2016 are shown in Section 3.2.3.2.

Table 3-1. Available data summary

Station(s)	Matrix	Parameter	Start date	End date
104	Water	Trace Metals of Concern	2/1/1985	11/9/2005
105	Water	Trace Metals of Concern	2/1/1985	11/12/1998
106, 107	Water	Trace Metals of Concern	2/1/1985	10/19/2015
108	Water	Trace Metals of Concern	11/1/1987	10/19/2015
Outfall 002 (035NPDES)	Water	Trace Metals of Concern	7/2/2007	8/12/2015
Greens Creek stations 6, 46, 48, 49, 54, 61, 62	Water	Water temp, conductivity, pH, alk, sulfate, hardness, dissolved As, Ba, Cd, Cr, Cu, Pb, Ni, Ag, Zn, Se, Hg	10/25/2001	9/14/2015
Tributary Creek station 9	Water	Water temperature, conductivity, pH, alk, sulfate, hardness, dissolved As, Ba, Cd, Cr, Cu, Pb, Ni, Ag, Zn, Se, Hg	5/17/2006	9/1/2015
Althea Creek station 60	Water	Water temperature, conductivity, pH, alk, sulfate, hardness, dissolved As, Ba, Cd, Cr, Cu, Pb, Ni, Ag, Zn, Se, Hg	5/17/2006	9/1/2015
Greens Creek stations GCBA1, GCBA2, GCBA5, GCBA6, Near BSBA7, Near GCBA3	Water	Trace Metals of Concern	April 1978	May 1980
S. ore dock, Sill @ 002, Ore chute, Deep hole	Water	Trace Metals of Concern	May 2015	May 2015
S-1, S-2	Sediment	Trace Metals of Concern	9/1/1984	9/1/2015
S-3	Sediment	Trace Metals of Concern	1984	2014
S-4	Sediment	Trace Metals of Concern	5/1/1986	9/11/2015
S-5N, S-5S	Sediment	Trace Metals of Concern	4/1/1989	9/11/2015
48 (Greens Cr.), 54 (Greens Cr.), 9 (Tributary Cr.)	Sediment	Cd, Cu, Pb, Se, Ag, Zn, Hg	7/23/2013	7/23/2013
Hawk Inlet stations 97HIS03Z, 97HIS04, 97HIS05, MS01, MS02, MS06	Sediment	Trace Metals of Concern	April 1997	April 1997
Hawk Inlet Stations Cannery intertidal, Cannery subtidal, Greens Creek Delta intertidal, Greens Creek Delta subtidal, Head of Inlet intertidal, Head of Inlet subtidal	Sediment	Trace Metals of Concern	7/8/1981	7/8/1981
Head of Hawk, Near S3 Head, East Head, Near Empire Mine, GCD near S2, Near S4-S5, Near HI-1, Outfall 002, Near HI-3, Butch Beach, Near S3 Head, Mid Inlet Grn FltHs	Sediment	Trace Metals of Concern	May 2015	May 2015
S-1, S-2, STN-1, STN-2, STN-4, ESL	Tissue	Trace Metals of Concern	9/1/1984	9/21/2015
S-3	Tissue	Trace Metals of Concern	9/21/2001	9/29/2015
S-4	Tissue	Trace Metals of Concern	5/1/1988	9/24/2015
48 (Greens Cr.), 54 (Greens Cr.), 9 (Tributary Cr.), 6 (Middle Greens Cr.)	Tissue	Trace Metals of Concern	7/21/2000	7/16/2015
Throughout Hawk Inlet	Tissue	Trace Metals of Concern	May 2015	July 2016

Station(s)	Matrix	Parameter	Start date	End date
Hawk Inlet Stations: Greens Creek Delta, Hawk Inlet (near Greens Creek), Hawk Inlet (near the cannery),	Tissue	Trace Metals of Concern	8/1/1980	7/8/1981
Hawk Inlet stations M01, M02, M03, M04, M05, M06, MM01, MM02, MM03, MM04, MM04, MM06	Tissue	Trace Metals of Concern	April 1997	April 1997
Upper Greens Creek, Lower Greens Creek, Zinc Creek, Tributary to Zinc Creek	Tissue	Trace Metals of Concern	8/1/1980	7/8/1981
Empire Mine stations 1, 6, 11, 14 US001S, US003S, US002S, LS002S, LS001S, LS003S, US004S	Sediment	As, Cd, Cu, Pb, Hg, Se	8/6/2014	9/19/2014
Empire Mine stations 1, 3, 11, 13, 14, US001W, US003W, US002W, LS002W, LS001W, LS003W, US004W, US005W	Water	As, Cd, Cu, Pb, Hg, Se	8/6/2014	9/19/2014
Empire Mine stations 4, 5, 6, and anadromous stream section	Tissue	As, Ba, Cd, Cu, Cr, Pb, Hg, Se, Zn	8/6/2014	8/6/2014

Note: alk = alkalinity, As = arsenic, Ba = barium, Cd = cadmium, Cr = chromium, Cu = copper, Pb = lead, Ni = nickel, Ag = silver, Zn = zinc, Se = selenium, Hg = mercury

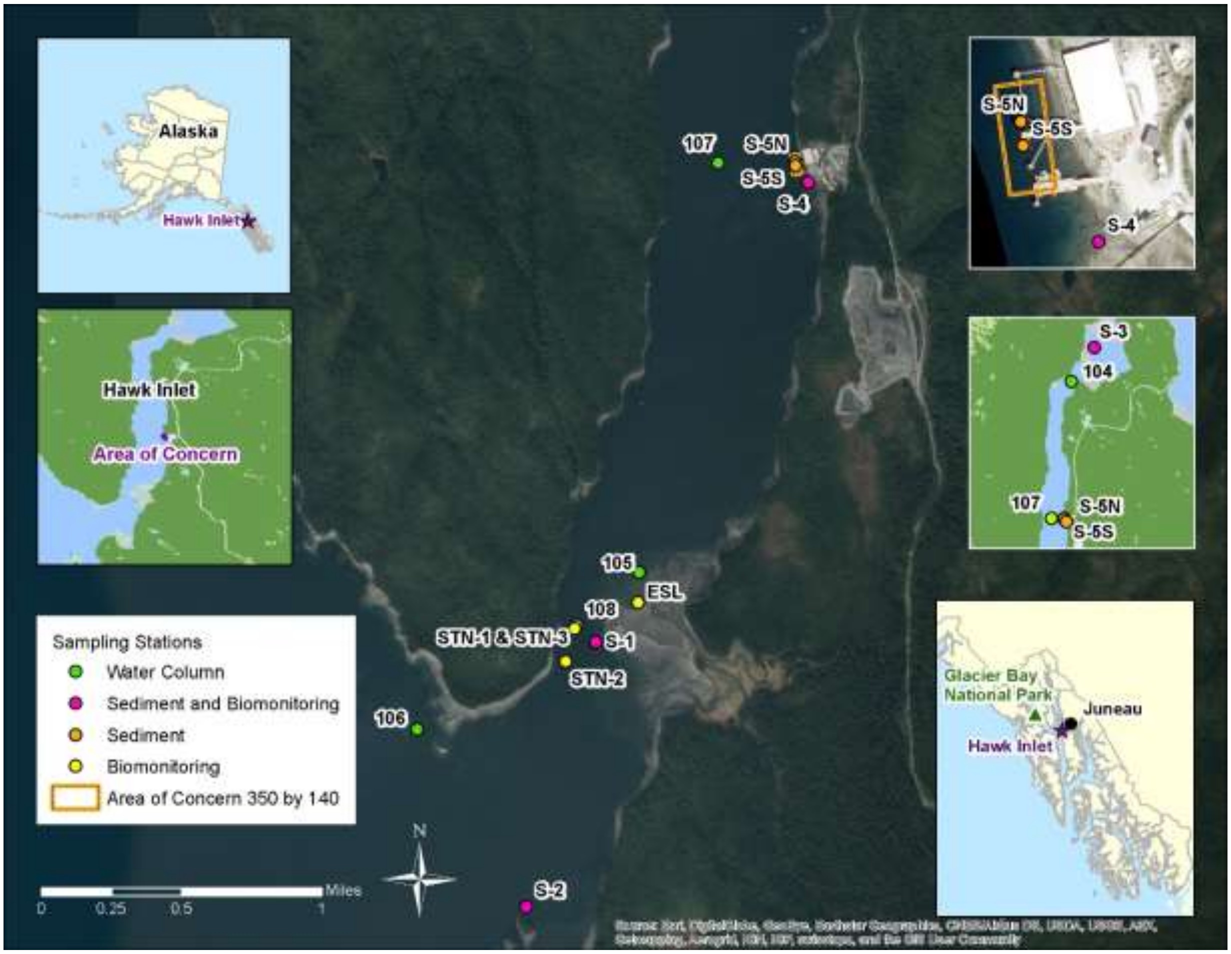


Figure 3-1. Long term sediment, water quality, and biota sampling stations in Hawk Inlet

Note: Area of concern is associated with the 303(d) listing; Station S-5 not shown – exact location is unknown, but assumed coincident with S-5N.

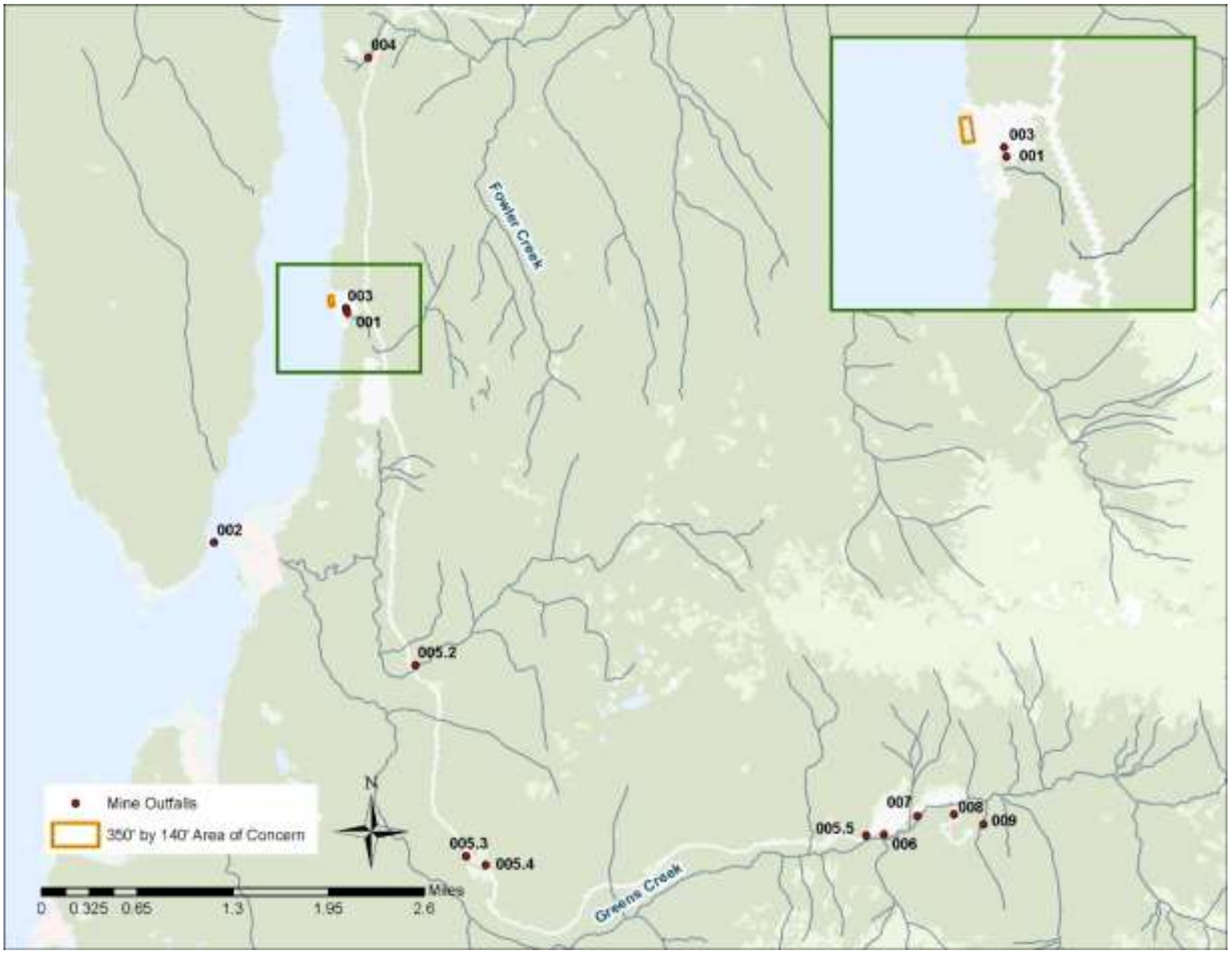


Figure 3-2. Hecla Greens Creek Mining Company outfalls

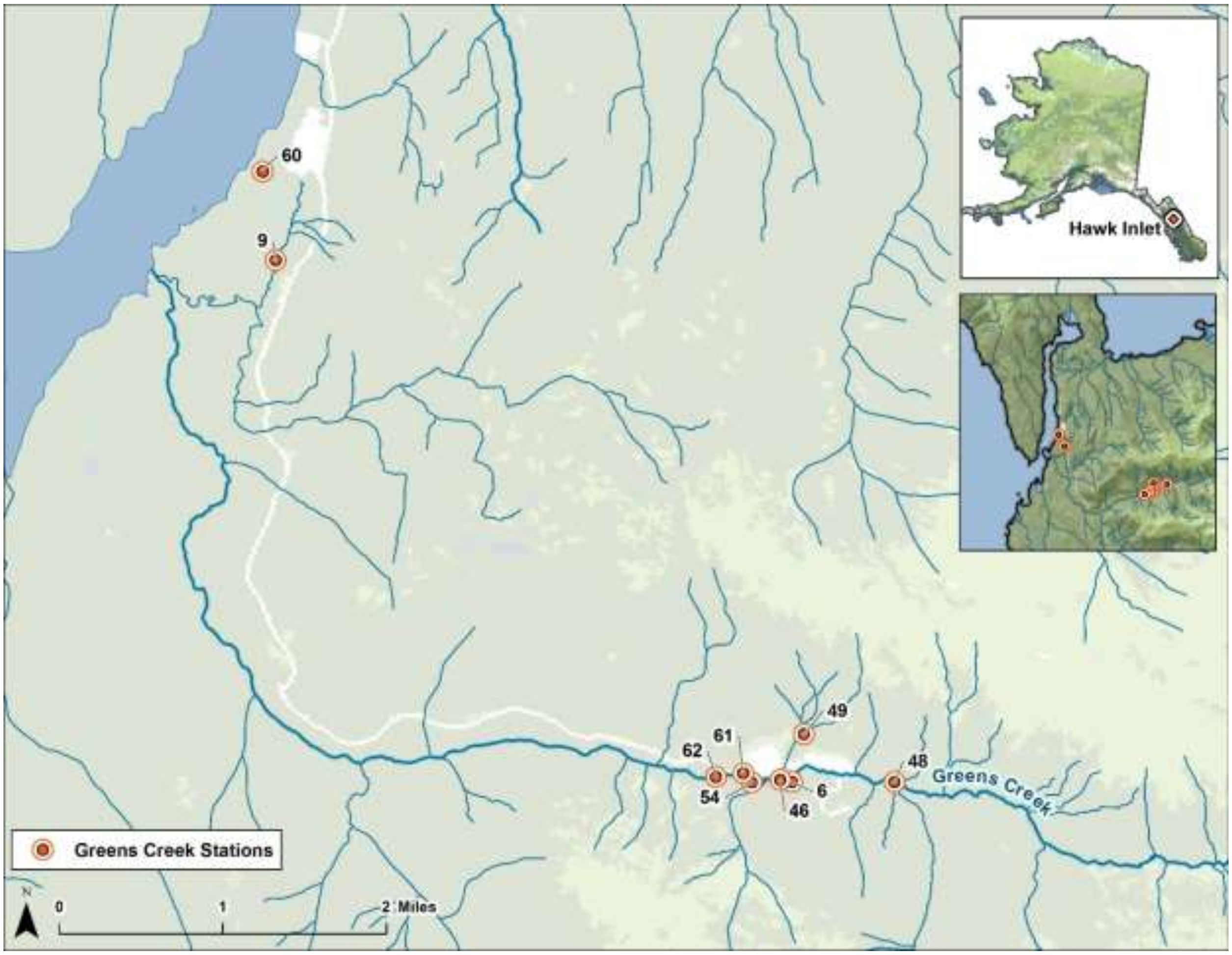


Figure 3-3. Greens Creek and tributaries' sampling stations

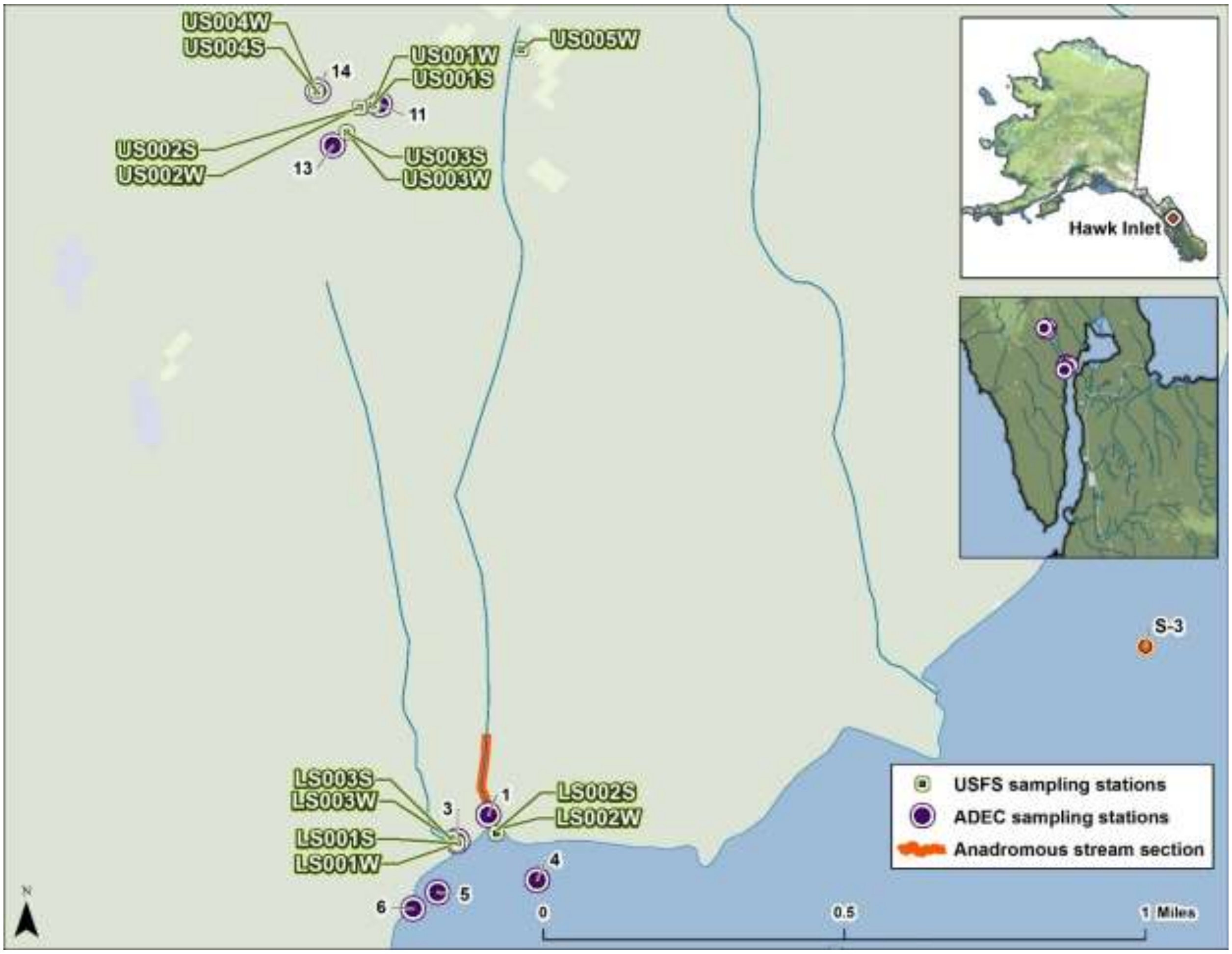


Figure 3-4. Empire Mine monitoring stations

3.2 Impairment, Spatial and Temporal Analyses

The following sections discuss data analyses conducted to evaluate any important trends or impairments in Hawk Inlet. The TMDL was derived through extensive data analysis for the entire inlet. This approach takes into account any known potential sources to the waterbody, both within and outside of the 303(d)-listed area (near the ore concentrate spill). Looking at the data both temporally and spatially provides a review of historic and more recent trends, and characterizes all known potential sources of metals (cadmium, copper, lead, mercury, and zinc) to the inlet.

Detailed analyses of the metals data for cadmium, copper, lead, mercury, and zinc are described below for stations in three main areas in the Hawk Inlet area: (1) tributaries to Hawk Inlet, (2) the abandoned Empire Mine, and (3) Hawk Inlet. Data include water column, sediment, as well as biological data (fish and invertebrate tissue). The data were compared to the appropriate TMDL numeric targets as well as to other applicable screening values to confirm impairment in Hawk Inlet and identify potential sources. The data at the tributaries and Empire Mine were evaluated as potential metals sources to Hawk Inlet, while data in Hawk Inlet were analyzed both spatially and temporally to confirm impairments and identify trends within the inlet itself. The analysis of data from the freshwater areas was used to describe potential sources and natural background contributions to the marine waterway. Potential impairment to these freshwater waterbodies should be evaluated after additional data are collected.

3.2.1 Tributaries to Hawk Inlet

3.2.1.1 Water Quality in Freshwater Tributaries to Hawk Inlet

Post-Mining Water Quality Data in Tributaries to Hawk Inlet

There are nine stations with post-mining (after 1988) cadmium, copper, lead, mercury, and zinc surface water quality data for freshwater tributaries to Hawk Inlet (stations 6, 9, 46, 48, 49, 54, 60, 61, and 62) (Figure 3-3) collected by HGCMC. The hardness-based aquatic life chronic freshwater criteria were calculated for cadmium, copper, lead, and zinc based on the average hardness at each station. The average was used because, in general, there was not a strong variation in the measured hardness values (note: for any exceedance of a criterion calculated using the average hardness value, the criterion was also calculated using the actual hardness measurement to confirm the finding). The mercury criterion of 0.012 µg/L (chronic) is not based on hardness (EPA 2004). Evaluation of freshwater water quality is provided for characterization and discussion of sources. More data collection and evaluation may be needed to characterize potential freshwater impairments.

The only stations showing exceedances of some of the criteria in Hawk Inlet tributaries are stations 9, 60, and 61 (Table 3-2). Station 9 is on Tributary Creek (Figure 3-3). Tributary Creek is a tributary to Zinc Creek, which discharges to Hawk Inlet. Seven exceedances (out of 35 samples; 20 percent) of the lead water quality criterion of 0.76 µg/L were observed at station 9. These exceedances occurred in 2006, 2007, 2008, 2009, 2012, and 2014. The reason for these water quality results at station 9 is unknown. Recent samples collected at this location (20 samples from 2010 to 2015) have been below criteria except for three samples in July and September 2012 and November 2014. The HGCMC Fresh Water Monitoring Report (HGCMC 2012) indicates that the 2012 lead exceedances are the first exceedances for lead in more than 2.5 years. The report indicated that these values are unusual because, compared to other years, fugitive dust emissions were minimal (HGCMC 2012).

Station 60 on Althea Creek showed 18 exceedances (out of 26 samples; 69 percent) of the chronic freshwater mercury water quality criterion of 0.012 µg/L for aquatic life. However, no water samples exceeded the acute freshwater mercury criterion of 2.4 µg/l or chronic marine water criterion of 0.94 µg/l for Hawk Inlet. Mercury has exceeded the water quality criterion at this station on and off from 2007 through 2015. The watershed associated with Station 60 was disturbed when construction began on a new settling pond (Pond 7) in 2004, which resulted in a change in water quality from naturally acidic to alkaline conditions (HGCMC 2015e). HGCMC believes that the increase in pH and alkalinity increases the potential for adsorption of mercury on sediments in the drainage. The pH at station 60 fluctuates seasonally and from year to year and may control the storage and release of mercury from the adsorbed fraction. Dissolution of dust particles from tailings is a potential source of mercury at this location (HGCMC 2015e).

Exceedances of the cadmium, mercury, and zinc water quality criteria occurred at station 61 in May 2013. Station 61 is a new surface water sampling station (as of May 2013) on the floodplain of Greens Creek, downstream of station 6 (Figure 3-3). Although station 61 shows exceedances of the cadmium, mercury, and zinc WQS, the downgradient station (62), which receives this drainage, does not show any exceedances of the WQS (Table 3-2). HGCMC has switched the sampling frequency at station 61 from quarterly to monthly to characterize any issues of concern at this station (HGCMC 2013a). The second cadmium, mercury, and zinc sampling event at station 61 took place in August 2013. Both observations were below WQS at that time.

Table 3-2. Summary of water quality data in Tributaries to Hawk Inlet[a]

Station	Period of record	Number of observations	Minimum (µg/L)	Maximum (µg/L)	Average (µg/L)	Water quality criteria[b,c] (µg/L)	Percent exceeding WQS[b]
Cadmium							
6	10/25/2001–9/14/2015	168	0.022	0.107	0.051	0.17	0%
9	5/17/2006–9/1/2015	31	0.019	0.067	0.036	0.12	0%
46	10/25/2001–8/10/2015	104	0.017	0.061	0.028	0.19	0%
48	10/25/2001–9/14/2015	168	0.023	0.094	0.037	0.16	0%
49	10/25/2001–8/10/2015	119	0.017	0.049	0.029	0.20	0%
54	10/25/2001–9/14/2015	167	0.023	0.096	0.049	0.17	0%
60	5/15/2007–9/1/2015	24	0.011	0.027	0.019	0.12	0%
61	5/6/2013–8/10/2015	21	0.221	2.79	0.43	0.45	5%
62	3/18/2013–9/14/2015	30	0.031	0.088	0.049	0.18	0%
Copper							
6	10/25/2001–9/14/2015	169	0.189	1.67	0.508	5.6	0%
9	5/17/2006–9/1/2015	31	1.34	3.36	1.93	3.7	0%
46	10/25/2001–8/10/2015	104	0.240	1.59	0.574	6.7	0%
48	10/25/2001–9/14/2015	168	0.179	1.38	0.455	5.3	0%
49	10/25/2001–8/10/2015	119	0.268	2.94	0.544	6.8	0%
54	10/25/2001–9/14/2015	167	0.191	1.76	0.508	5.7	0%
60	5/15/2007–9/1/2015	24	0.513	1.65	1.12	3.7	0%
61	5/16/2013–8/10/2015	21	0.170	3.21	0.517	18.6	0%
62	3/18/2013–9/14/2015	30	0.251	1.99	0.554	5.9	0%
Lead							
6	10/25/2001–9/14/2015	167	0.003	0.915	0.070	1.4	0%
9	2/16/1989–9/1/2015	35	0.261	1.49	0.570	0.76	20%
46	10/25/2001–8/10/2015	104	0.003	0.531	0.038	1.7	0%
48	10/25/2001–9/14/2015	168	0.003	0.538	0.025	1.3	0%
49	10/25/2001–8/10/2015	119	0.003	0.357	0.025	1.8	0%

Station	Period of record	Number of observations	Minimum (µg/L)	Maximum (µg/L)	Average (µg/L)	Water quality criteria[b,c] (µg/L)	Percent exceeding WQS[b]
54	10/25/2001–9/14/2015	167	0.003	0.830	0.067	1.4	0%
60	5/15/2007–9/1/2015	24	0.053	0.642	0.282	0.8	0%
61	5/16/2013–8/10/2015	21	0.01	1.46	0.088	6.3	0%
62	3/18/2013–9/14/2015	30	0.004	0.593	0.037	1.5	0%
Mercury							
6	10/25/2001–9/14/2015	168	0.0004	0.00782	0.001	0.012	0%
9	5/17/2006–9/1/2015	31	0.0022	0.0114	0.0043	0.012	0%
46	10/25/2001–8/10/2015	104	0.0006	0.0050	0.0020	0.012	0%
48	10/25/2001–9/14/2015	168	0.0003	0.0080	0.0010	0.012	0%
49	10/25/2001–8/10/2015	119	0.0006	0.0048	0.0016	0.012	0%
54	10/25/2001–9/14/2015	167	0.0030	0.0048	0.0010	0.012	0%
60	5/17/2006–9/1/2015	26	0.0026	0.0227	0.0132	0.012	69%
61	5/16/2013–8/10/2015	21	0.0001	0.2000	0.0097	0.012	5%
62	3/18/2013–9/14/2015	30	0.0004	0.0050	0.0010	0.012	0%
Zinc							
6	10/25/2001–9/14/2015	168	1.61	16.7	6.62	74	0%
9	5/17/2006–9/1/2015	31	0.02	10.8	5.72	46	0%
46	10/25/2001–8/10/2015	104	1.01	9.6	2.35	88	0%
48	10/25/2001–9/14/2015	168	1.24	11.9	3.28	70	0%
49	10/25/2001–8/10/2015	119	0.99	9.2	2.46	90	0%
54	10/25/2001–9/14/2015	167	1.81	15.0	6.24	75	0%
60	5/15/2007–9/1/2015	24	2.15	8.4	5.56	49	0%
61	5/16/2013–8/10/2015	21	45.90	393	98.39	247	5%
62	3/18/2013–9/14/2015	30	2.38	11.1	6.19	78	0%

[a] Data Sources: HGCMC 2002, 2003, 2004, 2005, 2006, 2007, 2010, 2011, 2012, 2013a, and 2015c.

[b] The water quality data in freshwater tributaries to Hawk Inlet were compared to Alaska water quality criteria for toxic and other deleterious organic and inorganic substances in fresh waters (Source: 18 AAC 70.020 [ADEC 2012]).

[c] Water quality criteria for cadmium, copper, lead and zinc are based on average hardness values at each stations. The range of hardness for each station is as follows: Station 6 (21.9 – 86.3); Station 9 (21.6 – 45.9); Station 46 (38.2 – 101.0); Station 48 (18.4 – 78.2); Station 49 (36.2 – 101.0); Station 54 (23.5 – 129.0); Station 60 (18.9 – 209.0); Station 61 (168.0-291.0); Station 62 (27.7 – 90.6).

Pre-Mining Water Quality Data in Tributaries to Hawk Inlet

Pre-mining (1978 – 1980) water quality data were collected from six stations along Greens Creek (Richkus and Johnson 1981). The exact locations of these stations were not provided in the Richkus and Johnson (1981) report so they are not illustrated on a map; however, the average results from the sampling effort are presented in Table 3-3. There were no associated hardness data for comparison to the hardness-based freshwater metals criteria for cadmium, copper, lead or zinc. There is a non-hardness based freshwater mercury criterion (0.012 µg/L); however, all of the mercury observations were below the detection limit (2 µg/L) and could not be directly compared to the criterion as the detection limit is greater than the criterion.

All data were compared to the more recent post-mining data (Table 3-2) to determine if there has been any change in cadmium, copper, lead, mercury and zinc concentrations in the tributaries to Hawk Inlet since mining at Greens Creek began in 1989. All cadmium, lead and mercury data were below the detection limits (2, 10 and 2 µg/L, respectively) and therefore, were not useful in comparison to existing concentrations of those metals in freshwater tributaries. The pre-mining copper observations ranged from 3 to 30 µg/L although it appears that 30 µg/L may be an outlier. These values are similar to the maximum copper concentrations presented in the current tributary water quality data in Table 3-2, but above the average concentrations. The pre-mining zinc observations ranged from 5 to 23 µg/L. These values fall within the range of maximum and average zinc concentrations presented in the current tributary water quality data in Table 3-2. The sample size of the pre-mining data set is too small for a statistical comparison with the post-mining dataset, but the available pre- and post-mining data do not suggest an increase in the concentrations of the metals of concern in freshwater tributaries since mining began at Greens Creek Mine.

Table 3-3. Pre-mining water quality data in tributaries to Hawk Inlet

Station[a]	Period of record	Number of observations	Average concentration (µg/L)	Water quality criteria (µg/L)	Percent exceeding WQS
Cadmium					
GCBA1	April 1978 – May 1980	4	<2	N/A	N/A
GCBA2		4	<2		
GCBA6		23	<2		
Near GCBA3		23	<2		
GCBA5		21	<2		
Near BSBA7		11	<2		
Copper					
GCBA1	April 1978 – May 1980	4	3	N/A	N/A
GCBA2		4	30		
GCBA6		23	3		
Near GCBA3		23	3		
GCBA5		21	4		
Near BSBA7		11	3		
Lead					
GCBA1	April 1978 – May 1980	4	<10	N/A	N/A
GCBA2		4	<10		
GCBA6		23	<10		
Near GCBA3		23	<10		
GCBA5		21	<10		
Near BSBA7		11	<10		
Mercury					
GCBA1	April 1978 – May 1980	4	<2	0.012	N/A
GCBA2		4	<2		
GCBA6		23	<2		
Near GCBA3		23	<2		

Station[a]	Period of record	Number of observations	Average concentration (µg/L)	Water quality criteria (µg/L)	Percent exceeding WQS
GCBA5		21	<2		
Near BSBA7		11	<2		
Zinc					
GCBA1	April 1978 – May 1980	4	5	N/A	N/A
GCBA2		4	7		
GCBA6		23	10		
Near GCBA3		23	23		
GCBA5		21	9		
Near BSBA7		11	18		

[a] Data Source: Richkus and Johnson (1981); N/A = not applicable

3.2.1.2 HGCMC Outfall Data

There are several outfalls at the HGCMC site (outfalls 001 through 009; see Figure 3-2). The only outfalls from the HGCMC (APDES permit # AK0043206) permitted to discharge directly to Hawk Inlet are outfalls 002 and 003 (Figure 3-2). The APDES-permitted discharge site 002 is an underwater discharge point in Hawk Inlet. All mine, mill, process, and the majority of on-site stormwater runoff is collected, treated, and discharged through this outfall. Discharge is limited and monitored in accordance with the HGCMC permit requirements (HGCMC 2015b). The data at outfall 002 (ADEC 2015a) were compared to their applicable permit limits (Table 3-4). All water quality data at outfall 002 met the applicable permit limits. See Section 4.1.1 for more details on the current permits for the HCGMC.

Outfall 003 is the only stormwater outfall that is permitted to discharge directly to Hawk Inlet; however, as of 2011, tanks were installed to collect seepage around outfall 003 as well as discharge from outfall 003 (HGCMC 2015d). These flows are captured and sent to the wastewater treatment plant. Numeric effluent limits were not developed for individual stormwater outfalls because of the difficulty in developing numeric limits for stormwater discharges that are variable in flow and pollutant concentrations, and the uncertainty regarding the effect of the stormwater discharges on the receiving waters. For the stormwater outfall, the permit requires the HGCMC to implement corrective action(s) if a stormwater discharge exceeds a water quality criterion and results in a statistically significant reduction in receiving water quality.

Table 3-4. Summary of Outfall 002 water quality data

Parameter of concern	Period of record	Number of observations	Minimum (µg/L)	Maximum (µg/L)	Average (µg/L)	Percent exceeding permit limit[a]
Cadmium	7/3/2007–12/30/2013	314	0.06	2	0.53	0%
Copper			0.1	26	3.8	0%
Lead			2.3	174	21.4	0%
Mercury			0.05	0.38	0.18	0%
Zinc			3.8	234	49.8	0%

[a] Permit limits: Cadmium = 100 µg/L; Copper = 99 µg/L; Lead = 321 µg/L; Mercury = 1.9 µg/L; Zinc = 1,000 µg/L

3.2.1.3 Biological Data in Freshwater Tributaries to Hawk Inlet

Post-mining Biological Data in Tributaries to Hawk Inlet

Four stations in tributaries to Hawk Inlet include post-mining (after 1988) fish tissue data (stations 6, 9, 48, and 54; see Figure 3-3) collected by ADF&G (Durst and Jacobs 2010; Kanouse 2015). Station 48 is upstream of all mining, except exploratory drilling, and the data are used as reference data for comparison to station 54 data collected downstream. ADEC has not adopted tissue quality standards for the evaluation of impacts to harvesting for consumption of raw mollusks or other raw aquatic life;

therefore, the available fish tissue data were compared to the EPA tissue quality guidelines for recreational and subsistence fisheries (USEPA 2000, 2001) to determine whether metals in the sediments are having a deleterious effect on tissue concentrations. The fish tissue data were compared to both the recreational and subsistence EPA recommended values for cadmium and mercury (Table 2-4; values are not available for copper, lead, and zinc) because the downstream waterway, Hawk Inlet, is used for subsistence fishing by the community of Angoon. Specific information on where subsistence gathering occurs in Hawk Inlet is unavailable. In addition, Dolly Varden Char, sampled in the freshwater segments, are part of a subsistence diet. While Hawk Inlet is used for subsistence fishing, the freshwater tributaries near the Greens Creek Mine are not generally used for fishing since they are on property owned and leased by HGGMC. Station 9 is located on Tributary Creek, while stations 6, 48, and 54 are located on Greens Creek. Dolly Varden Char are abundant in Greens Creek and moderately occur in Tributary Creek (Oceanus Alaska 2003). Greens Creek does support anadromous runs of Dolly Varden Char. Evaluation of freshwater fish tissue quality is provided for background and discussion of sources. More data collection and evaluation may be needed to characterize potential freshwater impairments.

All of the tissue data from the freshwater tributaries are whole body dry weight samples. The EPA recommended values are based on wet weight; therefore, the dry weight data were converted to wet weight for comparison to the values using the assumption that fish and invertebrates have a moisture content of 80 and 83.3 percent, respectively (USEPA 2000, 2001). Note that “composites of skin-on fillets and edible portions of shellfish are recommended for contaminant analyses in screening studies to provide conservative estimates of typical exposures for the general population. However, if the target population of consumers includes primarily ethnic or subsistence fishers who consume the whole fish or tissues of the fish not typically consumed by the general population, state monitoring programs should include the fish sample type associated with the target consumers’ dietary and/or culinary preference” (USEPA 2000).

Table 3-5 presents a summary of the tributary tissue data. None of the tissue samples exceeded the recreational EPA recommended values. Twelve of the 95 (13 percent) Dolly Varden Char samples at station 9 and one of the 89 (1 percent) samples at station 48 exceed the cadmium subsistence EPA recommended value of 0.491 mg/kg. These exceedances at station 9 occurred in 2007, 2013, and 2015 while the exceedance at station 48 occurred in 2012. For total mercury, 27 of the 34 (79 percent) Dolly Varden Char samples at station 9 and two of the 34 (6 percent) samples at station 48 exceed the methylmercury subsistence EPA recommended value of 0.03 mg/kg (note: as a conservative approach, total mercury data were compared to the recommended methylmercury value because most mercury in fish and shellfish is present as methylmercury [USEPA 2001]). The exceedances at station 9 occurred in 2010, 2012, 2013, 2014 and 2015 while the exceedances at station 48 occurred in 2013 and 2014.

Table 3-5. Summary of tissue data in tributaries to Hawk Inlet

Station	Period of record	Tissue type	Number of observations	Minimum (mg/kg)	Maximum (mg/kg)	Average (mg/kg)	Recreational value (mg/kg)[a]	Percent exceeding recreational value	Subsistence value (mg/kg)[a]	Percent exceeding subsistence value
Cadmium										
6	7/23/2001–7/21/2011	Dolly Varden Char	13	0.112	0.388	0.183	4	0%	0.491	0%
9	6/21/2000–7/14/2015	Dolly Varden Char	95	0.044	1.272	0.272	4	0%	0.491	13%
48	7/23/2001–7/16/2015	Dolly Varden Char	89	0.094	0.532	0.219	4	0%	0.491	1%
54	7/23/2001–7/15/2015	Dolly Varden Char	89	0.042	0.44	0.196	4	0%	0.491	0%
54	6/21/2000	Coho Salmon	6	0.132	0.294	0.203	4	0%	0.491	0%
Mercury[b]										
9	7/20/2010–7/14/2015	Dolly Varden Char	34	0.037	0.116	0.063	0.3	0%	0.03	79%
48	7/21/2010–7/16/2015	Dolly Varden Char	34	0.018	0.055	0.031	0.3	0%	0.03	6%
54	7/20/2010–7/15/2015	Dolly Varden Char	34	0.014	0.036	0.024	0.3	0%	0.03	0%

[a] Compared to the cadmium recreational and subsistence EPA recommended values of 4 and 0.491 mg/kg wet weight, respectively and to the methylmercury recreational and subsistence EPA recommended values of 0.3 and 0.03 mg/kg wet weight, respectively (USEPA 2000, 2001).

[b] Data are in total mercury, but are compared to the methylmercury EPA recommended values. As noted by USEPA, “because most mercury in fish and shellfish is present primarily as methylmercury and because of the relatively high cost of analyzing for methylmercury, it is recommended that total mercury be analyzed and the conservative assumption be made that all mercury is present as methylmercury” (USEPA 2000).

Pre-mining Biological Data in Tributaries to Hawk Inlet

Pre-mining (1980 and 1981) fish tissue data were collected from Greens Creek and Zinc Creek in 1980 (Richkus and Johnson 1981) and a tributary to Zinc Creek in 1981 (Holland et al. 1981). The exact locations of these stations were not provided in their respective reports. Therefore, the stations are not shown on a map, but the average concentration reported in these studies are presented in Table 3-6. Greens Creek has a set of natural falls approximately 3.6 and 5 miles upstream from the mouth that are barriers to fish passage, including salmon (Tetra Tech 2012); however, the area below the falls is considered to contain good to excellent spawning habitat for pink, chum, and coho salmon. Rearing habitat is generally fair to good for salmonids in the main stem and excellent where the channel is braided. A natural upstream barrier also occurs on Zinc Creek at approximately river mile 2.2. High quality salmon spawning habitat occurs in the lower reaches of Zinc Creek, as well as good coho rearing habitat. The downstream portion of Tributary Creek also provides good rearing habitat for coho salmon and the lower reaches are accessible to salmon, providing limited spawning habitat for coho, chum, and pink salmon.

As with the recent fish tissue data, the available pre-mining fish tissue data were compared to the EPA tissue quality guidelines for recreational and subsistence fisheries (USEPA 2000, 2001) to evaluate whether metals in the sediments are having a deleterious effect on tissue concentrations. The pre-mining fish tissue data were compared to the EPA recommended values for cadmium and mercury (Table 2-4; values are not available for copper, lead, and zinc). The post-mining cadmium and mercury tissue data are shown in Table 3-5. None of the pre-mining cadmium tissue data exceeded the recommended EPA screening values for cadmium (4 and 0.491 mg/kg wet weight), while the post-mining data (2000-2015) do show some exceedances of the recommended cadmium subsistence fishing screening value in Tributary Creek and Greens Creek. The pre-mining data demonstrate exceedances of the EPA recommended mercury screening values for recreational and subsistence fisheries (0.3 and 0.03 mg/kg wet weight). The average mercury concentration in tissue from juvenile Coho salmon exceed EPA's recommended recreational screening value of 0.3 mg/kg wet weight in 1981 at a station located on a tributary to Zinc Creek. There are no exceedances of the recommended recreational screening value at any other sampling locations. The pre-mining mercury tissue samples exceed the recommended subsistence fishing screening value of 0.03 mg/kg wet weight at all sampling locations except for lower Greens Creek.

Table 3-6. Summary of average pre-mining tissue data in tributaries to Hawk Inlet

Station	Date of sample	Tissue type	Number of observations	Average concentration[a,b] (mg/kg wet weight)	Recreational value (mg/kg)[c,d]	Exceeding recreational value	Subsistence value (mg/kg)[c,d]	Exceeding subsistence value
Cadmium								
Upper Greens Creek	8/1/1980	Dolly Varden Char	5	0.14	4	No	0.491	No
lower Greens Creek	8/1/1980	Dolly Varden Char	5	0.01	4	No	0.491	No
Zinc Creek	8/1/1980	Coho salmon - small juveniles	7	0.03	4	No	0.491	No
Zinc Creek	8/1/1980	Coho salmon - large juveniles	5	0.04	4	No	0.491	No
Zinc Creek	8/1/1980	sculpin	5	0.05	4	No	0.491	No
Tributary to Zinc Creek	7/8/1981	Coho salmon juveniles	9	0.12	4	No	0.491	No
Tributary to Zinc Creek	7/8/1981	Coho salmon juveniles	9	0.11	4	No	0.491	No
Tributary to Zinc Creek	7/8/1981	Coho salmon juveniles	9	0.08	4	No	0.491	No
Tributary to Zinc Creek	7/8/1981	Coho salmon juveniles	9	0.11	4	No	0.491	No
Tributary to Zinc Creek	7/8/1981	Coho salmon juveniles	9	0.11	4	No	0.491	No
Mercury								
Upper Greens Creek	8/1/1980	Dolly Varden Char	5	0.05	0.3	No	0.03	Yes
Lower Greens Creek	8/1/1980	Dolly Varden Char	5	0.02	0.3	No	0.03	No
Zinc Creek	8/1/1980	Coho salmon - small juveniles	7	0.07	0.3	No	0.03	Yes
Zinc Creek	8/1/1980	Coho salmon - large juveniles	5	0.06	0.3	No	0.03	Yes
Zinc Creek	8/1/1980	sculpin	5	0.06	0.3	No	0.03	Yes
Tributary to Zinc Creek	7/8/1981	Coho salmon juveniles	9	0.95	0.3	Yes	0.03	Yes
Tributary to Zinc Creek	7/8/1981	Coho salmon juveniles	9	0.11	0.3	No	0.03	Yes
Tributary to Zinc Creek	7/8/1981	Coho salmon juveniles	9	0.08	0.3	No	0.03	Yes
Tributary to Zinc Creek	7/8/1981	Coho salmon juveniles	9	0.10	0.3	No	0.03	Yes
Tributary to Zinc Creek	7/8/1981	Coho salmon juveniles	9	0.09	0.3	No	0.03	Yes

[a] Data Sources: Richkus and Johnson (1981) and Holland et al. (1981)

[b] Concentration is an average value based on all samples. This is how the data were presented in Richkus and Johnson (1981) and Holland et al. (1981).

[c] Compared to the cadmium recreational and subsistence EPA recommended values of 4 and 0.491 mg/kg wet weight, respectively and to the methylmercury recreational and subsistence EPA recommended values of 0.3 and 0.03 mg/kg wet weight, respectively (USEPA 2000, 2001).

[d] Data are in total mercury, but are compared to the methylmercury EPA recommended values. As noted by USEPA, “because most mercury in fish and shellfish is present primarily as methylmercury and because of the relatively high cost of analyzing for methylmercury, it is recommended that total mercury be analyzed and the conservative assumption be made that all mercury is present as methylmercury” (USEPA 2000).

3.2.1.4 Sediment Quality Data in Freshwater Tributaries to Hawk Inlet

In an effort to identify all sources of metals to Hawk Inlet, sediment observations from three freshwater stations in tributaries to Hawk Inlet (9, 48, and 54; see Figure 3-3) collected by ADF&G were analyzed. Station 9 is in lower Tributary Creek, station 48 is in upper Greens Creek, and station 54 is in lower Greens Creek (below D-pond). Few sediment data are available at these stations. There is one sample for each metal of concern at each station collected in July 2013.

Alaska does not have numeric sediment quality criteria for the metals of concern. Therefore, the sediment data from these stations were compared to the freshwater lowest effect level (LEL) and PEL NOAA SQuiRT values. Data were also compared to the marine sediment ERLs being applied as targets in this TMDL (since the sediment in the tributaries likely makes its way downstream into Hawk Inlet). The LEL is a level of sediment contamination that can be tolerated by the majority of benthic organisms. If a single parameter equals or exceeds the LEL screening value, it is anticipated that material represented by that sample could have an adverse effect on some benthic resources. If all analytes are below LELs, no significant effects are predicted. The PEL is a chemical concentration that is likely to cause an adverse effect (Buchman 2008). Table 3-7 presents the screening values that were used for review of the tributary sediment data.

Table 3-7. Screening values for freshwater and marine sediment applied to tributaries of Hawk Inlet

Parameter of concern	Freshwater LEL (mg/kg)	Freshwater PEL (mg/kg)	Marine ERL (mg/kg)
Cadmium	0.6	3.53	1.2
Copper	16	197	34
Lead	31	91.3	46.7
Mercury	0.2	0.486	0.15
Zinc	120	315	150

Source: Buchman 2008

Table 3-8 shows the available sediment data for all three stations and whether or not they exceeded the LEL, PEL, and ERL screening values. Cadmium, copper, and zinc exceeded the LELs and ERLs at stations 48 and 54. The only exceedance of a PEL screening value was cadmium at station 54. None of the metals exceeded any of the screening values at station 9 on Tributary Creek and none of the stations exceeded the lead or mercury screening values. In summary, cadmium, copper, and zinc exceeded the screening values in Greens Creek. This does not necessarily indicate that the sediment in Greens Creek is impaired by metals. There might be naturally elevated background levels of metals in sediment in the area and only one data point was available at each station. Continued monitoring would provide a better representation of metals concentrations in Greens Creek sediments.

Table 3-8. Comparison of tributary metals sediment data to LEL, PEL and ERL

Station	Sample date	Sediment concentration (mg/kg)	Exceeds freshwater LEL	Exceeds freshwater PEL	Exceeds marine ERL
Cadmium					
9	7/23/2013	0.39	No	No	No
48	7/25/2013	1.84	Yes	No	Yes
54	7/24/2013	3.63	Yes	Yes	Yes
Copper					
9	7/23/2013	15.5	No	No	No
48	7/25/2013	60.8	Yes	No	Yes
54	7/24/2013	51.7	Yes	No	Yes

Station	Sample date	Sediment concentration (mg/kg)	Exceeds freshwater LEL	Exceeds freshwater PEL	Exceeds marine ERL
Lead					
9	7/23/2013	11.8	No	No	No
48	7/25/2013	12.8	No	No	No
54	7/24/2013	29.8	No	No	No
Mercury					
9	7/23/2013	0.0357	No	No	No
48	7/25/2013	0.0476	No	No	No
54	7/24/2013	0.0784	No	No	No
Zinc					
9	7/23/2013	68.9	No	No	No
48	7/25/2013	232	Yes	No	Yes
54	7/24/2013	232	Yes	No	Yes

3.2.2 Empire Mine

Data near the abandoned Empire Mine (see Section 4.2.1 for more details) site were collected in August and September 2014 as part of a cooperative effort between ADEC, ADF&G, and the U.S. Forest Service (USFS) (Figure 3-4) to represent conditions at this abandoned mine (both upper and lower areas). Past reports note field observations of a mass wasting event in the watershed above station S-3 (Oceanus Alaska 2003). ADF&G staff (personal communication 2015) reported that there is no evidence of a mass wasting event near Empire Mine or above station S-3 based on observations made through years of flying over the area when doing biological monitoring for Greens Creek mine. The August and September 2014 data were used to determine if Empire Mine is a potential source of metals to Hawk Inlet.

3.2.2.1 Empire Mine Water Quality

Surface water samples near Empire Mine were collected by ADEC at five freshwater sampling stations (1, 3, 11, 13, and 14; see Figure 3-4). Stations 1 and 3 are at the lower camp of the abandoned mine (ADEC 2014). Station 1 is 200 to 250 ft upstream from Hawk Inlet and station 3 is on a small stream adjacent to the main stream. Station 11 is adjacent to tailings piles at the upper camp, station 13 is in the water flowing from the adit at the upper camp, and station 14 is above the upper camp in an area suspected to represent water conditions not impacted by the Empire Mine. All of the observations at these stations were below the detection limits and, therefore, not exceeding water quality criteria for cadmium, copper, lead, or mercury (ADEC 2012). Zinc data were not collected during this monitoring event.

The USFS collected cadmium, copper, lead, mercury, and zinc samples at eight freshwater stations at Empire Mine in September 2014. Five samples were at the upper site (stations US002W, US003W, US001W, US005W, and US004W) and three samples were at the lower site (stations LS002W, LS001W, and LS003W) (Figure 3-4). Most of the data collected were non-detects (Table 3-9). All but one of the cadmium observations were non-detects; all but two of the copper observations were non-detects; and all of the lead and mercury observations were non-detects. The only metal that was detected in all samples was zinc. The zinc observations ranged from 6.14 µg/L at station US0004W to 1,260 µg/L at station US003W.

No hardness data were collected at the time of the metals sampling at Empire Creek. Therefore, the applicable water quality criteria for cadmium, copper, and zinc, which are hardness-based (ADEC 2012), could not be calculated and compared to the observations. Hardness data are expected to be collected during the next sampling effort.

Table 3-9. USFS water quality data at Empire Mine (samples collected September 16-19, 2014)

Number of observations	Station	Results[a,b] (µg/L)
Cadmium		
1	US002W	ND
1	US003W	11
1	US001W	ND
1	US005W	ND
2	LS002W	ND
1	LS001W	ND
1	US004W	ND
1	LS003W	ND
Copper		
1	US002W	ND
1	US003W	119
1	US001W	ND
1	US005W	ND
2	LS002W	ND
1	LS001W	3.84
1	US004W	ND
1	LS003W	ND
Lead		
1	US002W	ND
1	US003W	ND
1	US001W	ND
1	US005W	ND
2	LS002W	ND
1	LS001W	ND
1	US004W	ND
1	LS003W	ND
Mercury		
1	US002W	ND
1	US003W	ND
1	US001W	ND
1	US005W	ND
2	LS002W	ND
1	LS001W	ND
1	US004W	ND
1	LS003W	ND
Zinc		
1	US002W	9.41
1	US003W	1,260
1	US001W	13
1	US005W	6.26
2	LS002W	14.6, 17.2
1	LS001W	21.4
1	US004W	6.14
1	US003W	21.2

[a] *Source:* Portage, Inc. 2015

[b] ND = Non-detect

3.2.2.2 Empire Mine Biological Data

Wet weight clam and mussel samples were collected at three stations (4, 5, and 6) on August 6, 2014, at Empire Mine (ADEC 2014) (Figure 3-4) by ADEC. Clams were collected at stations 4 and 5 while mussels were collected at station 6. Station 4 was adjacent to the main creek, station 5 was adjacent to a smaller creek (near station 3), and station 6 was below the dock pilings. In addition to the clam and mussel samples, 10 Dolly Varden Char samples were collected in the anadromous portion of Empire Creek on August 6, 2014 (ADF&G 2015) (Figure 3-4).

Table 3-10 presents the tissue results at Empire Mine. None of the samples exceeded the recreational EPA recommended values of 4 mg/kg cadmium or 0.3 mg/kg methylmercury (Table 2-4; USEPA 2000, 2001). There is one exceedance of the cadmium subsistence EPA recommended value of 0.491 mg/kg (mussel at station 6) and all 10 of the total mercury Dolly Varden Char tissue samples exceed the methylmercury subsistence EPA recommended value of 0.03 mg/kg (note: as a conservative approach, total mercury data were compared to the methylmercury EPA recommended value because most mercury in fish and shellfish is present as methylmercury [USEPA 2000]). The fish tissue data were compared to both the recreational value and the subsistence value because Hawk Inlet is used for subsistence fishing by the community of Angoon. Specific information on where subsistence gathering occurs in Hawk Inlet is unavailable. In addition, Dolly Varden Char, which were sampled in the freshwater segment, are part of a subsistence diet. Evaluation of freshwater fish tissue quality is provided for background and discussion of sources. More data collection and evaluation may be needed to characterize potential freshwater impairments, especially since the available data were all collected on a single day.

In addition to comparison to the EPA recommended recreational and subsistence values for cadmium and mercury, the marine species (clams and mussels) were also compared to the DHSS recommended maximum safe tissue concentrations for cadmium, mercury, and copper (DHSS 2016). None of the clam or mussels tissue data exceed the DHSS recommended maximum safe tissue values.

Table 3-10. Tissue data at Empire Mine

Sample date	Number of observations	Station	Tissue type	Tissue concentration (mg/kg)	Exceeds recreational EPA recommended value[a]	Exceeds subsistence EPA recommended value[a]	Exceeds DHSS recommended value[b]
Cadmium							
8/6/2014	1	4	Clams[c]	0.25	No	No	No
		5		0.23	No	No	No
		6	Mussels[c]	0.61	No	Yes	No
8/6/2014	10	Anadromous section of Empire Creek	Dolly Varden Char[d]	0.097	No	No	N/A
				0.13	No	No	N/A
				0.11	No	No	N/A
				0.16	No	No	N/A
				0.12	No	No	N/A
				0.11	No	No	N/A
				0.08	No	No	N/A
				0.14	No	No	N/A
				0.13	No	No	N/A
				0.17	No	No	N/A

Sample date	Number of observations	Station	Tissue type	Tissue concentration (mg/kg)	Exceeds recreational EPA recommended value[a]	Exceeds subsistence EPA recommended value[a]	Exceeds DHSS recommended value[b]
Mercury[e]							
8/6/2014	1	4	Clams[c]	0.021	No	No	No
		5		0.019	No	No	No
		6	Mussels[c]	0.012	No	No	No
8/6/2014	10	Anadromous section of Empire Creek	Dolly Varden Char[d]	0.059	No	Yes	N/A
				0.079	No	Yes	N/A
				0.065	No	Yes	N/A
				0.11	No	Yes	N/A
				0.058	No	Yes	N/A
				0.068	No	Yes	N/A
				0.087	No	Yes	N/A
				0.083	No	Yes	N/A
				0.072	No	Yes	N/A
				0.066	No	Yes	N/A
Copper							
8/6/2014	1	4	Clams[c]	1.6	N/A	N/A	No
		5		1.5	N/A	N/A	No
		6	Mussels[c]	0.8	N/A	N/A	No

[a] Compared to the cadmium recreational and subsistence EPA recommended values of 4 and 0.491 mg/kg wet weight, respectively, and to the methylmercury recreational and subsistence EPA recommended values of 0.3 and 0.03 mg/kg wet weight, respectively (USEPA 2000, 2001). No recommended values are available for copper (N/A = not applicable).

[b] Compared to DHSS recommended maximum values for cadmium, mercury and copper in clams and mussels. The DHSS recommended values apply to marine species only; therefore, they were not compared to the Dolly Varden Char samples (N/A = not applicable). Cadmium: 33.2 and 137 mg/kg wet weight in clams and mussels, respectively. Mercury: 4.89 and 20.2 mg/kg wet weight in clams and mussels, respectively. Copper: 1,635 and 6,770 mg/kg wet weight in clams and mussels, respectively.

[c] *Source:* ADEC 2015a

[d] *Source:* ADF&G 2015

[e] Data are in total mercury, but are compared to the methylmercury EPA recommended values. As noted by USEPA, "because most mercury in fish and shellfish is present primarily as methylmercury and because of the relatively high cost of analyzing for methylmercury, it is recommended that total mercury be analyzed and the conservative assumption be made that all mercury is present as methylmercury" (USEPA 2000).

3.2.2.3 Empire Mine Sediment Quality

Table 3-11 presents a summary of the sediment data collected at Empire Mine. In August 2014, ADEC collected sediment samples at four stations (1, 6, 11, and 14; see Figure 3-4) and analyzed them for cadmium, copper, lead, and mercury (zinc was not included in the analysis). Station 1 is located at the lower camp on the main stream about 200 to 250 ft upstream of Hawk Inlet (ADEC 2014). Station 6 is a marine site below the dock pilings, in intertidal sediment. Stations 11 and 14 are freshwater sites at the upper camp. Station 11 is below two piles of tailings at the upper camp and station 14 is located above all of the mine workings. It is anticipated that station 14 is upgradient of all potential impacts of past mining activities and could be considered a background site.

Sediment samples for cadmium, copper, lead, mercury, and zinc were collected by the USFS at seven locations in September 2014 (stations US001S, US003S, US002S, LS002S, LS001S, LS003S, and US004S; see Figure 3-4). Four locations were sampled at the upper mine camp (stations US001S, US003S, US002S, and US004S) and three locations were sampled at the lower mine camp (stations LS002S, LS001S, and LS003S). The only sampling station not on the main stem of the stream running through the Empire Mine location is station US003S, which is adjacent to the stream in Canyon Bog (Portage, Inc. 2015).

As mentioned in Section 2.1.3, Alaska does not have numeric sediment quality criteria for the metals of concern. Therefore, sediment data from the Empire Mine stations were compared to the freshwater LEL and PEL values (Buchman 2008). Data were also compared to the marine sediment ERLs being applied as targets in this TMDL (since the sediment from the abandoned Empire Mine can theoretically migrate downstream into Hawk Inlet). Table 3-7 presents the screening values used in the data analyses.

The sediment observations at station 6 were compared only to the marine sediment ERLs for cadmium, copper, mercury, and lead since this is considered a marine site. All observations for cadmium, copper, lead, and mercury were below the marine ERLs at this station.

The freshwater cadmium observations exceeded the marine cadmium ERL screening benchmark (1.2 mg/kg) at all Empire Mine sampling locations except for station US003S in the bog adjacent to the stream at the upper camp. All freshwater cadmium observations exceeded the freshwater LEL of 0.6 mg/kg. In addition, four exceedances of the freshwater cadmium PEL of 3.53 mg/kg were observed (at stations 1, LS001S, and LS003S). All of the freshwater cadmium exceedances of the screening benchmark were at the lower camp.

The freshwater copper observations exceeded the marine copper ERL screening benchmark (34 mg/kg) at seven of the eleven stations sampled (1, 11, US001S, US003S, LS002S, LS001S, and LS003S). The freshwater copper LEL (16 mg/kg) was exceeded at all stations except station 14, which is upper camp sampling site that is assumed to represent background conditions. None of the copper observations exceeded the freshwater copper PEL (197 mg/kg).

The freshwater lead observations exceeded the marine lead ERL screening benchmark (46.7 mg/kg) and freshwater LEL (31 mg/kg) at station US003S (Canyon Bog, adjacent to the stream at the upper camp). All other freshwater lead observations were below the marine ERL, freshwater LEL, and freshwater PEL (91.3 mg/kg) for lead.

The freshwater mercury observations exceeded the marine mercury ERL screening benchmark (0.15 mg/kg) at five of the 11 sampling stations, exceeded the freshwater LEL (0.2 mg/kg) at four sampling stations, and exceeded the freshwater PEL (0.486 mg/kg) at three sampling stations. Most of these exceedances of the sediment screening benchmark occurred at the upper camp, except for sampling station LS002S, which is at the stream’s confluence with Hawk Inlet.

All three freshwater zinc observations in the lower camp (at stations LS002S, LS001S, and LS003S) exceeded the marine zinc ERL screening benchmark (150 mg/kg), as did one observation in the upper camp (at station US004S). All but one freshwater zinc observation exceeded the freshwater LEL (120 mg/kg); three of the eight freshwater zinc observations exceeded the freshwater zinc PEL (315 mg/kg).

In summary, there were several cadmium, copper, mercury, and zinc exceedances of the sediment screening benchmarks at multiple stations at Empire Mine. However, there were fewer mercury exceedances than cadmium, copper, and zinc. There was only one exceedance of the lead screening benchmarks at station US003S.

Table 3-11. Sediment data at Empire Mine

Station	Sample date	Sediment concentration (mg/kg)[a]	Exceeds marine ERL[b]	Exceeds freshwater LEL[c,d]	Exceeds freshwater PEL[d,e]
Cadmium					
1	8/6/2014	5.6	Yes	Yes	Yes
6[f]	8/6/2014	0.17	No	N/A	N/A
11	8/7/2014	1.5	Yes	Yes	No
11	8/7/2014	1.7	Yes	Yes	No
14	8/7/2014	1.4	Yes	Yes	No
US001S	9/16–19/2014	1.36	Yes	Yes	No
US003S		0.716	No	Yes	No
US002S		2.0	Yes	Yes	No
LS002S		1.58	Yes	Yes	No
LS001S		5.39, 4.53	Yes	Yes	Yes
LS003S		4.55	Yes	Yes	Yes
US004S		2.37	Yes	Yes	No
Copper					
1	8/6/2014	35	Yes	Yes	No
6[f]	8/6/2014	9.2	No	N/A	N/A
11	8/7/2014	17	No	Yes	No
11	8/7/2014	35	Yes	Yes	No
14	8/7/2014	12	No	No	No
US001S	9/16–19/2014	52.9	Yes	Yes	No
US003S		106.0	Yes	Yes	No
US002S		22.0	No	Yes	No
LS002S		55.7	Yes	Yes	No
LS001S		55.7, 52.9	Yes	Yes	No
LS003S		67.2	Yes	Yes	No
US004S		31.2	No	Yes	No
Lead					
1	8/6/2014	8.9	No	No	No
6[f]	8/6/2014	3.4	No	N/A	N/A
11	8/7/2014	4.2	No	No	No
11	8/7/2014	4.8	No	No	No
14	8/7/2014	2.2	No	No	No
US001S	9/16–19/2014	ND	No	No	No
US003S		71.7	Yes	Yes	No
US002S		ND	No	No	No
LS002S		13.5	No	No	No
LS001S		9.84, 10.7	No	No	No
LS003S		11.2	No	No	No
US004S		ND	No	No	No
Mercury					
1	8/6/2014	0.13	No	No	No
6[f]	8/6/2014	0.017	No	N/A	N/A
11	8/7/2014	0.16	Yes	No	No
11	8/7/2014	0.029	No	No	No
14	8/7/2014	0.0058	No	No	No
US001S		2.85	Yes	Yes	Yes

Station	Sample date	Sediment concentration (mg/kg)[a]	Exceeds marine ERL[b]	Exceeds freshwater LEL[c,d]	Exceeds freshwater PEL[d,e]
US003S	9/16–19/2014	3.13	Yes	Yes	Yes
US002S		1.36	Yes	Yes	Yes
LS002S		0.263	Yes	Yes	No
LS001S		0.0901, 0.0559	No	No	No
LS003S		0.038	No	No	No
US004S		0.050	No	No	No
Zinc					
US001S	9/16–19/2014	142	No	Yes	No
US003S		84.5	No	No	No
US002S		141	No	Yes	No
LS002S		295	Yes	Yes	No
LS001S		490, 403	Yes	Yes	Yes
LS003S		509	Yes	Yes	Yes
US004S		175	Yes	Yes	No

[a] *Sources*: ADEC 2015a; Portage, Inc. 2015

[b] ERLs: cadmium = 1.2 mg/kg; copper = 34 mg/kg; lead = 46.7 mg/kg; mercury = 0.15 mg/kg; zinc = 150 mg/kg

[c] LELs: cadmium = 0.6 mg/kg; copper = 16 mg/kg; lead = 31 mg/kg; mercury = 0.2 mg/kg; zinc = 120 mg/kg

[d] N/A = not applicable.

[e] PELs: cadmium = 3.53 mg/kg; copper = 197 mg/kg; lead = 91.3 mg/kg; mercury = 0.486 mg/kg; zinc = 315 mg/kg

[f] This station (6) is below the dock pilings and was considered to be in marine water, so only the ERL, which is a marine value, was compared to the observations.

3.2.3 Hawk Inlet

The following sections present water quality, biological, and sediment data for Hawk Inlet. The sampling stations with the post-mining data are presented first for each data type. The biological data and sediment data sections present comparisons between pre- and post-mining data following the more recent data summaries. These comparisons are performed for stations with data covering a longer time period. In addition, pre-mining data at supplementary stations are also presented below. These are separate from the other comparisons because they are often at different stations than the post-mining data and cannot be directly compared.

3.2.3.1 Hawk Inlet Marine Water Quality

Long-term Water Quality Monitoring Data

HGCMC continually collects water quality data at three ambient stations (106, 107, and 108; see Figure 3-1) in Hawk Inlet at a depth of five feet. Data at these stations are available since 1987 (stations 106 and 107) and 1989 (station 108). In addition, data for stations 104 and 105 are available from 1987 through 2005 and 1998, respectively. Table 3-12 provides a summary of the water column data at stations 104 through 108 for the metals of concern, which were compared to Alaska water quality criteria for toxic and other deleterious organic and inorganic substances in marine waters (Section 2.1.2; ADEC 2012).

There were no exceedances of the cadmium, lead, or zinc water quality criteria at any of the ambient Hawk Inlet stations. There were exceedances of the 3.1 µg/L copper criterion at station 104. Specifically, eleven samples exceeded the copper criterion at station 104. All of these exceedances occurred between 1986 and 1993; there have been no exceedances since 1993 (data are available until 2005 at this station). In addition, there was one exceedance of the mercury criterion (0.050 µg/L) at station 104 in June 2003 (observed concentration was 0.421 µg/L). It is important to note that this mercury observation appears to be an outlier, as it is by far the largest observation and possibly a data error as the next closest observation was 0.015 µg/L in August 1988. In general, the water column data throughout Hawk Inlet appear to be meeting Alaska's water quality criteria for the metals of concern with only a few exceedances in the late 1980s and early 1990s.

Table 3-12. Summary of water quality data at stations 104, 105, 106, 107, and 108 in Hawk Inlet

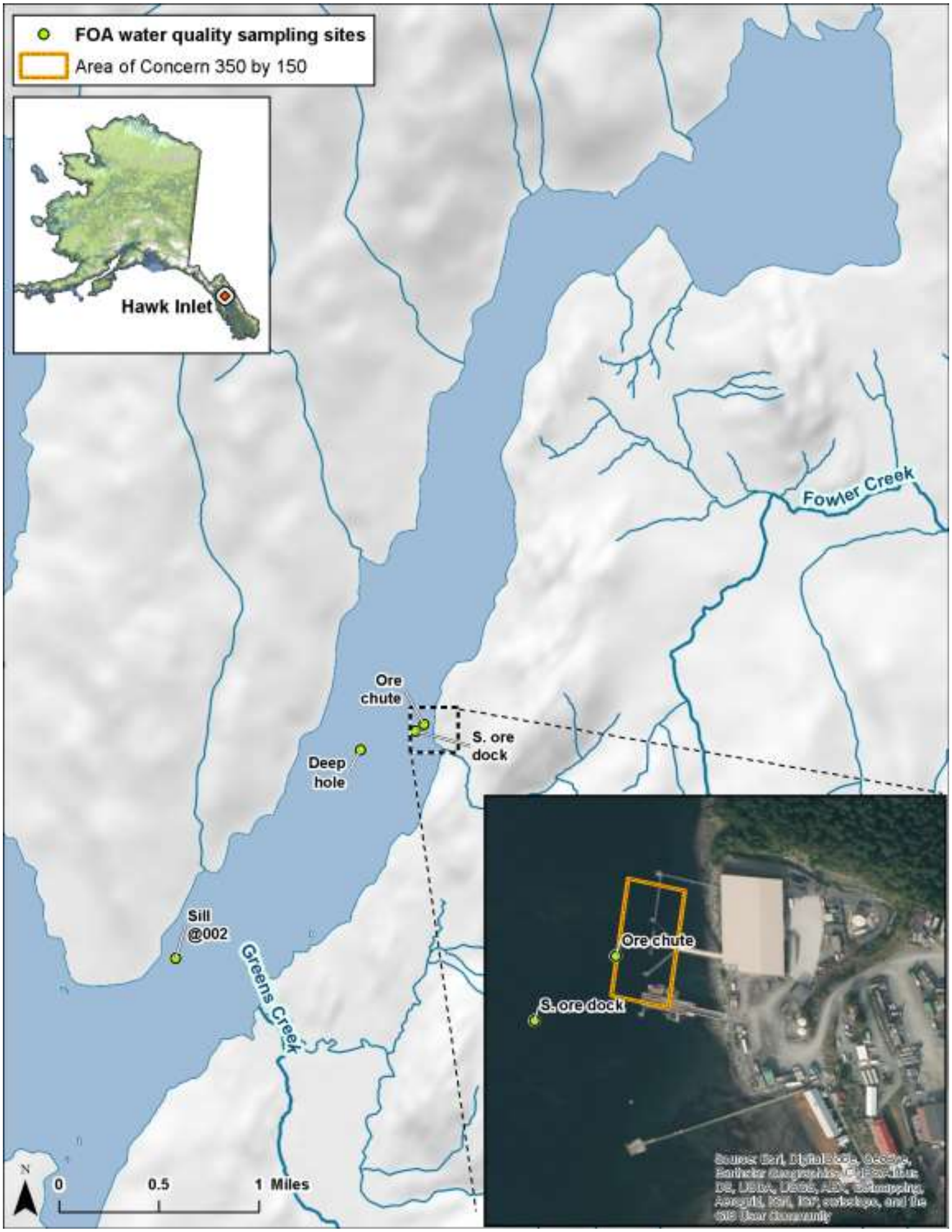
Station	Period of record	Number of observations	Minimum (µg/L)	Maximum (µg/L)	Average (µg/L)	Percent exceeding WQS[a]
Cadmium						
104	2/1/1987–8/9/2005	119	0.052	1.988	0.133	0%
105	2/21/1987–11/12/1998	90	0.048	1.988	0.152	0%
106	2/21/1987–10/19/2015	159	0.039	1.988	0.111	0%
107	2/21/1987-10/19/2015	159	0.049	3.310	0.123	0%
108	2/1/1989-10/19/2015	155	0.002	1.988	0.122	0%
Copper						
104	2/1/1985–11/9/2005	139	0.166	17.804	1.174	8%
105	2/1/1985–11/12/1998	109	0.180	1.959	0.494	0%
106	2/21/1985–10/19/2014	178	0.139	2.058	0.398	0%
107	2/1/1985-10/19/2015	179	0.178	2.573	0.503	0%
108	11/1/1987-10/19/2015	155	0.134	1.660	0.418	0%
Lead						
104	2/1/1985–8/9/2005	141	0.005	6.781	0.381	0%
105	2/1/1985–11/12/1998	111	0.010	0.951	0.108	0%
106	2/1/1985–10/19/2015	181	0.002	5.069	0.155	0%
107	2/1/1985-10/19/2015	181	0.004	1.503	0.140	0%
108	11/1/1987-10/19/2015	158	0.004	2.435	0.148	0%
Mercury						
104	2/21/1987–8/9/2005	120	0.00005	0.421	0.005	1%
105	2/21/1987–11/12/1998	92	0.00009	0.010	0.001	0%
106	2/21/1987–10/19/2015	162	0.00005	0.012	0.001	0%
107	2/21/1987-10/19/2015	159	0.00005	0.019	0.001	0%
108	5/20/1988-10/19/2015	155	0.00004	0.011	0.001	0%
Zinc						
104	2/1/1985–8/9/2005	141	0.131	77.761	3.037	0%
105	2/1/1985–11/12/1998	112	0.151	11.636	1.248	0%

Station	Period of record	Number of observations	Minimum (µg/L)	Maximum (µg/L)	Average (µg/L)	Percent exceeding WQS[a]
106	2/1/1985–10/19/2015	179	0.086	15.798	1.259	0%
107	2/1/1985-10/19/2015	180	0.132	8.164	1.409	0%
108	11/1/1987-10/19/2015	158	0.132	10.217	1.312	0%

[a] The water quality data at Hawk Inlet were compared to Alaska water quality criteria for toxic and other deleterious organic and inorganic substances in marine waters (Source: 18 AAC 70.020 [ADEC 2012]). See Section 2.1.2 for more detail. Water quality criterion: cadmium = 8.8 µg/L; copper = 3.1 µg/L; lead = 8.1 µg/L; mercury = 0.050 µg/L; and zinc = 81 µg/L.

Discrete Water Quality Monitoring Data

Additional water quality data for Hawk Inlet were collected in May 2015 from four locations near the HGCMC loading dock and closer to the outlet (Figure 3-5) (Ridgway 2016). These data are presented in Table 3-13. All of the cadmium, mercury, zinc and two of the lead observations were below the limit of quantification and were, therefore, halved for comparison to the associated water quality criteria. Copper was the only metal showing exceedances of its water quality criterion. All five copper observations in Hawk Inlet exceeded the copper water quality criterion of 3.1 µg/L. These observations are not consistent with the copper observations at the long-term water quality monitoring stations throughout Hawk Inlet (104 through 108) presented in Table 3-12. Additional water quality monitoring should be conducted to confirm these observations (see monitoring recommendations in Section 6.2).



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 3-5. Locations of May 2015 water quality sampling stations

Table 3-13. Summary of water quality data collected near loading dock and near the outlet

Station	Date collected	Number of observations	Results (µg/L)[a]	Exceeding WQS[b]
Cadmium				
S. ore dock	5/18/2015	1	1[c]	No
Sill @ 002	5/19/2015	1	1[c]	No
Ore chute	5/19/2015	1	1[c]	No
Ore chute	5/19/2015	1	1[c]	No
Deep hole	5/19/2015	1	1[c]	No
Copper[d]				
S. ore dock	5/18/2015	1	20	Yes
Sill @ 002	5/19/2015	1	20	Yes
Ore chute	5/19/2015	1	30	Yes
Ore chute	5/19/2015	1	20	Yes
Deep hole	5/19/2015	1	30	Yes
Lead				
S. ore dock	5/18/2015	1	3	No
Sill @ 002	5/19/2015	1	1[c]	No
Ore chute	5/19/2015	1	3	No
Ore chute	5/19/2015	1	1[c]	No
Deep hole	5/19/2015	1	4	No
Mercury				
S. ore dock	5/18/2015	1	0.05[c]	No
Sill @ 002	5/19/2015	1	0.05[c]	No
Ore chute	5/19/2015	1	0.05[c]	No
Ore chute	5/19/2015	1	0.05[c]	No
Deep hole	5/19/2015	1	0.05[c]	No
Zinc				
S. ore dock	5/18/2015	1	50[c]	No
Sill @ 002	5/19/2015	1	50[c]	No
Ore chute	5/19/2015	1	50[c]	No
Ore chute	5/19/2015	1	50[c]	No
Deep hole	5/19/2015	1	50[c]	No

[a] Source: Ridgway (2016)

[b] The water quality data at Hawk Inlet were compared to Alaska water quality criteria for toxic and other deleterious organic and inorganic substances in marine waters (Source: 18 AAC 70.020 [ADEC 2012]). See Section 2.1.2 for more detail. Water quality criterion: cadmium = 8.8 µg/L; copper = 3.1 µg/L; lead = 8.1 µg/L; mercury = 0.050 µg/L; and zinc = 81 µg/L.

[c] These observations were below the limit of quantification (LoQ), but the LoQ was greater than the limit of detection (LoD); therefore, these data were halved for comparison to water quality criteria.

[d] The data provided by source Ridgway (2016) were shown in "µg/kg (ppm)". Since analytical laboratories present water quality data in µg/L, the raw analytical data was not available, and confirmation of the units could not be made, the presumption included in this summary table is that the data is in µg/L.

3.2.3.2 Hawk Inlet Biological Data

Long-term Biological Monitoring Data

Tissue data have been collected by HGCMC at eight marine monitoring stations in Hawk Inlet (ESL, S-1, S-2, S-3, S-4, STN-1, STN-2, and STN-3; see Figure 3-1). Only mussels (*Mytilus edulis*) are collected at stations ESL and STN-2 and mussels and brachiopods are collected at STN-1 and STN-3 (all near outfall 002) because there are no fine-grained sediments in this location. Additional species are sampled in areas where fine-grained sediments do occur (S-1, S-2, and S-4) (HGCMC 2015b). ADEC has not adopted tissue quality standards for the evaluation of impacts to harvesting for consumption of raw mollusks or other raw aquatic life; therefore, the available tissue data from Hawk Inlet were compared to the EPA tissue quality guidelines for recreational and subsistence fisheries (USEPA 2000, 2001) (see Table 2-4) and the DHSS recommended safe tissue concentrations (DHSS 2016) (see Table 2-5) to determine whether the metals in the sediments are being taken up by aquatic life (represented by tissue concentrations above recommended values). Subsistence EPA recommended values were included because Hawk Inlet is used for subsistence fishing by the community of Angoon. Any exceedances of these EPA recommended values should be taken as an indication that more intensive site-specific monitoring and/or evaluation of human health risk should be conducted (USEPA 2000, 2001). EPA recommended values are only available for cadmium and mercury (Table 2-4); therefore, only the cadmium and mercury tissue data were compared below. The recommended DHSS maximum values are based on the 95th percentile harvest data for the Angoon community (ADEC and DHSS 2016). The DHSS recommended values provide the concentrations for cadmium, copper, mercury and zinc in each species that are not likely to cause adverse health effects if these species are consumed at the 95th percentile harvest rates (see Table 2-5).

All of the tissue data for Hawk Inlet are dry weight measurements. The EPA and DHSS recommended values are based on wet weight; therefore, the dry weight data were converted to wet weight for comparison to the EPA and DHSS recommended values. The data were converted using associated percent moisture data when available. Observations without percent moisture data were converted using the assumption that fish and invertebrates have a moisture content of 80 and 83.3 percent, respectively (USEPA 2000).

Table 3-14 summarizes the longer-term Hawk Inlet tissue data. None of the tissue samples exceeded the DHSS recommended cadmium, mercury, copper and zinc maximum safe tissue concentrations for marine species. None of the tissue samples in Hawk Inlet exceeded the recreational EPA recommended values. The only tissue samples in Hawk Inlet that exceeded the subsistence EPA recommended value for methylmercury of 0.03 mg/kg were five observations in 1986 and 1989 at station STN-1; however, there are several exceedances of the cadmium subsistence EPA recommended value of 0.491 mg/kg. All of the mussels tissue data (245 observations) and all but three of the brachiopod tissue data (62 observations) exceeded the cadmium subsistence EPA recommended value (at stations ESL, S-2, STN-1, STN-2, and STN-3) and there are smaller exceedances for the tissue of other shellfish and worms (*Nephtys procera*) at station S-1 (54 exceedances), S-2 (seven exceedances), S-3 (nine exceedances) and S-4 (four exceedances). All of the cadmium exceedances at station S-1 were for *Nephtys procera* (marine worms). None of the clams were exceeding the EPA recommended value at S-1. The seven cadmium exceedances at station S-2 occurred in 1988, 2003, 2005, 2007, and 2012 and included *Nephtys procera*, clams, and mussels. The nine cadmium exceedances at station S-3 occurred in 2002, 2003, 2007, 2014, and 2015 and included clams, *Nephtys procera*, and *Nereis sp.*.The four cadmium exceedances at station S-4 occurred in 1989 (clams) and 1991 and 1992 (*Nephtys procera*); there have been no exceedances since that time. Tissue data in Hawk Inlet have only been collected from first order benthic organisms. No data have been collected from upper trophic level consumers, fish and marine mammals and raptors that would support the investigation of rates and trends of metal loading in the food chain and upper trophic level animals.

Table 3-14. Summary of long-term Hawk Inlet tissue data

Station	Period of record	Tissue type	Number of observations	Minimum (mg/kg)	Maximum (mg/kg)	Average (mg/kg)	Percent exceeding recreational EPA recommended value[a,b]	Percent exceeding subsistence EPA recommended value[a,b]	Percent exceeding DHSS recommended value[c]
Cadmium									
ESL	9/1/1984–9/25/2015	Mussels	64	0.57	2.04	1.11	0%	100%	0%
S-1	5/30/1999–9/25/2015	Cockle clams	34	0.06	0.24	0.14	0%	0%	0%
S-1	9/1/1984–9/24/2015	*Nephtys procera*	113	0.14	1.39	0.52	0%	48%	N/A[d]
S-2	5/30/1999–9/25/2015	Cockle clams	34	0.06	0.22	0.14	0%	0%	0%
S-2	9/25/1999-9/27/2015	Littleneck clams	32	0.25	0.61	0.39	0%	9%	0%
S-2	5/29/2005	Mussels	1	1.44	1.44	1.44	100%	100%	0%
S-2	9/1/1984–9/27/2015	*Nephtys procera*	113	0.04	0.58	0.19	0%	3%	N/A[d]
S-3	9/21/2001–9/29/2015	Abarenicola	27	0.07	0.18	0.12	0%	0%	N/A[d]
S-3	9/21/2001–9/29/2015	Cockle clams	29	0.04	0.17	0.09	0%	0%	0%
S-3	9/21/2001–9/29/2015	Littleneck clams	29	0.28	0.65	0.41	0%	14%	0%
S-3	5/29/2005	*Nereis sp.*	29	0.10	0.50	0.27	0%	3%	N/A[d]
S-3	9/21/2001–9/29/2015	*Nephtys procera*	75	0.16	0.90	0.30	0%	5%	N/A[d]
S-3	9/21/2001–9/29/2015	Softshell clams	29	0.18	0.49	0.27	0%	0%	0%
S-4	5/1/1988–9/24/2015	Cockle clams	58	0.04	0.43	0.12	0%	0%	0%
S-4	5/1/1988–9/6/1998	Littleneck clams	24	0.18	0.55	0.29	0%	4%	0%
S-4	6/1/1995-6/22/1995	*Nereis sp.*	2	0.06	0.28	0.17	0%	0%	0%
S-4	5/1/1988–9/24/2015	*Nephtys procera*	106	0.05	0.56	0.14	0%	3%	N/A[d]
S-4	4/1/1991-9/6/1998	Softshell clams	13	0.11	0.34	0.19	0%	0%	0%
STN-1	9/1/1984–9/21/2015	Mussels	58	0.50	2.66	1.39	0%	100%	0%
STN-1	9/1/1984-9/6/1998	Brachiopods	31	0.40	1.4	0.93	0%	97%	N/A[d]
STN-2	9/1/1984–9/25/2015	Mussels	58	0.54	2.54	1.53	0%	100%	0%
STN-3	9/1/1984–9/21/2015	Mussels	64	0.73	2.63	1.43	0%	100%	0%
STN-3	9/1/1984-9/6/1998	Brachiopods	31	0.46	1.76	0.95	0%	94%	N/A[d]
Mercury[b]									
ESL	9/1/1984–9/25/2015	Mussels	65	0.002	0.012	0.006	0%	0%	0%
S-1	5/30/1999-–9/25/2015	Cockle clams	34	0.003	0.012	0.006	0%	0%	0%
S-1	9/1/1984-9/24/2015	*Nephtys procera*	113	0.003	0.017	0.008	0%	0%	N/A[d]

Station	Period of record	Tissue type	Number of observations	Minimum (mg/kg)	Maximum (mg/kg)	Average (mg/kg)	Percent exceeding recreational EPA recommended value[a,b]	Percent exceeding subsistence EPA recommended value[a,b]	Percent exceeding DHSS recommended value[c]
S-2	5/30/1999–9/25/2015	Cockle clams	34	0.003	0.008	0.005	0%	0%	0%
S-2	9/25/1999–9/27/2015	Littleneck clams	33	0.003	0.007	0.004	0%	0%	0%
S-2	5/29/2005	Mussels	1	0.005	0.005	0.005	0%	0%	0%
S-2	9/1/1984–9/27/2015	*Nephtys procera*	113	0.002	0.008	0.004	0%	0%	N/A[d]
S-3	9/21/2001–9/29/2015	Abarenicola	26	0.003	0.015	0.007	0%	0%	N/A[d]
S-3	9/21/2001–9/29/2015	Cockle clams	28	0.003	0.015	0.008	0%	0%	0%
S-3	9/21/2001–9/29/2015	Littleneck clams	28	0.003	0.022	0.011	0%	0%	0%
S-3	9/21/2001–9/29/2015	*Nereis sp.*	28	0.003	0.012	0.006	0%	0%	N/A[d]
S-3	9/21/2001–9/29/2015	*Nephtys procera*	72	0.003	0.013	0.008	0%	0%	N/A[d]
S-3	9/21/2001–9/29/2015	Softshell clams	28	0.003	0.023	0.014	0%	0%	0%
S-4	5/1/1988–9/24/2015	Cockle clams	58	0.001	0.020	0.006	0%	0%	0%
S-4	5/1/1988–9/24/2015	Littleneck clams	24	0.000	0.011	0.005	0%	0%	0%
S-4	5/1/1988–9/24/2015	*Nephtys procera*	106	0.000	0.028	0.005	0%	0%	N/A[d]
S-4	5/1/1988–9/24/2015	*Nereis sp*.	2	0.003	0.003	0.003	0%	0%	N/A[d]
S-4	5/1/1988–9/24/2015	Softshell clams	13	0.003	0.013	0.007	0%	0%	0%
STN-1	9/1/1984–9/21/2015	Mussels	58	0.003	0.077	0.009	0%	3%	0%
STN-1	9/1/1984–9/6/1998	Brachiopods	31	0.002	0.120	0.019	0%	10%	N/A[d]
STN-2	9/1/1984–9/21/2015	Mussels	58	0.003	0.012	0.007	0%	0%	0%
STN-3	9/1/1984–9/21/2015	Mussels	63	0.002	0.012	0.007	0%	0%	0%
STN-3	9/1/1984–9/6/1998	Brachiopods	31	0.003	0.014	0.009	0%	0%	N/A[d]
Copper									
ESL	9/1/1984–9/29/2015	Mussels	64	0.014	92.7	3.03	N/A[d]	N/A[d]	0%
S-1	5/30/1999–9/29/2015	Cockle clams	34	0.40	4.0	0.96			0%
S-2	5/30/1999–9/29/2015	Cockle clams	34	0.33	2.2	0.78			0%
S-2	9/25/1999–9/29/2015	Littleneck clams	33	1.0	5.9	1.5			0%
S-2	5/31/2005	Mussels	1	1.0	1.0	1.0			0%
S-3	9/21/2001–9/29/2015	Cockle clams	29	0.37	11.4	1.2			0%
S-3	9/21/2001–9/29/2015	Littleneck clams	29	1.2	5.0	1.8			0%
S-3	9/21/2001–9/29/2015	Softshell clams	29	1.7	15.0	3.4			0%

Station	Period of record	Tissue type	Number of observations	Minimum (mg/kg)	Maximum (mg/kg)	Average (mg/kg)	Percent exceeding recreational EPA recommended value[a,b]	Percent exceeding subsistence EPA recommended value[a,b]	Percent exceeding DHSS recommended value[c]
S-4	5/1/1988–9/29/2015	Cockle clams	58	0.37	7.2	1.4			0%
S-4	5/1/1988–9/6/1998	Littleneck clams	24	1.3	8.8	2.7			0%
S-4	4/1/1991–9/6/1998	Softshell clams	13	2.6	21.4	8.3			0%
STN-1	9/1/1984–9/29/2015	Mussels	56	0.77	5.6	1.3			0%
STN-2	9/1/1984–9/29/2015	Mussels	56	0.73	3.1	1.3			0%
STN-3	9/1/1984–9/29/2015	Mussels	63	0.75	7.0	1.5			0%
Zinc									
ESL	9/1/1984–9/29/2015	Mussels	64	8.5	81.8	16.9	N/A[d]	N/A[d]	0%
S-1	5/30/1999–9/29/2015	Cockle clams	34	8.3	19.7	13.0			0%
S-2	5/30/1999–9/29/2015	Cockle clams	34	8.0	16.6	11.6			0%
S-2	9/25/1999–9/29/2015	Littleneck clams	33	8.8	18.5	13.6			0%
S-2	5/31/2005	Mussels	1	16.7	16.7	16.7			0%
S-3	9/21/2001–9/29/2015	Cockle clams	29	7.9	24.9	12.7			0%
S-3	9/21/2001–9/29/2015	Littleneck clams	29	10.4	19.4	14.6			0%
S-3	9/21/2001–9/29/2015	Softshell clams	29	11.0	24.5	15.0			0%
S-4	5/1/1988–9/29/2015	Cockle clams	58	8.6	75.3	16.0			0%
S-4	5/1/1988–9/6/1998	Littleneck clams	24	9.4	58.9	15.6			0%
S-4	4/1/1991–9/6/1998	Softshell clams	13	12.6	88.0	26.3			0%
STN-1	9/1/1984–9/29/2015	Mussels	56	10.2	75.9	15.8			0%
STN-2	9/1/1984–9/25/2015	Mussels	56	9.1	40.7	14.8			0%
STN-3	9/1/1984–9/29/2015	Mussels	63	8.7	92.3	17.8			0%

[a] Compared to the cadmium recreational and subsistence EPA recommended values of 4 and 0.491 mg/kg wet weight, respectively and to the methylmercury recreational and subsistence EPA recommended values of 0.3 and 0.03 mg/kg wet weight, respectively (USEPA 2000, 2001).

[b] Data are in total mercury, but are compared to the methylmercury EPA recommended values. As noted by USEPA, "because most mercury in fish and shellfish is present primarily as methylmercury and because of the relatively high cost of analyzing for methylmercury, it is recommended that total mercury be analyzed and the conservative assumption be made that all mercury is present as methylmercury" (USEPA 2000).

[c] Compared to the DHSS recommended maximum safe tissue concentrations in marine species for clams, cockle clams and mussels. Cadmium recommended concentrations are 33.2, 41.5 and 137 mg/kg wet weight for clams, cockle clams and mussels, respectively. Copper recommended concentrations are 1,635, 2,046 and 6,770 mg/kg wet weight for clams, cockle clams and mussels, respectively. Mercury recommended concentrations are 4.89, 6.12 and 20.2 mg/kg wet weight for clams, cockle clams and mussels, respectively. Zinc recommended concentrations are 4,891, 6,122 and 20,258 mg/kg wet weight for clams, cockle clams and mussels, respectively.

[d] N/A = Not applicable. There are no DHSS recommended maximum values for marine worms and there are no EPA recommended recreational or subsistence screening values for copper and zinc.

Discrete Biological Monitoring Data

Mussels tissue data were also collected in 1997 from several stations throughout Hawk Inlet (Rudis and Jacobson 2001). The exact locations of the stations are not known so they are not shown on a map, but the individual results associated with multiple stations are presented in Table 3-15. These data were also compared to the EPA tissue quality guidelines for recreational and subsistence fisheries (USEPA 2000, 2001) (see Table 2-4) and the DHSS recommended maximum safe concentrations for marine species (see Table 2-5). None of the mussels samples exceed the DHSS recommended maximum safe concentrations for cadmium, mercury, copper or zinc. None of the cadmium or mercury samples exceed the EPA recommended recreational screening values of 4 and 0.3 mg/kg, respectively. All 18 of the cadmium observations in 1997 exceed EPA's recommended subsistence cadmium screening value of 0.491 mg/kg wet weight. None of the mercury observations in Table 3-15 exceeded the recommended mercury subsistence screening value for fish tissue of 0.03 mg/kg wet weight.

Table 3-15. Summary of mussels tissue data collected in Hawk Inlet in 1997

Station	Date of sample	Tissue type	Number of observations	Result (mg/kg wet weight)	Exceeding recreational EPA recommended value[a,b]	Exceeding subsistence EPA recommended value[a,b]	Exceeding the DHSS recommended maximum value[c]
Cadmium							
MM01	4/1/1997	Mussels	1	1.07	No	Yes	No
MM02	4/1/1997	Mussels	1	1.03	No	Yes	No
MM03	4/1/1997	Mussels	1	1.38	No	Yes	No
MM04	4/1/1997	Mussels	1	2.51	No	Yes	No
MM05	4/1/1997	Mussels	1	1.48	No	Yes	No
MM06	4/1/1997	Mussels	1	1.48	No	Yes	No
97HIM01	4/1/1997	Mussels	1	0.93	No	Yes	No
97HIM01 (dup)	4/1/1997	Mussels	1	1.05	No	Yes	No
97HIM02	4/1/1997	Mussels	1	0.90	No	Yes	No
97HIM02 (dup)	4/1/1997	Mussels	1	0.87	No	Yes	No
97HIM03	4/1/1997	Mussels	1	1.34	No	Yes	No
97HIM03 (dup)	4/1/1997	Mussels	1	1.09	No	Yes	No
97HIM04	4/1/1997	Mussels	1	2.46	No	Yes	No
97HIM04 (dup)	4/1/1997	Mussels	1	2.16	No	Yes	No
97HIM05	4/1/1997	Mussels	1	1.21	No	Yes	No
97HIM05 (dup)	4/1/1997	Mussels	1	1.05	No	Yes	No
97HIM06	4/1/1997	Mussels	1	1.36	No	Yes	No
97HIM06 (dup)	4/1/1997	Mussels	1	1.30	No	Yes	No
Mercury							
97HIM01	4/1/1997	Mussels	1	0.027	No	No	No
97HIM01(dup)	4/1/1997	Mussels	1	0.026	No	No	No
97HIM02	4/1/1997	Mussels	1	0.025	No	No	No
97HIM02(dup)	4/1/1997	Mussels	1	0.026	No	No	No
97HIM03	4/1/1997	Mussels	1	0.026	No	No	No
97HIM03(dup)	4/1/1997	Mussels	1	0.025	No	No	No
97HIM04	4/1/1997	Mussels	1	0.026	No	No	No
97HIM04(dup)	4/1/1997	Mussels	1	0.027	No	No	No
97HIM05	4/1/1997	Mussels	1	0.024	No	No	No
97HIM05(dup)	4/1/1997	Mussels	1	0.020	No	No	No

Station	Date of sample	Tissue type	Number of observations	Result (mg/kg wet weight)	Exceeding recreational EPA recommended value[a,b]	Exceeding subsistence EPA recommended value[a,b]	Exceeding the DHSS recommended maximum value[c]
97HIM06	4/1/1997	Mussels	1	0.025	No	No	No
97HIM06(dup)	4/1/1997	Mussels	1	0.026	No	No	No
Copper							
MM01	4/1/1997	Mussels	1	1.5	N/A[d]	N/A[d]	No
MM02	4/1/1997	Mussels	1	1.2			No
MM03	4/1/1997	Mussels	1	1.4			No
MM04	4/1/1997	Mussels	1	1.3			No
MM05	4/1/1997	Mussels	1	1.2			No
MM06	4/1/1997	Mussels	1	1.6			No
97HIM01	4/1/1997	Mussels	1	1.4			No
97HIM01(dup)	4/1/1997	Mussels	1	1.4			No
97HIM02	4/1/1997	Mussels	1	1.0			No
97HIM02(dup)	4/1/1997	Mussels	1	1.1			No
97HIM03	4/1/1997	Mussels	1	1.2			No
97HIM03(dup)	4/1/1997	Mussels	1	1.2			No
97HIM04	4/1/1997	Mussels	1	1.2			No
97HIM04(dup)	4/1/1997	Mussels	1	1.2			No
97HIM05	4/1/1997	Mussels	1	1.1			No
97HIM05(dup)	4/1/1997	Mussels	1	0.82			No
97HIM06	4/1/1997	Mussels	1	1.5			No
97HIM06(dup)	4/1/1997	Mussels	1	1.5			No
Zinc							
MM01	4/1/1997	Mussels	1	15.7	N/A[d]	N/A[d]	No
MM02	4/1/1997	Mussels	1	17.5			No
MM03	4/1/1997	Mussels	1	24.7			No
MM04	4/1/1997	Mussels	1	18.4			No
MM05	4/1/1997	Mussels	1	16.2			No
MM06	4/1/1997	Mussels	1	28.4			No
97HIM01	4/1/1997	Mussels	1	14.4			No
97HIM01(dup)	4/1/1997	Mussels	1	14.5			No
97HIM02	4/1/1997	Mussels	1	14.5			No
97HIM02(dup)	4/1/1997	Mussels	1	15.7			No
97HIM03	4/1/1997	Mussels	1	21.4			No
97HIM03(dup)	4/1/1997	Mussels	1	21.7			No
97HIM04	4/1/1997	Mussels	1	18.2			No
97HIM04(dup)	4/1/1997	Mussels	1	15.7			No
97HIM05	4/1/1997	Mussels	1	14.4			No
97HIM05(dup)	4/1/1997	Mussels	1	10.5			No
97HIM06	4/1/1997	Mussels	1	24.6			No
97HIM06(dup)	4/1/1997	Mussels	1	26.1			No

Data Source: Rudis et al (2001)

[a] Compared to the cadmium recreational and subsistence EPA recommended values of 4 and 0.491 mg/kg wet weight, respectively and to the methylmercury recreational and subsistence EPA recommended values of 0.3 and 0.03 mg/kg wet weight, respectively (USEPA 2000, 2001).

[b] Compared to the DHSS recommended maximum safe tissue concentrations in marine species for mussels. Recommended concentrations for cadmium, mercury, copper and zinc are 137, 20.2, 6,770 and 20,258 mg/kg wet weight for mussels, respectively.

[c] N/A = Not applicable. There are no DHSS recommended maximum values for marine worms and there are no EPA recommended recreational or subsistence screening values for copper and zinc.

[d] Data are in total mercury, but are compared to the methylmercury EPA recommended values. As noted by USEPA, "because most mercury in fish and shellfish is present primarily as methylmercury and because of the relatively high cost of analyzing for methylmercury, it is recommended that total mercury be analyzed and the conservative assumption be made that all mercury is present as methylmercury" (USEPA 2000).

In addition to the Hawk Inlet tissue data summarized above, Friends of Admiralty (FOA) collected tissue data (*Nephtys* sp., clams, cockles, mussels, sculpin, sole and seaweed) from Hawk Inlet in May 2015, June 2016, and July 2016. (Ridgway 2016). Fresh shrimp and crab were also received from sport fisherman. The data also included tissue from one adult male harbor seal contributed by a subsistence hunter at Hawk Point near the mouth of Hawk Inlet (Oceanus Alaska 2015a, 2015b). The harbor seal tissue results are included, but there is no quantitative information regarding the time spent in Hawk Inlet to confirm the source(s) of metals to the seal. The seal was collected at Hawk Point, which is at the mouth of Hawk Inlet, not within the inlet. A study of the movements of harbor seals in Prince William Sound, Alaska found that average monthly home ranges were <100 square kilometers (km^2) to >1,500 km^2 (Lowry et al. 2001). Juvenile seals tend to travel farther than adults. The research found that the average maximum distance traveled from the initial location by the 27 adult harbor seals in the study was 61 kilometers (km) with a range of 22 to 189 km. The locations of the sampling sites are presented in Figure 3-6.

Table 3-16 presents a comparison of the FOA tissue data to the recreation and subsistence EPA recommended values for cadmium and methylmercury as well as the DHSS recommended maximum safe values for cadmium, copper, mercury, and zinc. These data were collected at different sampling locations than the tissue data collected by HGCMC; therefore, the data were presented separately from the long-term Hawk Inlet tissue data presented in Table 3-14. There were no exceedances of the applicable DHSS recommended maximum safe concentrations (DHSS 2016). All but three of the FOA tissue data samples from 2015 and 2016 were below the recreational EPA recommended values for cadmium and mercury of 4 and 0.3 mg/kg, respectively (USEPA 2000, 2001). One triton snail sample exceeded the cadmium recommended recreational value. There were eight exceedances of the EPA recommended cadmium subsistence value of 0.491 mg/kg (USEPA 2000, 2001). These exceedances included one Red King crab sample, one helmet crab sample, one triton snail sample, one yellow fin sole sample, and all four mussel samples. There were exceedances of the mercury subsistence EPA recommended value of 0.03 mg/kg (USEPA 2000, 2001) in one side-stripe shrimp sample, one Dungeness crab sample, one Red King crab sample, one triton snail sample, one mussel sample, two yellow fin sole samples, and two sculpin samples. None of the FOA harbor seal fat or muscle data from May 2015 exceed the EPA recommended recreational or subsistence values for cadmium; however, both the liver and kidney samples exceed both of the recommended values. The harbor seal fat sample does not exceed the EPA recommended recreational value for mercury, but all other harbor seal samples exceed both the recommended recreational and subsistence values for mercury (Table 3-16).

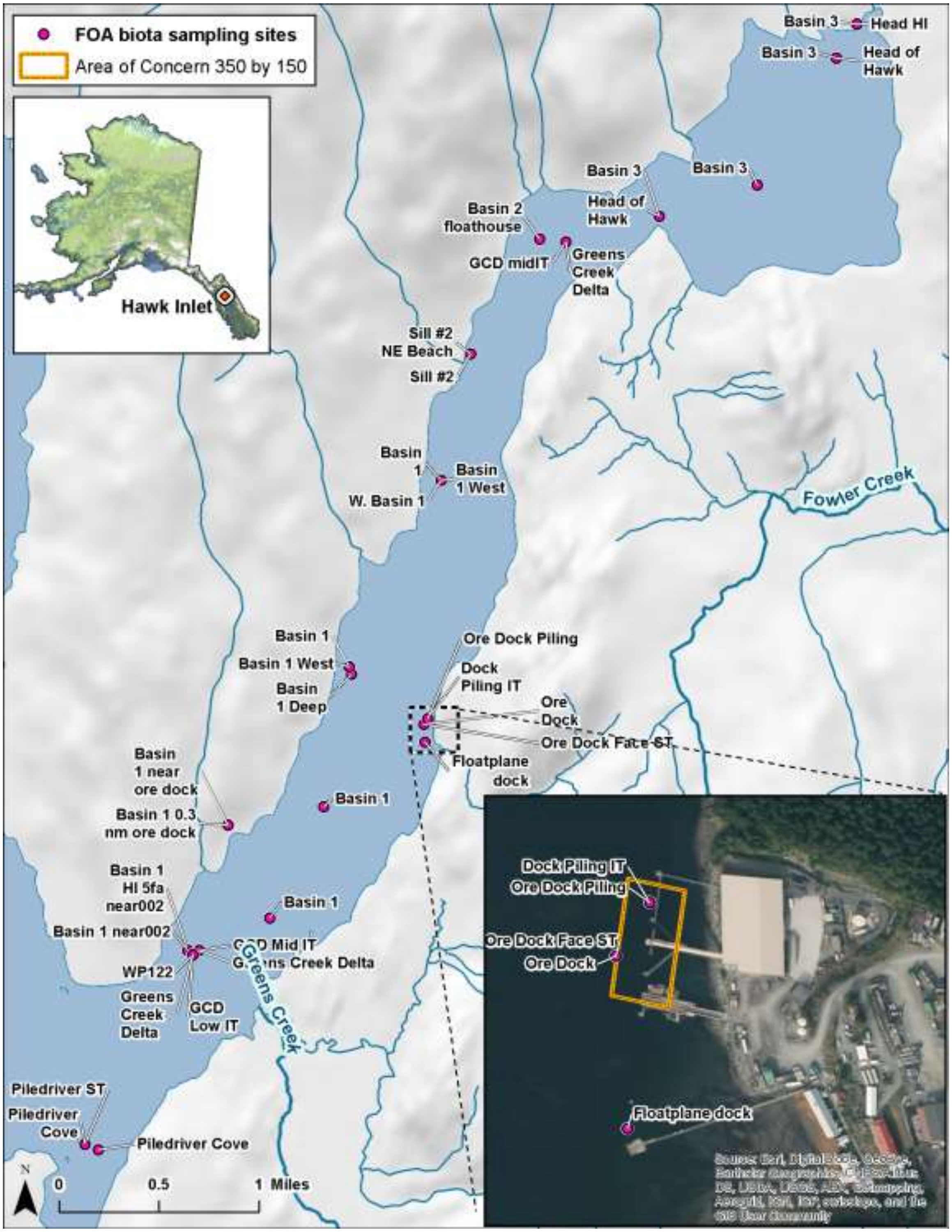


Figure 3-6. Location of Friends of Admiralty tissue sampling sites (Source: Ridgway 2016)

Table 3-16. Summary of Friends of Admiralty Hawk Inlet tissue data

Station/Sample ID	Tissue type	Date sampled	Number of organisms per composite sample	Results (mg/kg wet weight	Exceeding recreational EPA recommended value[a]	Exceeding subsistence EPA recommended value[a]	Exceeding DHSS recommended maximum value[b]
Cadmium							
69-Greens Creek Delta	Black Seaweed Nori - blade	5/19/15	6	0.09	No	No	No
70-Greens Creek Delta	Fucus Seaweed - blade+stipe	5/19/15	3	0.26	No	No	No
117-Floatplane dock	Laminaria kelp - blade	5/9/2016	3	0.36	No	No	No
112-Piledriver Cove	Sea Cucumber - skin,musc,intest	5/20/2015	1	0.064	No	No	N/A[c]
105-Ore dock	Sea Cucumber - 1st x-section	11/7/2015	0.5	0.149	No	No	N/A[c]
106-Ore dock	Sea Cucumber - 2nd x-section	11/7/2015	0.5	0.173	No	No	N/A[c]
64-Basin 1 West	Side-Stripe Shrimp - peeled, whole	5/18/2015	8	0.13	No	No	No
110-Basin 1 Deep	Spot shrimp - whole w/shell	10/15/2015	4	0.251	No	No	No
1110Basin 1 Deep	Spot shrimp - peeled, whole	10/15/2015	6	0.104	No	No	No
124-Basin 1 near 002	Dungeness crab - muscle	6/26/2016	1	0.371	No	No	No
89-Basin 1 near ore dock	Dungeness crab - viscera	8/15/2015	2	0.41	No	No	No
86-Basin 1 near ore dock	Dungeness crab - muscle	8/15/2015	2	0.02	No	No	No
120-Basin 1 West	Red King Crab - muscle+viscera	6/26/2016	1	1.18	No	Yes	No
119-Basin 1 West	Red King Crab - ova	6/26/2016	1	0.08	No	No	No
65-Basin 3	Helmet Crab - muscle	5/18/2015	4	1.07	No	Yes	No
123-Basin 1	Triton - whole, shucked	6/26/2016	1	4.34	Yes	Yes	N/A[c]
116-Basin 3	Blue Mussel - whole, shucked	5/18/2015	14	0.503	No	Yes	No
114-Ore Dock Piling	Blue Mussel - whole, shucked	11/8/2015	34	0.498	No	Yes	No

Station/Sample ID	Tissue type	Date sampled	Number of organisms per composite sample	Results (mg/kg wet weight	Exceeding recreational EPA recommended value[a]	Exceeding subsistence EPA recommended value[a]	Exceeding DHSS recommended maximum value[b]
29-Greens Creek Delta	Blue Mussel - whole, shucked	5/18/2015	8-12	1.69	No	Yes	No
67-Piledriver Cove	Blue Mussel - whole, shucked	5/20/2015	8-12	1.37	No	Yes	No
102-Sill #2	Steamer clam - whole, shucked	5/9/2016	4	0.223	No	No	No
103-Sill #2	Steamer clam - whole, shucked	5/9/2016	4	0.296	No	No	No
104-Sill #2	Steamer clam - whole, shucked	5/9/2016	4	0.278	No	No	No
16-Basin 3	Cockle - whole, shucked	5/17/2015	3-5	0.07	No	No	No
101-Sill #2	Cockle - whole, shucked	5/9/2016	1	0.036	No	No	No
19-Basin 3	Cockle - whole, shucked	5/17/2015	3-5	< 0.2	No	No	No
24B-Greens Creek Delta	Cockle - whole, shucked	5/18/2015	3-5	0.25	No	No	No
24-Greens Creek Delta	Cockle - whole, shucked	5/18/2015	3-5	0.25	No	No	No
31-Greens Creek Delta	Butter Clam - shucked compos	5/18/2015	1-7	0.29	No	No	No
100-Floatplane Dock	Butter Clam - whole, shucked	5/9/2016	1	0.106	No	No	No
25-Greens Creek Delta	Horse Clam - whole, shucked	5/18/2015	1	0.29	No	No	No
66-Piledriver Cove	Mixed Clams - whole, shucked	5/20/2015	4	0.24	No	No	No
125-Basin 1	Yellow fin Sole - liver	6/30/2016	1	0.8	No	Yes	N/A[c]
126-Basin 1	Yellow fin Sole - all non-liver	6/30/2016	1	< 0.05	No	No	N/A[c]
127-Basin 1	Sculpin - liver	7/1/2016	1	0.47	No	No	N/A[c]
128-Basin 1	Sculpin - x-section	7/1/2016	1	0.0143j	No	No	N/A[c]
Hawk Point	Harbor seal fat	May 2015	1	0.04	No	No	N/A[c]
Hawk Point	Harbor seal muscle	May 2015	1	0.04	No	No	N/A[c]

Station/Sample ID	Tissue type	Date sampled	Number of organisms per composite sample	Results (mg/kg wet weight	Exceeding recreational EPA recommended value[a]	Exceeding subsistence EPA recommended value[a]	Exceeding DHSS recommended maximum value[b]
Hawk Point	Harbor seal liver	May 2015	1	4.31	Yes	Yes	N/A[c]
Hawk Point	Harbor seal kidney	May 2015	1	12.3	Yes	Yes	N/A[c]
Mercury[d]							
69-Greens Creek Delta	Black Seaweed Nori - blade	5/19/15	6	< 0.005	No	No	No
70-Greens Creek Delta	Fucus Seaweed - blade+stipe	5/19/15	3	< 0.005	No	No	No
117-Floatplane dock	Laminaria kelp - blade	5/9/2016	3	0.006	No	No	No
112-Piledriver Cove	Sea Cucumber - skin,musc,intest	5/20/2015	1	0.00183	No	No	N/A[c]
105-Ore dock	Sea Cucumber - 1st x-section	11/7/2015	0.5	0.007	No	No	N/A[c]
106-Ore dock	Sea Cucumber - 2nd x-section	11/7/2015	0.5	0.007	No	No	N/A[c]
64-Basin 1 West	Side-Stripe Shrimp - peeled, whole	5/18/2015	8	0.032	No	Yes	No
110-Basin 1 Deep	Spot shrimp - whole w/shell	10/15/2015	4	0.025	No	No	No
1110Basin 1 Deep	Spot shrimp - peeled, whole	10/15/2015	6	0.018	No	No	No
124-Basin 1 near 002	Dungeness crab - muscle	6/26/2016	1	0.029	No	No	No
89-Basin 1 near ore dock	Dungeness crab - viscera	8/15/2015	2	0.007	No	No	No
86-Basin 1 near ore dock	Dungeness crab - muscle	8/15/2015	2	0.035	No	Yes	No
120-Basin 1 West	Red King Crab - muscle+viscera	6/26/2016	1	0.067	No	Yes	No
119-Basin 1 West	Red King Crab - ova	6/26/2016	1	< 0.005	No	No	No
65-Basin 3	Helmet Crab - muscle	5/18/2015	4	0.029	No	No	No
123-Basin 1	Triton - whole, shucked	6/26/2016	1	0.060	No	Yes	N/A[c]
116-Basin 3	Blue Mussel - whole, shucked	5/18/2015	14	0.036	No	Yes	No

Station/Sample ID	**Tissue type**	**Date sampled**	**Number of organisms per composite sample**	**Results (mg/kg wet weight**	**Exceeding recreational EPA recommended value[a]**	**Exceeding subsistence EPA recommended value[a]**	**Exceeding DHSS recommended maximum value[b]**
114-Ore Dock Piling	Blue Mussel - whole, shucked	11/8/2015	34	0.009	No	No	No
29-Greens Creek Delta	Blue Mussel - whole, shucked	5/18/2015	8-12	0.013	No	No	No
67-Piledriver Cove	Blue Mussel - whole, shucked	5/20/2015	8-12	0.013	No	No	No
102-Sill #2	Steamer clam - whole, shucked	5/9/2016	4	0.013	No	No	No
103-Sill #2	Steamer clam - whole, shucked	5/9/2016	4	0.017	No	No	No
104-Sill #2	Steamer clam - whole, shucked	5/9/2016	4	0.016	No	No	No
16-Basin 3	Cockle - whole, shucked	5/17/2015	3-5	0.014	No	No	No
101-Sill #2	Cockle - whole, shucked	5/9/2016	1	0.009	No	No	No
19-Basin 3	Cockle - whole, shucked	5/17/2015	3-5	0.025	No	No	No
24B-Greens Creek Delta	Cockle - whole, shucked	5/18/2015	3-5	0.006	No	No	No
24-Greens Creek Delta	Cockle - whole, shucked	5/18/2015	3-5	0.006	No	No	No
31-Greens Creek Delta	Butter Clam - shucked compos	5/18/2015	1-4	0.009	No	No	No
100-Floatplane Dock	Butter Clam - whole, shucked	5/9/2016	1	0.008	No	No	No
25-Greens Creek Delta	Horse Clam - whole, shucked	5/18/2015	1	0.012	No	No	No
66-Piledriver Cove	Mixed Clams - whole, shucked	5/20/2015	4	0.007	No	No	No
125-Basin 1	Yellow fin Sole - liver	6/30/2016	1	0.05	No	Yes	N/A[c]
126-Basin 1	Yellow fin Sole - all non-liver	6/30/2016	1	0.04	No	Yes	N/A[c]
127-Basin 1	Sculpin - liver	7/1/2016	1	0.1	No	Yes	N/A[c]
128-Basin 1	Sculpin - x-section	7/1/2016	1	0.1	No	Yes	N/A[c]
Hawk Point	Harbor seal fat	May 2015	1	0.057	No	Yes	N/A[c]

Station/Sample ID	**Tissue type**	**Date sampled**	**Number of organisms per composite sample**	**Results (mg/kg wet weight**	**Exceeding recreational EPA recommended value[a]**	**Exceeding subsistence EPA recommended value[a]**	**Exceeding DHSS recommended maximum value[b]**
Hawk Point	Harbor seal muscle	May 2015	1	2.18	Yes	Yes	N/A[c]
Hawk Point	Harbor seal liver	May 2015	1	222	Yes	Yes	N/A[c]
Hawk Point	Harbor seal kidney	May 2015	1	6.3	Yes	Yes	N/A[c]
Copper							
GCD Mid IT	Black Seaweed Nori – blade	5/19/15	6	10.1	N/A[c]	N/A[c]	No
GCD midIT	Fucus Seaweed-blade+strip	5/19/15	3	0.26	N/A[c]	N/A[c]	No
Floatplane dock	Laminaria kelp – blade	5/9/2016	3	1.97	N/A[c]	N/A[c]	No
Basin 1	Side-Stripe Shrimp – peeled, whole	5/18/2015	8	11.9	N/A[c]	N/A[c]	No
Basin 1 Deep	Spot shrimp – whole with shell	10/15/2015	4 (2 w/eggs)	24.4	N/A[c]	N/A[c]	No
Basin 1 Deep	Spot shrimp – peeled, whole	10/15/2015	6 (3w/eggs)	10.2	N/A[c]	N/A[c]	No
Basin 1 HI 5fa near002	Dungeness crab – muscle	6/26/2016	1	15	N/A[c]	N/A[c]	No
Basin 1 0.3 nm ore dock	Dungeness crab – viscera	8/15/2015	2	5.2	N/A[c]	N/A[c]	No
Basin 1 0.3 nm ore dock	Dungeness crab – muscle	8/15/2015	2	3.5	N/A[c]	N/A[c]	No
W. Basin 1	Red King Crab – muscle+viscera	6/26/2016	1	44.5	N/A[c]	N/A[c]	No
W. Basin 1	Red King Crab – ova	6/26/2016	1	10	N/A[c]	N/A[c]	No
Basin 3	Helmet Crab – muscle	5/18/2015	4	10.4	N/A[c]	N/A[c]	No
Basin 2 floathouse	Lyre crab – whole	6/26/2016	2	14.9	N/A[c]	N/A[c]	No
Head HI	Blue Mussel – whole, shucked	5/18/2015	14	1.51	N/A[c]	N/A[c]	No
Dock Piling IT	Blue Mussel – whole, shucked	11/8/2015	34	2.96	N/A[c]	N/A[c]	No

Station/Sample ID	Tissue type	Date sampled	Number of organisms per composite sample	Results (mg/kg wet weight	Exceeding recreational EPA recommended value[a]	Exceeding subsistence EPA recommended value[a]	Exceeding DHSS recommended maximum value[b]
GCD midIT	Blue Mussel – whole, shucked	5/18/2015	8-12	7.36	N/A[c]	N/A[c]	No
Piledriver Cove	Blue Mussel – whole, shucked	5/20/2015	8-12	11.7	N/A[c]	N/A[c]	No
Sill #2 NE Beach	Steamer clam – whole, shucked	5/9/2016	4	12.4	N/A[c]	N/A[c]	No
Sill #2 NE Beach	Steamer clam – whole, shucked	5/9/2016	4	2.12	N/A[c]	N/A[c]	No
Sill #2 NE Beach	Steamer clam – whole, shucked	5/9/2016	4	1.43	N/A[c]	N/A[c]	No
Head of Hawk	Cockle – whole, shucked	5/17/2015	3-5	6.03	N/A[c]	N/A[c]	No
Sill #2 NE Beach	Cockle – whole, shucked	5/9/2016	1	0.82	N/A[c]	N/A[c]	No
Head of Hawk	Cockle – whole, shucked	5/17/2015	3-5	3	N/A[c]	N/A[c]	No
GCD Low IT	Cockle – whole, shucked	5/18/2015	3-5	3.65	N/A[c]	N/A[c]	No
GCD Low IT	Cockle – whole, shucked	5/18/2015	3-5	2.47	N/A[c]	N/A[c]	No
GCD Low IT	Butter Clam – shucked compos	5/18/2015	1-7	4.42	N/A[c]	N/A[c]	No
Floatplane dock	Butter Clam – whole, shucked	5/9/2016	1	1.35	N/A[c]	N/A[c]	No
WP122	Horse Clam – whole, shucked	5/18/2015	1	6.17	N/A[c]	N/A[c]	No
Piledriver Cove	Mixed Clams – whole, shucked	5/20/2015	4	3.09	N/A[c]	N/A[c]	No
Zinc							
GCD Mid IT	Black Seaweed Nori – blade	5/19/15	6	2.9	N/A[c]	N/A[c]	No
GCD midIT	Fucus Seaweed- blade+strip	5/19/15	3	3.7	N/A[c]	N/A[c]	No
Floatplane dock	Laminaria kelp – blade	5/9/2016	3	11.2	N/A[c]	N/A[c]	No
Basin 1	Side-Stripe Shrimp – peeled, whole	5/18/2015	8	15	N/A[c]	N/A[c]	No

Station/Sample ID	Tissue type	Date sampled	Number of organisms per composite sample	Results (mg/kg wet weight	Exceeding recreational EPA recommended value[a]	Exceeding subsistence EPA recommended value[a]	Exceeding DHSS recommended maximum value[b]
Basin 1 Deep	Spot shrimp – whole with shell	10/15/2015	4 (2 w/eggs)	15.9	N/A[c]	N/A[c]	No
Basin 1 Deep	Spot shrimp – peeled, whole	10/15/2015	6 (3w/eggs)	13	N/A[c]	N/A[c]	No
Basin 1 HI 5fa near002	Dungeness crab – muscle	6/26/2016	1	31.8	N/A[c]	N/A[c]	No
Basin 1 0.3 nm ore dock	Dungeness crab – viscera	8/15/2015	2	8.2	N/A[c]	N/A[c]	No
Basin 1 0.3 nm ore dock	Dungeness crab – muscle	8/15/2015	2	27.8	N/A[c]	N/A[c]	No
W. Basin 1	Red King Crab – muscle+viscera	6/26/2016	1	30.2	N/A[c]	N/A[c]	No
W. Basin 1	Red King Crab – ova	6/26/2016	1	41.2	N/A[c]	N/A[c]	No
Basin 3	Helmet Crab – muscle	5/18/2015	4	32.4	N/A[c]	N/A[c]	No
Basin 2 floathouse	Lyre crab – whole	6/26/2016	2	16.5	N/A[c]	N/A[c]	No
Head HI	Blue Mussel – whole, shucked	5/18/2015	14	12.2	N/A[c]	N/A[c]	No
Dock Piling IT	Blue Mussel – whole, shucked	11/8/2015	34	34.7	N/A[c]	N/A[c]	No
GCD midIT	Blue Mussel – whole, shucked	5/18/2015	8-12	25	N/A[c]	N/A[c]	No
Piledriver Cove	Blue Mussel – whole, shucked	5/20/2015	8-12	23.3	N/A[c]	N/A[c]	No
Sill #2 NE Beach	Steamer clam – whole, shucked	5/9/2016	4	16.9	N/A[c]	N/A[c]	No
Sill #2 NE Beach	Steamer clam – whole, shucked	5/9/2016	4	17.5	N/A[c]	N/A[c]	No
Sill #2 NE Beach	Steamer clam – whole, shucked	5/9/2016	4	17.6	N/A[c]	N/A[c]	No
Head of Hawk	Cockle – whole, shucked	5/17/2015	3-5	13.9	N/A[c]	N/A[c]	No
Sill #2 NE Beach	Cockle – whole, shucked	5/9/2016	1	10.8	N/A[c]	N/A[c]	No
Head of Hawk	Cockle – whole, shucked	5/17/2015	3-5	11	N/A[c]	N/A[c]	No

Station/Sample ID	Tissue type	Date sampled	Number of organisms per composite sample	Results (mg/kg wet weight	Exceeding recreational EPA recommended value[a]	Exceeding subsistence EPA recommended value[a]	Exceeding DHSS recommended maximum value[b]
GCD Low IT	Cockle – whole, shucked	5/18/2015	3-5	18	N/A[c]	N/A[c]	No
GCD Low IT	Cockle – whole, shucked	5/18/2015	3-5	15.7	N/A[c]	N/A[c]	No
GCD Low IT	Butter Clam – shucked compos	5/18/2015	1-7	16.4	N/A[c]	N/A[c]	No
Floatplane dock	Butter Clam – whole, shucked	5/9/2016	1	17.2	N/A[c]	N/A[c]	No
WP122	Horse Clam – whole, shucked	5/18/2015	1	16.6	N/A[c]	N/A[c]	No
Piledriver Cove	Mixed Clams – whole, shucked	5/20/2015	4	13.8	N/A[c]	N/A[c]	No

Data Source: Ridgway (2016)

[a] Compared to the cadmium recreational and subsistence EPA recommended values of 4 and 0.491 mg/kg wet weight, respectively and to the methylmercury recreational and subsistence EPA recommended values of 0.3 and 0.03 mg/kg wet weight, respectively (USEPA 2000, 2001).

[b] Compared to the DHSS recommended maximum safe tissue concentrations in marine species. Recommended concentrations (in mg/kg wet weight) are as follows: Cadmium – clams (33.2), cockles (41.5), mussels (137), crab (25.1), shrimp (103), seaweed (49.5); Copper – clams (1,635), cockles (2,046), mussels (6,770), crab (1,239), shrimp (5,072), seaweed (2,442); Mercury – clams (4.89), cockles (6.12), mussels (20.2), crab (3.7), shrimp (15.2), seaweed (7.3); Zinc – clams (4,891), cockles (6,122), mussels (20,258), crab (3,708), shrimp (15,177), seaweed (7,307).

[c] N/A = Not applicable. There are no DHSS recommended maximum values for marine worms, sea cucumber, triton snail, sole, sculpin or harbor seal and there are no EPA recommended recreational or subsistence screening values for copper and zinc.

[d] Data are in total mercury, but are compared to the methylmercury EPA recommended values. As noted by USEPA, “because most mercury in fish and shellfish is present primarily as methylmercury and because of the relatively high cost of analyzing for methylmercury, it is recommended that total mercury be analyzed and the conservative assumption be made that all mercury is present as methylmercury” (USEPA 2000).

Pre- and Post-Mining Data Comparison for Fish Tissue in Hawk Inlet

In addition to comparing tissue data to the USEPA and DHSS recommended values, the data were separated and also compared to conditions in the 1980s before mining began in Hawk Inlet (referred to as "pre-mining" below to maintain consistency with the Oceanus Alaska [2003] report). Cadmium and mercury data for the pre-mining years 1984 through 1988 at stations S-1, S-2, S-3, S-4, STN-1, STN-2, STN-3, and ESL were compared to more recent data. The pre-mining data were for worms (Nephtys procera), mussels, and clams (Table 3-17, Table 3-18, and Table 3-19, respectively). There were no exceedances of the mercury recreational and subsistence EPA recommended values for any of the pre- or post-mining Nephtys procera, mussel or clam observations. However, there were exceedances of the cadmium subsistence EPA recommended value of 0.491 mg/kg (USEPA 2000, 2001) for Nephtys procera and mussels. Both pre-mining and post-mining Nephtys procera tissue averages exceeded the cadmium subsistence EPA recommended value at station S-1. The pre-mining Nephtys procera average at station S-3 also exceeded the subsistence EPA recommended value (Table 3-17). All of the average mussels tissue concentrations, both pre- and post-mining, exceeded the cadmium subsistence EPA recommended value (Table 3-18). The clam tissue did not exceed the cadmium screening values (Table 3-19).

Table 3-17. Comparison of pre- and post-mining tissues averages for worms (*Nephtys procera*) in Hawk Inlet

Metal	S-1		S-2		S-3		S-4	
	Pre-Mining Avg (1984-1988)[a,b]	Post-Mining Avg (2005-2015)[a,b]	Pre-Mining Avg (1984-1988)[a,b]	Post-Mining Avg (2005-2015)[a,b]	Pre-Mining Avg (1984-1988)[a,c]	Post-Mining Avg (2005-2015)[a,b]	Pre-Mining Avg (1984-1988)[a,b]	Post-Mining Avg (1988-2015)[a,b]
Cadmium (mg/kg)	0.668	0.531	0.284	0.182	0.695	0.293	0.201	0.118
Mercury[d] (mg/kg)	0.008	0.008	0.003	0.004	0.021	0.009	0.018	0.005

[a] Compared to the cadmium recreational and subsistence EPA recommended values of 4 and 0.491 mg/kg wet weight, respectively and to the methylmercury recreational and subsistence EPA recommended values of 0.3 and 0.03 mg/kg wet weight, respectively (USEPA 2000, 2001).

[b] Source: HGCMC, personal communication May 2016

[c] Source: Oceanus Alaska 2003

[d] Data are in total mercury, but are compared to the methylmercury EPA recommended values. As noted by USEPA, "because most mercury in fish and shellfish is present primarily as methylmercury and because of the relatively high cost of analyzing for methylmercury, it is recommended that total mercury be analyzed and the conservative assumption be made that all mercury is present as methylmercury" (USEPA 2000). Shaded cells exceeding one or more of the EPA recommended values.

Table 3-18. Comparison of pre- and post-mining tissues averages for mussels in Hawk Inlet

Metal	STN-1		STN-2		STN-3		ESL	
	Pre-Mining Avg (1984-1988)[a,b]	Post-Mining Avg (2005-2014)[a,b]	Pre-Mining Avg (1984-1988)[a,b]	Post-Mining Avg (2005-2014)[a,b]	Pre-Mining Avg (1984-1988)[a,b]	Post-Mining Avg (2005-2014)[a,b]	Pre-Mining Avg (1984-1988)[a,b]	Post-Mining Avg (2005-2015)[a,b]
Cadmium (mg/kg)	1.237	1.594	1.437	1.600	1.549	1.558	1.113	1.206
Mercury[c] (mg/kg)	0.012	0.007	0.006	0.007	0.007	0.006	0.005	0.005

[a] Compared to the cadmium recreational and subsistence EPA recommended values of 4 and 0.491 mg/kg wet weight, respectively and to the methylmercury recreational and subsistence EPA recommended values of 0.3 and 0.03 mg/kg wet weight, respectively (USEPA 2000, 2001).

[b] Source: HGCMC, personal communication May 2016

[c] Data are in total mercury, but are compared to the methylmercury EPA recommended values. As noted by USEPA, "because most mercury in fish and shellfish is present primarily as methylmercury and because of the relatively high cost of analyzing for methylmercury, it is recommended that total mercury be analyzed and the conservative assumption be made that all mercury is present as methylmercury" (USEPA 2000).

Shaded cells exceeding one or more of the EPA recommended values.

Table 3-19. Comparison of pre- and post-mining tissues averages for cockle clams in Hawk Inlet

	S-4	
Metal	**Pre-Mining Avg (1988)[a,b]**	**Post-Mining Avg (2005-2015)[a,b]**
Cadmium (mg/kg)	0.125	0.164
Mercury[c] (mg/kg)	0.003	0.005

[a] Compared to the cadmium recreational and subsistence EPA recommended values of 4 and 0.491 mg/kg wet weight, respectively and to the methylmercury recreational and subsistence EPA recommended values of 0.3 and 0.03 mg/kg wet weight, respectively (USEPA 2000, 2001).

[b] Source: HGCMC, personal communication May 2016

[c] Data are in total mercury, but are compared to the methylmercury EPA recommended values. As noted by USEPA, “because most mercury in fish and shellfish is present primarily as methylmercury and because of the relatively high cost of analyzing for methylmercury, it is recommended that total mercury be analyzed and the conservative assumption be made that all mercury is present as methylmercury” (USEPA 2000).

Shaded cells exceeding one or more of the EPA recommended values.

Pre-mining tissue data are also available for three Hawk Inlet stations in 1980 and 1981 (Richkus and Johnson 1981 and Holland et al. 1981). The stations are located in Hawk Inlet at the Greens Creek delta, near Greens Creek, and near the cannery. The exact locations of these stations are unknown, but the data are presented in Table 3-20. There were no exceedances of the EPA recommended recreational cadmium and mercury screening values of 4 and 3 mg/kg wet weight, respectively. There were exceedances of the recommended subsistence cadmium screening value of 0.491 mg/kg wet weight in mussels at all three stations. None of the other tissue types (polychaetes, clams, starfish, albacore tuna, and Coho smolt) exceeded the recommended cadmium subsistence screening value. Mussels also exceeded the recommended subsistence mercury screening value of 0.03 mg/kg wet weight at the Greens Creek delta and Hawk Inlet near Greens Creek. Additional pre-mining exceedances of the recommended mercury subsistence screening value included albacore tuna and Coho smolt near the cannery. There were no exceedances of the DHSS recommended maximum safe concentrations for cadmium, mercury, copper, or zinc for mussels and clams. There are no DHSS screening values currently available for marine worms, starfish tuna or Coho smolt.

For the current monitoring stations (S-1 through S-4, STN-1, STN-2, STN-3 and ESL), the similarity of the pre-mining and post-mining values, as well as the exceedance of the subsistence EPA recommended value before and after mining operations began in the watershed, indicates that the increased metals concentrations in Hawk Inlet tissue may not be related to metals impairment but to naturally elevated levels of metals in the Hawk Inlet area (see Section 4.2.3). The pre-mining data at additional stations in 1980 and 1981 (Table 3-20) support this conclusion as well. As discussed in Section 2.1, 18 AAC 70.235(b) includes a clause considering the natural condition of a waterway, indicating that natural condition can be used as the standard for that water (ADEC 2003). In this analysis, pre-mining data were assumed to represent the natural condition (note: this is consistent with the 2003 Oceanus Alaska report that characterized the pre-mining data as baseline data). Therefore, when comparing the 2005-2014 tissue concentrations with the natural condition data (represented by the pre-mining results above), no impairment of tissue was observed in Hawk Inlet. This assessment should be repeated with additional data, preferably with the full suite of raw data to represent pre-mining conditions as well as new data collected at the monitoring stations identified in Tables 3-17 through 3-20 above.

Table 3-20. Summary of pre-mining cadmium and mercury tissue data in Hawk Inlet

Station	Period of record	Tissue type	Number of observations	Average concentration (mg/kg)[a]	Exceeding recreational EPA recommended value[b]	Exceeding subsistence EPA recommended value[b]	Exceeding DHSS recommended maximum value[c]
Cadmium							
Greens Creek Delta	8/1/1980	Polychaetes	5	0.09	No	No	N/A[d]
Greens Creek Delta	8/1/1980	Mussels	5	0.67	No	Yes	No
Hawk Inlet near Greens Creek	8/1/1980	Mussels	5	1.05	No	Yes	No
Hawk Inlet near the cannery	7/8/1981	Clams	5	0.14	No	No	No
Hawk Inlet near the cannery	7/8/1981	Mussels	5	1.26	No	Yes	No
Hawk Inlet near the cannery	7/8/1981	Starfish	5	0.42	No	No	N/A[d]
Hawk Inlet near the cannery	7/8/1981	Albacore tuna	1	0.01	No	No	N/A[d]
Hawk Inlet near the cannery	7/8/1981	Coho smolt	5	0.03	No	No	N/A[d]
Mercury[e]							
Greens Creek Delta	8/1/1980	Polychaetes	5	0.01	No	No	N/A[d]
Greens Creek Delta	8/1/1980	Mussels	5	0.05	No	Yes	No
Hawk Inlet near Greens Creek	8/1/1980	Mussels	5	0.08	No	Yes	No
Hawk Inlet near the cannery	7/8/1981	Clams	5	0.01	No	No	No
Hawk Inlet near the cannery	7/8/1981	Mussels	5	0.01	No	No	No
Hawk Inlet near the cannery	7/8/1981	Starfish	5	0.01	No	No	N/A[d]
Hawk Inlet near the cannery	7/8/1981	Albacore tuna	1	0.13	No	Yes	N/A[d]
Hawk Inlet near the cannery	7/8/1981	Coho smolt	5	0.06	No	Yes	N/A[d]
Copper							
Greens Creek Delta	8/1/1980	Mussels	5	0.86	N/A[d]	N/A[d]	No
Hawk Inlet near Greens Creek	8/1/1980	Mussels	5	1.4	N/A[d]	N/A[d]	No

Station	Period of record	Tissue type	Number of observations	Average concentration (mg/kg)[a]	Exceeding recreational EPA recommended value[b]	Exceeding subsistence EPA recommended value[b]	Exceeding DHSS recommended maximum value[c]
Hawk Inlet near the cannery	7/8/1981	Clams	5	2.7	N/A[d]	N/A[d]	No
Hawk Inlet near the cannery	7/8/1981	Mussels	5	1.2	N/A[d]	N/A[d]	No
Zinc							
Greens Creek Delta	8/1/1980	Mussels	5	14	N/A[d]	N/A[d]	No
Hawk Inlet near Greens Creek	8/1/1980	Mussels	5	22	N/A[d]	N/A[d]	No
Hawk Inlet near the cannery	7/8/1981	Clams	5	17.6	N/A[d]	N/A[d]	No
Hawk Inlet near the cannery	7/8/1981	Mussels	5	16.7	N/A[d]	N/A[d]	No

[a] Sources: Richkus and Johnson 1981 and Holland et al. 1981. Data in Richkus and Johnson (1981) were only presented as average values, while the data in Holland et al. (1981) were presented as individual values. Data are presented as average values in Table 3-20 for consistency purposes.

[b] Compared to the cadmium recreational and subsistence EPA recommended values of 4 and 0.491 mg/kg wet weight, respectively and to the methylmercury recreational and subsistence EPA recommended values of 0.3 and 0.03 mg/kg wet weight, respectively (USEPA 2000, 2001).

[c] Compared to the DHSS recommended maximum safe tissue concentrations in marine species for mussels and clams. Recommended concentrations for cadmium in mussels and clams are 137 and 33.2 mg/kg wet weight, respectively. Recommended concentrations for mercury in mussels and clams are 20.2 and 4.89 mg/kg wet weight, respectively. Recommended concentrations for copper in mussels and clams are 6,770 and 1,635 mg/kg wet weight, respectively. Recommended concentrations for zinc in mussels and clams are 20,258 and 4,891 mg/kg wet weight, respectively.

[d] N/A = Not applicable. There are no DHSS recommended maximum values for marine worms, starfish, tuna or Coho smolt and there are no EPA recommended recreational or subsistence screening values for copper and zinc.[e] Data are assumed to be measured in total mercury, but are compared to the methylmercury EPA recommended values. As noted by USEPA, “because most mercury in fish and shellfish is present primarily as methylmercury and because of the relatively high cost of analyzing for methylmercury, it is recommended that total mercury be analyzed and the conservative assumption be made that all mercury is present as methylmercury” (USEPA 2000).

3.2.3.3 Hawk Inlet Sediment Quality

Long-term Sediment Monitoring Data

This section presents a summary of the sediment data collected by HGCMC at stations S-1, S-2, S-3, S-4, S-5N, and S-5S in Hawk Inlet (Figure 3-1). The data have been analyzed both spatially and temporally to show trends throughout the entire inlet. The percent exceedance of the marine sediment ERL screening benchmarks for each station is provided for the entire period of record as well as the last 5 years (2011–2015) to show recent trends. Table 3-21, Table 3-22, Table 3-23, Table 3-24, and Table 3-25 provide summaries of the data at all Hawk Inlet sediment stations for each metal of concern.

Table 3-21. Summary of cadmium at sediment stations in Hawk Inlet

Station	Period of record	Number of observations	Minimum (mg/kg)	Maximum (mg/kg)	Median (mg/kg)	Average (mg/kg)	Number of exceedances	Percent exceedance[a] (entire period of record)	Percent exceedance[a] (2011–2015)
S-1	9/1/1984–9/24/2015	113	0.03	0.89	0.15	0.24	0	0%	0%
S-2	9/1/1984–9/27/2015	111	0.06	0.90	0.13	0.16	0	0%	0%
S-3	9/1/1984–9/29/2015	115	0.06	2.76	0.67	0.69	5	4%	3%
S-4	5/1/1986–9/24/2015	112	0.06	4.23	0.30	0.55	11	10%	0%
S-5N	4/1/1989–9/24/2015	104	0.16	256	2.00	7.33	85	82%	89%
S-5S	9/7/1994–9/24/2015	89	0.18	17.8	2.89	3.79	76	85%	96%

[a] Hawk Inlet sediment data compared to the cadmium ERL screening benchmark of 1.2 mg/kg (Buchman 2008).

Table 3-22. Summary of copper at sediment stations in Hawk Inlet

Station	Period of record	Number of observations	Minimum (mg/kg)	Maximum (mg/kg)	Median (mg/kg)	Average (mg/kg)	Number of exceedances	Percent exceedance[a] (entire period of record)	Percent exceedance[a] (2011–2015)
S-1	9/1/1984–9/24/2015	113	8.4	39.5	14.9	17.0	3	3%	0%
S-2	9/1/1984–9/27/2015	111	6	29.5	9.5	11.1	0	0%	0%
S-3	9/1/1984–9/29/2015	115	8.0	105	35	34.5	63	55%	43%
S-4	5/1/1986–9/24/2015	112	8.2	286	20.7	36.1	34	30%	10%
S-5N	4/1/1989–9/24/2015	103	23.7	1,371	105	164.7	99	96%	93%
S-5S	9/7/1994–9/24/2015	91	26.2	506	80.7	105.7	86	95%	100%

[a] Hawk Inlet sediment data compared to the copper ERL screening benchmark of 34 mg/kg (Buchman 2008).

Table 3-23. Summary of lead at sediment stations in Hawk Inlet

Station	Period of record	Number of observations	Minimum (mg/kg)	Maximum (mg/kg)	Median (mg/kg)	Average (mg/kg)	Number of exceedances	Percent exceedance[a] (entire period of record)	Percent exceedance[a] (2011–2015)
S-1	9/1/1984–9/24/2015	113	4.1	23.7	6.6	7.6	0	0%	0%
S-2	9/1/1984–9/27/2015	111	1.3	8.3	2.0	2.7	0	0%	0%
S-3	9/1/1984–9/29/2015	115	3.1	34.4	13.2	13.2	0	0%	0%
S-4	5/1/1986–9/24/2015	112	9.3	658	23.6	64.7	35	31%	3%
S-5N	4/1/1989–9/24/2015	104	37	15,050	288	773.5	102	98%	100%
S-5S	9/7/1994–9/24/2015	89	5.4	2,180	267	349.0	84	94%	100%

[a] Hawk Inlet sediment data compared to the lead ERL screening benchmark of 46.7 mg/kg (Buchman 2008).

Table 3-24. Summary of mercury at sediment stations in Hawk Inlet

Station	Period of record	Number of observations	Minimum (mg/kg)	Maximum (mg/kg)	Median (mg/kg)	Average (mg/kg)	Number of exceedances	Percent exceedance[a] (entire period of record)	Percent exceedance[a] (2011–2015)
S-1	9/1/1984–9/24/2015	111	0.01	0.14	0.03	0.04	0	0%	0%
S-2	9/1/1984–9/27/2015	106	0.002	0.09	0.02	0.02	0	0%	0%
S-3	9/1/1984–9/29/2015	112	0.0	0.21	0.07	0.07	2	2%	0%
S-4	5/1/1986–9/24/2015	112	0.0	3.7	0.03	0.10	11	10%	0%
S-5N	7/1/1989–9/24/2015	101	0.02	27.05	0.20	1.10	62	61%	33%
S-5S	9/7/1994–9/24/2015	89	0.0	1.18	0.28	0.34	68	76%	74%

[a] Hawk Inlet sediment data compared to the mercury ERL screening benchmark of 0.15 mg/kg (Buchman 2008).

Table 3-25. Summary of zinc at sediment stations in Hawk Inlet

Station	Period of record	Number of observations	Minimum (mg/kg)	Maximum (mg/kg)	Median (mg/kg)	Average (mg/kg)	Number of exceedances	Percent exceedance[a] (entire period of record)	Percent exceedance[a] (2011–2015)
S-1	9/1/1984–9/24/2015	113	53.5	188	94.2	101.2	6	5%	0%
S-2	9/1/1984–9/27/2015	111	26.1	93.4	41.0	44.6	0	0%	0%
S-3	9/1/1984–9/29/2015	115	51	310	121	127	30	26%	10%
S-4	5/1/1986–9/24/2015	112	34	920	65.4	119	24	21%	0%
S-5N	5/1/1989–9/24/2015	103	99	34,800	471	1,246	99	96%	100%
S-5S	6/1/1995–9/24/2015	89	12	3,770	707	810	80	90%	100%

[a] Hawk Inlet sediment data compared to the zinc ERL screening benchmark of 150 mg/kg (Buchman 2008).

Sediment Stations S-1 and S-2

Stations S-1 and S-2 in Hawk Inlet are considered to be reference or background stations. Sediment data have been collected at these stations since 1984. None of the observations at station S-2 were above the ERLs for any of the metals of concern (Table 3-21 through Table 3-25). No exceedances of the cadmium, lead, or mercury ERL screening benchmarks were observed at station S-1 (Table 3-21, Table 3-23, and Table 3-24). There were 113 copper observations at station S-1, and three of them (2.7 percent) were above the copper ERL of 34 mg/kg (Table 3-22). The concentrations associated with these exceedances are 38 mg/kg (2006), 40 mg/kg (1993), and 39 mg/kg (1990). For the same 113 observations at station S-1, six samples (5.2 percent) were above the zinc ERL of 150 mg/kg (Table 3-25). These concentrations were 188, 186, and 166 mg/kg (2006); 185 mg/kg (1993); 179 mg/kg (1990); and 155 mg/kg (1989). No concentrations at stations S-1 and S-2 were above any of the ERLs since 2006.

Sediment Stations S-3, S-4, S-5N, and S-5S

A more detailed analysis was completed for stations S-3, S-4, S-5N, and S-5S because they show more exceedances of the marine sediment ERL screening benchmarks than stations S-1 and S-2. Sediment monitoring began at station S-4 in 1986, at station S-5N in 1989, and at station S-5S in 1994; monitoring continues at all three stations through present day. Monitoring data at station S-3 are available from 1984 through 2015. This station was initially considered to be a background station. Sampling was not required by HECLA's APDES permit at station S-3 after 2005 because data collected from station S-3 exhibited different trends when compared to the other two background stations (S-1 and S-2). Most metals at station S-3 were found at higher levels than at stations S-1 or S-2. A possible mass wasting event in the watershed above S-3 could have released metals from abandoned historic mine workings into the environment (Oceanus Alaska 2003); however, as described in Section 3.2.2, this event is under question so the metals in the sediment at station S-3 might be associated with other factors. When the reissued permit for HGCMC became effective in 2005, station S-3 was dropped from the list of required sediment sampling stations; however, the site continued to be sampled through 2015.

Table 3-21 through Table 3-25 provide a summary of all sediment data in Hawk Inlet. The figures in the remainder of this section (Figure 3-7 through Figure 3-26) show comparisons of stations S-3, S-4, S-5N, and S-5S over time, as well as box plots of the four stations to illustrate the concentrations spatially throughout the inlet. The box plots show the maximum, minimum, median, 75th percentile, and 25th percentile concentration values for each sediment monitoring station. The box plots include stations S-1 and S-2 as a reference for background conditions in the inlet. Figures that show seasonal variations at these stations are also presented below (Figure 3-10, Figure 3-14, Figure 3-18, Figure 3-22, and Figure 3-26). The results of these spatial and temporal comparisons are discussed below for each metal of concern.

<u>Cadmium</u>

Table 3-21 provides a summary of all cadmium sediment data in Hawk Inlet. The 115 cadmium observations at station S-3 range from 0.06 to 2.76 mg/kg. Five of the observations (4 percent) exceeded the cadmium ERL of 1.2 mg/kg. One hundred and twelve cadmium observations at sediment station S-4 have concentrations ranging from 0.06 to 4.23 mg/kg. Ten percent of these observations exceeded the ERL. There are 104 cadmium observations at station S-5N that range from 0.16 to 256 mg/kg. Eighty two percent of these observations exceeded the ERL. Cadmium observations at station S-5S range from 0.18 to 17.8 mg/kg and 85 percent of the 89 observations exceeded the ERL.

Figure 3-7 compares the cadmium observations at stations S-3, S-4, S-5N, and S-5S over time, while Figure 3-8 and Figure 3-9 compare the cadmium concentrations spatially throughout Hawk Inlet. Cadmium concentrations at stations S-5S and S-5N were much higher than concentrations at stations S-3 and S-4; however, the cadmium ERL was exceeded at all four stations (Figure 3-8). Cadmium concentrations at stations S-4 and S-5N appeared to be decreasing (although observations at S-5N still routinely exceeded the cadmium ERL). The most recent exceedance of the cadmium ERL at station S-4 was in 2006. Concentrations at station S-5S did not show this same decreasing trend; however, data at this station only go back to 1994 and do not represent the conditions shortly after the ore concentrate spill in 1989. Existing data showed few exceedances at station S-3. The most recent exceedance of the cadmium ERL at station S-3 was in September 2014 (Figure 3-7). This was the first cadmium exceedance at this station since 2002. Figure 3-9 shows both the water quality (square symbols) and sediment (circle symbols) stations in Hawk Inlet. This figure indicates that the stations with the highest cadmium concentrations were located at the ore concentrate spill site at Greens Creek Mine.

Figure 3-10 compares the average seasonal cadmium concentrations at station S-3, S-4, S-5N, and S-5S. Spring is characterized as April, May, and June while summer is considered to be July, August, and September. The months were grouped this way to represent spring and summer seasons because the most precipitation typically occurs August through November and the least precipitation occurs March through June (USDA 2003). Cadmium concentrations were higher during the spring months than the summer months at stations S-4, S-5N, and S-5S, and higher during the summer months at S-3, although the difference at stations S-3 and S-4 was minimal.

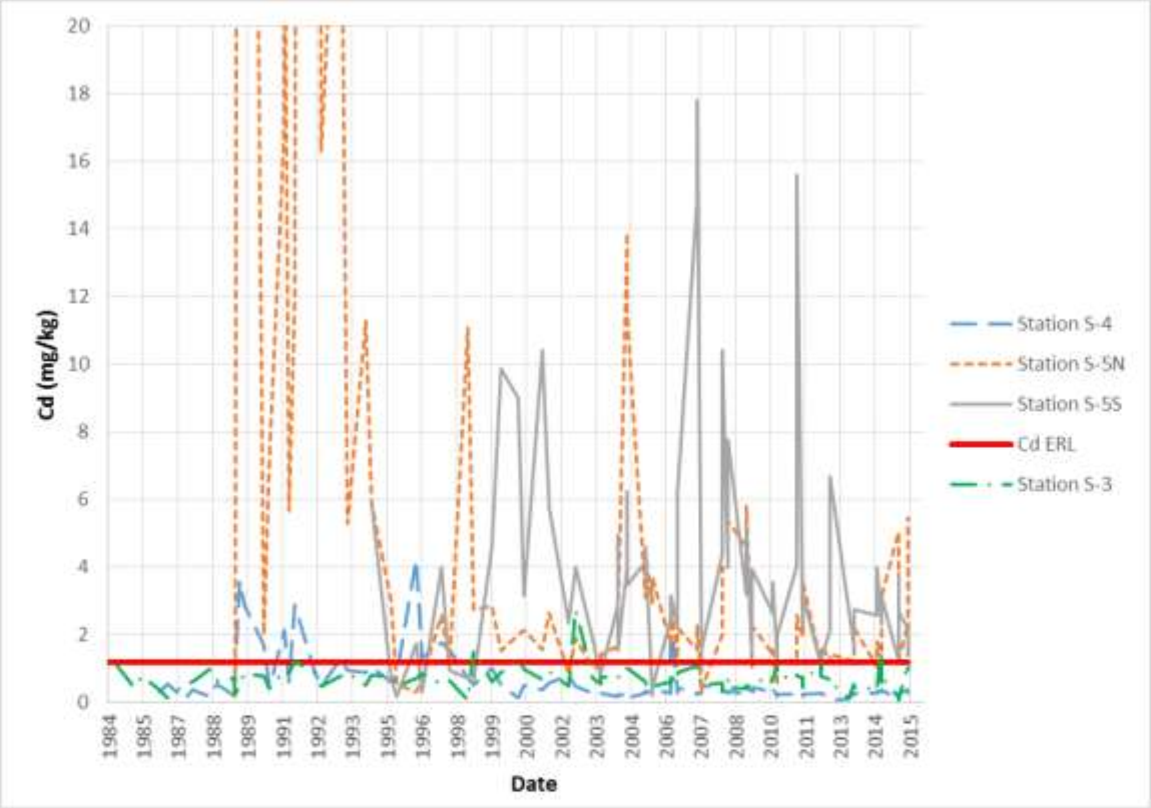


Figure 3-7. Comparison of cadmium data at stations S-3, S-4, S-5N, and S-5S

Note: Four observations at station S-5N are not shown in this figure because they are much larger than the observations at stations S-4 and S-5S and distorted the scale of the figure. They are 28 mg/kg in June 1993, 68 in September 1989, 76 in July 1989, and 256 in June 1992.

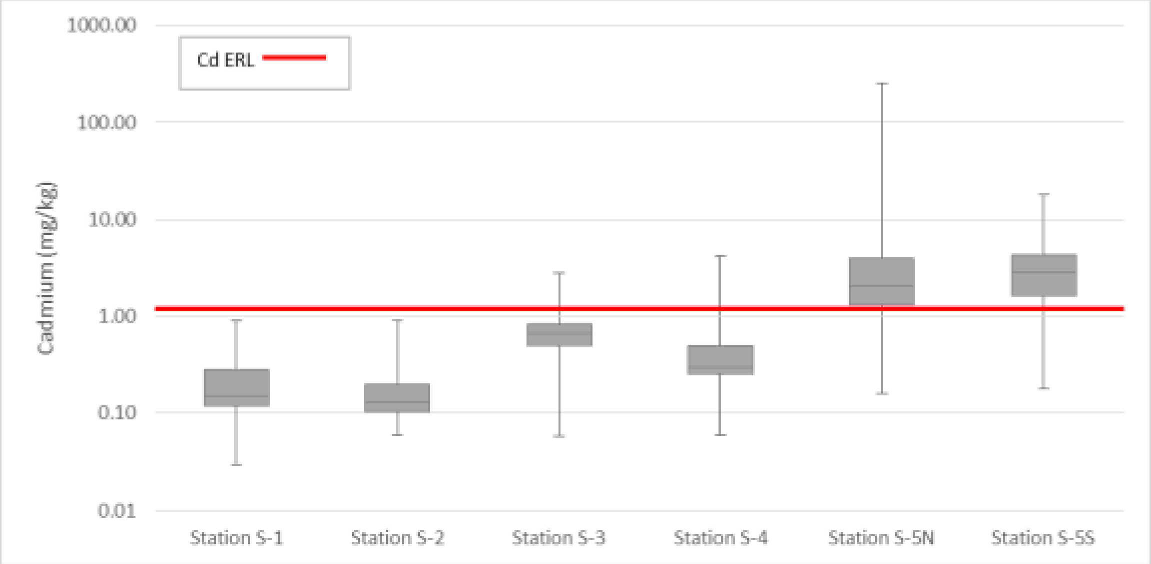


Figure 3-8. Box and whisker plots of cadmium data at stations S-3, S-4, S-5N, and S-5S (1984-2015)

Note: The box plots show the maximum, minimum, median, 75th percentile, and 25th percentile concentration values for each sediment monitoring station.

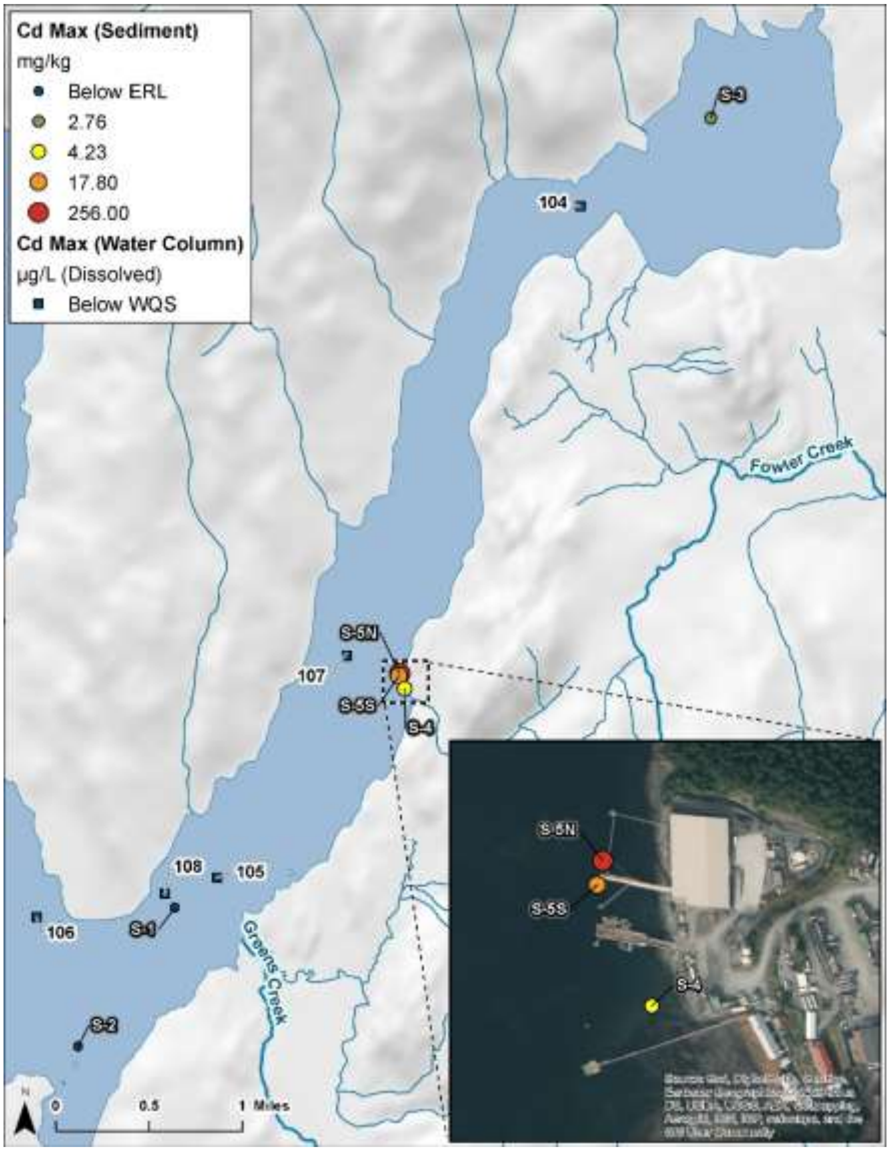


Figure 3-9. Spatial representation of maximum cadmium observations throughout Hawk Inlet

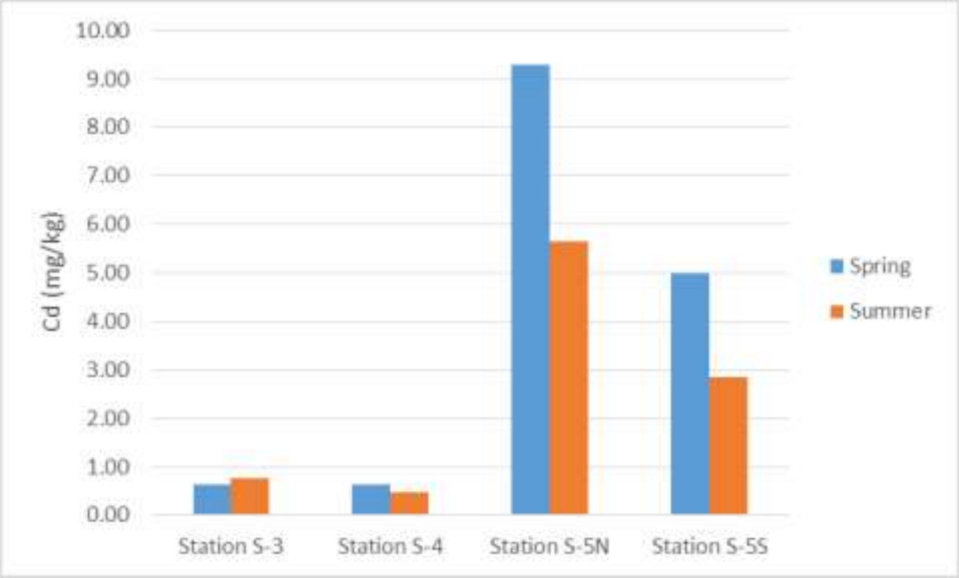


Figure 3-10. Comparison of seasonal cadmium averages at stations S-3, S-4, S-5N, and S-5S

Copper

Table 3-22 provides a summary of all copper sediment data in Hawk Inlet. Sixty three (55 percent) of the copper observations at station S-3 exceeded the 34 mg/kg copper ERL. At station S-4, the copper observations ranged from 8.2 to 286 mg/kg; 30 percent of the 112 samples exceeded the ERL. There are 103 copper observations at sediment station S-5N and these ranged from 23.7 to 1,371 mg/kg; 96 percent of these values exceeded the ERL. Copper observations at station S-5S ranged from 26.2 to 506 mg/kg and exceeded the ERL 95 percent of the time (86 out of 91 samples exceeded the ERL).

Figure 3-11 compares the copper observations at stations S-3, S-4, S-5N, and S-5S over time, while Figure 3-12 and Figure 3-13 compare the stations spatially throughout the inlet. Copper concentrations at stations S-5S and S-5N tended to be higher than concentrations at S-3 and S-4; however, there were exceedances of the copper ERL at all four stations. All four of these stations also had concentrations typically higher than the background stations S-1 and S-2 (Figure 3-12). Copper concentrations at station S-4 appeared to be decreasing (Figure 3-11). The most recent exceedance of the copper ERL at S-4 was in 2013, with a concentration of 36 mg/kg. Concentrations at station S-5N and S-5S did not show this same decreasing trend; however, data at station S-5S only go back to 1994 and do not represent conditions associated with the 1989 ore concentrate spill (Figure 3-11). Data at S-3 typically showed lower values than the other three stations; however, there were still multiple exceedances of the ERL. The most recent exceedances at station S-3 were in September 2015.

Figure 3-13 illustrates the spatial extent of the maximum water (square symbols) and sediment (circle symbols) concentrations at each station. The highest copper concentrations in the sediment were located near the ore concentrate spill site; however, other stations did show maximum concentrations above the ERL, particularly station S-3 near the head of Hawk Inlet. The highest maximum water column concentrations were also observed in this same geographic area (Figure 3-13). Figure 3-14 compares the average seasonal copper concentrations at station S-3, S-4, S-5N, and S-5S. As with cadmium, spring is considered to be April, May, and June while summer is considered to be July, August, and September. Copper concentrations were higher during the spring months than the summer months at stations S-4 and S-5S. The summer concentrations were higher at station S-3 and there was no seasonal difference at station S-5N.

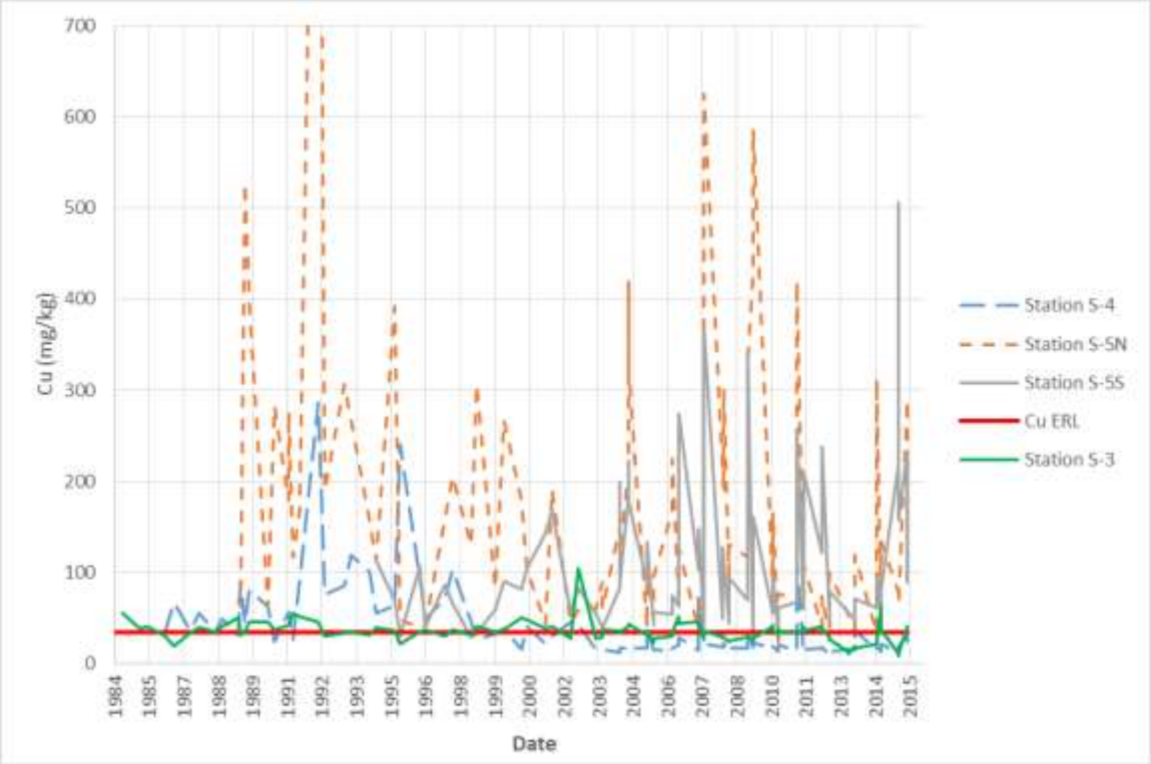


Figure 3-11. Comparison of copper data at stations S-3, S-4, S-5N, and S-5S

Note: Two observations at station S-5N are not shown in this figure because they are much larger than the observations at stations S-4 and S-5S and distorted the scale of the figure. They are 1,371 mg/kg in June 1992 and 2,270 mg/kg in September 1993.

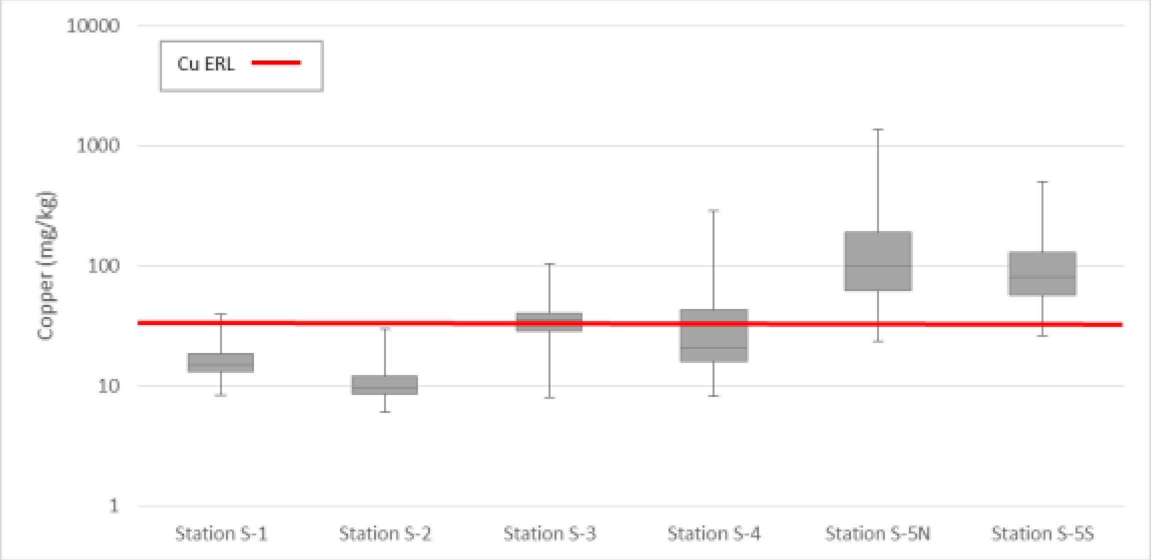


Figure 3-12. Box and whisker plots of copper data at stations S-3, S-4, S-5N, and S-5S (1984-2015)

Note: The box plots show the maximum, minimum, median, 75th percentile, and 25th percentile concentration values for each sediment monitoring station.

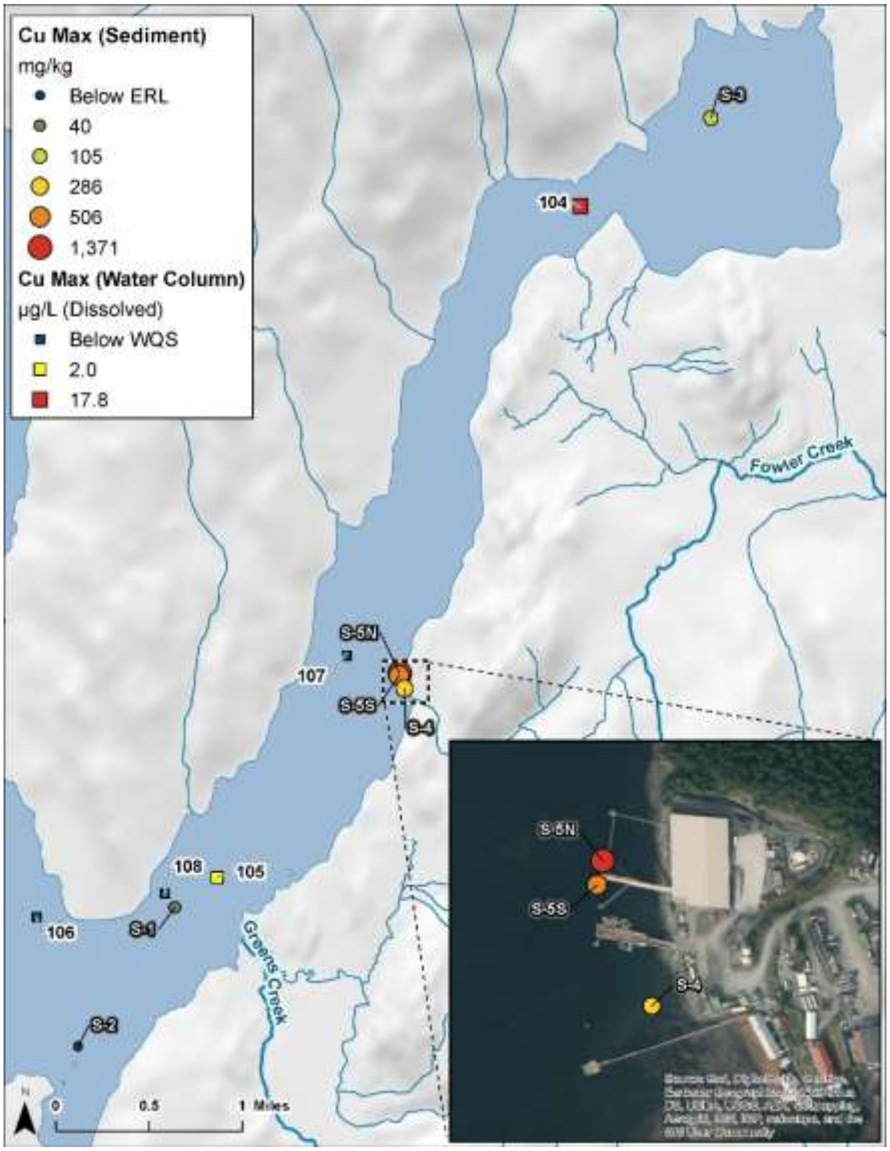


Figure 3-13. Spatial representation of maximum copper observations throughout Hawk Inlet

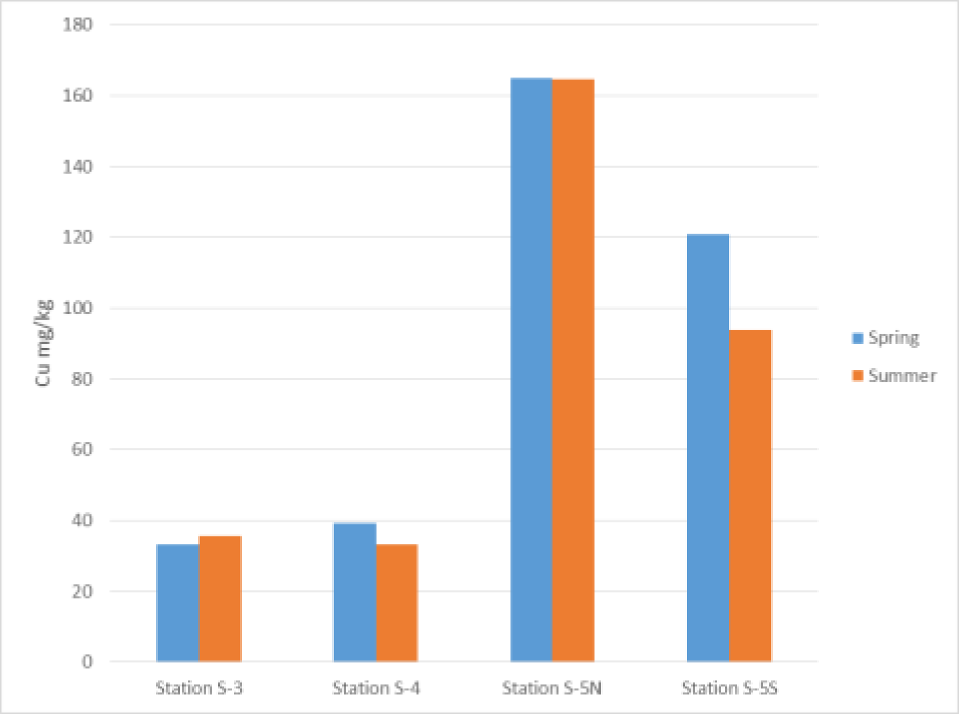


Figure 3-14. Comparison of seasonal copper averages at stations S-3, S-4, S-5N, and S-5S

Lead

Table 3-23 provides a summary of all lead sediment data in Hawk Inlet. No exceedances of the lead ERL of 46.7 mg/kg were observed at station S-3. Thirty-one percent of the 112 lead observations at station S-4 exceeded the ERL, with observations ranging from 9.3 to 658 mg/kg. The 104 lead observations at station S-5N ranged from 37 to 15,050 mg/kg, with 98 percent of the values above the ERL. Lead concentrations at station S-5S ranged from 5.4 to 2,180 mg/kg and had a percent exceedance of 94 percent.

Figure 3-15 compares the lead observations at stations S-3, S-4, S-5N, and S-5S over time, while Figure 3-16 and Figure 3-17 compare the stations spatially. Lead concentrations at stations S-5S and S-5N tended to be higher than concentrations at station S-4; however, there were exceedances of the lead ERL at these three stations. There were no exceedances of the ERL at station S-3 (Figure 3-16). The most recent exceedance of the ERL at S-4 was in 2015 and concentrations showed a decreasing trend (Figure 3-15). Concentrations at station S-5N also appeared to be decreasing over time, although the lead concentrations still exceeded the ERL. Station S-5S did not show this decreasing trend; however, the data at this station do not represent conditions shortly after the ore concentrate spill in 1989 because data collection did not begin until 1994.

The map in Figure 3-17 shows that concentrations for both sediment (square symbols) and water (circle symbols) are low except near the ore concentrate spill site. Figure 3-18 compares the average seasonal lead concentrations at station S-3, S-4, S-5N, and S-5S. Lead concentrations were higher during the spring months than the summer months at stations S-4, S-5N, and S-5S, although the difference at station S-4 were minimal. There was no difference between spring and summer concentrations at station S-3 (Figure 3-18).

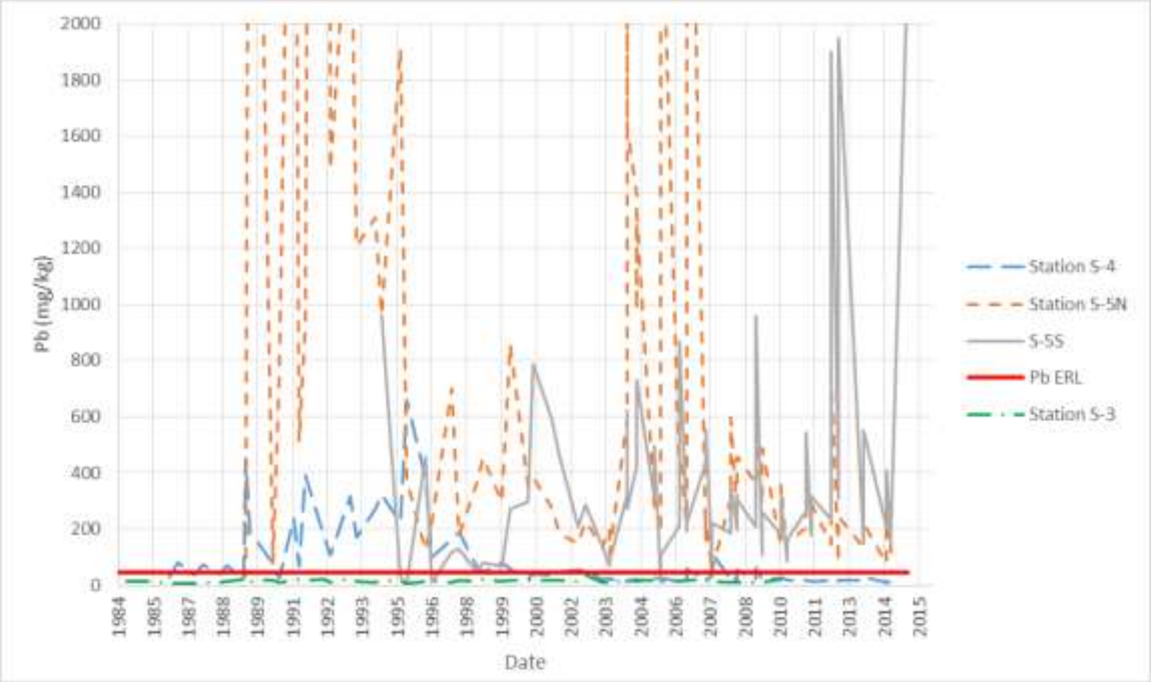


Figure 3-15. Comparison of lead data at stations S-3, S-4, S-5N, and S-5S

Note: Six observations at station S-5N are not shown in this figure because they are much larger than the observations at stations S-4 and S-5S and distorted the scale of the figure. They are 2,560 mg/kg in June 1993; 2,630 mg/kg in September 2005; 3,680 mg/kg in September 2006; 3,890 mg/kg in September 1989; 4,990 mg/kg in July 1989; and 15,050 mg/kg in June 1992.

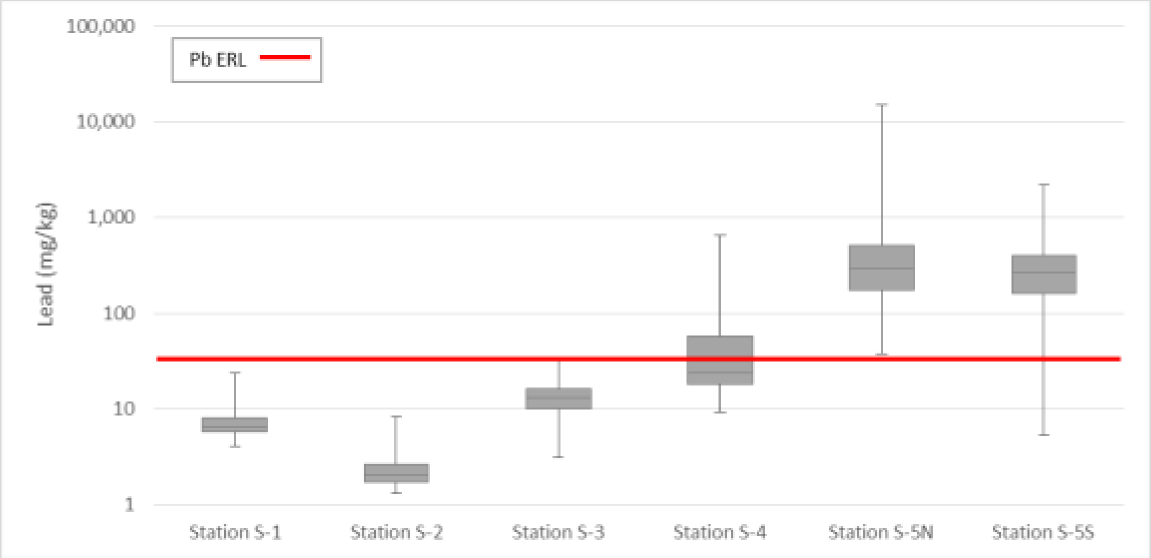


Figure 3-16. Box and whisker plots of lead data at stations S-3, S-4, S-5N, and S-5S (1984-2015)

Note: The box plots show the maximum, minimum, median, 75th percentile, and 25th percentile concentration values for each sediment monitoring station.

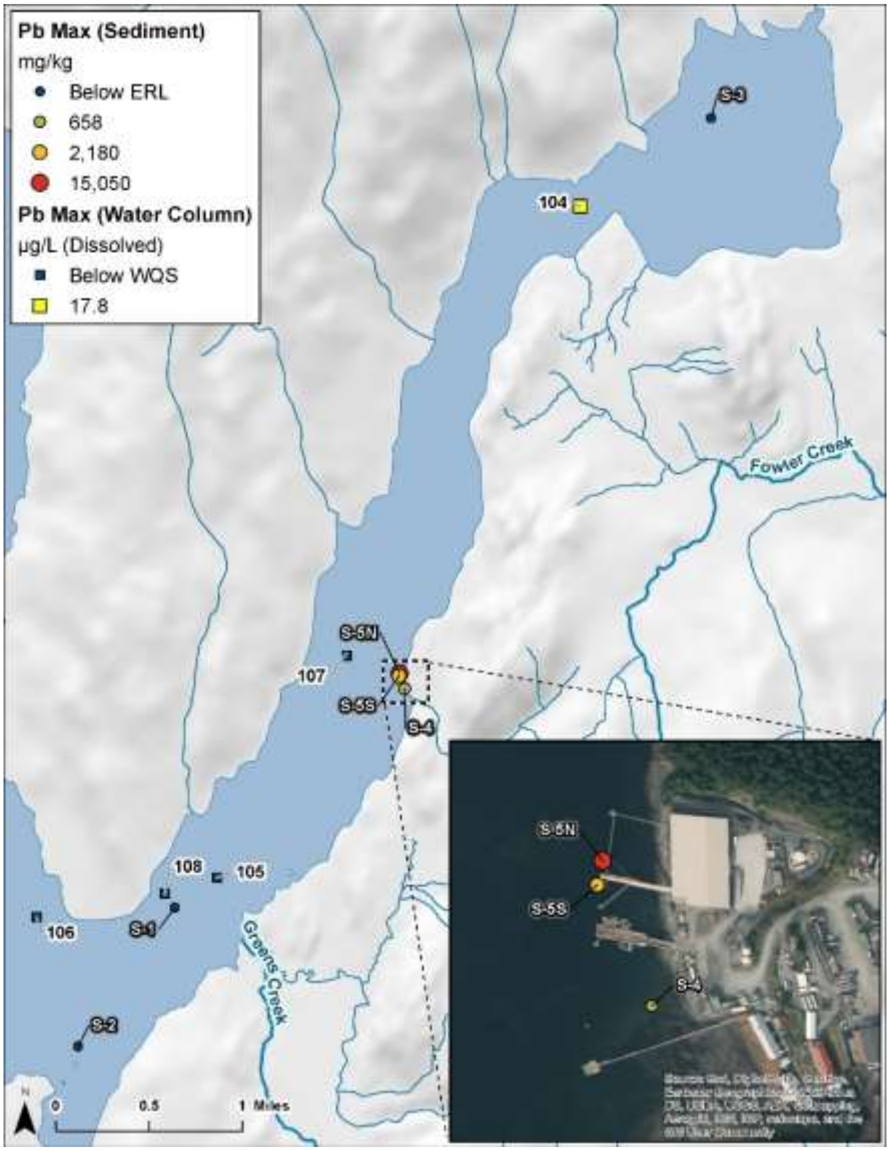


Figure 3-17. Spatial representation of maximum lead observations throughout Hawk Inlet

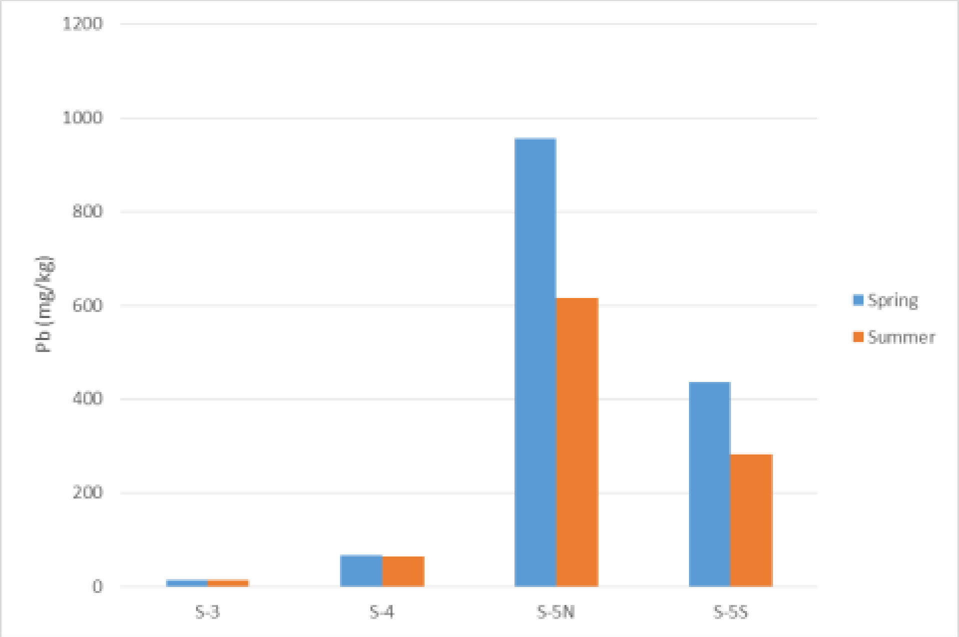


Figure 3-18. Comparison of seasonal lead averages at stations S-3, S-4, S-5N, and S-5S

Mercury

Table 3-24Table 3-24 provides a summary of all mercury sediment data in Hawk Inlet. Two of the 112 mercury observations (2 percent) at station S-3 and 10 percent of the 112 mercury observations at station S-4 exceeded the mercury ERL of 0.15 mg/kg. The mercury observations at station S-4 ranged from 0.0 to 3.7 mg/kg. Of the 101 mercury observations at station S-5N, 61 percent exceeded the ERL with a range of 0.02 to 27.05 mg/kg. Similarly, 76 percent of the 89 measurements at station S-5S exceeded the mercury ERL and ranged between 0.0 and 1.18 mg/kg.

Figure 3-19 compares mercury observations at stations S-3, S-4, S-5N, and S-5S over time, Figure 3-20 and Figure 3-21 compare the stations spatially throughout Hawk Inlet, and Figure 3-22 illustrates seasonal variation. Mercury concentrations at stations S-5S and S-5N tended to be higher than at stations S-3 and S-4; however, there were exceedances of the ERL at all four stations (Figure 3-20). Mercury concentrations at stations S-5N and S-4 appeared to be decreasing over time with occasional spikes. The most recent exceedance of the ERL at S-4 was in 2009. Station S-5S did not show this decreasing trend; however, data at station S-5S only go back to 1994 and do not represent the conditions shortly after the ore concentrate spill in 1989 (Figure 3-19). The mercury observations at station S-3 were all below the ERL except for two observations; one in June 1990 (0.16 mg/kg) and one in September 2002 (0.21 mg/kg).

Figure 3-21 illustrates similar trends to the copper results, where sediment concentrations were highest near the ore concentrate loading site (circle symbols), but maximum concentrations of both water (square symbols) and sediment (circle symbols) were observed near the head of the inlet. Figure 3-22 compares the average seasonal mercury concentrations at stations S-3, S-4, S-5N, and S-5S. Concentrations were higher in the spring than in summer months at stations S-5N and S-5S. Summer mercury concentrations were higher than spring concentrations at stations S-4 and S-3; however, the difference between the two average concentrations was minimal.

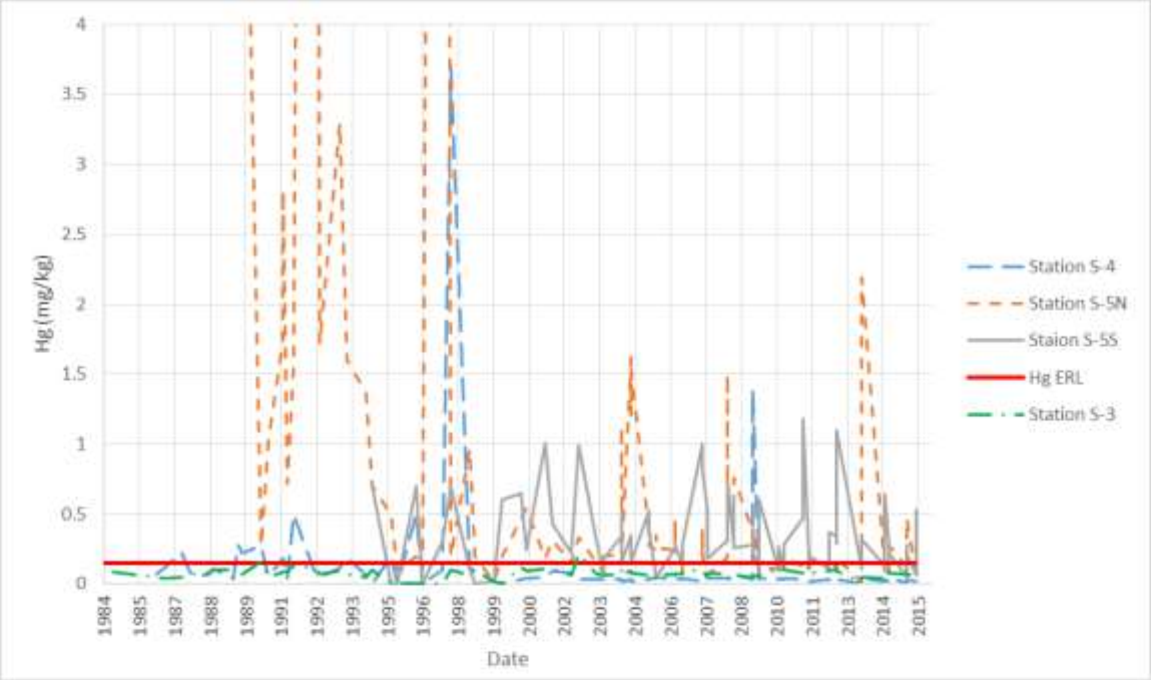


Figure 3-19. Comparison of mercury data at stations S-3, S-4, S-5N, and S-5S

Note: Four observations at station S-5N are not shown in this figure because they are much larger than the observations at stations S-4 and S-5S and distorted the scale of the figure. They are 6.96 mg/kg in September 1989, 7.45 mg/kg in July 1989, 26 mg/kg in June 1997, and 27.05 mg/kg in in June 1992.

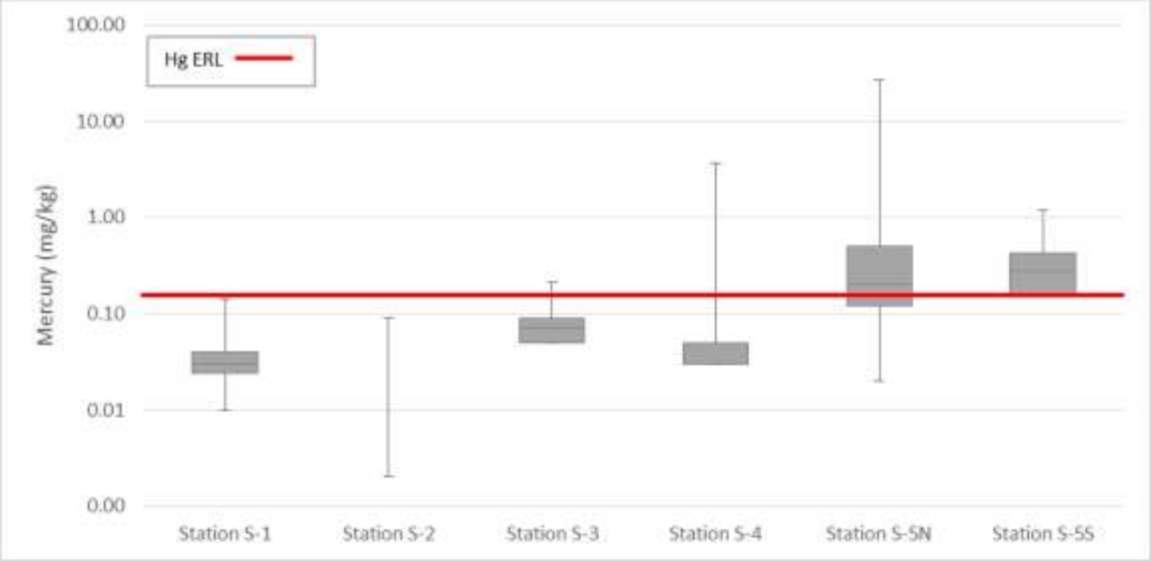


Figure 3-20. Box and whisker plots of mercury data at stations S-3, S-4, S-5N, and S-5S (1984-2015)

Note: The box plots show the maximum, minimum, median, 75th percentile, and 25th percentile concentration values for each sediment monitoring station.

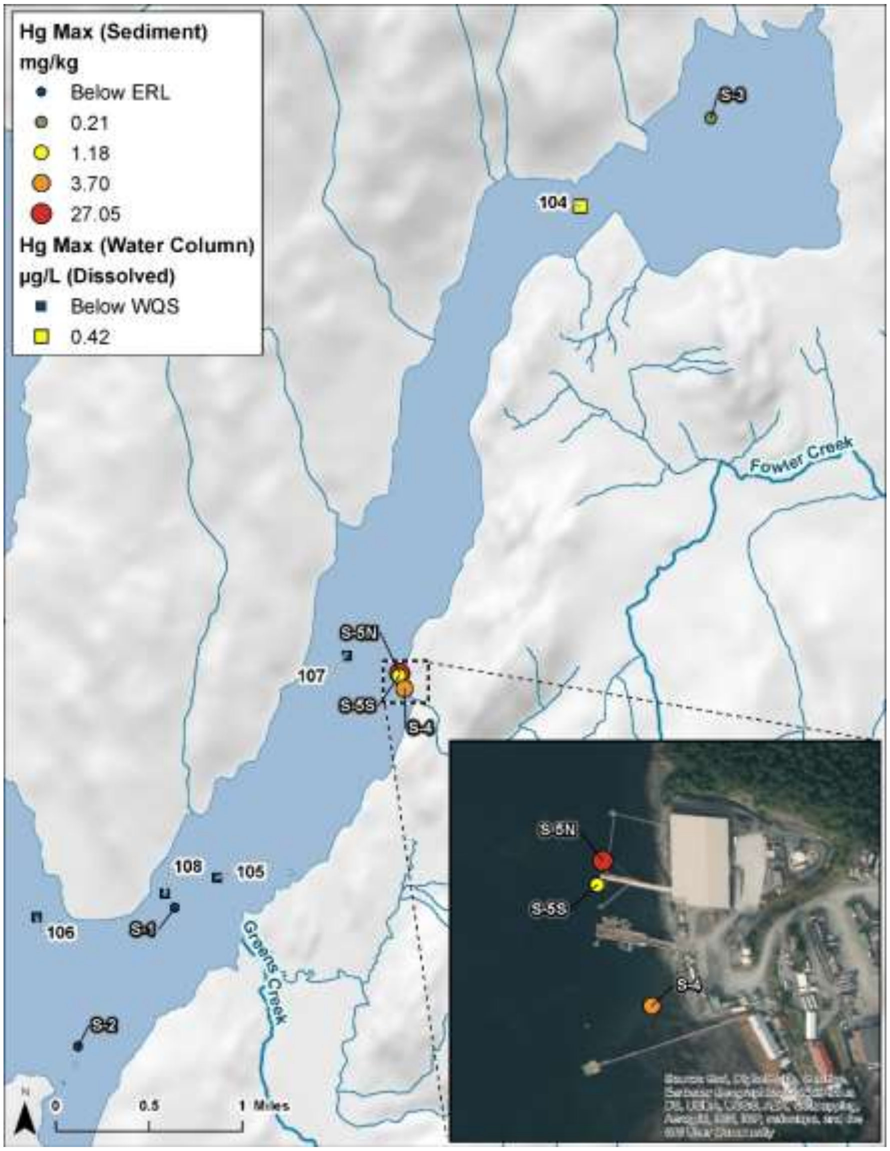


Figure 3-21. Spatial representation of maximum mercury observations throughout Hawk Inlet

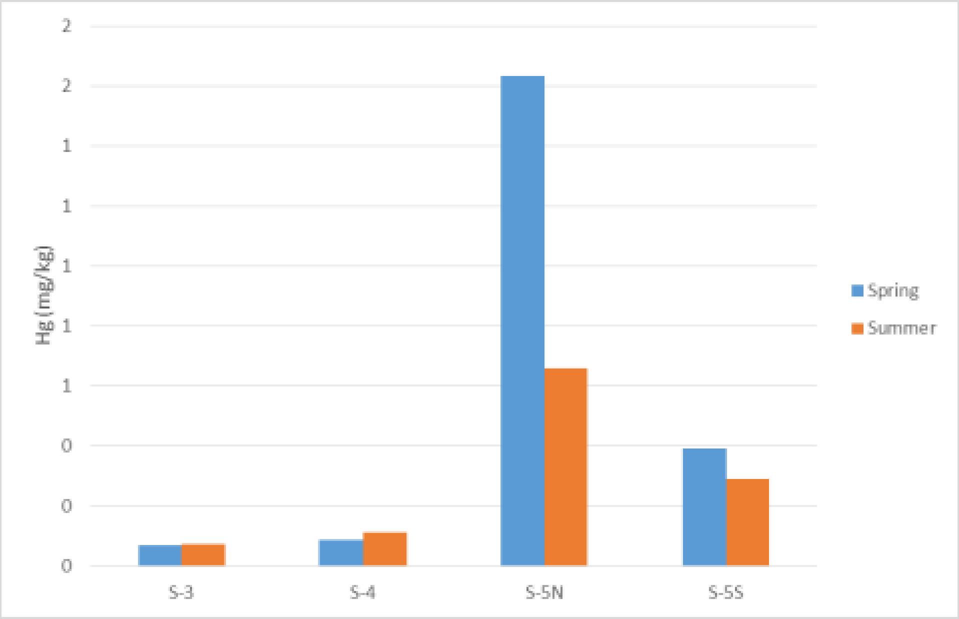


Figure 3-22. Comparison of seasonal mercury averages at stations S-3, S-4, S-5N, and S-5S

Zinc

Table 3-25 provides a summary of all zinc sediment data in Hawk Inlet. Thirty (26 percent) of the observations at station S-3 exceeded the zinc ERL of 150 mg/kg. Twenty-one percent of the 112 zinc measurements at station S-4 exceeded the ERL, with observations ranging from 34 to 920 mg/kg. Of the 103 samples at station S-5N, 96 percent exceeded the ERL (observed range is 99 to 34,800 mg/kg). Similarly, at station S-5S, 90 percent of the 89 observations exceeded the ERL. The range of zinc observations at S-5S was 12 to 3,770 mg/kg.

Figure 3-23 compares the zinc observations at these monitoring stations over time, while Figure 3-24 and Figure 3-25 compare the stations spatially throughout Hawk Inlet. Like the other metals of concern, zinc concentrations at stations S-5S and S-5N tended to be higher than concentrations at stations S-3 and S-4; however, there were exceedances of the ERL at all four stations. Zinc concentrations at stations S-5N and S-4 appeared to be decreasing, but zinc at station S-5S still exceeded the ERL at most times (Figure 3-24). The most recent exceedance of the ERL at S-4 was in 2007. Station S-5S did not show a decreasing trend; however, data at this station do not date back to the ore concentrate spill in 1989. The most recent exceedance of the ERL at S-3 was in September 2015 (152 mg/kg). Exceedances of the ERL screening value at station S-3 in 2014 and 2015 were the first exceedances of the ERL at station S-3 since 2007.

Figure 3-25 shows a similar spatial picture as cadmium. Specifically, the highest maximum sediment concentrations (circle symbols) were near the ore concentrate spill site, but maximum sediment concentrations were also observed hear the head of Hawk Inlet. Figure 3-26 compares the average seasonal zinc concentrations at stations S-3, S-4, S-5N, and S-5S. Zinc concentrations were higher during the spring months than the summer months at stations S-5N and S-5S. Summer zinc concentrations were higher than spring concentrations at stations S-3 and S-4; however, the difference between the two average concentrations was minimal.

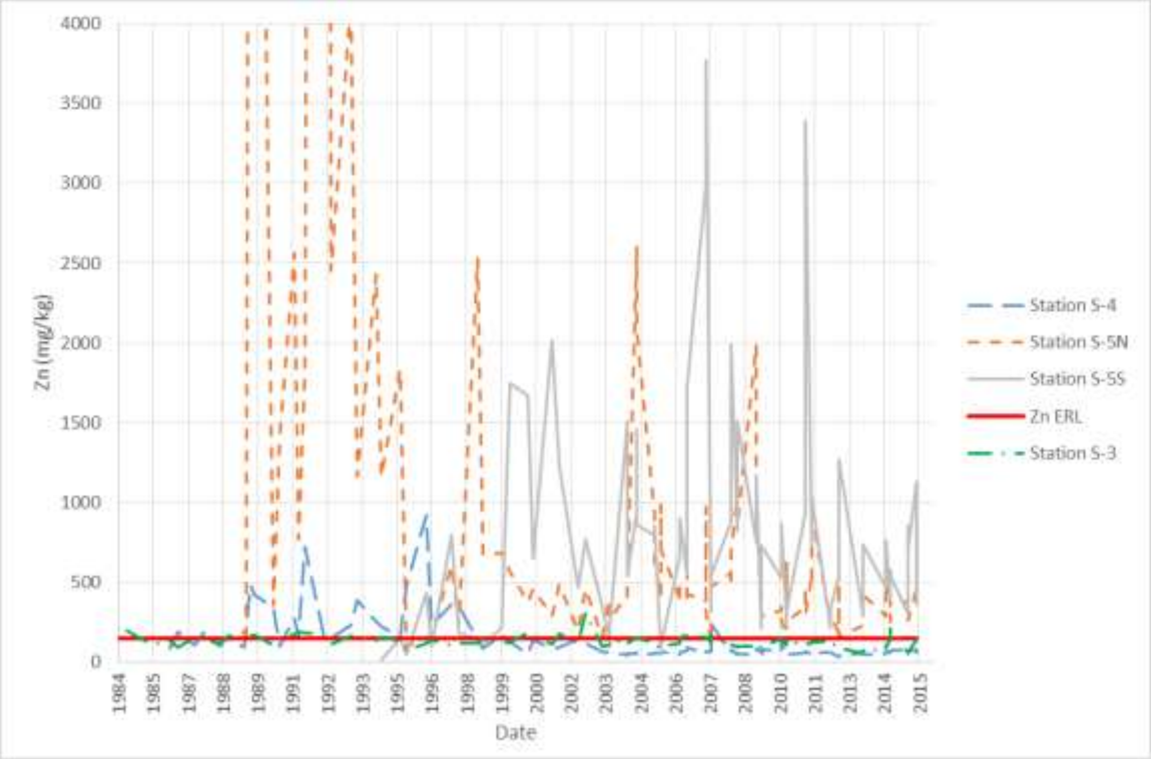


Figure 3-23. Comparison of zinc data at stations S-3, S-4, S-5N, and S-5S

Note: Four observations at station S-5N are not shown in this figure because they are much larger than the observations at stations S-4 and S-5S and distorted the scale of the figure. They are 4,140 mg/kg in June 1993; 9,600 mg/kg in September 1989; 11,650 mg/kg in July 1989; and 34,800 mg/kg in in June 1992.

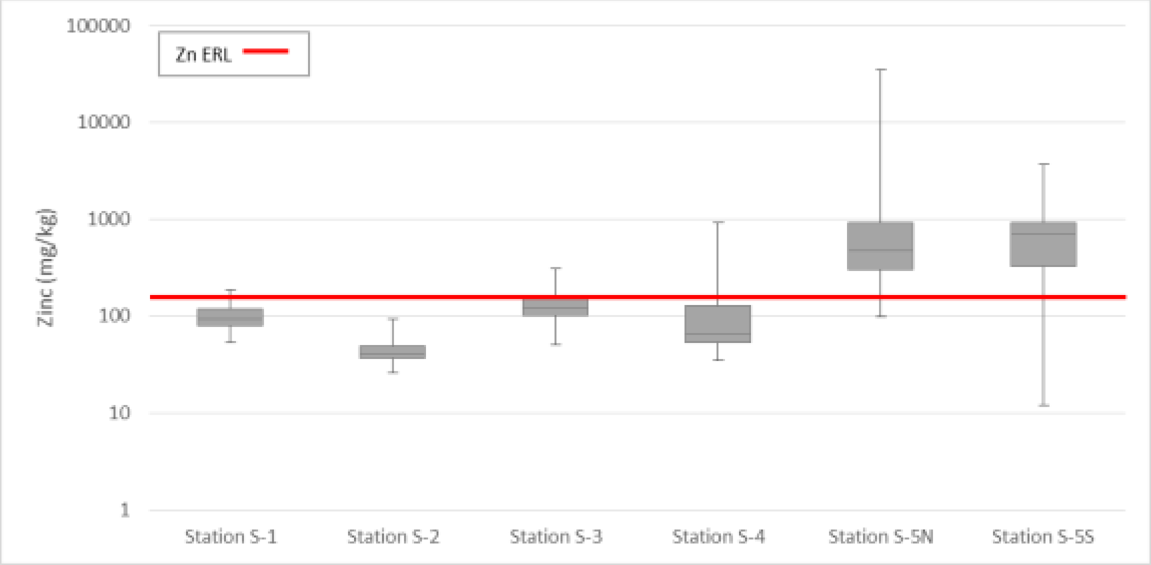


Figure 3-24. Box and whisker plots of zinc data at stations S-3, S-4, S-5N, and S-5S (1984-2015)

Note: The box plots show the maximum, minimum, median, 75th percentile, and 25th percentile concentration values for each sediment monitoring station.

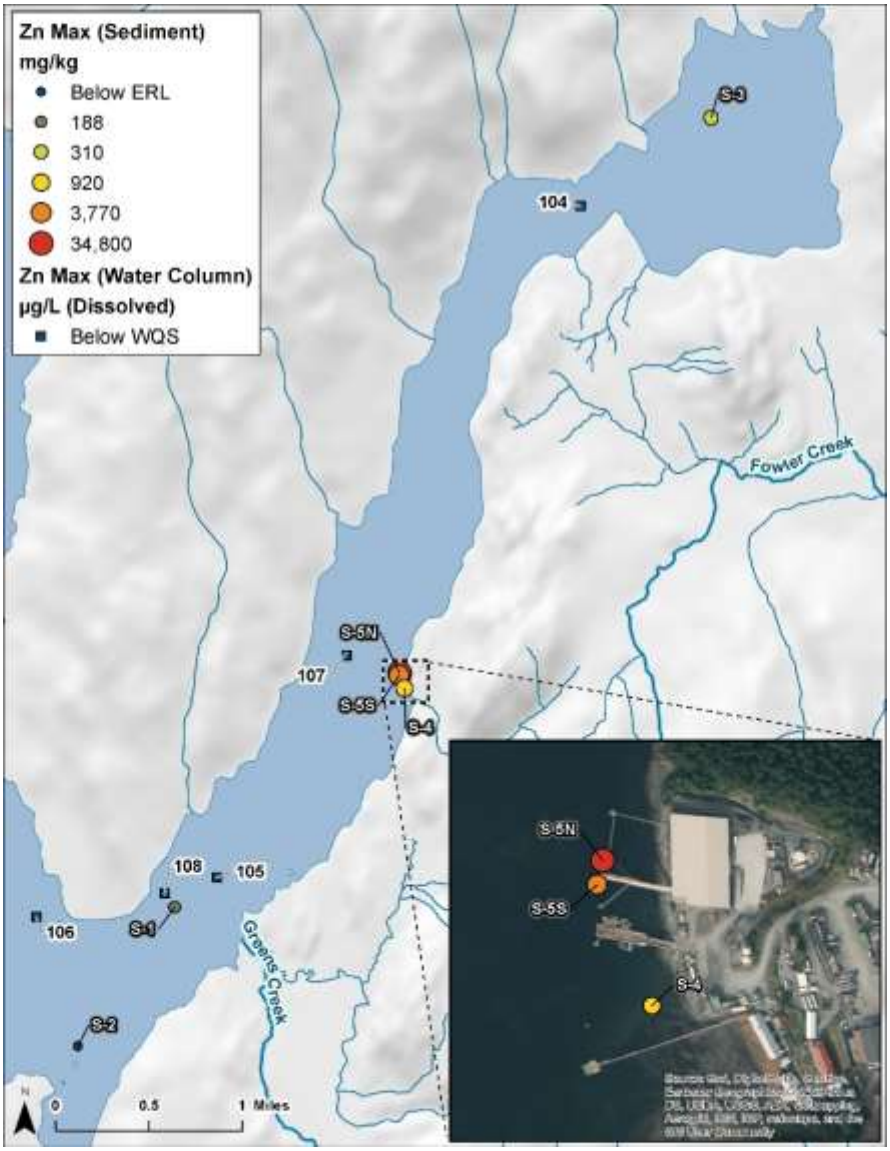


Figure 3-25. Spatial representation of maximum zinc observations throughout Hawk Inlet

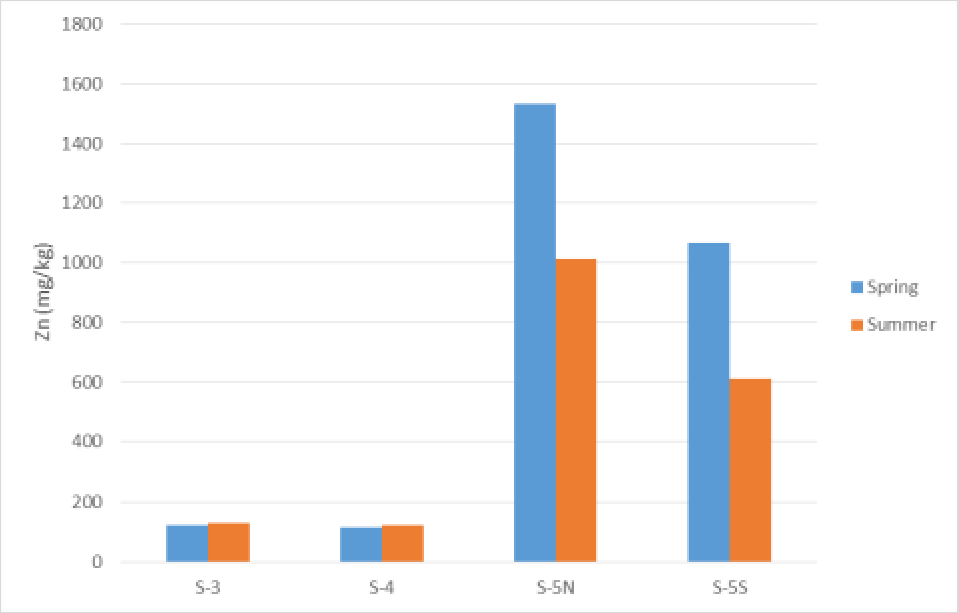
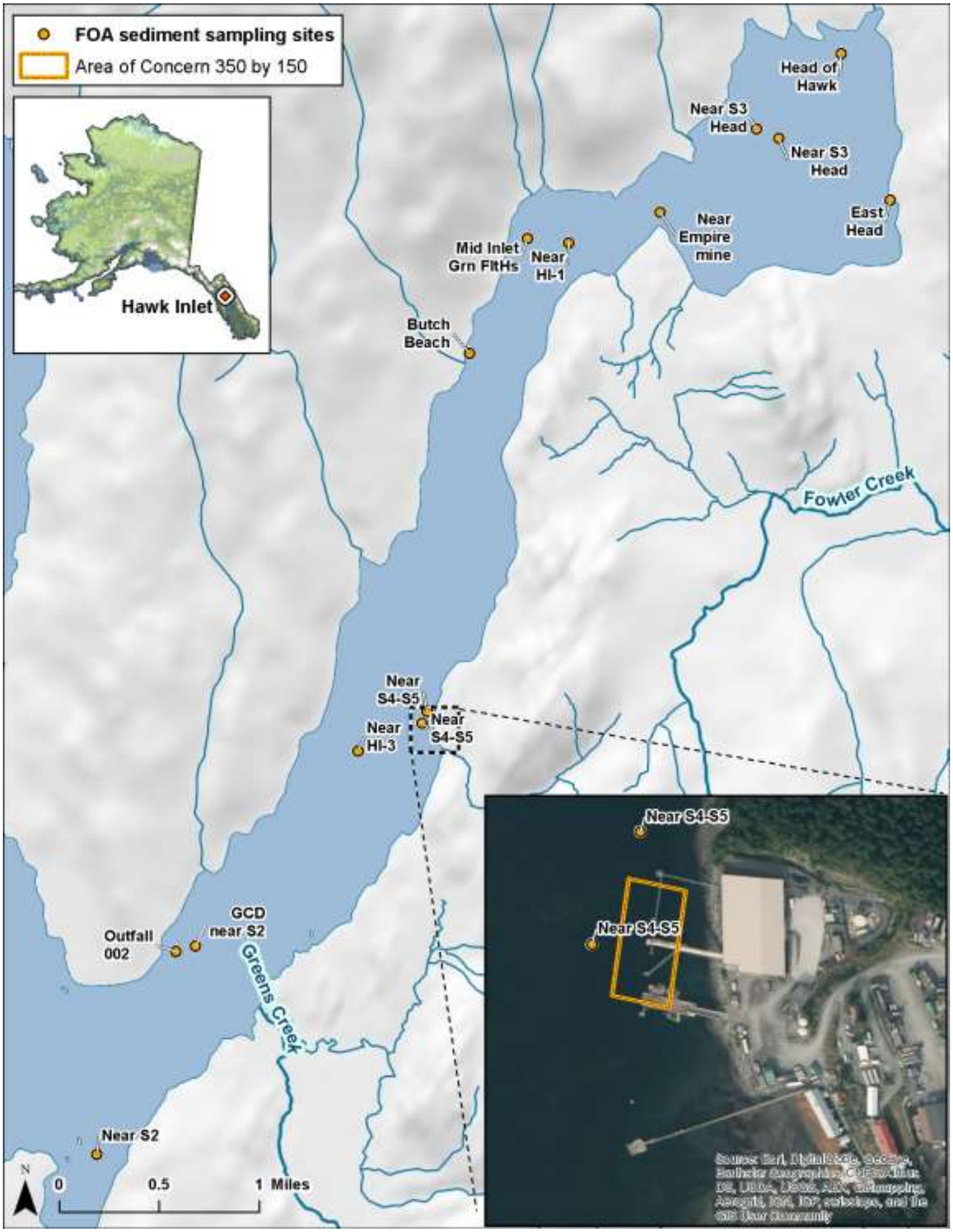


Figure 3-26. Comparison of seasonal zinc averages at stations S-3, S-4, S-5N, and S-5S

Discrete Sediment Monitoring Data

Additional marine sediment data for Hawk Inlet were collected in May 2015 (Ridgway 2016). The locations of the 13 sampling sites are shown in Figure 3-27. The data are presented in Table 3-26. None of the cadmium or mercury observations exceed the ERL screening benchmarks of 1.2 and 0.15 mg/kg, respectively. There were exceedances of the copper, lead, and zinc screening benchmarks at the sampling site ‘near S4-S5’. Two of the three observations at the ‘near S-S5’ site were exceeding the cadmium and lead screening benchmarks of 1.2 and 46.7 mg/kg, respectively. One of the three zinc observations at the ‘near S4-S5’ site was exceeding the zinc ERL screening benchmark of 150 mg/kg.



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 3-27. Locations of FOA sediment sampling sites.

Table 3-26. Summary of sediment data collected throughout Hawk Inlet in 2015

Station	Date of sample	Number of observations	Concentration (mg/kg)[a]	Exceeding ERL screening benchmark[b]
Cadmium				
Head of Hawk	5/17/2015	1	0.4	No
Near S3 Head	5/17/2015	1	0.7	No
East Head	5/17/2015	1	0.5	No
Near Empire mine	5/17/2015	1	0.3	No
GCD near S2	5/18/2015	2	0.5, 0.4	No
Near S4-S5	5/18/2015-5/19/2015	3	0.5, 0.5, 0.4	No
Near HI-1	5/19/2015	2	0.4, 0.4	No
Outfall 002	5/18/2015-5/19/2015	2	0.2, 0.1	No
Near S2	5/19/2015	1	0.3	No
Near HI-3	5/19/2015	1	0.9	No
Butch Beach	5/9/2015	2	0.5, 0.5	No
Near S3 Head	5/9/2015	1	0.2	No
Mid Inlet Grn FltHs	7/20/2015	1	0.6	No
Copper				
Head of Hawk	5/17/2015	1	25.7	No
Near S3 Head	5/17/2015	1	22.0	No
East Head	5/17/2015	1	15.6	No
Near Empire mine	5/17/2015	1	21.6	No
GCD near S2	5/18/2015	2	27.2, 27.4	No
Near S4-S5	5/18/2015-5/19/2015	3	58.0, 60.9, 19.8	Yes
Near HI-1	5/19/2015	2	23.0, 24.0	No
Outfall 002	5/18/2015-5/19/2015	2	13.5, 16.5	No
Near S2	5/19/2015	1	10.0	No
Near HI-3	5/19/2015	1	23.0	No
Butch Beach	5/9/2015	2	15.6	No
Near S3 Head	5/9/2015	1	10.5	No
Mid Inlet Grn FltHs	7/20/2015	1	10.5	No
Lead				
Head of Hawk	5/17/2015	1	5.3	No
Near S3 Head	5/17/2015	1	6.5	No
East Head	5/17/2015	1	4.5	No
Near Empire mine	5/17/2015	1	3.2	No
GCD near S2	5/18/2015	2	10.4, 9.8	No
Near S4-S5	5/18/2015-5/19/2015	3	53.5, 61.6, 25.3	Yes
Near HI-1	5/19/2015	2	9.4, 10.5	No
Outfall 002	5/18/2015-5/19/2015	2	13.5, 16.5	No
Near S2	5/19/2015	1	1.8	No
Near HI-3	5/19/2015	1	11.1	No
Butch Beach	5/9/2015	2	5.2, 3.9	No
Near S3 Head	5/9/2015	1	20.6	No
Mid Inlet Grn FltHs	7/20/2015	1	14.0	No
Mercury				
Head of Hawk	5/17/2015	1	0.05	No
Near S3 Head	5/17/2015	1	0.08	No
East Head	5/17/2015	1	0.08	No
Near Empire mine	5/17/2015	1	0.03	No
GCD near S2	5/18/2015	2	0.05, 0.07	No

Station	Date of sample	Number of observations	Concentration (mg/kg)[a]	Exceeding ERL screening benchmark[b]
Near S4-S5	5/18/2015-5/19/2015	3	0.1, 0.1, 0.05	No
Near HI-1	5/19/2015	2	0.09, 0.09	No
Outfall 002	5/18/2015-5/19/2015	2	0.03, 0.04	No
Near S2	5/19/2015	1	0.03	No
Near HI-3	5/19/2015	1	0.13	No
Butch Beach	5/9/2015	2	0.03, 0.02	No
Near S3 Head	5/9/2015	1	0.02	No
Mid Inlet Grn FltHs	7/20/2015	1	0.09	No
Zinc				
Head of Hawk	5/17/2015	1	79	No
Near S3 Head	5/17/2015	1	82	No
East Head	5/17/2015	1	54	No
Near Empire mine	5/17/2015	1	55	No
GCD near S2	5/18/2015	2	141, 127	No
Near S4-S5	5/18/2015-5/19/2015	3	124, 171, 92	Yes
Near HI-1	5/19/2015	2	78, 82	No
Outfall 002	5/18/2015-5/19/2015	2	93, 85	No
Near S2	5/19/2015	1	50	No
Near HI-3	5/19/2015	1	130	No
Butch Beach	5/9/2015	2	71, 66	No
Near S3 Head	5/9/2015	1	59	No
Mid Inlet Grn FltHs	7/20/2015	1	104	No

[a] Data Source: Ridgway (2016)

[b] Compared to the ERL screening benchmarks for cadmium (1.2 mg/kg); copper (34 mg/kg); lead (46.7 mg/kg); mercury (0.15 mg/kg); and zinc (150 mg/kg) (Buchman 2008).

Marine sediment data for Hawk Inlet were also available from April 1997 (Rudis and Jacobson 2001). The locations of the six sampling stations were only provided on a rough map in Rudis and Jacobson (2001). The exact sampling locations were not provided, but they are located throughout Hawk Inlet. The data are presented in Table 3-27. The only exceedance of the ERL benchmarks was copper at station MS06. This is a minor exceedance with an observation of 34.2 mg/kg and an ERL screening benchmark of 34 mg/kg for copper.

Table 3-27. Summary of sediment data from six stations throughout Hawk Inlet collected in 1997

Station	Date of sample	Number of observations	Concentration (mg/kg)[a]	Exceeding ERL screening benchmark[b]
Cadmium				
MS01	4/1/1997	1	0.73	No
MS02			0.59	No
97HIS03Z			0.72	No
97HIS04			0.85	No
97HIS05			0.44	No
MS06			0.61	No
Copper				
MS01	4/1/1997	1	17.1	No
MS02			13.6	No
97HIS03Z			20.7	No
97HIS04			9.27	No
97HIS05			17.2	No

Station	Date of sample	Number of observations	Concentration (mg/kg)[a]	Exceeding ERL screening benchmark[b]
MS06			34.2	Yes
MS01			17.1	No
Lead				
MS01	4/1/1997	1	3.98	No
MS02			3.25	No
97HIS03Z			8.89	No
97HIS04			1.07	No
97HIS05			2.27	No
MS06			31.80	No
Mercury				
MS01	4/1/1997	1	0.103	No
MS02			0.103	No
97HIS03Z			0.101	No
97HIS04			0.100	No
97HIS05			0.100	No
MS06			0.102	No
Zinc				
MS01	4/1/1997	1	55.2	No
MS02			46.4	No
97HIS03Z			126	No
97HIS04			33.7	No
97HIS05			50.6	No
MS06			76.2	No

[a] Data Source: Rudis and Jacobson (2001)

[b] Compared to the ERL screening benchmarks for cadmium (1.2 mg/kg); copper (34 mg/kg); lead (46.7 mg/kg); mercury (0.15 mg/kg); and zinc (150 mg/kg) (Buchman 2008).

Pre- and Post-Mining Comparison of Sediment Data in Hawk Inlet

In addition to comparing sediment data to the sediment ERL screening benchmarks, data were also compared to conditions in the 1980s before mining began in Hawk Inlet (referred to as “pre-mining” below to maintain consistency with the Oceanus Alaska [2003] report). Cadmium, copper, lead, mercury and zinc data in sediment for the pre-mining years 1984 through 1988 at stations S-1, S-2, S-3 and S-4 were compared to post-mining data (2005 through 2015) (Table 3-28). No pre-mining data were available at stations S-5S and S-5N. None of the average concentrations of metals in marine sediment exceeded the cadmium, mercury or zinc ERL screening benchmarks at any of the stations pre- or post-mining. The post-mining average metals concentrations were typically below the pre-mining average concentrations. The only average metals concentrations that exceeded the ERL screening benchmarks were the pre-mining averages for copper at stations S-3 and S-4 and the pre-mining lead average at station S-4. While the average concentrations were often below the ERL screening benchmarks, there were several individual pre-mining observations that exceeded the screening benchmarks. No pre-mining observations exceeded any of the ERL screening benchmarks at stations S-1 or S-2, but copper and zinc pre-mining observations exceeded the copper recommended ERL of 34 mg/kg at station S-3 and copper, lead, mercury and zinc pre-mining observations exceeded their respective recommended ERLs at station S-4.

Table 3-28. Comparison of pre-mining and post-mining metals in sediment in Hawk inlet

Metal (mg/kg)	Station S-1		Station S-2		Station S-3		Station S-4	
	Pre-mining average (1984-1988)[a,b,c]	Post-mining average (2005-2015) [a,b,c]	Pre-mining average (1984-1988) [a,b,c]	Post-mining average (2005-2015) [a,b,c]	Pre-mining average (1984-1988) [a,b,c]	Post-mining average (2005-2015) [a,b,c]	Pre-mining average (1986-1988) [a,b,c]	Post-mining average (2005-2015) [a,b,c]
Cadmium	0.22	0.22	0.27	0.14	0.62	0.63	0.34	0.31
Copper	21.8	15.4	14.9	9.7	37.0	31.1	46.2	21.7
Lead	7.8	6.8	5.3	2.0	10.0	12.4	53.8	23.9
Mercury	0.043	0.034	0.030	0.020	0.070	0.070	0.109	0.051
Zinc	125.0	95.7	60.5	39.7	138.1	114.5	136.5	63.2

[a] Compared to the ERL screening benchmarks for cadmium (1.2 mg/kg); copper (34 mg/kg); lead (46.7 mg/kg); mercury (0.15 mg/kg); and zinc (150 mg/kg) (Buchman 2008).

[b] Source: HGCMC, personal communication May 2016

[c] Shaded cells exceeding the ERL screening benchmark.

Pre-mining sediment data were also collected in 1981 at three locations in Hawk Inlet (Holland et al 1981). The exact locations of the sampling sites were not provided in Holland et al. (1981), but were in the vicinity of the Greens Creek delta, the cannery, and the head of Hawk Inlet. The data are provided in Table 3-29. There were no exceedances of the lead or zinc ERL screening benchmarks, but there were some exceedances of the cadmium, copper and mercury ERL screening benchmarks. These exceedances occurred at the head of Hawk Inlet for cadmium; at the cannery for copper; and at the Greens Creek delta for mercury.

Table 3-29. Summary of pre-mining sediment data in Hawk Inlet (1981)

Station	Date of collection	Number of observations	Concentration (mg/kg)[a]	Exceeding ERL screening benchmark[b]
Cadmium				
Greens Creek Delta - intertidal	7/8/1981	1	0.24	No
Greens Creek Delta - subtidal			0.15	No
Cannery - intertidal			1	No
Cannery - subtidal			0.22	No
Head of Inlet - intertidal			1.3	Yes
Head of Inlet - subtidal			0.48	No
Copper				
Greens Creek Delta - intertidal	7/8/1981	1	18	No
Greens Creek Delta - subtidal			17	No
Cannery - intertidal			39	Yes
Cannery - subtidal			18	No
Head of Inlet - intertidal			27	No
Head of Inlet - subtidal			16	No
Lead				
Greens Creek Delta - intertidal	7/8/1981	1	11	No
Greens Creek Delta - subtidal			8.4	No
Cannery - intertidal			19	No
Cannery - subtidal			4.8	No
Head of Inlet - intertidal			8.7	No
Head of Inlet - subtidal			7.4	No
Mercury				
Greens Creek Delta - intertidal	7/8/1981	1	0.078	No
Greens Creek Delta - subtidal			0.35	Yes
Cannery - intertidal			0.15	No
Cannery - subtidal			0.049	No
Head of Inlet - intertidal			0.11	No
Head of Inlet - subtidal			0.034	No

Station	**Date of collection**	**Number of observations**	**Concentration (mg/kg)[a]**	**Exceeding ERL screening benchmark[b]**
Zinc				
Greens Creek Delta - intertidal	7/8/1981	1	59	No
Greens Creek Delta - subtidal			110	No
Cannery - intertidal			110	No
Cannery - subtidal			50	No
Head of Inlet - intertidal			57	No
Head of Inlet - subtidal			110	No

[a] Source: Holland et al. (1981)

[b] Compared to the ERL screening benchmarks for cadmium (1.2 mg/kg); copper (34 mg/kg); lead (46.7 mg/kg); mercury (0.15 mg/kg); and zinc (150 mg/kg) (Buchman 2008).

As with the tissue data, exceedances of the ERL screening values for the metals of concern before mining operations began in the watershed, indicate that the increased metals concentrations in Hawk Inlet sediment may not be entirely related to metals impairment from the ore concentrate spill, but may be related to naturally elevated levels of metals in the Hawk Inlet area (see Section 4.2.5). In addition, the lack of pre-mining data exceeding ERL screening benchmarks at stations S-1 and S-2 indicate that additional historical operations such as abandoned mines and the cannery could also be contributing to the increased metals concentrations in marine sediment. However, the much higher magnitude of the post-mining exceedances of the ERL benchmarks at stations S-4, S-5N and S-5S after 1989 support the ore concentrate spill as the largest source (see Section 4.2).

3.3 Summary

3.3.1 Water Quality

The water quality data from Empire Mine do not show a metals impairment in the surface water, as the concentrations were all below the criteria. However, no hardness data were collected at the time of the metals sampling at Empire Creek; therefore, the applicable water quality criteria for cadmium, copper, and zinc, which are hardness-based (ADEC 2012), could not be calculated and compared to the observations. Collection of hardness data is recommended for any future sampling efforts. Water quality in Greens Creek and other freshwater tributaries to Hawk Inlet also did not typically exceed the cadmium, copper, lead, mercury, or zinc criteria. However, there were exceedances of the lead criterion at station 9 and the cadmium, mercury, and zinc criteria at station 61. The freshwater station downgradient of station 61 did not show any exceedances and subsequent samples at station 61 were below criteria as well. Although exceedances were observed in freshwater tributaries to Hawk Inlet, the exceedances typically occurred at a specific time period due to known reasons (see Section 3.2.1.1). There were no exceedances of the Greens Creek Mine’s permit limits at outfall 002. Permitted discharge from the mine does not appear to be contributing to the toxic sediment issue in Hawk Inlet. In addition, water quality data at the long-term Hawk Inlet stations (all marine stations) did not show impairment of the water column.

3.3.2 Tissue Quality

Tissue data from Greens Creek and tributaries, Empire Mine, and Hawk Inlet were compared to the cadmium and methylmercury recreational and subsistence EPA recommended values (USEPA 2000, 2001; EPA recommended values are not available for the other metals of concern) and the DHSS recommended maximum safe concentrations for cadmium, copper, mercury and zinc in the marine species clams, cockle clams, mussels, crab, shrimp and seaweed (DHSS 2016; there are no DHSS recommended concentrations for lead). At all of the freshwater stations, the recreational EPA recommended values were consistently attained. For the freshwater tributary and Empire Mine stations, exceedances of the cadmium and methylmercury subsistence EPA recommended values were observed, particularly in the Dolly Varden Char (which can be part of a subsistence diet). It is important to note that subsistence fishing does not generally occur in the freshwater tributaries near the Greens Creek Mine since they are on property owned and leased by HGCMC. Regular fishing could occur in creeks near Empire Mine; therefore, additional data from existing Empire Mine sampling locations are needed to improve the suite of available data, which is currently limited to a single day. Overall, the freshwater data were evaluated to characterize potential sources to Hawk Inlet. The observed exceedances indicate the need for future monitoring in the freshwater inputs to Hawk Inlet to fully characterize conditions and the potential for impairments. Sampling should consider the subsistence use of the area as well as the potential for naturally elevated metals in the sediment. Section 6.2 provides specific monitoring recommendations.

Consistent with the freshwater stations, nearly all tissue data within Hawk Inlet itself attained the recreational EPA recommended values and the DHSS recommended values. One triton snail collected in June 2016 exceeded the EPA recommended recreational cadmium and mercury screening values. When compared to the subsistence EPA recommended values, cadmium exceedances were observed in data associated with several different species at stations throughout the inlet, including those sampled by FOA. Five mercury exceedances of the subsistence EPA recommended values were observed between 1986 and 1989 at station STN-1 and several exceedances were observed in 2015 and 2016 at several stations throughout the inlet. Average cadmium and mercury concentrations were also available associated with a pre-mining period at eight stations. These were assumed to represent the natural condition of Hawk Inlet. There were no exceedances of the mercury EPA subsistence or recreational recommended values; however, average cadmium levels exceeded the subsistence EPA recommended value in both *Nephtys procera* and mussel observations during the pre- and post-mining conditions.

Overall, the average concentrations associated with pre- and post-mining conditions were similar at stations throughout Hawk Inlet and exceedances were also observed in both periods (see section 3.2.3.2). This indicates that the increased metals concentrations in Hawk Inlet fish tissue may not be related to metals impairment but to naturally elevated levels of metals in the Hawk Inlet area. Therefore, based on the data available for this study, it was determined that there is no impairment of tissue in Hawk Inlet and additional data collection is needed to verify this assessment.

3.3.3 Sediment Quality

Some concentrations of cadmium, copper, and zinc above the freshwater LEL and marine ERL screening benchmarks were found in in freshwater tributary sediment samples. Observations were only available for 2013, so no trend exists, but sediment quality in this area should be monitored in the future. These concentrations are not a likely source of metals to Hawk Inlet sediment because the sediment monitoring station near the mouth of Greens Creek (S-1) did not show impairment. Occasional samples of copper and zinc have been observed above their respective ERLs at station S-1, but no exceedances were found since 2006. Station S-1 is considered to be a background station.

August and September 2014 monitoring at Empire Mine showed exceedances of the cadmium, copper, lead, mercury, and zinc sediment screening values (ERLs, LELs, and PELs) at some stations. Cadmium, copper, and zinc exhibited the most frequent exceedances. This is consistent with the sediment concentrations at nearby station S-3 in Hawk Inlet. Specifically, copper demonstrated the highest exceedance rate at this inlet station (followed by zinc, and then cadmium and mercury).

Within Hawk Inlet, stations S-1 and S-2 are representative of background conditions, with little to no observations above the ERLs for the metals of concern (Table 3-21 through Table 3-25). The only metals concentrations above the ERLs at these two stations were copper and zinc at station S-1 with 3 and 5 percent of observations exceeding the ERL, respectively. The copper observations above the ERL occurred in September 1990, June 1993, and September 2006 with a maximum observation of 39.5

mg/kg, which is not much higher than the copper ERL of 34 kg/kg. The zinc observations above the ERL occurred in July 1989, September 1990, September 1993, and September 2006 with a maximum observation of 188 mg/kg (zinc ERL is 150 mg/kg).

The metals at station S-3 all exceeded the ERL screening benchmark except for lead; however, the exceedances were much lower in magnitude compared to stations S-4, S-5, and S-5N. Concentrations at station S-3 hovered near the ERL and never showed extremely high concentrations (copper was the only metal where the average observed concentration was above the ERL). Copper continues to regularly exceed the ERL with exceedances occurring in 2010, 2011, 2012, 2014 and 2015. Cadmium and zinc also continue to show occasional exceedances of the ERL at S-3. Cadmium exceeded the ERL in September 2014 for the first time since 2002. Zinc also exceeded the ERL in September 2014 for the first time since 2009. Mercury has not exceeded the ERL at S-3 since 2002. Monitoring at station S-3 should continue to determine whether metal concentrations continue to decrease below the ERL. It is possible that the metals concentrations at S-3 may also represent natural conditions since there is no known source at this station.

The metals observations at stations S-4, S-5N, and S-5S were very different from the other stations in Hawk Inlet. There were multiple exceedances of marine sediment screening benchmarks for all five metals of concern at these stations. The greatest number of exceedances occurred at stations S-5N and S-5S within the 303(d)-listed area of concern. Station S-4, just outside the 303(d)-listed area, also showed a large percentage of exceedances of the ERL for all metals of concern, but these concentrations seemed to be decreasing over time. Although station S-4 showed exceedances for all five metals, there have been no exceedances of the cadmium ERL since 2006; of the mercury ERL since 2009; and the zinc ERL since 2007. The most recent exceedance of the lead ERL at station S-4 was in 2015, which was the first exceedance of the ERL at this station since 2009. The most recent exceedance of the copper ERL was in 2013. Stations S-5N and S-5S tended to have much higher metals concentrations than station S-4, with station S-5N showing the highest observed values of all five metals.

The average metals concentrations in the marine sediments at stations S-5N and S-5S were typically higher in the spring than summer months, except for copper at station S-5N, which showed no seasonal difference (Figure 3-14). This might be because spring runoff causes more turbulence in the inlet, which turns up the sediment. The concentrations at station S-3 and S-4 did not show strong seasonal differences.

Overall, toxic concentrations of metals in the sediments of Hawk Inlet appeared to be the sole impairment in Hawk Inlet. Based on the data analyses, the primary source of impairment to stations S-4, S-5N, and S-5S appears to be the historic spill at the ore concentrate loading site. Given the concentrations at station S-4 above marine sediment screening benchmarks, contaminated sediment from the original area of concern (near stations S-5N and S-5S) could have migrated over time, or the original area might not have been large enough to fully encompass the impairment. In addition, sediments near station S-3 historically showed impairment, especially for copper and zinc. The source(s) of metals in the marine sediment at station S-3 is unknown. The metals-laden sediment loading from the Empire Mine is a potential source, although the mine is located about a mile downstream from station S-3. It is unknown whether tidal influences in the inlet have caused contaminated sediment from Empire Mine to be transported to the area near station S-3. Recent data show that copper still continues to exceed the ERL at S-3 on a regular basis. Reductions are necessary at this station to attain WQS.

4 Source Assessment

This section discusses the potential sources of cadmium, copper, lead, mercury, and zinc to Hawk Inlet, including point and nonpoint sources. Although the historic ore concentrate spill is the expected primary source (ADEC 2013a), other possible sources were evaluated through the TMDL development effort. These potential sources include abandoned mines, mining outfalls, the ore concentrate spill, fugitive dust, the historic fish cannery and natural background. The following sections summarize the available information for these known potential sources.

4.1 Point Sources

4.1.1 Hecla Greens Creek Mine

The HGCMC is the only known point source discharging to Hawk Inlet (permit number AK0043206). The mine is permitted to discharge cadmium, copper, lead, mercury, and zinc from outfall 002 to Hawk Inlet (Table 4-1). Outfall 002 does discharge directly to Hawk Inlet, but data analyses indicate that all water quality data met the applicable permit limits and therefore it is not a source of impairment to Hawk Inlet (see Section 3.2.1). Moreover, outfall 002 does not discharge directly to either of the impaired areas of the inlet, so a wasteload allocation (WLA) was not incorporated into the TMDL. Although the previous discharge permit included Outfall 001, it is a domestic wastewater outfall and data are limited. The Discharge Monitoring Reports (DMR) submitted for the NPDES permit from 2008 to 2014 stated that "There were no Outfall 001 discharges during this current report period." In 2000, the flows were directed from Outfall 001 to Outfall 002, and Outfall 001 was abandoned and the current permit excludes Outfall 001 (ADEC 2015b).

Table 4-1 displays the outfall effluent limitations currently in place for outfall 002. Effluent limits apply at the point of discharge. All of these limits exceed the recommended chronic aquatic life criteria for marine waters. Under 18 AAC 70.240, ADEC can authorize a mixing zone within which water quality criteria may be exceeded. A mixing zone can only be authorized if all regulatory requirements are met and the authorization satisfies the terms of the state's antidegradation policy. The authorized mixing zone for outfall 002 is a rectangle, centered along the length of the diffuser, with dimensions of 165 ft by 80 ft. All WQS must be met beyond the boundary of this authorized mixing zone. ADEC's permitting section states that "According to daily, weekly, monthly, and quarterly effluent and quarterly ambient permit-required monitoring from three sites in Hawk Inlet, all effluent and water column data indicate that designated and existing beneficial uses have been protected and Alaska Water Quality Standards upheld" (personal communication with Tim Pilon, ADEC permitting section, 2015).

Table 4-1. Outfall 002 effluent limitations

Parameter	Units	Daily	Monthly
		APDES permit limits	
Discharge	MGD[1]	4.6	3.7
Cadmium	µg/L	100	50
Copper	µg/L	99	39
Lead	µg/L	321	123
Mercury	µg/L	1.9	1.0
Zinc	µg/L	1,000	500

[1] MGD = million gallons per day

BMPs at this facility, including an enclosed conveyor, now minimize the potential of another ore concentrate spill directly to Hawk Inlet. The effluent has the potential to influence water quality in the inlet because of tidal processes; however, data analyses indicate that the current mixing zone adequately ensures ambient water quality does not deteriorate.

4.2 Nonpoint Sources

Nonpoint sources in Hawk Inlet include erosion from historically mined areas, the historic ore concentrate spill, fugitive dust, natural sources, and internal loading (recycling of metals at the sediment and water interface). These sources are discussed below. Confirmed sources receive a load allocation (LA) in the TMDL.

4.2.1 Abandoned Mines

Empire Mine
The Empire Mine, formerly called the Williams Group Mine, is an abandoned gold mine on the western side of Admiralty Island. The mine is 18 miles southwest of Juneau, on the north end of Hawk Inlet and about 6 miles from Greens Creek Mine (ADEC 2014). Production at the mine started in 1934. Only small-scale exploration and assessment work has occurred on the site since 1942 (Portage, Inc. 2014). In 1995, the USFS conducted a site investigation at the mine which included a site reconnaissance at both the upper mine area where ore was mined and milled and the lower mine area where ore concentrate was shipped out. Contamination was found at the upper mine area; however, the USFS felt that the risk was a low priority and no further investigation nor cleanup actions have occurred to date.

The Empire Mine was identified as a focus of a study by the ADF&G in 2013 because of the documented presence of tailings adjacent to an anadromous stream (ADEC 2014). ADF&G and the ADEC Contaminated Sites Program partnered to conduct an in-depth site characterization in August 2014. The data collected as part of this effort are described above in Section 3.2.2. These data indicate that the abandoned mine is a potential source of metals in the sediment at station S-3. However, Empire Mine is located about a mile south of station S-3. It is unknown whether tidal influences in Hawk Inlet are responsible for transporting metal-laden sediment from Empire Mine to the area near S-3. Although Empire Mine is considered a potential source of metals to the marine sediments near S-3, this cannot be confirmed without additional research. Therefore, the LA near station S-3 in this TMDL is assigned to unknown sources.

4.2.2 Historic Ore Concentrate Spill

In 1989 the first attempt to load a barge with ore concentrate resulted in a spill of the material into Hawk Inlet at the loading conveyor. The Greens Creek Mine was owned by the Kennecott Mining Company at the time. HGCMC became the sole owner of the Greens Creek Mine in 2008 and assumed liability of the ore concentrate spill when they purchased the property. Stations S-5N and S-5S are positioned near the approximate spill location based on ship and loader dimensions. Station S-4 is situated just outside the estimated spill location. In 1995 a suction dredge was used to remove as much of the spilled ore concentrate as possible. Prior to Greens Creek Mine operations, a fire in 1974 at the cannery dock left debris on the floor of the inlet near the ore concentrate loading site. This debris complicated cleanup efforts and liter-sized pockets of concentrate were not removed (Oceanus Alaska 2003, ADEC 2013a, and KGCMC 1990). However, based on dive inspections following the cleanup, no physical signs of ore concentration were observed on the seafloor at the loading facility (MTS 2016). It has been noted in previous reports that prop-wash from tug boats maneuvering barges and ore ships during loading operations continue to re-suspend and mix concentrate with natural sediment in the vicinity of the spill, yet based on MTS observations and experience “it is unlikely that berthing operations for ore shipments have any significant transport effects on sediments” (MTS 2016). For over 30 years, usually twice per year, MTS staff have gathered data from the loading facility and no increase in turbidity associated with ore-loading operations has been observed.. Furthermore, MTS states that due to the seafloor drop off at the loading facility area, the currents generated by the tug boats have to travel a significant distance before contacting the seafloor.

Based on data analyses, the area of impairment extends beyond the 303(d)-listed area of concern (which contains stations S-5N and S-5S) and also includes station S-4 (Section 3.2.3.3). These analyses confirm that the historic ore concentrate spill is a source of metals to the sediment of Hawk Inlet. This source receives a LA in this TMDL.

4.2.3 Fugitive Dust

Fugitive dust is considered nonpoint source air pollution, since it is caused by small airborne particles that do not originate from a specific point. Sources of fugitive dust from the Greens Creek Mine include the TDF and the transportation of mining materials on the property. Dust has been observed from the TDF during dry and windy conditions (USDA 2013). These conditions typically occur between mid-December and late February when high pressure systems can create strong northern winds and dry, cold conditions. Snow samples have been collected prior to spring melt since 2007 and these samples have shown that metals loading concentrations have decreased since 2007. Dust mitigation measures put in place by HGCMC have likely contributed to the decrease (USDA 2013). Steps taken to address fugitive dust are included in Section 6.1. A margin of safety has been included in the TMDL to account for the current unknown effects of fugitive dust in the inlet (see Section 5.5).

4.2.4 Historic Fish Cannery

Prior to the existence of the Greens Creek Mine, a fish cannery owned by Peter Pan Seafoods, Inc. was located on piers over Hawk Inlet near the site of the existing loading dock (Oceanus Alaska 2003). The cannery is a potential source of metals to Hawk Inlet; however, there is limited knowledge regarding the effects of the cannery on Hawk Inlet. The cannery processed salmon, herring, and ground fish for decades, but burned in 1974. Most of the structure fell to the floor of Hawk Inlet where it was left until the site was developed for future ship loading facilities at the current mine. Although some of the cannery debris was dredged prior to the ship loading dock, some debris remains, especially in the deep water area west of the ship loading area. Divers have reported seeing debris including metal and batteries in the deep water area (west of the ship loading dolphins) as well as a pile of can lids larger than 54 cubic feet just inshore of the ship loading dolphins (Oceanus Alaska 2003). A margin of safety has been included in the TMDL to account for the current unknown effects of the historic fish cannery (see Section 5.5).

4.2.5 Natural Sources

Natural sources are not expected to contribute to the cadmium, copper, lead, mercury, or zinc loads in the Hawk Inlet 303(d)-listed area based on the available background data at stations S-1 and S-2 (see Section 3.2.3.3). Natural sources are considered to be a minor source to the areas of concern when compared with the ore concentrate spill. Therefore, natural sources are not assigned a LA in this TMDL. Stations S-1 and S-2 are considered to be reference or background stations. None of the observations at station S-2 were above the ERLs for any of the metals of concern and all cadmium, lead, and mercury measurements were below their respective ERLs at station S-1. Occasional copper and zinc concentrations above marine sediment screening benchmarks were measured at station S-1; however, these observations were only minimally above the ERLs of copper (34 mg/kg) and zinc (150 mg/kg). The copper concentrations above the ERL were 38 mg/kg (2006), 40 mg/kg (1993), and 39 mg/kg (1990). The zinc observations above the ERL were 188, 186, and 166 mg/kg (2006); 185 mg/kg (1993); 179 mg/kg (1990); and 155 mg/kg (1989). Since 2006, all measurements have been below the ERLs at stations S-1 and S-2.

4.2.6 Internal Loading

Recycling of cadmium, copper, lead, mercury, and zinc is expected at the sediment and water interface in Hawk Inlet. Metals in the water column might precipitate out as co-precipitated and/or adsorbed phases over time, but some of this sediment-associated load could go through chemical reduction and dissolve back into the water column (thereby increasing the water column concentration), especially due to potential changes in pH, redox conditions, and temperature. These internal cycling processes were not evaluated as part of the TMDL because no water column data were available in the 303(d)-listed area. A recommendation to conduct water quality sampling during future monitoring events in the 303(d)-listed area has been included in the Implementation section of this report (Section 6.2). The collection of water quality data at the impaired sites can be used to support potential future efforts to quantify internal loading to the Hawk Inlet system. A margin of safety has been included in the TMDL to account for the current unknown effects of internal loading in the inlet (see Section 5.5).

5 TMDL Allocation Analysis

A TMDL represents the total amount of a pollutant that can be assimilated by a receiving waterbody while still achieving WQS—also called the *loading capacity*. In TMDL development, allowable loadings from all pollutant sources that cumulatively amount to no more than the TMDL's loading capacity must be established and thereby provide the foundation for establishing water quality-based controls.

A TMDL is composed of the sum of individual WLAs for point sources, LAs for nonpoint sources and natural background loads, and a MOS that accounts for the uncertainty in the relationship between pollutant loads and the quality of the receiving waterbody. Conceptually, this definition is denoted by the equation:

$$TMDL = \Sigma\ WLAs + \Sigma\ LAs + MOS$$

Metals concentrations were observed in the marine sediment at stations S-3 (near the head of Hawk Inlet) and S-4, S-5S, and S-5N (near the historic ore concentrate spill location) above screening marine sediment benchmarks; therefore, TMDLs were developed for these areas. Although this TMDL only addresses marine sediment, additional media (i.e., surface water and fish tissue) were assessed throughout the entire waterbody, not just the 303(d)-listed area, and compared to applicable criteria. It is also important to note that the focus of the TMDL is on the marine waterway (Hawk Inlet). Evaluation of freshwater water, sediment, and tissue quality is provided for background and discussion of sources.

5.1 Loading Capacity

The loading capacity for a given pollutant is the greatest amount of pollutant that a waterbody can receive without exceeding the applicable WQS, as represented by the TMDL numeric target.

The TMDL technical approach expresses the TMDLs in Hawk Inlet as concentrations, equivalent to the NOAA SQuiRT screening benchmark ERLs of 1.2 mg/kg cadmium, 34 mg/kg copper, 46.7 mg/kg lead, 0.15 mg/kg mercury, and 150 mg/kg zinc, which are protective of all marine designated uses. No water column data are available for the two areas of concern and no water quality impairments were identified in other portions of Hawk Inlet. In addition, based on the assessment of available data throughout waterbody, there is no tissue impairment within Hawk Inlet. Therefore, the TMDL only pertains to the metals in the marine bottom sediment at the two areas of concern (stations S-5S, S-5N, and S-4 and station S-3). No water quality or tissue reductions were calculated as part of this TMDL. A concentration-based TMDL is directly comparable to the applicable sediment targets (based on a numeric interpretation of the narrative water quality criteria) and, as such, is easily communicated.

A concentration-based TMDL is recommended because using a more complicated analysis to estimate cadmium, copper, lead, mercury, and zinc mass loading from the historic ore concentrate spill would require additional data collection (particularly to capture the influence and variability associated with flow and tides) and would not provide additional guidance or benefit to the subsequent planning and implementation actions.

Conceptually, the loading capacity represents the sum of WLAs, LAs, and MOS. Therefore, when the loading capacity is expressed as a load, it is divided among WLAs for point sources and LAs for nonpoint sources, minus a MOS. In those cases, the allowable load is a finite mass of pollutant that can be divided into individual loads for each source, that when combined represent the total loading capacity. However, when the loading capacity is expressed as a concentration, this additive approach is not applicable. As a concentration, the loading capacity represents an allowable ratio of the pollutant to marine sediment.

Therefore, if the loading capacity is expressed as a concentration, all allocations are equivalent to, rather than a portion of, the loading capacity minus the MOS. In other words, the target concentration implicitly represents an acceptable (but undefined) loading rate.

Necessary reductions in existing concentrations were calculated for Hawk Inlet to identify the reductions needed to meet the loading capacity and corresponding numeric targets for the marine sediment. These reductions are provided for guidance and reference only (compliance will be determined based on attainment of the allocations, not reductions). Reductions were calculated based on the maximum observed cadmium, copper, lead, mercury, and zinc concentrations for stations S-5S, S-5N, and S-4 and the maximum observed cadmium, copper, mercury, and zinc concentrations for station S-3 (the maximum value subsequent to the cleanup effort near the spill site in the 1990s was used) relative to their respective load capacity (that is equal to the applicable sediment numeric targets):

$$\text{Percent Reduction} = \frac{(\text{Maximum Measured Concentration} - \text{Load Capacity})}{(\text{Maximum Measured Concentration})} \times 100$$

5.2 Wasteload Allocations

The WLA is the portion of the loading capacity allocated to point source discharges to the waterbody. As discussed above, the HGCMC is permitted to discharge cadmium, copper, lead, mercury, and zinc from outfall 002 to Hawk Inlet (Table 4-1). Outfall 002 does not discharge to either of the impaired areas in Hawk Inlet (near the historic ore concentrate spill site or near station S-3), but discharges to the southern portion of Hawk Inlet (see Figure 3-1). Therefore, HGCMC does not contribute to the concentrations of metals in marine sediments above marine sediment screening benchmarks at stations S-5S, S-5N, S-4, and S-3 and a WLA for HGCMC has not been included in this TMDL. The source of metals to the sediment at these stations is likely from historic loading and possibly abandoned mines, fugitive dust, the historic fish cannery, and internal cycling at the sediment-water interface.

5.3 Load Allocations

The LA is the portion of the loading capacity allocated to nonpoint source discharges to the waterbody. As discussed above, a historic ore concentrate spill is the primary source of cadmium, copper, lead, mercury, and zinc in Hawk Inlet sediments at stations S-5S, S-5N, and S-4. The primary source of cadmium, copper, mercury, and zinc in Hawk Inlet sediments at station S-3 is not entirely known, but potentially includes abandoned mines, mass wasting, natural background, and internal cycling at the sediment-water interface.

5.4 TMDL Allocation Summary

Table 5-1, Table 5-2 and Table 5-3 summarize the allocations at each location for each metal of concern in marine sediment along with the necessary percent reductions to meet the numeric targets. Allocations are provided for the 303(d)-listed area or the historic ore concentrate spill site (stations S-5S and S-5N; Table 5-1); just outside the 303(d)-listed area (station S-4; Table 5-2); and unknown sources (station S-3; Table 5-3). Separate allocations were provided for the area near station S-4 rather than grouping the area with the 303(d)-listed area at stations S-5S and S-5N because the data at S-4 showed different trends than the other two stations (e.g., much lower concentrations and a decreasing trend).

The reductions in existing metals concentrations in marine sediment illustrate the relative magnitude of impairment and associated reductions needed to meet the loading capacity. Using the highest observed concentration to calculate reductions reflects the worst-case scenario. Therefore, the reductions represent the levels needed to ensure that the ERLs are met during all conditions. The percent reductions at the 303(d)-listed area (stations S-5S and S-5N) and the area just outside of the 303(d)-listed area (station S-4) were calculated using the maximum observed concentration post-1995 cleanup efforts as well as the maximum observed concentration in the last 5 years (2011–2015) to show more recent trends. The percent reductions at the unknown sources site (station S-3) were calculated using a similar approach for consistency even though no cleanup effort has occurred near station S-3. The maximum observed concentration post-1995 cleanup efforts was used as well as the maximum observed concentration in the most recent 5 years of data (2010–2014). 2015 data were not available for station S-3. .

Reductions in marine sediment at the 303(d)-listed area (stations S-5S and S-5N) range from 93.3 percent for cadmium to 99.4 percent for mercury since 1995 (Table 5-1). Reductions in marine sediment at station S-4 just outside the 303(d)-listed area range from 69.1 percent for copper to 95.9 percent for mercury since 1995 (Table 5-2). Reductions in marine sediment at station S-3 at the head of Hawk Inlet range from 28.6 percent for mercury to 67.6 percent for copper since 1995 (Table 5-3) (note: a TMDL was not necessary for lead at station S-3 as it is meeting the lead TMDL numeric target since 1984). TMDLs are assigned to these sites to ensure that existing concentrations in marine sediment do not increase and the stations continue to move toward meeting numeric targets, especially considering current mining activities near stations S-5S, S-5N, and S-4 (see Section 4).

Table 5-1. TMDL allocation summary for metals in sediment in the delineated area of concern (stations S-5S and S-5N)

Metal	Loading capacity (mg/kg)	WLA (mg/kg)	LA (mg/kg)	MOS (mg/kg)	Future growth	Existing maximum concentration (1995–2015) (mg/kg)[a]	Percent reduction to meet TMDL (1995-2015) (%)	Existing maximum concentration (2011–2015) (mg/kg)[b]	Percent reduction to meet TMDL (2011–2015) (%)
Cadmium	1.2	n/a	1.08	0.12	n/a	17.8	93.3	15.6	92.3
Copper	34	n/a	30.6	3.4	n/a	625	94.6	506	93.3
Lead	46.7	n/a	42.03	4.67	n/a	3,680	98.7	2,180	97.9
Mercury	0.15	n/a	0.135	0.015	n/a	26	99.4	2.2	93.2
Zinc	150	n/a	135	15	n/a	3,770	96.0	3,390	95.6

n/a = not applicable; MOS = 10% of the loading capacity

[a] Existing concentration (mg/kg) = maximum observed concentration post-1995 cleanup efforts

[b] Existing concentration (mg/kg) = maximum observed concentration in last 5 years (2011–2015)

Table 5-2. TMDL allocation summary for metals in sediment in the area outside of the delineated area of concern (station S-4)

Metal	Loading capacity (mg/kg)	WLA (mg/kg)	LA (mg/kg)	MOS (mg/kg)	Future growth	Existing maximum concentration (1995-2015) (mg/kg)[a]	Percent reduction to meet TMDL (1995-2015) (%)	Existing maximum concentration (2011–2015) (mg/kg)[b]	Percent reduction to meet TMDL (2011–2015) (%)
Cadmium	1.2	n/a	1.08	0.12	n/a	4.23	71.6	0.38	0.0
Copper	34	n/a	30.6	3.4	n/a	110	69.1	110	69.1
Lead	46.7	n/a	42.03	4.67	n/a	378	87.6	49.7	6.0
Mercury	0.15	n/a	0.135	0.015	n/a	3.7	95.9	0.04	0.0

Metal	Loading capacity (mg/kg)	WLA (mg/kg)	LA (mg/kg)	MOS (mg/kg)	Future growth	Existing maximum concentration (1995-2015) (mg/kg)[a]	Percent reduction to meet TMDL (1995-2015) (%)	Existing maximum concentration (2011–2015) (mg/kg)[b]	Percent reduction to meet TMDL (2011–2015) (%)
Zinc	150	n/a	135	15	n/a	920	83.7	81	0.0

n/a = not applicable; MOS = 10% of the loading capacity

[a] Existing concentration (mg/kg) = maximum observed concentration post-1995 cleanup efforts

[b] Existing concentration (mg/kg) = maximum observed concentration in last 5 years (2011-2015)

Table 5-3. TMDL allocation summary for metals in sediment in the north end of Hawk Inlet (station S-3)

Metal	Loading capacity (mg/kg)	WLA (mg/kg)	LA (mg/kg)	MOS (mg/kg)	Future growth	Existing maximum concentration (1995–2014) (mg/kg)[a]	Percent reduction to meet TMDL (1995–2014) (%)	Existing maximum concentration (2010–2014) (mg/kg)[b]	Percent reduction to meet TMDL (2010–2014) (%)
Cadmium	1.2	n/a	1.08	0.12	n/a	2.76	56.5	1.67	28.1
Copper	34	n/a	30.6	3.4	n/a	105	67.6	64.1	47.0
Mercury	0.15	n/a	0.135	0.015	n/a	0.21	28.6	0.13	0.0
Zinc	150	n/a	135	15	n/a	310	51.6	210	28.6

n/a = not applicable; MOS = 10% of the loading capacity

[a] Existing concentration (mg/kg) = maximum observed concentration post-1995 cleanup efforts

[b] Existing concentration (mg/kg) = maximum observed concentration in last 5 years (2010-2014). No 2015 data were available for station S-3.

5.5 Margin of Safety

A MOS must be included in a TMDL to account for any uncertainty or lack of knowledge regarding the pollutant loads and the response of the receiving water. The MOS can be implicit (incorporated into the TMDL analysis through conservative assumptions) or explicit (expressed in the TMDL as a portion of the loadings) or a combination of both. These TMDLs use both an implicit and explicit MOS.

By using the maximum (as opposed to average or median) observed cadmium, copper, lead, mercury, and zinc concentrations to represent existing conditions, the necessary reductions reflect the worst-case scenario, thus adding an implicit MOS. An explicit MOS was also included as 10 percent of the loading capacity to account for uncertainty regarding the lack of water column data to represent interactions between the marine water/sediment interface, as well as the unknown quantification of inputs from stormwater or other nonpoint source contributions such as fugitive dusting from the tailings pile or atmospheric deposition, and prior historic uses (e.g., fish cannery). It also ensures that meeting the allocations will result in attainment of the designated uses since there is no adopted sediment quality criteria in Alaska.

5.6 Seasonal Variation and Critical Conditions

Seasonal variation and critical conditions associated with pollutant loadings, waterbody response, and impairment conditions can affect the development and expression of a TMDL. Therefore, TMDLs must be developed to ensure the waterbody will maintain WQS under all expected conditions.

For Hawk Inlet, the times of highest loading and worst impairment are expected to be during the summer months when the highest temperatures occur; however, based on the monitoring data, concentrations in the sediment were typically higher in the spring when compared to summer months (see Section 3.2). This could be due to spring runoff causing more turbulence at the sediment/water interface. Higher temperatures in the summer months typically decrease the solubility of oxygen in water, promote bacterial activity (bacteria production increases carbon dioxide and decreases pH, which affects the balance of pollutants between the water and sediment), and lead to more reducing conditions. These conditions would decrease the metal load that oxidizes and precipitates from the water column to the sediment, thus increasing the dissolved fraction in the water column.

It is important to note that the there is no statistical significance to seasonality in the data; therefore, numeric targets apply year round. Impairment has been observed during the entire monitoring period of April through September. No known data are available during the fall and winter months. Historically, data have only been collected during the spring, summer, and fall months, and the extent to which impairments occur during the winter is unknown.

In summary, available data on cadmium, copper, lead, mercury, zinc as well as aquatic life suggest that spring through the early fall months reflect the critical period. However, conditions during the winter months have not been assessed, and loading reductions should be pursued year-round to address impairments. The concentration-based TMDL approach is believed to meet water quality criteria during the unmonitored winter months.

5.7 Future Growth

No allocation will be provided for future growth as additional metals and sediment discharges are unlikely in the Hawk Inlet watershed. Admiralty Island, where Hawk Inlet is located, has a low population. Approximately 570 people live in a small community (Angoon) on the island (see Section 1.2). Future construction of homes and other communities is unlikely. HCGMC is currently located in the Hawk Inlet watershed, but no additional mines are expected to be developed in the area in the near future. HGCMC will likely continue to mine and explore the area under their existing APDES permit.

5.8 Daily Load

A TMDL is required to be expressed as a daily load; the amount of a pollutant the waterbody can assimilate during a daily time increment and meet WQS. The TMDLs for cadmium, copper, lead, mercury, and zinc are presented as maximum concentrations allowed in the marine sediment. The allowable concentrations are applicable at all times and can therefore be applied on a daily basis.

5.9 Reasonable Assurance

EPA requires that there is reasonable assurance that TMDLs can be implemented when the TMDL is a mixed source TMDL (USEPA 1991). A mixed source TMDL is a TMDL developed for waters that are impaired by both point and nonpoint sources. The WLA in a mixed source TMDL is based on the assumption that nonpoint source load reductions will occur. Reasonable assurance is necessary to determine that a TMDL’s WLAs and LAs, in combination, are established at levels that provide a high degree of confidence that the goals outlined in the TMDL can be achieved.

In waterbodies impaired solely by nonpoint sources, reasonable assurances that load reductions will be achieved are not required by EPA. There are no point sources contributing to the impairments in Hawk Inlet; therefore, reasonable assurance does not apply to the Hawk Inlet metals TMDLs.

6 Implementation and Monitoring Recommendations

Implementing management measures in Hawk Inlet is necessary to improve marine sediment quality to the point where the inlet can support its designated uses (water supply, water recreation, and growth and propagation of fish, shellfish, other aquatic life, and wildlife). Additional monitoring is desired to verify TMDL assumptions and measure progress toward meeting WQS. This section presents recommendations for additional implementation and monitoring to assist in meeting the numeric marine sediment targets and loading capacity for cadmium, copper, lead, mercury, and zinc in Hawk Inlet.

6.1 Implementation

Current impairments in Hawk Inlet near stations S-5S, S-5N and S-4 are located in the vicinity of a loading dock at the Hecla Greens Creek Mine. The dock operations have the potential to release metals to Hawk Inlet and impact water quality. The metals already attached to bottom sediments in the harbors could be allowed to naturally attenuate over time through burial by “clean” sediments or be physically removed. However, the benefits or necessity of dredging would require careful consideration because of the potential for damage to habitat and aquatic organisms. Dredging of the sediment (to recover metals) could disturb contaminated sediments, and might spread the contaminants throughout currently uncontaminated areas of Hawk Inlet. Dredging can damage the habitat of benthic macroinvertebrates and might directly kill some organisms. The process of stirring up suspended sediments during dredging can also damage the gills and/or sensory organs of benthic macroinvertebrates and fish. In addition, the resuspension of contaminated sediments provides organisms with additional exposure to toxic metals.

Dredging could also be complicated by the presence of debris on the floor of Hawk Inlet that was left after a fire at the cannery in 1974 (Oceanus Alaska 2003). In 1995, a suction dredge used to clean the site of the 1989 ore concentrate spill found its efforts hampered by the fire-related debris. Therefore, the metals already in the bottom sediments in the inlet are not likely to be remedied through physical removal (although targeted cleanup at extremely contaminated areas could be beneficial). Restoration will rely mainly on natural recovery as contaminated sediments are buried by “clean” sediment and on the control of any additional existing or future inputs. Concentrations of cadmium, copper, lead, mercury, and zinc will likely decrease with time, because of natural sedimentation processes, if the system is not disturbed. Therefore, the implementation of these TMDLs at stations S-5S, S-5N and S-4 will focus on the continued management of shipping and docking operations in Hawk Inlet at the Greens Creek Mine to prevent future spills.

Existing management plans and BMPs (HGCMC 2015d) provide a framework to minimize the risk of pollution from metals. The shiploader at the Greens Creek Mine installed in 1995 (after the ore concentrate spill) is fully contained (Oceanus Alaska 2003) to prevent concentrate from blowing or falling off the system into the environment. A telescoping pair of tubes fully encloses the conveyor from within the loadout building (see Figure 6-1). The process to load the ore concentrate from Greens Creek Mine onto a bulk cargo carrier has at least four HGCMC personnel involved (personal communication by with Chris Wallace, Environmental Manager at HGCMC, e-mail on April 28, 2016). The Hopper Loader Operator is responsible for loading the concentrate into the hopper that feeds the conveyor belt. Another person is functioning as the Load Master and he or she is watching over the conveyor system and the control room. On the deck of the ship is the On Deck Operator and he or she has remote control of the conveyor and the movement (in/out, up/down) of the chute, snorkel, or trunk. This person is keeping the trunk as close as possible to the pile as it is being discharged into the hold of the cargo ship. Typically the ship and the trunk will be moved in order to create three piles in the hold. The trunk is not brought outside of the cargo hold while loading and is at least 15 ft below the cargo hatch while loading. Once the piles are created in the hold of the carrier a dozer, run by the Trim Cat Operator, is used to distribute the piles evenly in the hold. In addition, all of the wash down water from the loading area is collected in Degrit Basin 4 and is pumped to Pond 7 for treatment.

Figure 6-1. Ore loading dock at the HGCMC

Under the current Title V Permit No. AQ0302TVP02 (Rev. 1), HGCMC must take reasonable precautions to prevent fugitive dust while materials are handled, transported, stored or engaged in industrial activity or construction (USDA 2013). In an effort to reduce dust loss from the TDF, HGCMC has employed a variety of voluntary abatement measures. Interim slopes not being used are covered with rock, outer slopes of the TDF are hydroseeded and snow fences and concrete blocks were installed on the crest of the TDF to serve as a wind break.

HGCMC’s BMP Plan (HGCMC 2015d) provides information on the areas of the site that are subject to BMP requirements including materials storage areas, loading, unloading, and material transport areas; plant transfer, processing, and handling of materials; and areas of material disposal. Storage for ore concentrate exists in the mill building prior to transport to Hawk Inlet in covered Max Haul trucks. The concentrates are completely enclosed with concrete floors and side walls. Bulk ore concentrates are loaded in the mill building concentrate room by front-end loader onto Max Haul trucks. Transfer of concentrates to trucks is also conducted within this mill building room to prevent spills to receiving waterbodies. Trucks must pass through a spray truck wash prior to driving outside of this mill building room. Runoff water from the truck wash collects in the sump and is pumped to the bulk thickener. Concentrate is then carried in covered Max Haul trucks from the mill building to the Hawk Inlet concentrate storage building. The Max Haul trucks dump the concentrate into the storage building from outside of the building through an opening for this purpose. Any vehicle that enters this building must have the wheels cleaned in a Truck Wash Building prior to leaving the concrete covered travel area. Concentrates are loaded onto a ship by an enclosed, telescoping conveyor and chute system from within this storage building as mentioned above.

Recent data at stations S-5S, S-5N, and S-4 indicate that levels of historically accumulated metals in the marine sediments are slowly decreasing (see Section 3.2.3.3). Management efforts should focus on controlling any additional or new inputs of metals. All permitted uses must adhere to existing Alaska WQS and may consider NOAA sediment guidelines to prevent sediment concentrations from remaining at levels that would contribute to continued impairment of the benthic environment. Continued and possibly additional sampling would provide useful data for determining whether natural recovery or migration of the contaminated sediments is occurring in the inlet (see Section 6.2). It should be noted that sites S-5N and S-5S at the loading facility are different from sites S-3 and S-4 in terms of their geomorphic settings. Sites S-5N and S-5S are located on a subtidal shelf approximately 45 ft deep while sites S-3 and S-4 are located on intertidal areas near Hawk Inlet tributary deltas. Sediment accumulation rates for the area at the loading dock may be much lower than sites S-3 and S-4, which are fed by sediments from their respective tributaries. Therefore, it should be noted that natural recovery may take longer to accomplish at sites S-5N and S-5S than sites S-3 and S-4.

No specific event or source is known to have caused the increased metals in the marine sediment at station S-3. Potential sources include abandoned mines, natural background, and internal cycling. As with stations S-5S, S-5N and S-4, the metals in the bottom sediments at station S-3 are not likely to be remedied through physical removal. Restoration will rely on natural recovery as contaminated sediments are buried by “clean” sediment and on the control of any additional existing or future inputs. If concentrations of cadmium, copper, lead, mercury, and zinc are not due to natural conditions they will likely decrease with time if the system is not disturbed. The decrease in metals concentrations will be a result of natural sedimentation processes.

Given that metals in Hawk Inlet will persist for a substantial but unknown period, it is not feasible to establish an exact time frame in which Hawk Inlet will achieve recovery to a “natural condition,” as immediate compliance with this target would require removal of all toxic metals and such action is not recommended for Hawk Inlet because of the high potential for resuspension of toxic metals in the water column, disruption to the fish and benthic community, technical feasibility, and costs. Therefore, monitored natural recovery (MNR) is the recommended alternative.

MNR is “a remedy for contaminated sediment that typically uses ongoing, naturally occurring processes to contain, destroy, or reduce the bioavailability or toxicity of contaminants in sediments…These processes may include physical, biological, and chemical mechanisms that act together to reduce the risk posed by the contaminants” (USEPA 2005). MNR includes various mechanisms that affect concentrations and/or availability of toxic metals at the surface and near surface of the sediment bed, including conversion to a less toxic chemical form through transformation processes such as biodegradation; reduction of chemical mobility or bioavailability through processes binding contaminants to the sediment matrix; and reduction of exposure levels by a decrease in chemical concentrations in the near-surface sediment through burial or mixing-in-place with cleaner sediment. The monitoring component of MNR is needed to track the progress of changes in the matrices of interest (e.g., sediment, water) and determine whether the expected and/or acceptable changes are actually occurring. Monitoring should focus on those measures that will be used to determine compliance with the TMDL. Specific monitoring recommendations are outlined in Section 6.2.

If, however, natural recovery does not result in decreased concentrations of the metals and compliance with the targets set by this TMDL, then other options, such as targeted removal, should be explored. The remedial option of capping the contaminated sediment in the loading dock area was considered. However, due to the limited depth for adequate ship maneuvering and the abrupt seafloor drop off in this area, the option was not deemed feasible or effective. The Monitoring Recommendations section (Section 6.2) highlights recommendations to expand cadmium, copper, lead, mercury, and zinc monitoring in the sediment and water column within and outside of the 303(d)-listed area near stations S-4, S-5N and S-5S. This monitoring ensure the entire area is continuing to recover, and will help to identify and delineate area(s) where targeted removal might be necessary.

In addition to MNR, the following additional actions are recommended for Hawk Inlet:

1. Restrict future development activity in adjacent land areas that could disturb the marine sediments in Hawk Inlet. This includes working with the existing mine property owner in restricting activity that may disturb the spill site. This does not include current activity at HGCMC's loading dock area, but recommends that all future activities be mindful of the contamination and strive to minimize disturbance.
2. ADEC suggests that since the spill site is on private property, owned by HGCMC, a deed notice should be filed. The deed should include a notification of the contamination that has been left in place at the ore concentrate spill site. Note that HGCMC owns both the inter-tidal and sub-tidal land at the 303(d) listed area of concern.
3. Post warning signs about the contamination in the sediment and potential contamination in shellfish in consultation with ADF&G. HGCMC may want to consider posting signs that prohibit fishing and/or crabbing near the ore concentrate loading dock.

6.2 Monitoring Recommendations

Monitoring should be conducted to achieve the objectives identified in the numbered list below. Recommendations associated with this monitoring are described in more detail throughout the rest of this section.

1. Assess compliance with and progress toward attainment of the TMDLs through sediment monitoring at stations S-5N, S-5S, S-4, and S-3. Existing monitoring required as part of the permit should continue to satisfy this recommendation.
2. Perform monitoring at freshwater stations (including stations representing the natural condition) to assess for freshwater impairments.
3. Characterize the relationship between water, sediment, and tissue quality using coincident samples at stations S-5N, S-5S, S-4, and S-3.
4. Characterize water, sediment, and tissue quality at additional stations to better quantify the natural condition of Hawk Inlet and biological response(s) in resident species (and/or investigate the availability of additional historic data not available at the time of this study).

The HGCMC APDES Permit (AK0043206) requires the mine to implement a monitoring program for Hawk Inlet (HGCMC 2015b). The primary objective of the Hawk Inlet monitoring program is to document the water quality, sediment, and biological conditions in receiving waters and marine environments that could be affected by the mine's operations. The previous permit required annual monitoring. Sea water was sampled quarterly at three locations in Hawk Inlet, and sediment and invertebrate samples were taken each year in the spring and in the fall at four and seven locations, respectively (see Section 3.2.3). The current permit requires quarterly sea water sampling at three locations in Hawk Inlet (stations 106, 107 and 108), and annual sediment and invertebrate samples at three locations (stations S-1, S-2 and S-4) and seven locations (stations S-1, S-2, S-4, STN-1, STN-2, STN-3 and ESL), respectively (see Section 3.2.3). Sediment sampling is also required every five years at station S-5N and S-5S rather than every year. Collaboration with various partners are in progress to address further monitoring efforts.

Monitoring efforts in Hawk Inlet should continue to determine whether natural recovery is occurring and metals concentrations are continuing to decrease over time because of natural sedimentation processes if the system is not disturbed. Monitoring will allow ADEC to track the progress of changes in water and sediment and determine whether acceptable progress is being made.

It is also recommended that cadmium, copper, lead, mercury, and zinc monitoring in the marine sediment near the 303(d)-listed area of concern at Greens Creek Mine be expanded outside of stations S-4, S-5N, and S-5S to be sure the entire area is continuing to recover. Sediment sampling should occur outward from the known area of contamination near the loading dock in multiple directions until areas free of contamination are found. A comprehensive visual inspection of the area of concern should be included in the sampling plan. This information may be used to conduct further cleanup or remedial actions.

In addition to expanding the marine sediment monitoring in the area of concern, it is also recommended that water quality monitoring be conducted in this area. Future discharge permit monitoring should include water column sampling in the area of concern to determine whether the water column is being impacted by the contaminated sediments. Water quality sampling should include samples at multiple depths, including the sediment/water interface to represent the entire water column. Water column monitoring will be also useful in evaluating whether there is resuspension of marine sediment due to operations in the loading dock area including prop-wash. Based on MTS observations and experience “it is unlikely that berthing operations for ore shipments have any significant transport effects on sediments” (MTS 2016).

This TMDL-related monitoring in the discharge permit should include conditions allowing the permittee to cease monitoring when ADEC finds water quality and sediment results to be consistently below the respective WQS and ERLs for an assessment period of at least 2 years (consistent with Alaska’s listing assessment practices) and EPA approves the delisting of the ore spill area as attaining water quality standards. The evaluation of these data should be consistent with ADEC’s listing and delisting methodology. These data can also be used to confirm the extent of the ore concentrate spill contamination and to determine a targeted removal area if necessary.

Future monitoring should also include tissue sampling in the area of concern (near station S-5S, S-5N, and S-4) and tissue sampling should continue at the current seven sampling locations (S-1, S-2, S-3, STN-1, STN-2, STN-3, and ESL) to determine whether or not there is a tissue impairment in Hawk Inlet and to potentially conduct a dietary survey of the local population that may be practicing subsistence activities in Hawk Inlet or use other data sufficient to determine whether a local fish consumption rate is needed to establish site specific human health criteria. In addition to the sampling of first order benthic organisms such as shellfish, it is also recommended that tissue sampling include upper trophic level consumers to assess rates and trends of metal loading throughout the food chain. USEPA’s (2000, 2001) recommended recreational and subsistence tissue values for cadmium and mercury were used to assess potential tissue impairment in the Hawk Inlet area. Although the observed average concentrations were similar to pre-mining conditions, exceedances of these EPA recommended values should be taken as an indication that more intensive site-specific monitoring and/or evaluation of human health risk should be conducted for all metals of concern (USEPA 2000, 2001).

In addition to expanding monitoring at the 303(d)-listed area of concern, it is also recommended that cadmium, copper, lead, mercury, and zinc monitoring be expanded to include current characterization of water quality at station S-3 and continue to include sediment monitoring at S-3. Station S-3 shows some exceedances of the copper and zinc ERLs (and less so with cadmium and mercury). Monitoring should continue for all metals of concern at station S-3 and Empire Mine. As with the impaired area near stations S-5S, S-5N, and S-4, the water quality and sediment monitoring at station S-3 should include a condition allowing monitoring to end when ADEC and EPA find water and sediment results are attaining WQS for at least 2 years.

Data analyses of freshwater inputs suggest that additional data collection to characterize water, sediment, and tissue conditions would be useful. Monitoring should evaluate potentially undisturbed areas draining to Hawk Inlet (to quantify natural conditions) as well as areas potentially impacted by historic and current anthropogenic activities. Better characterizing tissue concentrations and consumption rates as well as identifying areas closed to fishing (either due to advisories or ownership) is particularly important to ensure protection of human health.

7 Public Comments

The notice for the 45-day public review period was posted on September 29, 2016, and the review period closed on [Date]. The notice was posted in the local newspaper Juneau Empire, on ADEC’s website, and on the State of Alaska’s Public Notice Web Site. A fact sheet was also available on ADEC’s website. Prior to the public review period, a stakeholder review period was held. The Hawk Inlet stakeholders included the Alaska Department of Fish and Game, Alaska Department of Natural Resources, Alaska Department of Environmental Conservation, Alaska Department of Health and Social Services, United States Environmental Protection Agency, National Oceanic and Atmospheric Administration, City and Borough of Juneau, Alaska Wildlife Alliance Southeast Chapter, Defenders and Friends of Admiralty Island and Tongass Wildlands Water, Hecla Greens Creek Mining Company, U.S. Forest Service, Hoonah Indian Association, Douglas Indian Association, Angoon Community Association, Central Council Tlingit & Haida Indian Tribes of Alaska, and Southeast Alaska Conservation Council. Comments from these stakeholders resulted in:

- The inclusion of additional data including the most recent data (2015 and 2016) and pre-mining data
- The comparison of tissue data to the DHSS calculated maximum recommended values, which are based on the 95th percentile of the 2012 Angoon harvest data (that serves as a proxy for consumption rates)
- The discussion of fugitive dust and the historic fish cannery as potential sources of metals to Hawk Inlet
- Additional implementation and monitoring recommendations

Comments on the TMDLs were received from XXXX. Comments and additional information submitted during this public comment period were used to inform or revise this TMDL document. See XXXX for detailed information on the response to comments.

8 References

ADEC (Alaska Department of Environmental Conservation). 2003. 18 AAC 70: Water Quality Standards. Amended as of June 26, 2003. Alaska Department of Environmental Conservation, Juneau, AK.

ADEC (Alaska Department of Environmental Conservation). 2008. *Alaska Water Quality Criteria for Toxic and Other Deleterious Organic and Inorganic Substances.* As amended through December 12, 2008. Alaska Department of Environmental Conservation. Juneau, AK.

ADEC (Alaska Department of Environmental Conservation). 2009. *Total Maximum Daily Load (TMDL) for Toxic and other Deleterious Organic and Inorganic Substances in Klag Bay, Alaska*. Alaska Department of Environmental Conservation, Anchorage, AK.

ADEC (Alaska Department of Environmental Conservation). 2011. *Total Maximum Daily Loads (TMDLs) for Petroleum Hydrocarbons in the Waters of Skagway Harbor in Skagway, Alaska*. Alaska Department of Environmental Conservation, Anchorage, AK.

ADEC (Alaska Department of Environmental Conservation). 2012. *18 AAC 70: Water Quality Standards*. Amended as of April 8, 2012. Alaska Department of Environmental Conservation, Juneau, AK.

ADEC (Alaska Department of Environmental Conservation). 2013a. *Alaska's Final2012 Integrated Water Quality Monitoring and Assessment Report*. December 23, 2013. Alaska Department of Environmental Conservation, Juneau, AK.

ADEC (Alaska Department of Environmental Conservation). 2013b. *Sediment Quality Guidelines*. Technical Memorandum, January 2013. Alaska Department of Environmental Conservation, Division of Spill Prevention and Response, Contaminated Sites Program, Juneau, AK.

ADEC (Alaska Department of Environmental Conservation). 2014. Trip Report: August 6–7, 2014. U.S. Forest Service Empire Mine. Admiralty Island, Alaska. Alaska Department of Environmental Conservation Division of Spill Prevention and Response Contaminated Sites Program, Juneau, AK.

ADEC (Alaska Department of Environmental Conservation). 2015a. Hecla Greens Creek Mine discharge data. ADEC's Wastewater Discharge Authorization Program, Mining and Technical Services Program, Juneau, AK.

ADEC (Alaska Department of Environmental Conservation). 2015b. Final Alaska Pollutant Discharge Elimination System Permit: AK0043206. Alaska Department of Environmental Conservation, Juneau, AK.

ADEC and HSS (Alaska Department of Environmental Conservation and Health and Social Services). 2016. Response Letter to Angoon. Juneau, AK.

ADF&G (Alaska Department of Fish and Game). 2015, July 24. Memorandum to Jackie Timothy regarding Empire Mine Investigation Stream No. 112-65-10110.

Buchman, M.F. 1999. *NOAA Screening Quick Reference Tables*. NOAA HAZMAT Report 99-1. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Coastal Protection and Restoration Division, Seattle, WA.

Buchman, M.F. 2008. *NOAA Screening Quick Reference Tables*. NOAA OR&R Report 08-1. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of Response and Restoration Division, Seattle, WA.

Durst, J.D. and L.L. Jacobs. 2010. Aquatic Biomonitoring at Greens Creek Mine, 2009. Technical Report No. 10-03. Alaska Department of Fish and Game. Juneau, AK.

DHSS (Department of Health and Social Services). 2016. Maximum safe tissue concentrations in marine species. Juneau, AK.

EDE (Environmental Design Engineering). 2002. *Kennecott Greens Creek Mining Company, Stage II Tailings Expansion Hydrologic Analysis*. Prepared for Greens Creek Mining Company by EDE Consultants, Sheridan, WY.

HGCMC (Hecla Greens Creek Mining Company). 2002. *Fresh Water Monitoring Program Annual Report: Water Year 2002*. Hecla Greens Creek Mining Company, Juneau, AK.

HGCMC (Hecla Greens Creek Mining Company). 2003. *Fresh Water Monitoring Program Annual Report: Water Year 2003*. Hecla Greens Creek Mining Company, Juneau, AK.

HGCMC (Hecla Greens Creek Mining Company). 2004. *Fresh Water Monitoring Program Annual Report: Water Year 2004*. Hecla Greens Creek Mining Company, Juneau, AK.

HGCMC (Hecla Greens Creek Mining Company). 2005. *Fresh Water Monitoring Program Annual Report: Water Year 2005*. Hecla Greens Creek Mining Company, Juneau, AK.

HGCMC (Hecla Greens Creek Mining Company). 2006. *Fresh Water Monitoring Program Annual Report: Water Year 2006*. Hecla Greens Creek Mining Company, Juneau, AK.

HGCMC (Hecla Greens Creek Mining Company). 2007. *Fresh Water Monitoring Program Annual Report: Water Year 2007*. Hecla Greens Creek Mining Company, Juneau, AK.

HGCMC (Hecla Greens Creek Mining Company). 2010. *Fresh Water Monitoring Program Annual Report: Water Year 2010*. Hecla Greens Creek Mining Company, Juneau, AK.

HGCMC (Hecla Greens Creek Mining Company). 2011. *Fresh Water Monitoring Program Annual Report: Water Year 2011*. Hecla Greens Creek Mining Company, Juneau, AK.

HGCMC (Hecla Greens Creek Mining Company). 2012. *Fresh Water Monitoring Program Annual Report: Water Year 2012*. Hecla Greens Creek Mining Company, Juneau, AK.

HGCMC (Hecla Greens Creek Mining Company). 2013a. *Fresh Water Monitoring Program Annual Report: Water Year 2013*. Hecla Greens Creek Mining Company, Juneau, AK.

HGCMC (Hecla Greens Creek Mining Company). 2015a. Greens Creek: Location. Accessed August 24, 2015. http://www.hecla-mining.com/operations/operations_greenscreek_location.php

HGCMC (Hecla Greens Creek Mining Company). 2015b. *Hawk Inlet Monitoring Program: 2014 Annual Report.* Hecla Greens Creek Mining Company, Juneau, AK.

HGCMC (Hecla Greens Creek Mining Company). 2015c. Personal communication between Chris Wallace, Environmental Manager, HGCMC and Gretchen Pikul, ADEC regarding HCGMC's *Fresh Water Monitoring Program Data – Water Year 2009*.

HGCMC (Hecla Greens Creek Mining Company). 2015d. *General Plan of Operations: Appendix 5 – Best Management Practices Plan*. Hecla Greens Creek Mining Company, Juneau, AK.

HGCMC (Hecla Greens Creek Mining Company). 2015e. *Fresh Water Monitoring Program Annual Report Water Year 2015*. Hecla Greens Creek Mining Company, Juneau, AK.

Holland, A.F., M. Hiegel and W. Richkus. 1981. Final Results of the 1981 Field Program for the Greens Creek Project. Part I – Hawk Inlet and Young Bay. Baltimore, MD.

Kanouse, K. M. 2015. Aquatic Biomonitoring at Greens Creek Mine, 2014. Technical Report No. 15-03. Alaska Department of Fish and Game, Douglas, AK.

KGCMC (Kennecott Greens Creek Mining Company). 1990. Kennecott Greens Creek Mining Company Report to Alaska Department of Environmental Conservation. Prepared for Alaska Department of Environmental Conservation, by Kennecott Greens Creek Mining Company, Salt Lake City, UT.

Lowry, L.F., K.J. Frost, J.M. Ver Hoef, and R.A. DeLong. 2001. Movements of Satellite-Tagged Subadult and Adult Harbor Seals in Prince William Sound, Alaska. Marine Mammal Science. 17(4) 835-861.

MTS (Marine Taxonomic Services, Ltd.). June 2016. Letter re: Historical Observations Relative to Contaminated Sediments and Sediment Transport During Berthing and Departure of Ore Ships.

MRLCC (Multi-Resolution Land Characteristics Consortium). 2001. *2001 National Land Cover Data*. http://www.mrlc.gov/nlcd01_data.php

National Park Service. 2015. *Admiralty Island Province.* Accessed June 2015. http://www.nps.gov/glba/learn/nature/admiralty-island-province.htm.

NOAA (National Oceanic and Atmospheric Administration). 2016. Coast Survey. Accessed May 23, 2016. http://www.charts.noaa.gov/OnLineViewer/17312.shtml

NRCS (Natural Resources Conservation Service). 1972. *National Engineering Handbook.* U.S. Department of Agriculture, Natural Resources Conservation Service, Washington DC.

NRCS (Natural Resources Conservation Service). No date. *State Soil Geographic Database (STATSGO).* http://datagateway.nrcs.usda.gov.

Oceanus Alaska. 2003. *Review of Essential Fish Habitat in Hawk Inlet Subsequent to Mining Operations*. Prepared for the U.S. Department of Agriculture, Forest Service, in connection with the Greens Creek Tailings Disposal Final Environmental Impact Statement, by Oceanus Alaska, Juneau, Alaska.

Oceanus Alaska. 2015a. Legacy Cove Project Note No. 3: Trace Metals in Edible Marine Species, Hawk Inlet, Admiralty Island, Alaska. Juneau, Alaska.

Oceanus Alaska. 2015b. Legacy Cove Project Note No. 2: Trace Metals in an Admiralty Island Harbor Seal (*Phoca vitulina*), Opportunistic Sample from Hawk Point, West Admiralty Island. Juneau, Alaska.

Portage, Inc. 2014. *Field Sampling Plan for Empire Mine Preliminary Assessment/Site Inspection*. PLN-5065. Prepared for U.S. Department of Agriculture, Forest Service by Portage, Inc., Idaho Falls, ID.

Portage, Inc. 2015. *Empire Mine Preliminary Assessment/ Site Inspection Report*. RPT-5046.0000-001. Prepared for U.S. Department of Agriculture, Forest Service by Portage, Inc., Idaho Falls, ID.

Richkus, W.A, and G.F. Johnson. (1981). Heavy Metal concentrations in Aquatic Biota of Greens Creek, Zinc Creek and Hawk Inlet. Baltimore, MD.

Ridgway, L.M. 2016. Ecological Reconnaissance of Hawk Inlet Marine Ecosystem following 25 years of Industrial Mining. Oceanus Alaska project report for Friends of Admiralty Legacy Cove Investigations. Auke Bay, AK.

Rudis, D., P. Schempf and M. Jacobson. 2001. Bald Eagle, Blue Mussel and Sediment Contamination Concentrations from Hawk Inlet. Poster Presentation. Juneau, AK.

SEAtrails (The Southeast Alaska Trail System). 2015. Destinations: Angoon. Accessed July 2015. http://www.seatrails.org/com_angoon/.

Tetra Tech, Inc. 2012. Essential Fish Habitat Assessment Greens Creek Mine Tailings Disposal Facility Expansion. Prepared for Admiralty Island National Monument Tongass National Forest. Bothwell, WA.

U.S. Census Bureau. 2015. *State & County QuickFacts*. U.S. Census Bureau. Accessed June 2015. http://quickfacts.census.gov/qfd/states/02/0236400.html.

USDA (U. S. Department of Agriculture). 2003. *Greens Creek Tailings Disposal: Final Environmental Impact Statement, Volume I*. U.S. Department of Agriculture, Forest Service, Tongass National Forest, Juneau, AK.

USDA (U. S. Department of Agriculture). 2013. *Greens Creek Mine Tailings Disposal Facility Expansion: Final Environmental Impact Statement and Record of Decision, Volume I*. U.S. Department of Agriculture, Forest Service, Tongass National Forest, Juneau, AK.

USEPA (U. S. Environmental Protection Agency). 1991. *Guidance for Water Quality-based Decisions: The TMDL Process*. EPA 440/4-91-001. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

USEPA (U. S. Environmental Protection Agency). 2000. *Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories*. EPA 823-B-00-007. U. S. Environmental Protection Agency, Office of Water, Washington, DC.

USEPA (U. S. Environmental Protection Agency). 2001. *Water Quality Criterion for the Protection of Human Health: Methylmercury*. Final. EPA 823-R-01-001. U. S. Environmental Protection Agency, Office of Science and Technology, Office of Water, Washington, DC.

USEPA (U. S. Environmental Protection Agency). 2004. *EPA Review of the 2003 Revisions to the Alaska Water Quality Standards Regulations*. Letter to ADEC February 27, 2004.

USEPA (U. S. Environmental Protection Agency). 2005. *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites*. EPA-540-R-05-012. U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington, D.C.