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DEC
Division of Water Quality
Wastewater Discharge Program

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 10
1200 Sixth Avenue, Suite 900
Seattle, WA 98101-3140

OFFICE OF
WATER AND WATERSHEDS

JUN 28 2013

Ms. Michelle Bonnet Hale, Director
Water Division
Department of Environmental Conservation
555 Cordova Street
Anchorage, Alaska 99501-2617

Re: Approval of the Total Maximum Daily Load (TMDL) for Iron and Manganese in Red Lake/Anton Road Pond, Kodiak, Alaska

Dear Ms. Bonnet Hale:

The Alaska Department of Environmental Conservation (ADEC) submitted the Red Lake/ Anton Road Pond TMDLs for iron and manganese, dated May 29, 2013, to the U.S. Environmental Protection Agency. Following our review, the EPA is pleased to approve the iron and manganese TMDLs for Red Lake/Anton Road Pond (Alaska ID Number 30102-409) in Kodiak, Alaska.

Our review indicates that these allocations have been established at a level that, when fully implemented, will lead to the attainment of the water quality criteria addressed by these TMDLs. Therefore, ADEC does not need to include Red Lake/ Anton Road Pond on the next 303(d) list of impaired waters for the pollutants covered by these TMDLs.

We greatly appreciate the opportunity to work with your staff throughout the development of these TMDLs. My staff brought to my attention in particular the hard work and commitment shown by Shane Serrano in the development of these TMDLs.

By EPA's approval, these TMDLs are now incorporated into the State's Water Quality Management Plan under Section 303(e) of the Clean Water Act. We look forward to continuing to work collaboratively on water quality issues in Red Lake/ Anton Road Pond. If you have any questions, please feel free to call me at (206) 553-1855, or Martha Turvey of my staff at (206) 553-1354.

Sincerely,

Daniel D. Opalski, Director
Office of Water and Watersheds

cc: Mr. Shane Serrano, Non-Point Source Section, ADEC
Ms. Cindy Gilder, Manager, Non-Point Source Section, ADEC
Ms. Nancy Sonafrank, Manager, WQ Standards, Assessment and Restoration Program, ADEC

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

Iron and Manganese TMDL Development for Red Lake/Anton Road Pond, Alaska

March 2013

CONTENTS

TABLES

FIGURES

ACRONYMS

AAC	Alaska Administrative Code
ADEC	Alaska Department of Environmental Conservation
ADNR	Alaska Department of Natural Resources
ADF&G	Alaska Department of Fish and Game
APDES	Alaska Pollutant Discharge Elimination System
BMP	best management practice
CCC	Criterion Continuous Concentration
CEC	cation exchange capacity
CFR	Code of Federal Regulations
CMS	corrective measures study
CWA	Clean Water Act
DEC	Department of Environmental Conservation
DOC	dissolved organic carbon
DOM	dissolved organic matter
KEA	Kodiak Electric Association
LA	load allocation
LC	loading capacity
LEL	Lowest Effect Level
µg/L	micrograms per liter
MOS	margin of safety
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
PEL	Probable Effects Levels
PHREEQC	pH-Redox-Equilibrium-Equations in C Model
POM	particulate organic matter
RCRA	Resource Conservation and Recovery Act
RFI	RCRA facility investigation
SAIC	Science Applications International Corporation
SEL	Severe Effect Level
SQuiRTs	Screening Quick Reference Tables
SWMU	solid waste management unit
TEL	Threshold Effects Levels
TMDL	Total Maximum Daily Load
TOC	total organic carbon
USACE	United States Army Corps of Engineers
USAED	United States Army Engineers District
USCG	United States Coast Guard
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WLA	wasteload allocation

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Total Maximum Daily Load (TMDL) for Iron and Manganese in Red Lake/Anton Road Pond, Alaska

TMDL at a Glance:

Water Quality Limited?	Yes
Alaska ID Number:	30102-409
Criteria of Concern:	Toxic & Other Deleterious Organic and Inorganic Substances: Total Recoverable Iron and Manganese
Designated Uses Affected:	(1) Water supply, (2) water recreation, and (3) growth and propagation of fish, shellfish, other aquatic life, and wildlife
Major Source(s):	Urban Runoff (specifically, landfill drainage)
Loading Capacity:	1,000 µg/L iron; 50 µg/L manganese;
Wasteload Allocation (WLA):	NA
Load Allocations (LA):	1,000 µg/L iron; 50 µg/L manganese;
Margin of Safety (MOS):	Implicit
Future Growth:	1,000 µg/L iron; 50 µg/L manganese;
Necessary Reductions:	Red Lake: 68% iron, 95% manganese Anton Road Pond: 92% iron, 93% manganese

Total Iron and Manganese Measured as Water Concentrations (µg/L)[a]

Waterbody	Pollutant	Loading Capacity	WLA	LA	MOS	Future Growth	Maximum Observed[b]	Percent Reduction to Meet LA
Red Lake	Iron	1,000	NA	1,000	Implicit	1,000	3,160	68%
Anton Road Pond	Iron	1,000	NA	1,000	Implicit	1,000	12,600	92%
Red Lake	Manganese	50	NA	50	Implicit	50	1,030	95%
Anton Road Pond	Manganese	50	NA	50	Implicit	50	728	93%

[a] Applicable water quality criteria for iron and manganese apply year round in Red Lake and Anton Road Pond.
[b] Maximum observed since 1999 drainage upgrades.

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Executive Summary

Red Lake and Anton Road Pond are located on the northeast shore of Kodiak Island about one mile northwest of the Kodiak Airport. The state of Alaska has included Red Lake and Anton Road Pond on its section 303(d) list since 1994 as water quality-limited due to iron and manganese. Red Lake and Anton Road Pond (Alaska ID Number 30102-409) are currently classified as Category 5 waterbodies (i.e., total maximum daily load [TMDL] is needed). A TMDL is established in this document to meet the requirements of section 303(d) of the Clean Water Act (CWA) and the U.S. Environmental Protection Agency's (USEPA) Water Quality Planning and Management Regulations (at Title 40 of the *Code of Federal Regulations* [CFR] Part 130), which require the establishment of a TMDL for the achievement of water quality standards when a waterbody is water quality-limited. A TMDL is composed of the sum of individual waste load allocations (WLAs) for point sources and load allocations (LAs) for nonpoint sources 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 water quality standards (USEPA 1991).

This document addresses the iron and manganese impairments in Red Lake and Anton Road Pond. Red Lake and Anton Road Pond are what remains of a former natural lake that was mostly covered by the construction of a Navy landfill (ADEC 1992). The former Navy Landfill is located to the northeast of Red Lake and to the northwest of Anton Road Pond. Red Lake is approximately 225 feet east of the Buskin River. Overflow from Red Lake is transported to the Buskin River via an engineered drainage ditch. Historically, the absence of a liner, cover, and leachate controls has resulted in releases of hazardous constituents to soils, groundwater, surface water and sediments downgradient of the landfill. While historic landfill drainage is the expected primary source of iron and manganese to Red Lake and Anton Road Pond, an additional potential source is internal loading within Red Lake and Anton Road Pond themselves from natural background sources. Internal loading refers to the recycling of iron and manganese at the sediment and water interface at the bottom of a waterbody. Iron and manganese precipitates may settle out of the water column over time, but some of this load may be reduced and dissolve back into the water column.

Red Lake and Anton Road Pond do not fully support their designated uses of water supply, water recreation, and growth and propagation of fish, shellfish, other aquatic life, and wildlife due to elevated concentrations of iron and manganese in the water column. Most iron and manganese loads entering Red Lake and Anton Road Pond are by groundwater pathways from the landfill and are not precisely known; however, the resulting concentrations in surface water are elevated. The TMDLs for iron and manganese in Red Lake and Anton Road Pond are expressed as concentrations, equivalent to Alaska's numeric water quality criteria of 1,000 µg/L for iron and 50 µg/L for manganese. These TMDL targets are the most stringent iron and manganese criteria for surface waters and are protective of all freshwater designated uses.

A concentration-based TMDL is appropriate for Red Lake and Anton Road Pond because using a more complicated analysis to estimate iron and manganese loads from landfill drainage would require additional data collection and would not provide additional guidance or benefit to the subsequent planning and implementation actions. The state water quality criteria directly address the basis for section 303(d) listing and the only known source of impairment, which is dissolved iron and manganese in drainage from the adjacent landfill.

Reducing concentrations of iron and manganese in Red Lake and Anton Road Pond may involve further efforts to control runoff from the landfill as well as considering the contribution of internal loadings from groundwater and sediment. The ADEC Contaminated Sites Program is coordinating with the United States Coast Guard (USCG) and the United States Army Corps of Engineers (USACE) throughout Base Kodiak to continue systematic investigations, monitoring programs and cleanup at sites under the Resource Conservation and Recovery Act (RCRA) hazardous waste management facility permit.

Monitoring activities are recommended to support TMDL implementation for Red Lake and Anton Road Pond. These monitoring activities include developing a water balance to estimate seasonal inflow from groundwater into Red Lake and Anton Road Pond; measuring iron and manganese concentrations during each season in groundwater and surface water; collecting additional iron and manganese concentrations in Anton Road Pond to verify current conclusions; collecting current groundwater and sediment background concentrations of iron and manganese; and monitor the contribution of internal loading from sediment by measuring iron and manganese concentrations in bottom sediments.

1. Overview

Section 303(d)(1)(C) of the Clean Water Act (CWA) and the U.S. Environmental Protection Agency's (USEPA) implementing regulations (40 CFR Part 130) require the establishment of a Total Maximum Daily Load (TMDL) to achieve state water quality standards when a waterbody is water quality-limited. A TMDL identifies the amount of a pollutant that a waterbody can assimilate and still maintain compliance with applicable water quality standards. TMDLs identify the level of pollutant control needed to reduce pollutant inputs to a level (or "load") that fully supports the designated uses of a given waterbody and include an appropriate margin of safety 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 USEPA's National Pollutant Discharge Elimination System (NPDES) permits (or in Alaska, the Alaska Pollutant Discharge Elimination System [APDES] permits).

Alaska's Department of Environmental Conservation (DEC) first listed Red Lake and Anton Road Pond on its section 303(d) list in 1994 as water quality-limited for iron and manganese. Table 1-1 summarizes the information included in the USEPA-approved Alaska 2010 section 303(d) list for Red Lake and Anton Road Pond. In particular, Red Lake and Anton Road Pond experience non-attainment of water quality criteria for total recoverable iron and manganese (ADEC 2010). The non-attainment affects the designated uses of (1) water supply, (2) water recreation, and (3) growth and propagation of fish, shellfish, other aquatic life, and wildlife. The section 303(d) listing is supported by recent water quality monitoring in 2002 and 2010 that confirmed exceedances of applicable criteria. Red Lake and Anton Road Pond are located at the site of a former Navy landfill. The landfill is now closed and is the only known anthropogenic source of metals to the waterbodies.

Red Lake and Anton Road Pond are located on the northeast shore of Kodiak Island about one mile northwest of the Kodiak Airport (Figure 1-1). The original section 303(d) listing in 1994 was for "Red Lake and Anton Road Ponds," implying that more than one pond was listed in addition to Red Lake. Drainage improvements were made to the site in 1999 to reduce offsite contamination and uncontrolled surface water runoff from the closed landfill. The changes in the hydrology of the site resulted in one pond in addition to Red Lake, referred to herein as "Anton Road Pond". Therefore, this TMDL covers both Red Lake and Anton Road Pond.

Table 1-1: Red Lake/Anton Road Pond section 303(d) listing information from DEC's draft 2012 Integrated Report.

<table>
<tr><th>Alaska ID Number</th><th>Waterbody</th><th>Area of Concern</th><th>Water Quality Standard</th><th>Pollutant Parameters</th><th>Pollutant Sources</th></tr>
<tr><td>30102-409</td><td>Red Lake Anton Road Pond</td><td>2 acres</td><td>Toxic & Other Deleterious Organic and Inorganic Substances</td><td>Metals - Iron, Manganese</td><td>Urban Runoff</td></tr>
<tr><td colspan="6">Red Lake and Anton Road Pond were placed on the 1994 Section 303(d) list for non-attainment of the toxic and other deleterious organic and inorganic substances standard for metal. Based on a 1992 memorandum released by DEC Kodiak Field Office, Red Lake lies less than 200 feet from a Navy landfill. This landfill was constructed without a liner or leachate collection system. Landfill waste, which may include solvents, paints, used oils, and contaminated fuel, occasionally leaches into Red Lake and two other small ponds near Anton Road. These two ponds are highly colored by bright orange-red iron precipitates caused by the oxidation of the leachate. Lake sediment samples were found to contain 8.6% iron. Chemical pollutants were documented at low levels in the lake and in the bottom sediments. DEC staff reviewed four reports from 1996 and 1997. The data presented in the reports are the best available. DEC concluded that (1) Red Lake clearly appears to have exceedances of WQS for iron and manganese because of human actions; (2) no existing controls are in place to ensure that the WQS will be met in a reasonable time period; (3) because the reports did not present any information showing levels of iron and manganese in groundwater above the landfill, no information shows that the abandoned landfill is not the source of these metals; and (4) although there were other parameters of concern observed in previous sampling, the available information indicates that Red Lake should only be listed for manganese and iron.</td></tr>
</table>

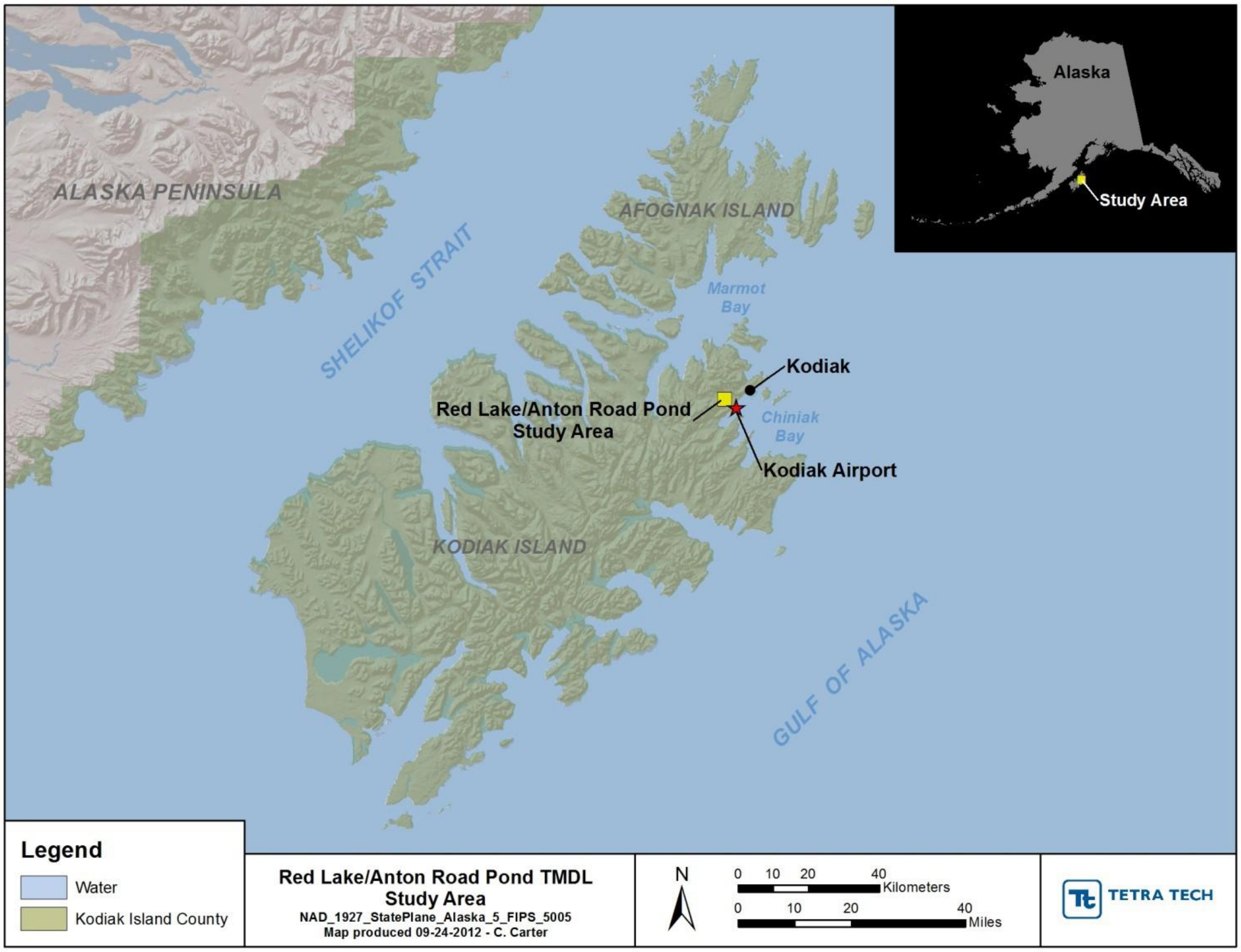

Figure 1-1: Regional Location of Red Lake and Anton Road Pond Study Area

2. Background Information

2.1. Setting

Red Lake and Anton Road Pond are located on the northeast shore of Kodiak Island about one mile northwest of the Kodiak Airport (Figure 1-1 and Figure 2-1). Red Lake and Anton Road Pond are what remains of a former natural lake that was mostly covered by the construction of a Navy landfill (ADEC 1992).The former Navy Landfill, which drains to Red Lake, occupies a relatively flat area (7.6 acres) and is approximately 40 to 55 feet above mean sea level. The landfill is located adjacent to a northwest-southeast trending ridge situated to the northeast of the subject waterbodies. Most of the landfill is vegetated with 4- to 8-foot high alder brush and native grasses (Jacobs Engineering Group 2004). The Kodiak Electric Association (KEA) erected a substation on the southeastern portion of the landfill in 1983. The KEA parcel is surrounded by a chain link fence that is separated from the current landfill boundary fence by approximately 10 feet. An unpaved access road is located south of the landfill and the KEA substation. An Alaska Department of Transportation and Public Facilities maintenance building and storage yard is located south of the access road (Windward Environmental 2010).

Anton Road Pond is about 100 feet northwest of the landfill. Red Lake lies at the southwest side of the landfill and approximately 225 feet east of the Buskin River. The landfill receives surface water runoff from precipitation and from the ridge located to the northeast of the landfill. Water moving through and around the landfill area eventually infiltrates the alluvial sediments of the Buskin River floodplain. Overflow from Red Lake is transported to the Buskin River via an engineered drainage ditch (Figure 2-1), which passes through a 12-inch-diameter culvert that traverses beneath Anton Larsen Bay Road. The confluence between the drainage ditch and the Buskin River forms an 8 to 10 foot pool with slow flow and eddies but limited downstream flow (USCG 2007). Red Lake and the drainage ditch are both colored orange/red from the presence of iron oxide. The larger watershed of the Buskin River includes a headwaters lake (Buskin Lake). Both the lake and the river provide habitat for a number of fish species (see section 2.3 Fish and Wildlife for the names of the species), including habitat for salmon spawning and rearing.

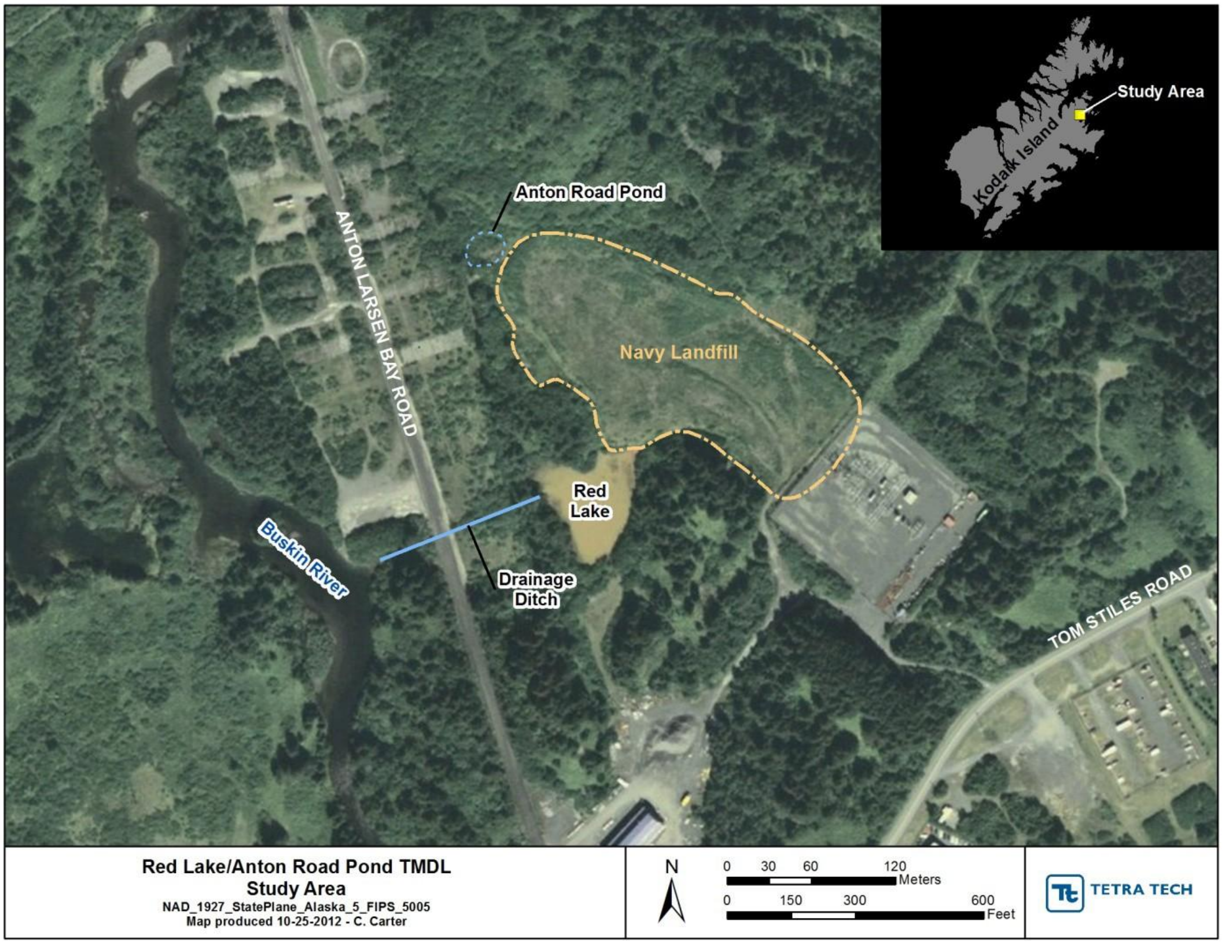

Figure 2-1: Red Lake/ Anton Road Pond Study Area

2.2. Climate

The climate within the vicinity of Red Lake and Anton Road Pond is characteristic of a maritime climate with small temperature variations. Relatively high annual precipitation and high velocity winds are typical for Kodiak Island (Hogan and Nakanishi 1995). Annual precipitation ranged from 54 to 106 inches with a mean of 77 inches (WRCC 2012a) for the period of record (1973 through 2012) at Kodiak Airport, near the subject waterbodies. The highest temperatures occur in August on average with a maximum average temperature of about 62 degrees Fahrenheit. The lowest temperatures occur in December and January with minimum average temperatures of about 26 degrees Fahrenheit (WRCC 2012b).

2.3. Fish and Wildlife

Red Lake and the drainage ditch have been observed to support various aquatic invertebrates, including zooplankton, copepods, ostracods, dragonfly larvae, and *Daphnia* species (Science Applications International Corporation [SAIC] and Morson 1997). Aquatic macrophytes have also been observed (SAIC 1997a). Observations of salmon fry have been documented in the drainage ditch where the culvert emerges from beneath Anton Larsen Bay Road; a physical barrier in the drainage infrastructure exists upstream of this location, which likely impedes the salmon fry from reaching Red Lake (Windward Environmental 2010). No information was available on aquatic life existing in Anton Road Pond. It is likely that Anton Road Pond supports some aquatic life but is probably connected only by groundwater to Red Lake and the drainage ditch, except during larger storm events.

The Buskin River functions as habitat for a variety of fish, including three species of salmon: *Oncorhynchus gorbusha* (pink salmon), *O. nerka* (sockeye salmon), and *O. kisutch* (coho salmon) (SAIC and Morson 1997). *O. keta* (chum salmon) have also been observed in the river (but do not have a run). Dolly varden and steelhead trout have also been known to forage and spawn in the river and Buskin Lake system (SAIC and Morson 1997). The Buskin River also supports aquatic invertebrates, which provide food for fish and other aquatic and semi-aquatic species (Windward Environmental 2010).

With the largest run in the Buskin system, pink salmon spawn in Buskin Lake and downstream to Bridge No. 1, primarily in riffle areas, including an area approximately 500 feet downstream of the confluence of the Red Lake drainage ditch and the Buskin River. Bridge No. 1 is located less than 0.5 mile downstream of the confluence of the Red Lake drainage ditch and the Buskin River. Having the next largest run, sockeye salmon typically spawn in Buskin Lake in the spring, and juveniles exist in the lake for up to a year (SAIC and Morson 1997). Spawning of coho salmon also occurs in Buskin Lake, and rearing occurs for up to a year in the lake and river (Windward Environmental 2010).

2.4. Waterbody Characteristics

Red Lake and Anton Road Pond receive surface runoff from the hills located north and northeast of the landfill (Windward Environmental 2010). Prior to the landfill development, a lake existed on the site, and the subject waterbodies are likely remnants of this original lake (SAIC 1995a). Red Lake is approximately one acre in size with a maximum depth of five feet (Figure 2-2). Anton Road Pond is smaller and approximately 0.1 to 0.15 acre in size (Figure 2-3). The depth of Anton Road Pond is unknown but is likely shallower compared to Red Lake; the pond appears very shallow in field photography (Figure 2-3).

SAIC (1997a) describes Red Lake as slightly alkaline, somewhat buffered, and soft but subject to pH shifts. Total organic carbon (TOC) concentrations in 1996 indicated that the waterbody did not support a high degree of algal productivity, and visual observations indicated that the lake was dominated by iron-oxidizing bacteria (SAIC 1997a). A similar assessment was not available for Anton Road Pond.

Figure 2-2: Red Lake, facing west from Navy Landfill
(Photo courtesy of Windward Environmental, LLC)

Figure 2-3: Anton Road Pond/wetland located north of Navy Landfill, facing northwest
(Photo courtesy of Windward Environmental, LLC)

2.5 Cultural and Economic History

Red Lake and Anton Road Pond are located in the Kodiak Island Borough (2010 population 13,592) which encompasses the entire expanse of Kodiak Island. The closest municipality is the City of Kodiak (2010 population 6,130), which is about 5 miles east of the subject waterbodies (U.S. Census Bureau 2012).

Kodiak Island was originally populated by the Koniag, a sub-group of the Inuit culture who are believed to have migrated from Asia near the end of the last ice age. The Koniag subsisted on whaling and fishing, and the pre-European population has been estimated at 8,000. The first permanent Russian settlement was established in 1783 on the island, with fur production being the primary focus of Russian activities. The United States acquired Alaska from Russia in 1867. Fur trading ceased in 1890 when fur seal populations had declined near extinction, and economic activities shifted to fishing. The first major salmon canneries were built in 1900. The first crab processing plant was built in 1949 (SAIC 1995b).

The fishing industry continues to be an important economic activity for Kodiak Island. Other economic activities on the island include tourism and mining of gold, sand, and gravel. Tourist activities include fishing, hunting, sea kayaking, mountain biking, and hiking (SAIC 1995b).

The U.S. Navy developed a base in the lower Buskin River valley during World War II. The installation operated as a base for aircraft, ships, and submarines during the war, providing coastal defense and supporting American military campaigns in the Aleutians. During this period, the peak population at the base was 50,000 (SAIC 1995b).

The 7.6-ac landfill site was used by the U.S. Navy for the disposal of solid wastes from the early 1940s to 1972. Soil borings found approximately 8 feet of plastic and metal landfill debris under 2 feet of cover material in the northwest portion of the landfill (Windward Environmental 2010). The installation property was transferred to the U.S. Coast Guard in 1972; the landfill was closed, covered with soil, and partially graded. At the time the landfill was closed, no engineering or access controls, including a liner, cover, or leachate controls, were implemented. The State of Alaska did not have landfill closure regulations at that time (Windward Environmental 2011).

In the early 1990s, the site was used to temporarily store home demolition debris. USEPA identified the site as a solid waste management unit (SWMU) in 1990 (SWMU No. 2). Also during the early 1990s, USEPA prepared a Resource Conservation and Recovery Act (RCRA) facility investigation (RFI)/corrective measures study (CMS) for the landfill (SAIC 1995a).

In 1999, the US Army Corps of Engineers (USACE) re-graded the landfill to improve the vegetative cover and surface water drainage with the purpose of reducing potential offsite migration of contaminants and uncontrolled surface water drainage that overflowed to Anton Larsen Bay Road during heavy rainfall (SAIC 1995a). The 1999 regrading was completed based on recommendations made in USEPA's RFI/CMS and included the construction of diversion ditches. Current maintenance activities include annual mowing of the vegetation cover and monitoring and repair of the fence surrounding the site (Windward Environmental 2011). ADEC Contaminated Sites, the Coast Guard and the USACE continue to coordinate systematic investigations, monitoring programs and cleanup throughout Base Kodiak under the RCRA hazardous waste management facility permit.

2.6 Soils and Geology

Soil borings in and near the landfill provide a general description of the soils and geology of the study area. Depth to bedrock in the landfill area is between 4 and 30 feet below the original surface (SAIC 1995). Bedrock north of the landfill has been described as low-grade metamorphic shale and slate. In general, bedrock porosity is low because of intense compaction and secondary mineral growth, although subsequent fracturing has resulted in localized increases in permeability. Glacial till has been identified as an outcrop unit in the landfill area. The glacial till is a mixture of clay and sand, containing pebbles, cobbles, and rare boulders. In general, the landfill was constructed on a gently sloping "bench" of low permeability till or bedrock. Soil borings show that this low permeability material is overlain by 2-10 feet of soils that consist of cobbles, gravel, silty gravel, and clay that probably originated from the surrounding upgradient low hills and was reworked and deposited by the Buskin River as it flowed through the floodplain (SAIC 1995; Windward 2010, 2011). A volcanic ash layer was also found in one of the borings between 5 and 6.5 feet below the surface and was underlain by alluvial gravel (Windward 2010, 2011).

Relatively thick clay extends more than 7 feet below ground surface southwest of the landfill, near Red Lake (SAIC 1995). Soil borings southwest of Red Lake consisted of silty gravel and clay overlying weathered bedrock and clay. Borings about 300 feet northwest of the landfill, adjacent to the Buskin River encountered unconsolidated silt, sand, clay, and gravel that likely represent alluvial deposits from the Buskin River (Windward 2010).

The area to the west of the Navy Landfill is generally underlain by a thin sequence of unconsolidated sediment overlying bedrock. The shallow soils are fill materials predominately composed of silty gravel. The western-most boring locations (to the west of Anton Larsen Bay Road) also indicated the presence of bedrock consisting of highly weathered and fractured slate 6 to 8 feet below the ground surface (Windward 2010, 2011).

2.7 Land Use/ Land Cover

The land surrounding Red Lake and Anton Road Pond is owned by the federal government and is currently under Coast Guard control (ADEC, personal communication, July 11, 2012). In 1983, the KEA erected a substation on the southeastern portion of the landfill (Windward 2011). The KEA parcel and the landfill are surrounded by a chain link fence. Concrete slabs of former buildings exist between the landfill and Anton Larsen Bay Road; however, runoff from these slabs appears to be directed away from both waterbodies.

Other than the closed landfill and KEA substation, the watershed area consists mostly of natural vegetation. Natural vegetation in the local area is representative of a high-brush system, which consists of coastal alder thickets, willow, blueberry, raspberry, lingonberry, Devil's club, grasses, ferns, lichens, and mosses (USGS, 1995). The landfill itself is vegetated with 4- to 8-foot high alder brush and native grasses (Jacobs Engineering Group 2004).

3. Water Quality Standards

Water quality standards designate the “uses” to be protected (e.g., water supply, recreation, aquatic life) 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 water quality standards, 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 water quality standards. The TMDL target may be equivalent to a numeric water quality standard where one exists, or it may represent a quantitative interpretation of a narrative standard. This section reviews the applicable water quality standards and identifies an appropriate target for calculation of the metals TMDLs in Red Lake and Anton Road Pond. Metals for which TMDLs are calculated are iron and manganese. Identification of metals of concern is discussed further in Section 4.

3.1. Applicable Water Quality Standards

Title 18, Chapter 70 of the Alaska Administrative Code (ACC) establishes water quality standards for the waters of Alaska, including the designated uses to be protected and the water quality criteria necessary to protect the uses. State water quality criteria are defined for both marine and fresh waterbodies. In the case of Red Lake and Anton Road Pond fresh water criteria are applicable.

Designated uses established in the State of Alaska Water Quality Standards (18 AAC 70) for fresh waters include (1) water supply, (2) water recreation, and (3) growth and propagation of fish, shellfish, other aquatic life, and wildlife and are applicable to all fresh waters, unless specifically exempted. Red Lake and Anton Road Pond are protected for all three designated uses. Table 3-1 lists water quality criteria for toxic and other deleterious organic and inorganic substances, on which the section 303(d) listing for Red Lake and Anton Road Pond is based.

Table 3-1: Fresh water quality criteria for toxic and other deleterious organic and inorganic substances (18 AAC 70.020).

Designated Use	Description of Criteria
(11) Toxic and other deleterious organic and inorganic substances, for fresh water uses	
(A) Water supply	
(i) Drinking, culinary, and food	The concentration of substances in water may not exceed the numeric criteria for drinking water and human health for consumption of water and aquatic organisms shown in the Alaska Water Quality Criteria Manual (see note 5). Substances may not be introduced at concentrations that cause, or can reasonably be expected to cause, either singly or in combination, odor, taste, or other adverse effects on the use.
(ii) Agriculture, including irrigation and stock watering	The concentration of substances in water may not exceed the numeric criteria for drinking water and stockwater and irrigation water shown in the Alaska Water Quality Criteria Manual (see note 5). Substances may not be introduced at concentrations that cause, or can reasonably be expected to cause, either singly or in combination, odor, taste, or other adverse effects on the use.
(iii) Aquaculture	Same as (11)(C).
(iv) Industrial	Concentrations of substances that pose hazards to worker contact may not be present.

Designated Use	Description of Criteria
(B) Water recreation	
(i) Contact recreation	The concentration of substances in water may not exceed the numeric criteria for drinking water shown in the Alaska Water Quality Criteria Manual (see note 5). Substances may not be introduced at concentrations that cause, or can reasonably be expected to cause, either singly or in combination, odor, taste, or other adverse effects on 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 fresh 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.

The State of Alaska's water quality criteria for priority and non-priority pollutants are established in the "Alaska Water Quality Criteria Manual for Toxic and Other Deleterious Organic and Inorganic Substances" document (ADEC 2008). Red Lake and Anton Road Pond cause of impairment is listed as iron and manganese. Alaska's water quality criteria for these metals are based on the total recoverable concentration in ambient water. Table 3-2 presents the applicable criteria for metals of concern in Red Lake and Anton Road Pond.

Table 3-2: Freshwater water quality criteria for metals of concern in Red Lake and Anton Road Pond (in µg/L).

Metal	Use	Criterion Value[1]
Iron	Irrigation Water	5,000
	Chronic Aquatic Life (Criterion Continuous Concentration [CCC])	1,000
Manganese	Irrigation Water	200
	Human Health for Consumption of Water & Aquatic Organisms	50
	Human Health for Consumption of Aquatic Organisms Only	100

[1]Criteria are not to be exceeded.

3.2. Impairments

Red Lake and Anton Road Pond were placed on the 1994 section 303(d) list for non-attainment of the freshwater quality criteria for metals. In particular, Red Lake and Anton Road Pond experience non-attainment of water quality criteria for total recoverable iron and manganese (ADEC 2010). The non-attainment affects the designated uses of (1) water supply, (2) water recreation, and (3) growth and propagation of fish, shellfish, other aquatic life, and wildlife. Recent (since 1999) and historical (1999 and before) monitoring indicate that metals concentrations in Red Lake and Anton Road Pond surface waters are greater than Alaskan water quality standards for applicable beneficial uses including drinking water, irrigation water, acute and chronic aquatic life uses and human health consumption of water and aquatic organisms (see Section 4).

The original listing in 1994 was for Red Lake and Anton Road "ponds", implying that more than one pond was listed in addition to Red Lake. Drainage improvements occurring in 1999 changed the hydrology of the site and resulted in one pond in addition to Red Lake, referred to herein as Anton Road Pond, draining the landfill in addition to Red Lake. Therefore, the two listed waterbodies considered for this TMDL document are Red Lake and Anton Road Pond.

3.3. TMDL Target

The TMDL targets for Red Lake and Anton Road Pond are equivalent to the state water quality criteria of 1,000 µg/L iron and 50 µg/L manganese. As documented in Section 3.1, these criteria represent the most protective criteria, addressing all designated uses. Specifically, the iron criterion addresses the Chronic Aquatic Life (CCC) use and the manganese criterion addresses the Human Health for Consumption of Water & Aquatic Organisms use. The state water quality criteria directly address the basis for section 303(d) listing and the only known source of impairment, which is dissolved iron and manganese in drainage from the adjacent landfill.

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4. TMDL Data Review

Monitoring has been conducted at the Navy landfill site for decades. The first surface water samples were taken at the Buskin River in 1968, and the earliest ground water was sampled in 1987. Since these years, a number of agencies have been involved with analysis and assessment of the site and its water resources. Agencies conducting studies at the site include USEPA, U.S. Geological Survey (USGS), USACE, U.S. Army Engineer District (USAED), and U.S. Coast Guard (USCG).

Data from 1999 and before have been collected by or for USGS, USACE, and USEPA. Coordinates for most monitoring locations in 1999 and before were not available. This TMDL report addresses the iron and manganese impairments, but all available data were reviewed for the purpose of identifying any additional impairments (see *Impairment Assessment for Red Lake and Anton Road Pond, Alaska* [ADEC 2012]).

Monitoring locations for iron and manganese data collected since 1999 are shown in Figure 4-1. Data since 1999 have been collected by USAED and Windward Environmental (for USCG). Figure 4-1 indicates categories used to display the data by matrix (e.g., the symbol shape represents the sample matrix [surface water, groundwater, etc.]). Data collected include surface water, groundwater, sediment, and soil observations, which are described in the following sections. The figure also identifies the general location sampled (e.g., the symbol color represents the station location).

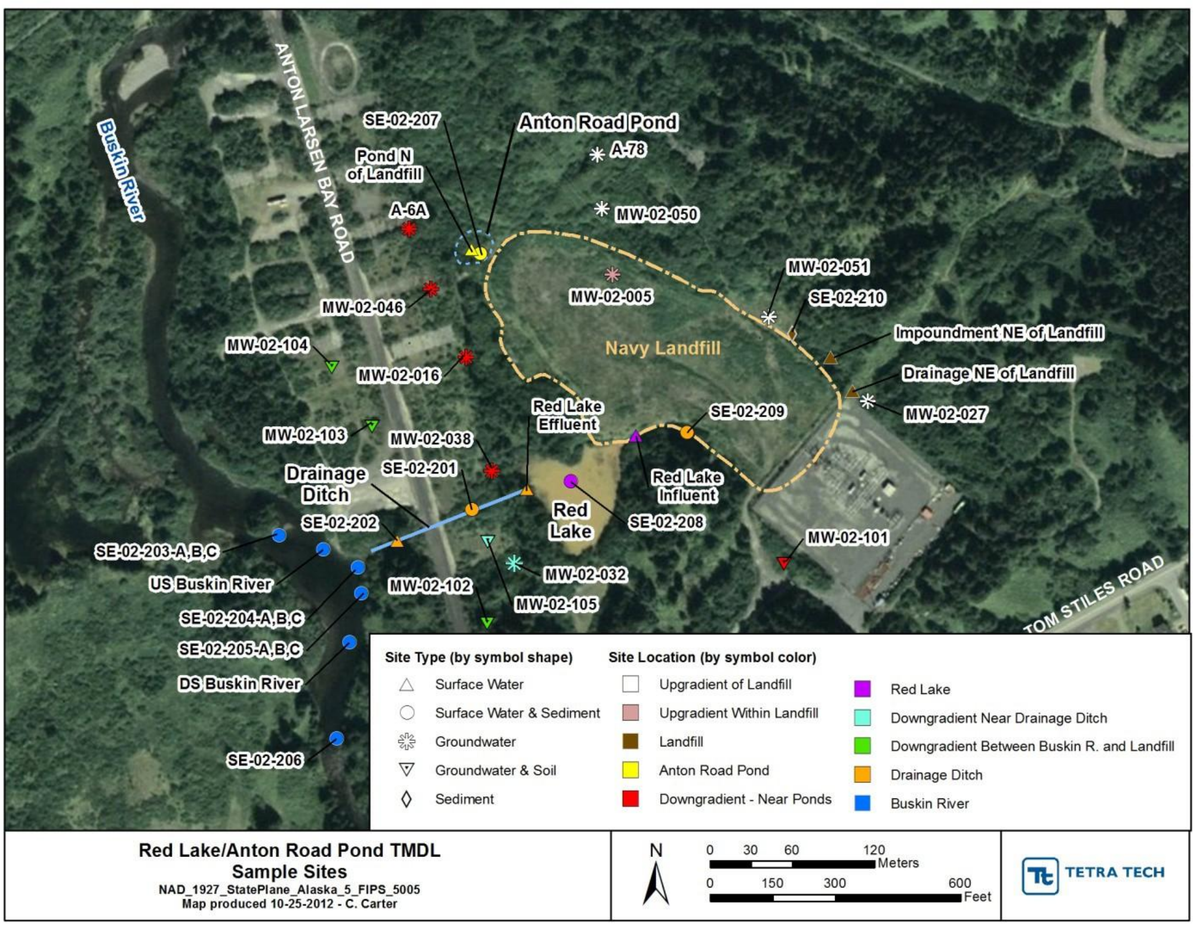

Figure 4-1: Monitoring locations within the vicinity of Red Lake and Anton Road Pond

Background data were also reviewed. The locations for these data are upstream of the confluence of the drainage ditch and Buskin River, at Buskin Lake or slightly downstream of Buskin Lake along the river (Figure 4-2).

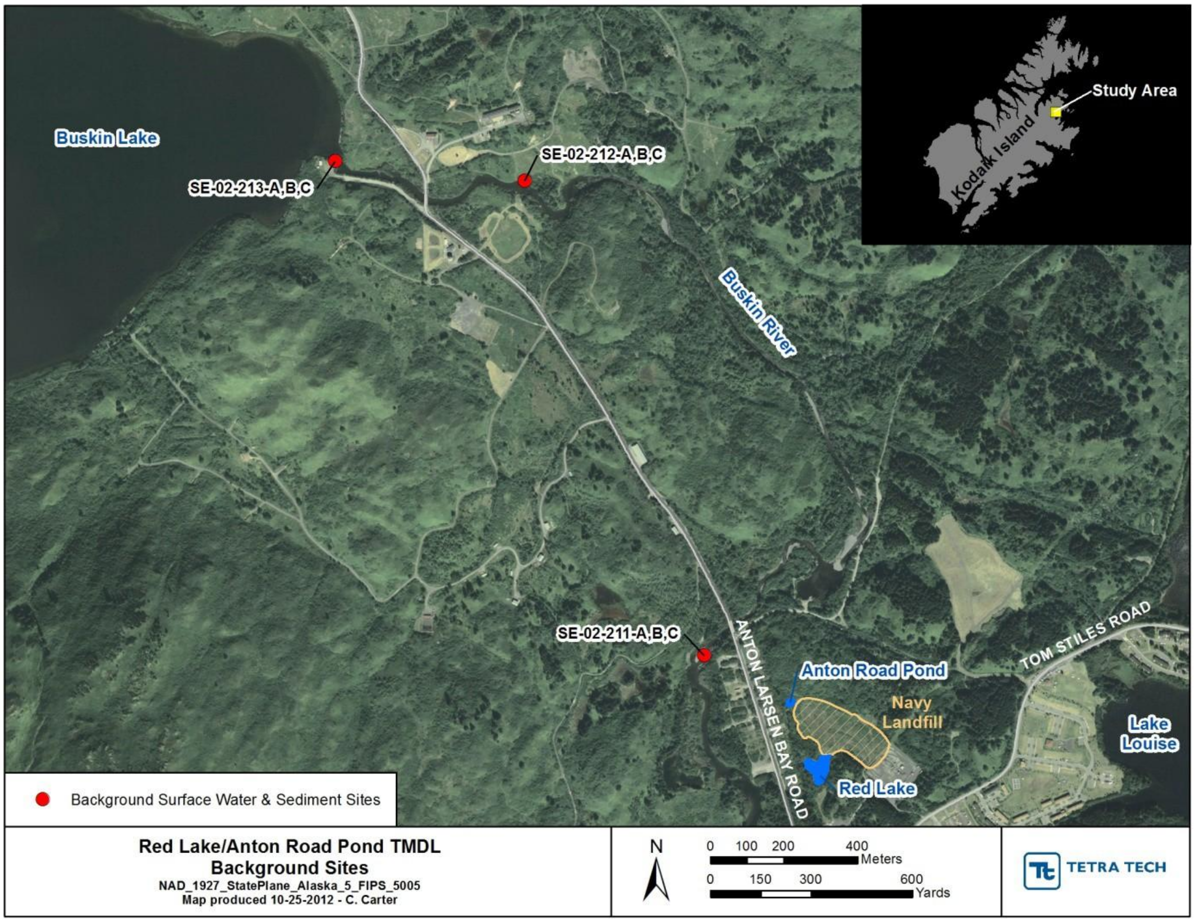

Figure 4-2: Background monitoring locations within the vicinity of Red Lake and Anton Road Pond

4.1. Surface Water Data

Figure 4-3 through Figure 4-10 compare water column iron and manganese data across the major monitoring locations in the vicinity of Red Lake and Anton Road Pond, separately for the time periods since 1999 and 1999 and before. For both time periods, Figure 4-3 and Figure 4-6 show that dissolved and total iron concentrations in Red Lake and Anton Road Pond have been, on average, above the water quality criteria. While fewer data have been collected for Anton Road Pond, the dissolved and total iron concentrations in this waterbody appear much higher, on average, than concentrations measured in the other surface waters. Total iron in Red Lake appears to have decreased in the more recent time period but remains above the TMDL target. Dissolved and total iron concentrations are elevated in the downstream drainage ditch at similar concentrations to Red Lake and Anton Road Pond. The TMDL targets for dissolved and total iron were not exceeded in the Buskin River during either time period. Background concentrations have been consistently measured below the TMDL targets, indicating that the landfill is the source of iron and manganese contamination.

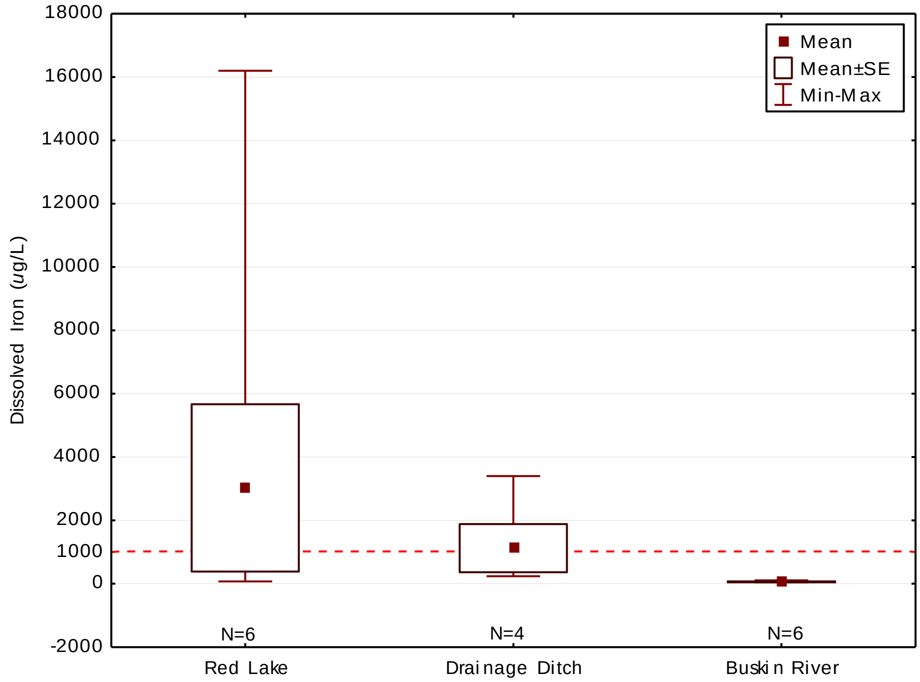

Figure 4-3: Dissolved Iron in Surface Waters near Red Lake prior to the year 2000
Note: Standard of 1,000 µg/L is based on total recoverable iron. Data source SAIC (1997a,b).

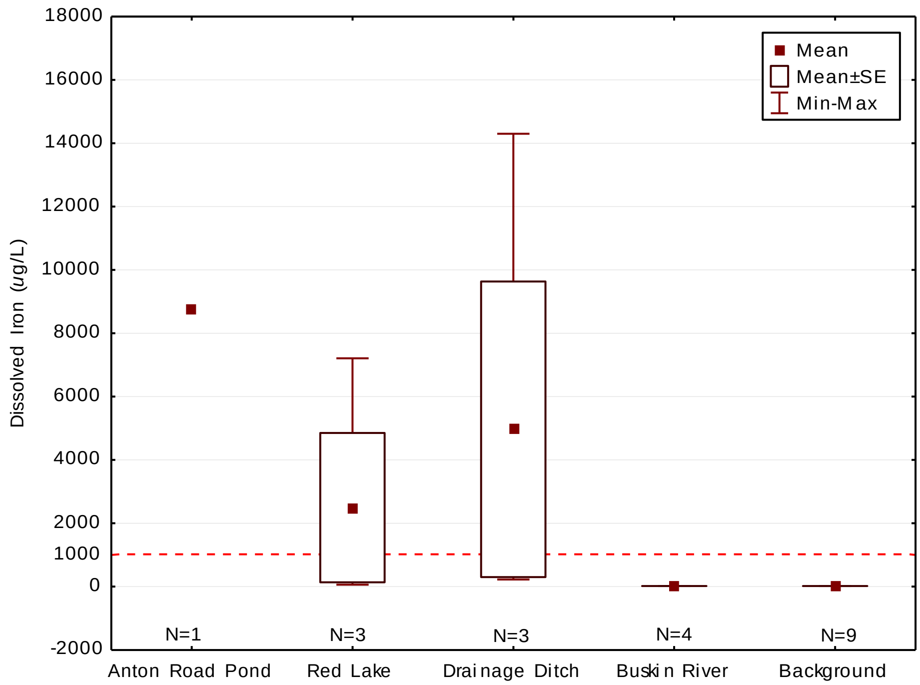

Figure 4-4: Dissolved Iron in Surface Waters near Red Lake after the year 2000
Note: Standard of 1,000 µg/L is based on total recoverable iron.
Data source USAED (2002) and Windward Environmental (2011).

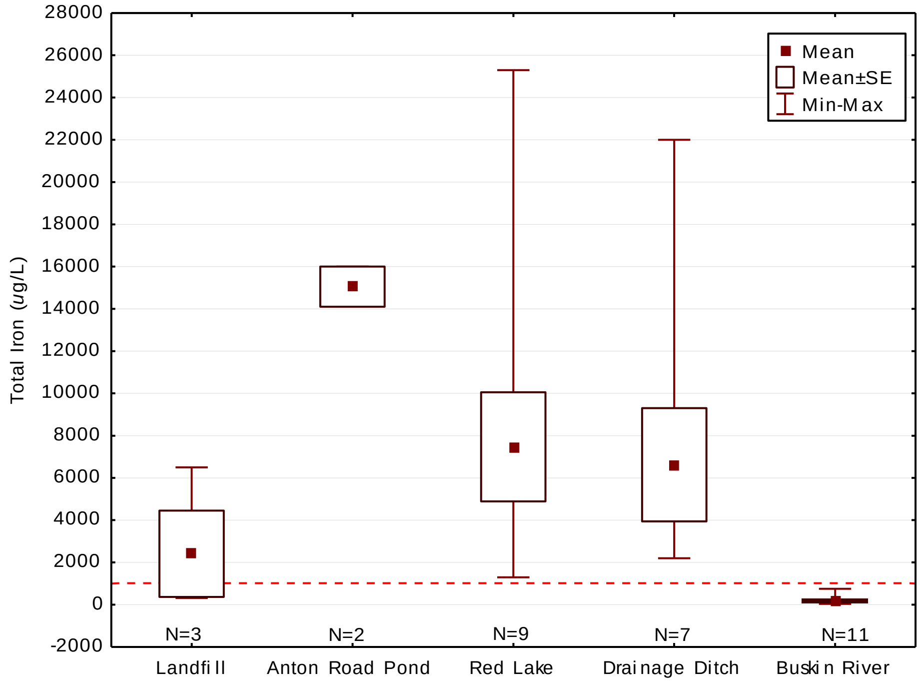

Figure 4-5: Total Iron in Surface Waters near Red Lake prior to the year 2000
Note: Data sources USGS (1996); SAIC (1997); and Radian International (1999).

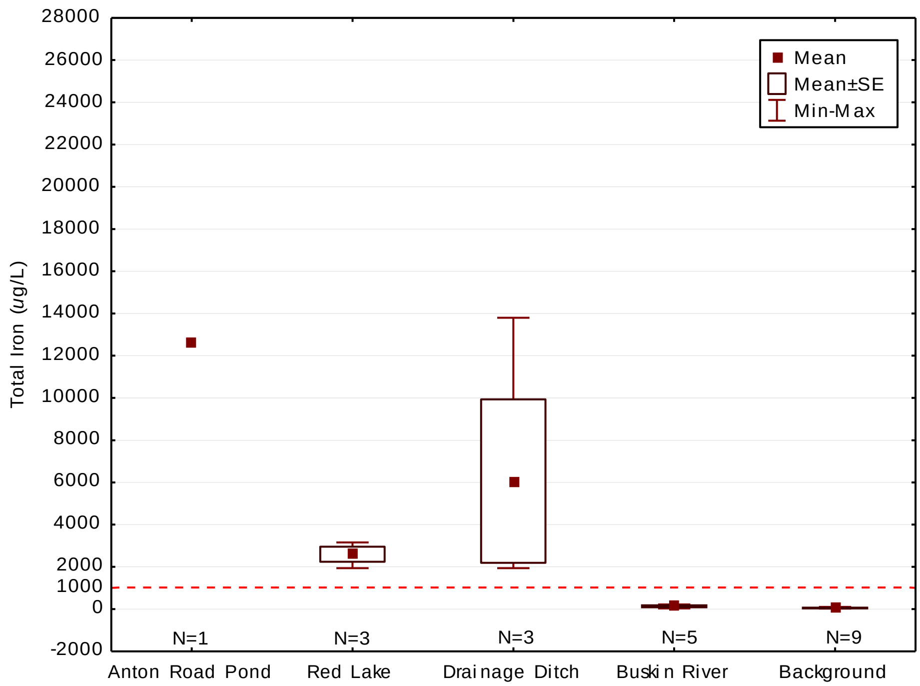

Figure 4-6: Total Iron in Surface Waters near Red Lake after the year 2000
Note: Data source USAED (2002) and Windward Environmental (2011).

Figure 4-7 through Figure 4-10 show that water column dissolved and total manganese concentrations in Red Lake and Anton Road Pond have measured consistently above the TMDL target during both time periods. While fewer data have been collected for Anton Road Pond, both total and dissolved manganese concentrations have measured lower, on average, compared to concentrations in Red Lake. Dissolved and total manganese in Red

Lake appear to have decreased slightly in the more recent time period but remains above the TMDL target. Dissolved and total manganese concentrations are elevated in the drainage ditch at similar concentrations to Red Lake and Anton Road Pond. Measurements in the Buskin River average below the manganese targets. However, dissolved and total manganese has been measured above the TMDL targets at the confluence of the drainage ditch and the Buskin River. Background concentrations have been consistently measured below the TMDL targets.

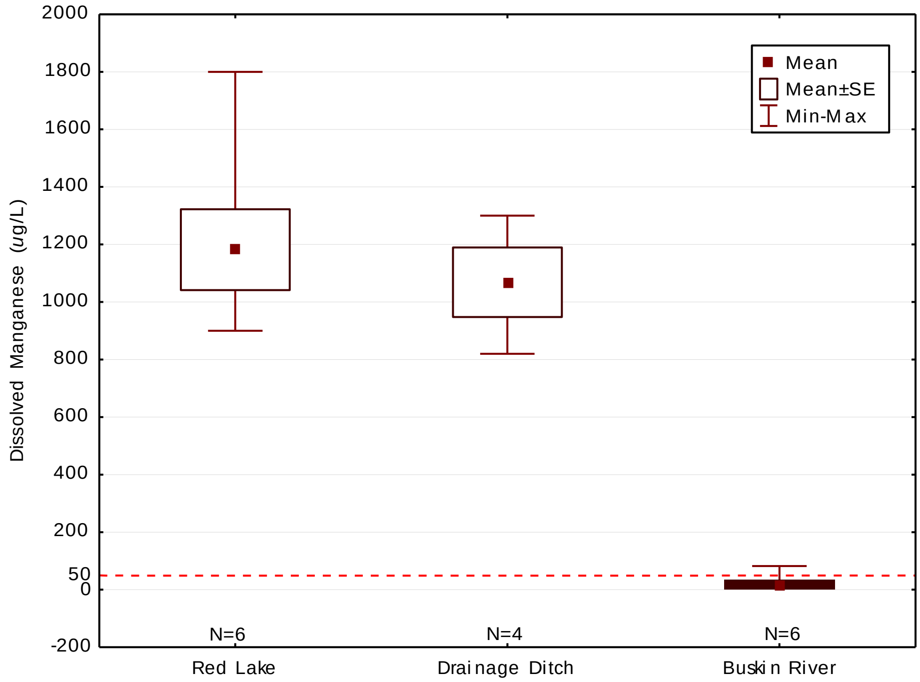

Figure 4-7: Dissolved Manganese in Surface Waters near Red Lake prior to the year 2000
Note: Standard of 50 µg/L is based on total recoverable manganese.
Data source SAIC (1997).

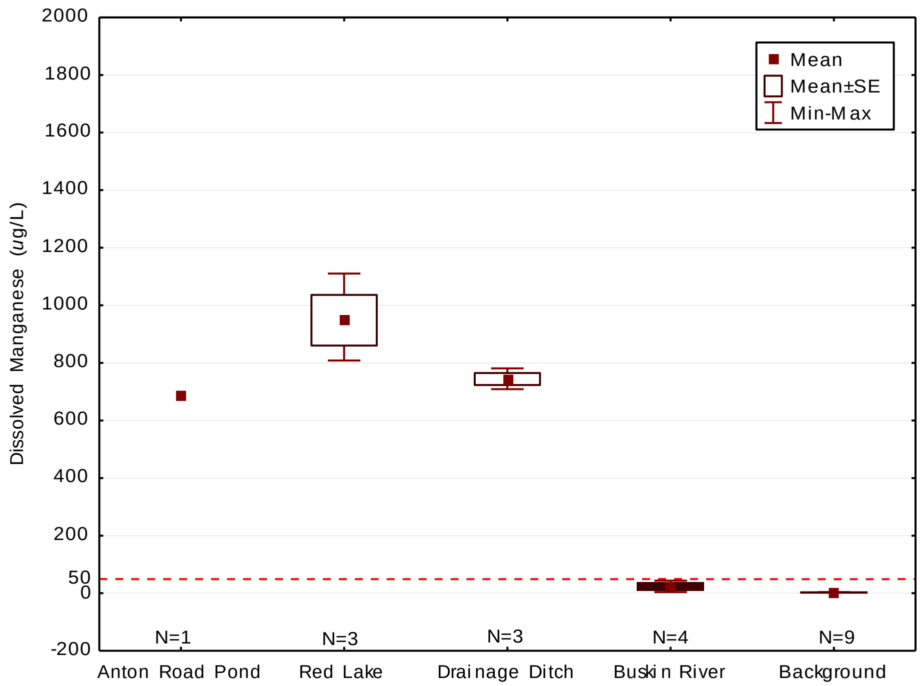

Figure 4-8: Dissolved Manganese in Surface Waters near Red Lake after the year 2000
Note: Standard of 50 µg/L is based on total recoverable manganese.
Data source USAED (2002) and Windward Environmental (2011).

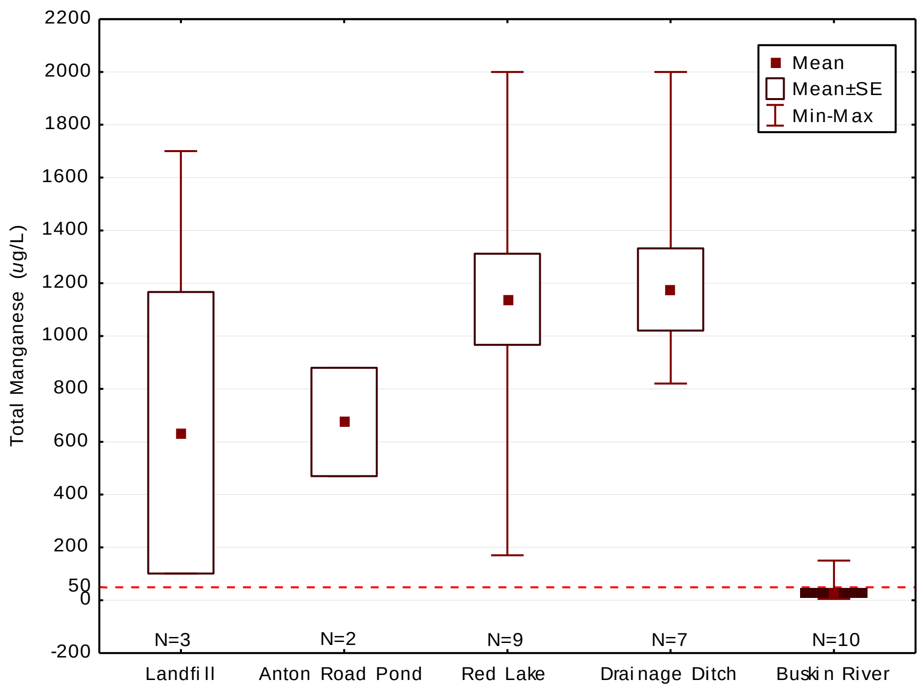

Figure 4-9: Total Manganese in Surface Waters near Red Lake prior to the year 2000
Note: Standard of 50 µg/L is based on total recoverable manganese. Data sources USGS (1996); SAIC (1997); and Radian International (1999).

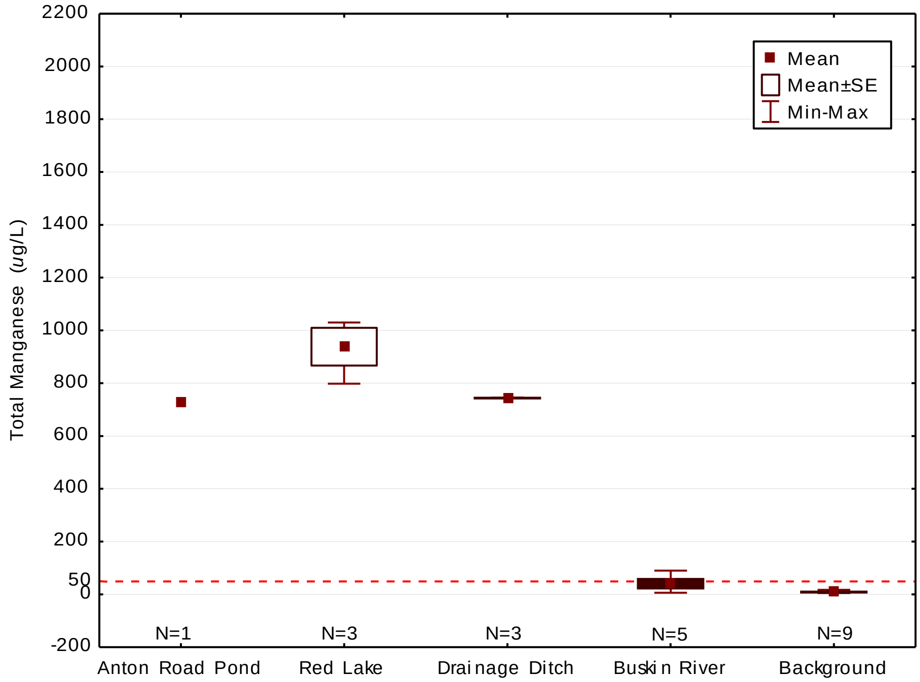

Figure 4-10: Total Manganese in Surface Waters near Red Lake after the year 2000
Note: Standard of 50 µg/L is based on total recoverable manganese.
Data source USAED (2002) and Windward Environmental (2011).

Recent surface water observations were limited to the summer months. However, SAIC (1997a) compared observations collected in Red Lake during May and September 1996. The pH changed from alkaline (8.6) in May to acidic (6.6) in September. SAIC (1997a) suggested that the decrease in pH may have been the result of increased organic material and bacteria productivity, which increase carbon dioxide concentrations and decrease pH. Redox potential was also observed to decrease between May and September. SAIC (1997a) suggested that these changes in pH and redox potential may increase the presence of the more soluble iron ion (Fe+2) compared to the less soluble ion (Fe+3) and decrease the precipitation of iron to the sediments. Manganese ions are similarly affected by pH and redox potential, but SAIC (1997a) did not collect manganese data. SAIC (1997a) also observed the majority of iron in Red Lake exists in particulate form but remains suspended in the water column, which may indicate that the iron is bound within bacteria biomass. Although data are not available during the winter months, the TMDLs were developed for the entire year (see Section 6.5).

4.2. Groundwater, Sediment, and Soil Data

Groundwater, sediment, and soil samples were analyzed for iron and manganese concentrations by USAED and Windward Environmental during the summers of 2002 and 2010. Although data collection has also occurred historically, the data review presented below in Section 4.2.1 through 4.2.3 focused on data collected after the 1999 drainage improvements.

4.2.1. Groundwater

Surface water quality standards were compared to groundwater sampling that has been conducted in the vicinity of Red Lake, Anton Road Pond, the Buskin River or the landfill. It is important to note that the surface water quality criteria do not apply to groundwater for iron and manganese. There are no applicable groundwater criteria for comparison to the iron and manganese observations; however, the comparison of groundwater samples to surface water quality criteria provides a general indication of how groundwater concentrations may be affecting surface water impairments. Table 4-1 and Table 4-2 summarize the groundwater data results for iron and manganese, both total and dissolved, based on major location (see Figure 4-1). The "Within Landfill" location represents one sampling site near the upgradient diversion ditch that is 11 feet below the ground surface. This location may not be fully representative of groundwater conditions in the landfill. Iron concentrations in this well appear similar to upgradient and background concentrations while manganese concentrations appear elevated compared to upgradient and background.

Downgradient of the landfill near the subject waterbodies, total iron concentrations in groundwater were observed to be greatest on average compared to other locations. In contrast, a large range in dissolved iron concentrations was observed at this general location, ranging from below the detection limit (20 µg/L) to greater than 40,000 µg/L.

Total and dissolved manganese concentrations were elevated and within similar ranges at the following three general locations: downgradient of the landfill near ponds, near drainage ditch, and between Buskin River and landfill. Total and dissolved manganese appears to decrease between the landfill and the Buskin River but remains elevated above the surface water TMDL target at the most downgradient wells. Despite these results, surface water observations in the Buskin River indicate that the elevated groundwater concentrations may not be affecting concentrations in the river. This is consistent with conclusions in USAED (2002).

Several past reports have theorized that natural background concentrations in groundwater contribute to the elevated iron and manganese concentrations in Red Lake and Anton Road Pond (Radian International 1999; SAIC 1997a; SAIC 1995a). Background groundwater concentrations of iron in the 1990s were much higher than the upgradient groundwater concentrations measured in the data since 1999. SAIC (1995) established a background groundwater iron concentration of 130,600 µg/L, and iron concentrations in the upgradient well at that time ranged from 79,000 to 265,500 µg/L. SAIC (1997a) estimated that background groundwater would need to contribute 2 to 8 percent of flow to the waterbody to produce the magnitude of total iron concentrations observed in Red Lake during that time period. The data collected since 1999 do not clearly support that background concentrations of iron are a major source of the high concentrations in Red Lake. Recent background groundwater concentrations, other than upgradient of the landfill, were not available. However, the upgradient iron concentrations average one order of magnitude less than the concentrations downgradient of the landfill and near the drainage ditch. The maximum upgradient iron concentrations are also lower than the TMDL target. Similar historical comparisons were not available for manganese concentrations.

It is important to note that the natural lake existing prior to the development of the Navy Landfill may have been iron-dominated and that a potential source of iron loading to Red Lake and Anton Road Pond is from background concentrations in groundwater. Recent data, however, do not support that background sources alone cause the high iron and manganese concentrations in Red Lake and Anton Road Pond.

Table 4-1: Summary of total and dissolved iron concentrations (µg/L) in groundwater in the vicinity of Red Lake/Anton Road Pond since 1999.

Constituent	Surface water criteria (µg/L)	Location	Number	Minimum	Median	Mean	Maximum
Total Iron	1,000	Upgradient of Landfill	7	55	122	228	800
		Within Landfill	2	60	80	80	100
		Downgradient of Landfill Near Ponds	9	20	482	8,711	43,800
		Near Drainage Ditch	2	2,500	8,500	8,500	14,500
		Between Buskin River and Landfill	3	166	419	522	982
Dissolved Iron	No dissolved criteria	Upgradient of Landfill	3	20 (BD)	20 (BD)	20 (BD)	20 (BD)
		Within Landfill	1	20 (BD)	20 (BD)	20 (BD)	20 (BD)
		Downgradient of Landfill Near Ponds	5	20 (BD)	79	8,820	43,900
		Near Drainage Ditch	1	20 (BD)	20 (BD)	20 (BD)	20 (BD)
		Between Buskin River and Landfill	3	54	142	147	246

BD = below detection limit; value equals detection limit.
Data source: USAED (2002) and Windward Environmental (2011).

Table 4-2: Summary of total and dissolved manganese concentrations (µg/L) in groundwater in the vicinity of Red Lake/Anton Road Pond since 1999.

Constituent	Surface water criteria (µg/L)	Location	Number	Minimum	Median	Mean	Maximum
Total Manganese	50	Upgradient of Landfill	7	5	10	12	27
		Within Landfill	2	194	244	244	294
		Downgradient of Landfill Near Ponds	9	5	199	443	1,570
		Near Drainage Ditch	2	476	1,173	1,173	1,870
		Between Buskin River and Landfill	3	145	563	536	900
Dissolved Manganese	No dissolved criteria	Upgradient of Landfill	3	3	4	4	4
		Within Landfill	1	116	116	116	116
		Downgradient of Landfill Near Ponds	5	0	195	251	860
		Near Drainage Ditch	1	346	346	346	346
		Between Buskin River and Landfill	3	132	548	506	839

BD = below detection limit; value equals detection limit.
Data source USAED (2002) and Windward Environmental (2011).

4.2.2. Sediment

Alaska has not adopted numeric sediment quality standards for the evaluation of impacts to aquatic life. However, the DEC Contaminated Sites Remediation Program has issued the technical memorandum Sediment Quality Guidelines (ADEC 2004) that 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. Iron and manganese, however, do not have defined TELs or PELs. They do have Lowest Effect Level (LEL) and Severe Effect Level (SEL) values, which are presented in Table 4-3, as provided in the National Oceanic and Atmospheric Administration (NOAA) Screening Quick Reference Tables (SQuiRTs) (Buchman 2008). The screening levels for iron and manganese were used to evaluate sediment and soil quality data in the vicinity of Red Lake, Anton Road Pond, the Buskin River and the landfill.

Table 4-3: Freshwater sediment screening levels for metals of concern in Red Lake and Anton Road Pond.

Metal	LEL (mg/kg dw)	SEL (mg/kg dw)
Iron	20,000	40,000
Manganese	460	1,100

Sediment sampling in 2002 and 2010 was conducted at locations consistent with surface water sampling (Figure 4-1). Table 4-4 summarizes the results of the sediment data analysis. It is important to note that only one sample point was available for sediments within the landfill site, Red Lake and Anton Road Pond. Iron concentrations at the single landfill site were similar to background concentrations, while manganese concentrations were similar to Red Lake values and slightly elevated compared to the LEL and SEL. Iron levels in Red Lake and Anton Road Pond sediment were extremely high compared to both background concentrations and the LEL and SEL screening levels (2-30 times greater than the screening levels). Iron concentrations in sediment downstream of the drainage ditch, in the Buskin River, are higher, on average, than those above the drainage ditch.

Manganese concentrations are an order of magnitude higher, on average, at the drainage ditch locations than all other locations. For the one sample analyzed for Anton Road Pond, manganese was observed at less than background concentrations, in contrast to the surface water measurements, which indicate manganese concentrations much higher than background. Manganese in Red Lake sediments is higher than background concentrations, but remains much less than the drainage ditch concentrations. This sharp contrast between the drainage ditch and other locations may indicate that a greater degree of oxidation and precipitation of insoluble manganese occurs in the drainage ditch compared to the landfill or ponds. Manganese concentrations in sediment downstream of the drainage ditch, in the Buskin River, are higher, on average, than those above the drainage ditch; however, this may indicate variations in soil composition rather than impairment.

Table 4-4: Summary of iron and manganese concentrations (mg/kg dw) in sediment in the vicinity of Red Lake/Anton Road Pond since 1999.

Constituent	Sediment LEL & SEL (mg/kg dw)	Category	Number	Minimum	Median	Mean	Maximum
Iron	LEL: 20,000 SEL: 40,000	Landfill	1	48,400	48,400	48,400	48,400
		Anton Road Pond	1	553,000	553,000	553,000	553,000
		Red Lake	1	456,000	456,000	456,000	456,000
		Drainage Ditch	3	84,400	336,000	296,133	468,000
		Upstream on Buskin River	5	31,500	44,500	42,220	46,900
		Downstream on Buskin River	8	36,000	42,900	61,863	107,000
		Background	9	30,200	39,000	40,622	52,000
Manganese	LEL: 460 SEL: 1,100	Landfill	1	1,400	1,400	1,400	1,400
		Anton Road Pond	1	356	356	356	356
		Red Lake	1	1,120	1,120	1,120	1,120
		Drainage Ditch	3	778	7,990	12,956	30,100
		Upstream on Buskin River	5	450	756	757	1,070
		Downstream on Buskin River	8	491	897	1,647	4,060
		Background	9	459	713	682	858

Data source USAED (2002) and Windward Environmental (2011).

4.2.3. Soil

Results of soils data analysis, collected in 2010, are summarized in Table 4-5. Data were not collected for the upgradient or at the landfill locations. Iron and manganese appear to be at similar concentrations at the three sampling locations.

Table 4-5: Summary of iron and manganese concentrations (mg/kg dw) in soil in the vicinity of Red Lake/Anton Road Pond since 1999.

Constituent	Sediment LEL & SEL (mg/kg dw)	Category	Number	Minimum	Median	Mean	Max
Iron	LEL: 20,000 SEL: 40,000	Upgradient of Landfill	NM	NM	NM	NM	NM
		Within Landfill	NM	NM	NM	NM	NM
		Downgradient of Landfill Near Ponds	1	36,000	36,000	36,000	36,000
		Near Drainage Ditch	1	36,300	36,300	36,300	36,300
		Between Buskin River and Landfill	5	28,100	37,800	36,240	40,500
Manganese	LEL: 460 SEL: 1,100	Upgradient of Landfill	NM	NM	NM	NM	NM
		Within Landfill	NM	NM	NM	NM	NM
		Downgradient of Landfill Near Ponds	1	690	690	690	690
		Near Drainage Ditch	1	953	953	953	953
		Between Buskin River and Landfill	5	443	833	924	1,620

Data source Windward Environmental (2011).

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5. Potential Sources of Pollutants

This section discusses the potential sources of iron and manganese to Red Lake and Anton Road Pond, including point, nonpoint and natural sources. While landfill drainage is the expected primary source of iron and manganese to Red Lake and Anton Road Pond, an additional potential source is internal loading.

5.1. Point Sources

No known permitted point sources, including those under individual or general permits, discharge to Red Lake and Anton Road Pond.

5.2. External Nonpoint Sources

According to the data reviewed in Section 4.2, recent monitoring of groundwater and soils upgradient of the landfill supports the assumption that stormwater sources do not seem to be a significant contributor of iron and manganese to Red Lake or Anton Road Pond. The KEA substation is not expected to be a significant source of iron and manganese in runoff. There are no specific sources of iron and manganese at the substation and stormwater does not appear to be a significant source of iron and manganese to the waterbodies in general.

5.3. Landfill Drainage

The former Navy landfill that drains to Red Lake and Anton Road Pond is the expected primary source of iron and manganese loading to the subject waterbodies. The historic absence of a liner, cover, and leachate controls until 1999 has resulted in releases of hazardous constituents to soils, groundwater, surface water and sediments downgradient of the landfill.

High concentrations of both iron and manganese have been measured in groundwater in and surrounding the landfill site (Windward 2011; USAED 2002). Anoxic and reducing conditions have been observed in the groundwater, which lead to greater concentrations of dissolved iron and manganese than under more oxidizing conditions, when greater dissolved oxygen is present. As groundwater leaches into Red Lake and Anton Road Pond, this water enters a more oxidizing environment where iron and manganese oxides can form and precipitate from the water column and into the bed sediment. As contaminated groundwater continues to leach into the subject waterbodies, the concentrations of iron and manganese are expected to remain elevated in Red Lake and Anton Road Pond. However, the oxidation process is expected to immobilize the iron and manganese load in the surface water over time (see Section 5.5).

5.4. Natural Sources

According to the data reviewed in Section 4, recent monitoring of background iron and manganese concentrations supports the assumption that natural sources are not significant contributors of iron and manganese load to Red Lake or Anton Road Pond. Background concentrations of both iron and manganese in surface water near Red Lake and Anton Road Pond have consistently measured below the TMDL targets (see Section 4.1). Recent groundwater observations upgradient of the landfill indicate that iron and manganese concentrations are well below the surface water criteria. Since historic data did suggest that background groundwater concentrations were contributing to high iron concentrations, natural background should continue to be evaluated through further monitoring.

5.5. Internal Loading

Recycling of iron and manganese is expected at the sediment and water interface in Red Lake and Anton Road Pond. Iron and manganese precipitates may settle out of the water column over time, but some of this load may be reduced and dissolve into the water column, especially during seasonal pH shifts.

Total and dissolved iron and manganese data collected in the water column show high concentrations in Red Lake and Anton Road Pond. Additionally, elevated iron and manganese concentrations at the bottom sediments of Red Lake and Anton Road Pond were also identified. Table 5-1 shows the most recent observed data (June 2010) for both the water column and the sediments (Windward Environmental 2011). The data indicate that the water column and the sediment concentrations of iron and manganese were considerably high, which could indicate the sediment as a source of iron and manganese to Red Lake and Anton Road Pond.

Table 5-1: Water column and sediment concentrations in Red Lake and Anton Road Pond.

Waterbody	Sediment Concentrations		Water Column Concentrations	
	Iron	Manganese	Iron	Manganese
	(mg/Kg)		(µg/L)	
Red Lake	456,000	1,120	2,600*	938*
Anton Road Pond	553,000	356	12,600	728

Source: Windward Environmental (2011)
*Depth averaged concentrations

The USGS's pH-Redox-Equilibrium-Equations in C Model (PHREEQC model; Parkhurst and Appelo 2002) was selected to evaluate and quantify the effects of bottom sediments on the iron and manganese concentrations in Red Lake and Anton Road Pond. PHREEQC is a computer program used to simulate chemical reactions and transport processes in a waterbody. The model is derived from the Fortran program PHREEQE (Parkhurst, et al. 1980) and is based on equilibrium chemistry of aqueous solutions interacting with minerals, gases, solid solutions, exchangers, and sorption surfaces, but also includes the capability to model kinetic reactions and transport reactions. Considering the potential cycling nature of iron and manganese between the sediment and water interface, the reactions included in the model are appropriate for this modeling study. The data used for the model input were the data collected in June 2010 to reflect the most recent conditions in Red Lake and Anton Road Pond. Data collected prior to 2010 were used for comparison purposes to observe whether depth trends were consistent over time (i.e., historically similar to 2010).

There are limited iron and manganese data available for Red Lake and Anton Road Pond. Three sets of data were available for Red Lake while only one set of data was collected from Anton Road Pond. The Red Lake data were collected at three different depths. The first dataset was collected in June 1996 at the depths of 1, 2.5 and 4.5 feet (the lake bottom) (SAIC 1997). The second dataset was collected in September 1996 at the same depths (SAIC 1997). Figure 5-1 and Figure 5-2 show the observed iron and manganese in the water column of Red Lake in June and September 1996. Additional samples were collected in June 2010 (Figure 5-3) (Windward Environmental 2011).

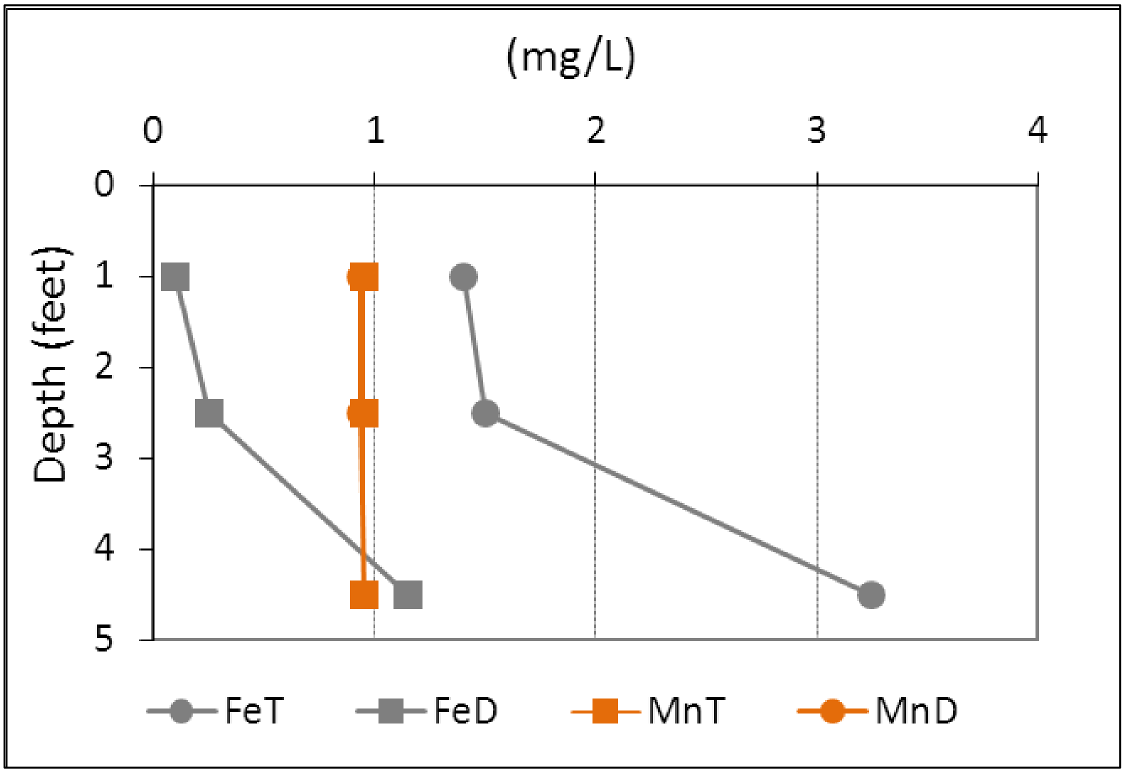

Figure 5-1: Total (T) and dissolved (D) iron and manganese concentrations in the water column of Red Lake (June 1996)

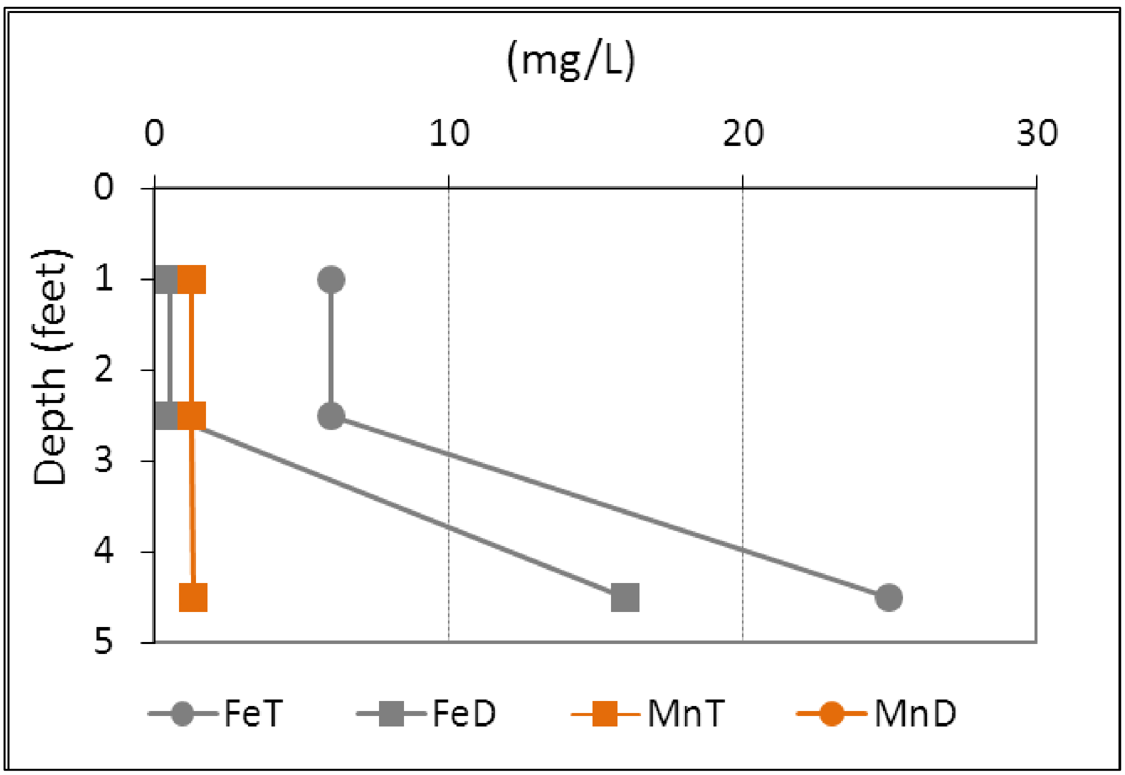

Figure 5-2: Total (T) and dissolved (D) iron and manganese concentrations in the water column of Red Lake (September 1996)

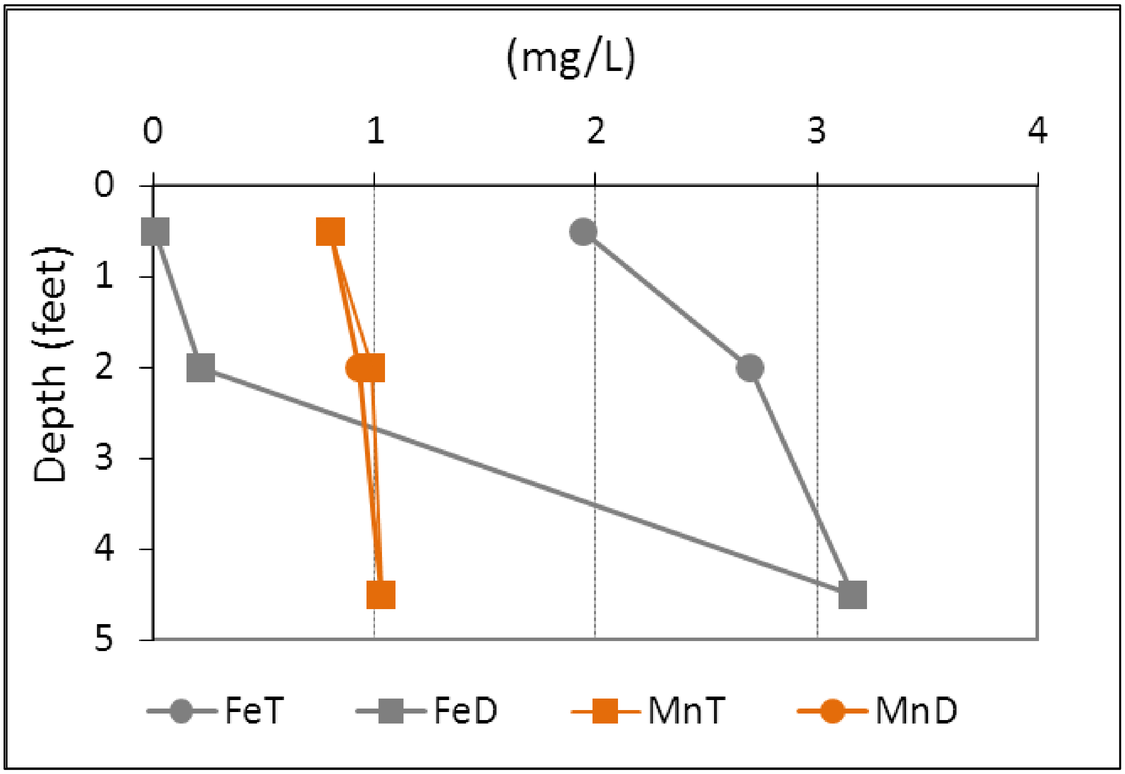

Figure 5-3: Total (T) and dissolved (D) iron and manganese data at different depths in the water column of Red Lake (June 2010)

Although there were temporal concentration differences and some differences in the depths at which the samples were collected, the iron data consistently showed higher concentrations at the bottom of Red Lake and lower concentrations at the surface. Total and dissolved manganese did not show the same strong trend of higher concentrations at the bottom of the lake, but did exhibit a slightly higher concentration at the bottom in June 2010.

Due to the shallow nature of Anton Road Pond, there was only one grab sample available at 0.5 feet. The data showed that the pond contained elevated concentrations of total iron (12,700 µg/L) and manganese (800 µg/L) (Windward Environmental 2011).

Possible causes of high metal concentrations at the sediment-water interface include upward diffusion of metals from the concentration gradient and reduced porewater conditions (Stumm 1985; Song and Muller 1999). This diffusion and redox condition results in accumulation of oxidized metals at and around the interface due to oxic and suboxic conditions of the interface. The depth trend of metal concentrations can be seen in the observed data in Red Lake.

This modeling study focused on whether the lake- and pond-bottom sediments are a source of the high metal concentrations at the bottom water. The model was used to quantify the acceptable level of iron and manganese in the sediment to meet the water quality standards for Red Lake and Anton Road Pond based on two different scenarios. The model results were used to confirm the importance of sediment concentrations and internal cycling in Red Lake and Anton Road Pond, which informed the loading capacity and implementation recommendations (see Section 6.1 and 7).

5.5.1. Model Input for Red Lake

This section discusses the characterization of sources and the derivation of model inputs for the Red Lake model. In addition to sediment, two potential loading inflows to the lake system were considered: groundwater and the

Navy landfill leachate. Surface runoff over and around the landfill is not expected to be a source of iron and manganese to Red Lake and Anton Road Pond since the drainage changes made in 1999. In 1999 the landfill surface was contoured and compacted, and additional cover material was placed to stabilize the landfill. The purpose of the new cover material and the modifications to the drainage system were to decrease percolation of precipitation into the landfill and increase surface water runoff (USCG 2007).

Groundwater

Groundwater data collected upgradient of the landfill represent rather pristine conditions indicated by low iron and manganese concentrations and low electric conductivity values (less than 150 mS/cm). Groundwater data collected upgradient of the landfill (MW-02-050 and MW-02-051) were averaged to represent background concentrations for model input. Table 5-2 shows the observed data used as representative background groundwater values for the model.

Table 5-2: Background groundwater data (June 2010).

	Site-MW-02-050	Site-MW-02-051	Average
Total iron (µg/L)	122	55.3	88.65
Dissolved iron (µg/L)	20	20	20
Total manganese (µg/L)	7.28	5.82	6.55
Dissolved manganese (µg/L)	2.92	4.14	3.53
Temperature (Celsius)	4.2	6.0	5.1
pH	5.09	4.60	4.85
ORP* (mV)	13	87	50

Source: Windward Environmental (2011)
*Oxidation reduction potential

The data showed the majority of iron and manganese were in the particulate phase, especially iron. The ORP of 50 mV can be recalculated to be the electron activity (pe) of 0.9. This is less than typical oxygenated water where pe is approximately 4.5. Figure 5-4 shows PHREEQC-derived different oxidation states of iron and manganese based on various pe and pH conditions. The figure is presented here to investigate dominant oxidation states of iron and manganese that can be found under the observed pH and pe. The observed iron and manganese are reduced valance metals as iron (II) and manganese (II), thus, mainly in the dissolved phase (see the red circles in Figure 5-4).

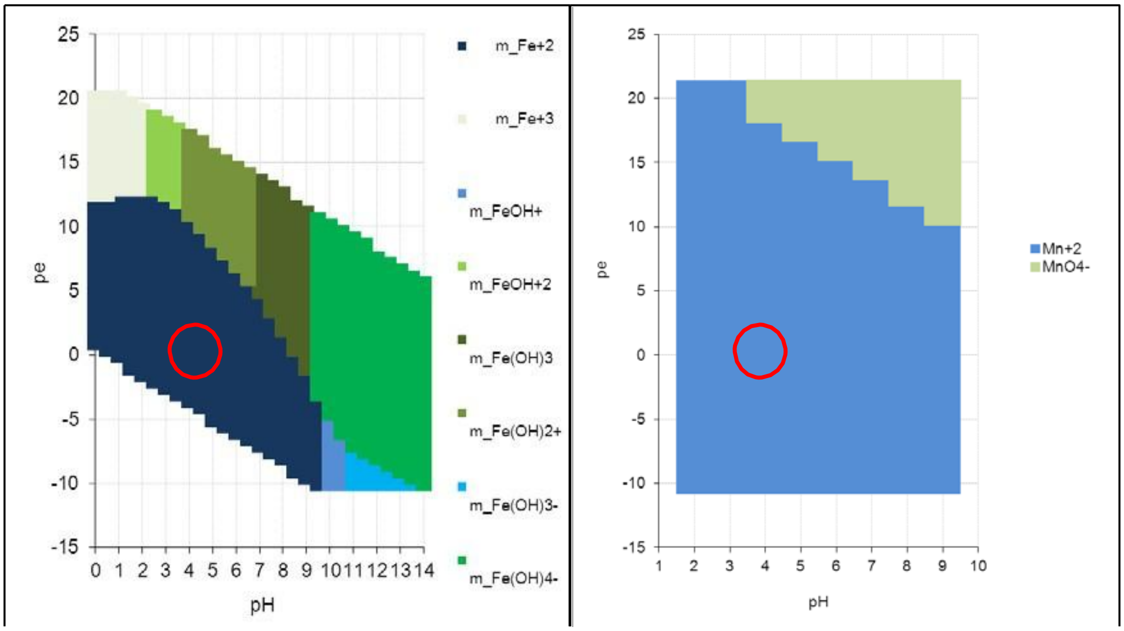

Figure 5-4: pe and pH diagram for iron and manganese

The potential contradiction of the observed and the theoretical conditions is probably caused by either the oxidation of the metals by mixing of reduced and oxidized water from different screening depths within wells (Deutsch 1999) or simply metal being oxidized during the sampling due to degassing of CO_2 to atmospheric conditions and ingassing of O_2. This information and the low pe and pH values suggest that the observed total metals can be assumed to be dissolved in groundwater, instead of metal particulates transported through the pores. Therefore, the averaged iron and manganese concentrations in groundwater were assigned as dissolved phase in the model along with other physico-chemcial data.

The data do not include any major cations data such as calcium and magnesium. Although the expected cation concentrations should be low judging from the low electricity conductivity, it is reasonable to consider some concentrations of these major cations as they are always a part of the chemical constituents to contribute dissolved ion concentrations. Additionally, it is also important to include some of the expected cations in the model as they affect complexation and compete for adsorption sites on clay and metal hydroxides. Without direct observation data, calcium concentrations (10 mg/L) were estimated from available hardness values around the sites and added to the groundwater input.

Navy Landfill Leachate

A map of equipotential created in the area of the Navy landfill clearly indicates that groundwater moves from the northeast through the landfill and Red Lake, and eventually reaches the Buskin River (Figure 5-5). As hydraulic gradients follow primarily the local relief, the downgradient ditch cut though the edge of the lower landfill could intercept the leachate plume originated from the landfill. Therefore, the chemical data from the diversion ditch (sampling station SW-02-209) is assumed to be fed by the leachate from the landfill and assumed to represent the leachate chemical characteristics (Table 5-3).

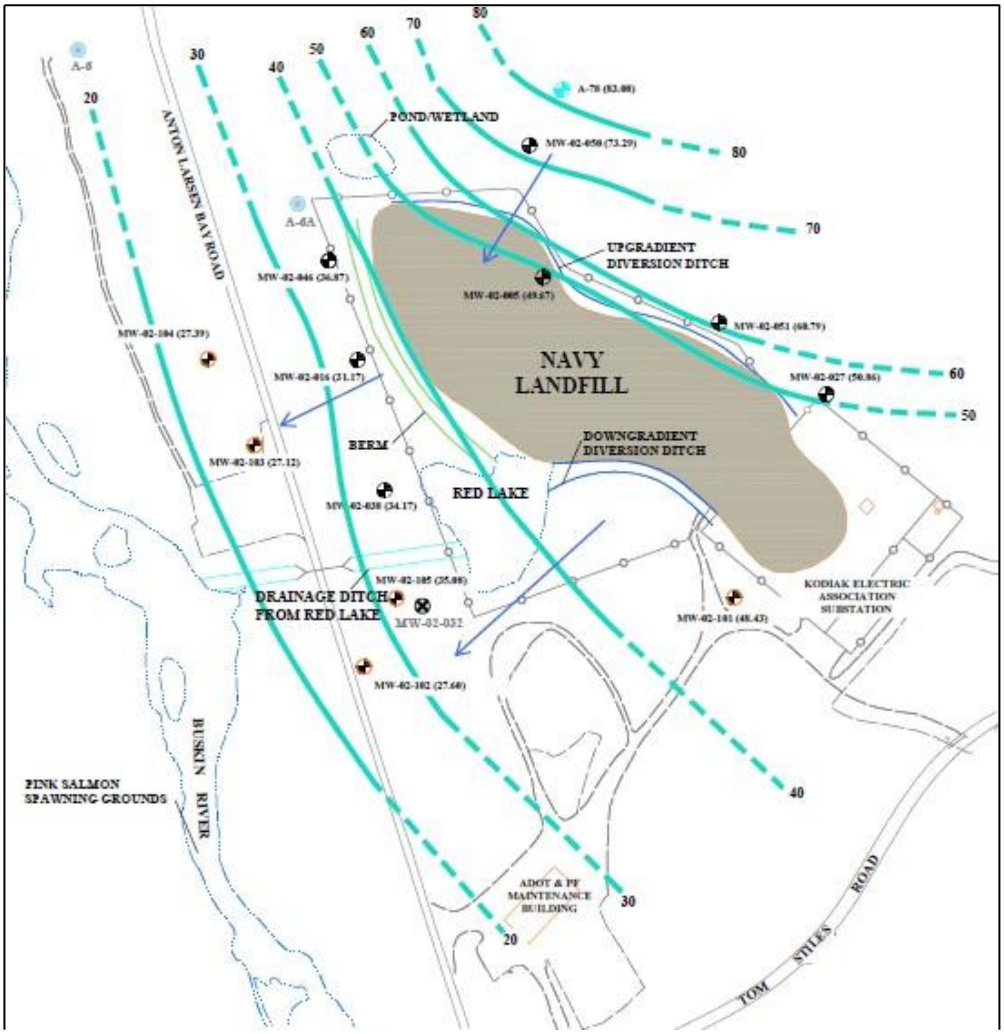

Figure 5-5: Groundwater contours and flow patterns – June 2010 (Windward Environmental 2011)

Table 5-3: Diversion ditch data (June 2010).

Dissolved Iron (µg/L)	Total Iron (µg/L)	Dissolved Manganese (µg/L)	Total Manganese (µg/L)	Temperature (Celsius)	pH	ORP* (mV)
14,300	13,800	781	742	6.4	5.9	-85

Source: Windward Environmental (2011)
*ORP = Oxidation reduction potential

The data in Table 5-3 show that metals in the solution exist as the dissolved phase since dissolved and total metal concentrations are almost identical. Higher dissolved concentrations compared to the corresponding total concentrations could be within analytical errors. Because of the potential for analytical error in the additional filtration step for the analysis of the dissolved fraction, the dissolved metals concentration was set to equal the total metals results in the model as it is likely the more accurate value. The low ORP of -85mV (calculated pe = -1.5) indicate that the solution is under reducing conditions.

The data also show a typical signature of the landfill leachate with low ORP and high dissolved metal concentrations. The high ionic concentrations with the reduced solution conditions are common downgradient of landfills (Deutsch 1999). This is because of the large mass of organic matter in landfills. The organic matter is oxidized by the oxidant such as oxygen, iron, and manganese, because the high free energy yielded from the redox reaction is favorable for microbial activities (Song and Muller 1999). As a result, lower valance states of iron and manganese (usually dissolved) become prevalent from mineral dissolutions.

The model was supplied with the observed iron and manganese data (13,800 µg/L dissolved iron and 742 µg/L dissolved manganese) along with pH, pe and temperature data as a leachate input. Dissolved inorganic carbon was also added to the leachate input. With iron and manganese containing minerals and depending on the solution conditions, dissolved inorganic carbon in the form of CO_2, CH_4, or bicarbonate could be released as a final product from the oxidation of organic matter. As iron shows the largest dissolved concentrations in the leachate data, the release of the carbon was estimated from the reductive dissolution of iron oxide as shown in the equation below (Appelo and Postma 2005).

$$CH_2O + 4FeOOH + 7H^+ \rightarrow 4Fe^{2+} + HCO3^- + 6H_2O \quad (1)$$

According to the equation, 4 mol of iron generates 1 mol of bicarbonate. Therefore, based on the iron concentration of 13,800 µg/L, 9E-4mol/L of bicarbonate could be generated and was assigned to the model explicitly.

Additional dissolved inorganic carbon along with dissolved calcium was also simulated and was assigned during the model simulation based on calcite dissolution affected by the acidic condition of the leachate. Calcium can be one of the expected cations in the leachate solution but there are no available observed data for the ion. As described earlier, the calcium ion can affect complexion and adsorption/desorption reactions, thus is included in the model.

Mixing

A mixing ratio between groundwater and landfill leachate was required to properly construct the model and to evaluate the solutions' effects on total iron and manganese. As chloride is a conservative chemical, not a reactive one, it was suitable for this purpose. Observed chloride concentrations collected at an uncontaminated groundwater site, a well sample from the landfill, and surface water data at Red Lake (SAIC 1995) were used to derive the ratio through USGS's NETPATH model (Plummer et al. 1991). Based on the analysis, the final mixing ratio applied to the PHREEQC model was determined to be 0.95 and 0.05 for the groundwater and leachate, respectively.

Metal Oxides in Sediments

Chemical reactions at the sediment particle surface and within the sediment pores can be important as it can either function as a sink for some chemicals or a source for others. Precipitated metal particles such as iron (II)- and manganese (II)-containing minerals can be an integral part of the metals in sediments. For example, in the suboxic/anoxic sediment layer, iron and manganese can be released into the porewater following the reduction of iron and manganese oxides by the organic matter. On the other hand, Fe^{2+} and Mn^{2+} diffusing into the sediment layer exposed to the overlying water can be oxidized to iron and manganese oxides (Stumm 1985). Therefore, it is important to model the interactions of these chemical components and model general redox conditions to predict the immobilization and release of the metals from sediments.

The observed data for iron and manganese were 456,000 mg/kg(dry) and 1,120 mg/kg(dry), respectively. The observed total iron and manganese in sediments should be the mix of various forms of minerals including reducible oxides (Peltier et al. 2005). Due to the limited sediment data availability, and because the reactive oxide components are components that can be mobilized and released to the water column under reduced conditions, the model assumes that only a percentage of the total metal concentrations are available for transport. The reactive oxide components of each metal used for the model were assumed to be 10 % of the total iron sediment concentration (Zhu and Anderson 2002; Sobczyński and Siepak 2001) and 30% of the total manganese sediment concentration (Sobczyński and Siepak 2001). The porosity (0.9) and density ($3.5 g/cm^3$) were used to convert the mass based to the volume based concentrations based on the study conducted for adsorption and desorption of metals onto and from hydrous iron oxides (Broshears et al. 1996). These metal concentrations were provided to the model for the purpose of simulating the metal cycle and adsorption and desorption of metal and other ions to control sediment and water column metal concentrations.

Cation Exchange Capacity in Sediments

Cation exchange occurring on the surface of clay can be important in controlling solution metal and other ion concentrations. As there was no cation exchange capacity (CEC) data at the bottom sediments and the limited available soil CEC data did not show consistent values, the equation below was used to derive a representative CEC (Appelo and Postma 2005).

$$CEC\ (meq/Kg) = 7 * (\%clay) + 35 * (\%C)$$

The percent clay was estimated from the soil texture type (find sand) in and around the landfill site. The particular soil type should contain around 10-20 percent of clay (Fetter 1994). Twenty percent clay was selected considering finer sediments potentially existing at the lake bottom. Percent carbon was derived using TOC values available from the soil samples around the landfill. TOC data are shown in Table 5-4.

Table 5-4: Soil TOC data.

Parameter	Site-101B	Site-102B	Site-103B	Site-104B	Site-105B
TOC (% dry weight)	0.77	0.37	0.95	0.16	0.17

Source: Windward Environmental (2011)

The average value of 0.48 percent TOC was used for %C derivation for the equation above. Using these two derived values in the equation, CEC was calculated to be 156 meq/Kg, which is similar to one of the available CEC values (144 meq/Kg) listed in *Technical Memorandum, 1999 Supplemental Data Collection, Navy Landfill (Site 2)* (Radian International 1999). The derived CEC value was assigned directly to the model without modifying it, assuming that the lake bottom contained a similar CEC to the soil surrounding the lake.

Organic Matter in Bottom Sediment

Organic matter can be an important part of the redox reaction. Without direct measurement of organic matter at the lake bottom sediments, their concentration in the sediments was estimated from observed TOC values and literature values. Table 5-5 shows the mean dissolved organic matter (DOM) and particulate organic matter (POM) in the saturated and unsaturated soil zone from all data available in USEPA's STORET database (USEPA 1996).

Table 5-5: Organic matter data.

Soil Zone	POM (mg/L)	DOM (mg/L)
Unsaturated zone	4,798.5	20.32
Saturated zone	2,634	14.4

Source: USEPA 1996
POM: particulate organic matter
DOM: dissolved organic matter

Not all TOC values shown in Table 5-4 are assumed to participate in the redox reaction. In fact, a rather small portion of the TOC data are assumed to be labile enough to be a part of the redox reactions. Thus, after the observed percent weight based TOC values were converted to mass-volume based values, dissolved organic carbon (DOC) that could potentially participate in the redox reaction was derived by applying the ratio between POM and DOM in Table 5-5 to represent reactive organic matter. After the calculation, 0.003 mol/L of CH_2O was assigned to the model as the organic matter existing in the sediments.

Mineral Representation in Sediments

Distinctions were made in the model between the sediment layer exposed to the overlying water (Layer 1) and the suboxic and anoxic sediment layer (Layer 2). No clear distinction was made between suboxic and anoxic, but rather, it is assumed that the sediments are spatially mixed conditions of suboxic and anoxic sediments. Differences between Layer 1 and Layer 2 were based on the existence or absence of organic matter, characteristics mineral phase (e.g., metal oxides), and potential dissolved oxygen (Langmuir 1997). Layer 2 pore solution was assumed to be equilibrium conditions with

1. The mixed solution of groundwater and the leachate
2. Metals (oxides and other potential minerals)
3. CEC
4. Organic matter

Layer 1 contained no organic matter. However, Layer 1 was assumed to receive chemicals from upward transport (diffusion) from Layer 2 and actively participated in the metal oxidation processes.

5.5.2. Model Input for Anton Road Pond

All the same groundwater, landfill leachate, and CEC values from the Red Lake model were assigned to the Anton Road Pond model. However, sediment concentrations were different, reflecting the different sediment values in the pond. The observed data for iron and manganese in the pond were 553,000 mg/kg(dry) and 356 mg/kg(dry), respectively. The values were converted to mass-volume and mol-volume units using the same assumptions used for Red Lake.

Without additional data in the water column, the adsorbed chemicals at the bottom sediment were initialized by applying the ratio developed between the observed data at the surface and at the lake bottom of Red Lake to Anton Road Pond data collected at a depth of 0.5 feet (pond surface). However, this initialization of the surface was adjusted through the model based on the solution conditions being simulated in the model.

5.5.3. The Conceptual Modeling Chart

Figure 5-6 depicts the reactions and the interactions considered in the model. The numbers in Figure 5-6 correspond with the numbered steps below the figure.

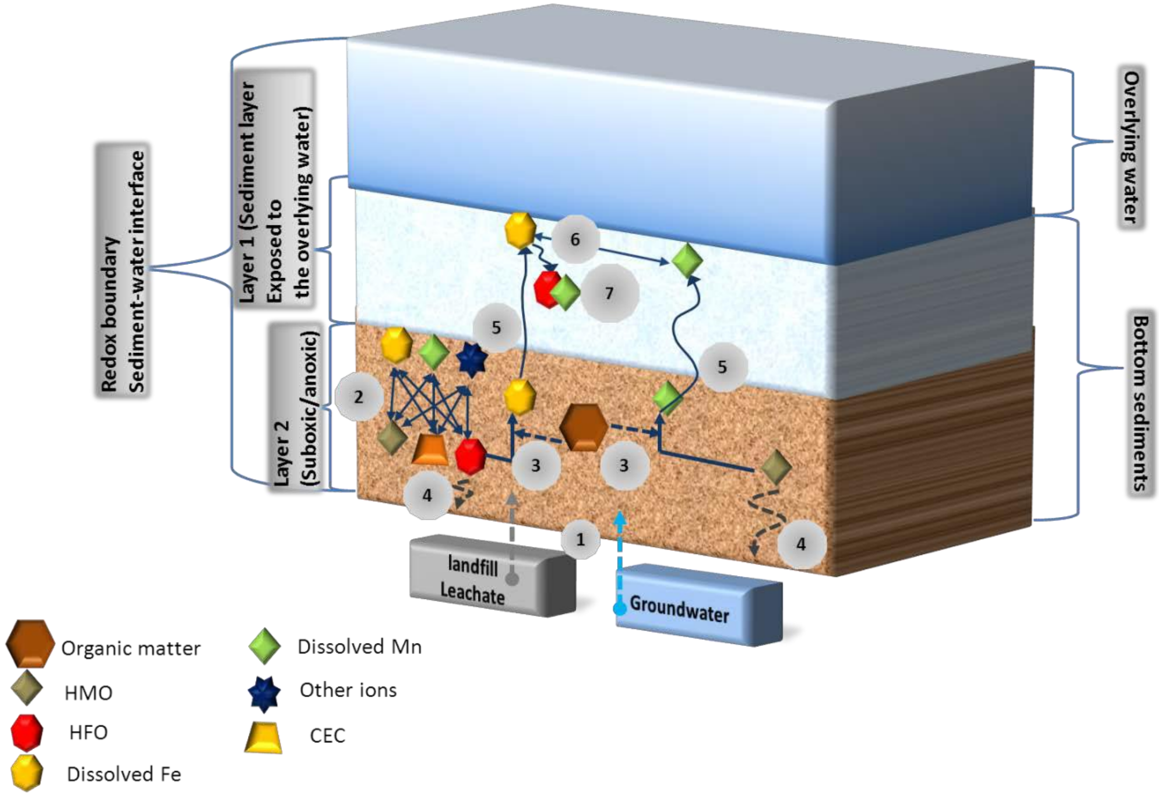

Figure 5-6: The conceptual modeling chart (HFO: hydrous ferric oxide, HMO: hydrous manganese oxide)

1. Mixing of the leachate and groundwater in Layer 2.

2. Chemical adsorption and desorption reactions on metal oxides and CEC with all ions including dissolved iron and manganese existing in the pore solution. As there was no surface electrical double layer model provided for manganese oxides in the PHFREEQC model, the surface chemical property of the manganese oxides were assumed to be the same as iron oxides. However, manganese's sediment concentrations were too small for the assumption to be a critical.

3. Reduction of iron and manganese oxides in the sediments by organic matter.

4. Potential precipitation of iron and manganese as rodochrosite, siderite, Fe(OH)3(a) and manganite.

5. Upward transport (diffusion) of dissolved iron and manganese in addition to other ions from the soil pores due to the concentration gradient developed in the sediments (higher dissolved metals in suboxic/anoxic layer). All the iron and manganese from Layer 2 was assumed to be transported to Layer 1 and subject to further reactions under the chemical and mineral conditions of Layer 1.

6. Adsorption of dissolved manganese onto freshly precipitated iron oxides. Mineral formation processes were usually kinetically controlled. Thus, kinetic reactions of homogenous iron oxidation by oxygen gas (Stumm and Morgan 1997) were simulated through the PHREEQC model to derive the potential particulate concentrations that could be generated during the course of the kinetic iron oxidation processes.

7. Deposition of iron oxides with adsorbed manganese. The deposition was not explicitly simulated but all the generated iron oxides were assumed to be deposited to the bottom. For manganese, homogenous oxidation can be very slow (Stumm and Morgan 1996). Davies and Morgan (1989) and Stumm and Morgan (1996) describe that dominant heterogeneous oxidation reactions occur on the surface and subsequent mineral formation occurs at the surface of the oxides surface (e.g., iron and aluminum oxides). Here, it was assumed that once reduced manganese was adsorbed onto the freshly precipitated iron oxide generated in Layer 1, it was oxidized and co-precipitated with iron oxide. The model formulation was constructed according to this concept.

5.5.4. Comparison of Model Results and Observed Water Quality Data

After applying all the chemical conditions described above, the model was run to simulate the current water quality conditions at the lake bottom to give reasonable assurance to the model setup and assumptions. The overlying water at the sediment interface was assumed to have the same chemical characteristics as the sediment layer exposed to the overlying water. Figures 5-7 and 5-8 show the comparison between the modeled and observed total and dissolved metals (iron and manganese) and the pH results. The observed data were from the depth of 4.5 feet for Red Lake and 0.5 feet for Anton Road Pond (only available data). The results indicate that the model reasonably simulated the observed data.

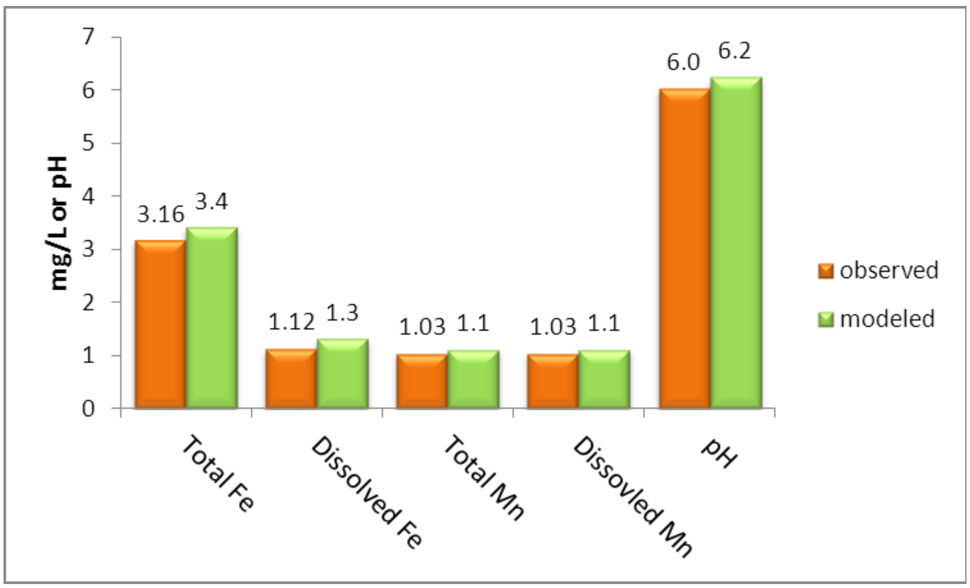

Figure 5-7: Comparison between model results and Red Lake observed iron, manganese, and pH data

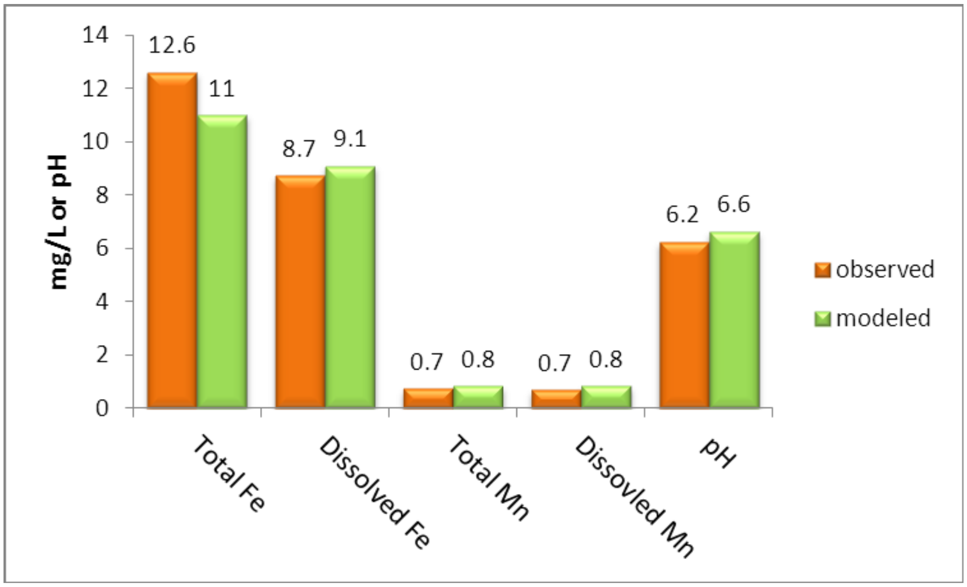

Figure 5-8: Comparison between model results and Anton Road Pond observed iron, manganese, and pH data

5.5.5. Iron and Manganese Sediment Reductions

After the model was constructed and evaluated, sediment reduction scenarios were examined. The first scenario diluted the upwelling groundwater (the mix of groundwater and the reduced leachate through current sediments) with the reduced concentration inflows with no change to the sediment concentrations. The second scenario, provided as a worst case, investigated the upwelling solution with sediment removal, assuming that the solution was majority lake/pond water.

Reduced Upwelling Groundwater and Leachate with Current Sediment Concentrations

A scenario was performed to examine the potentially acceptable mixing ratio between reduced inflows (inflows from the surface or the subsurface flow with no path through the bottom sediments and concentrations equal to the water quality standards) and the upwelling solution through the current bottom sediments. This scenario simulates saturated soil conditions, such as during high precipitation or snow melt season, where the water table is higher and the inflow could seep in from the side of the lake/pond without interacting with the lake/pond bottom sediments. As the leachate loading from the landfill was reduced, the reactive organic matter (loading carbon) should also be reduced. The reduced iron of 1,000 µg/L should be generated through organic matter oxidation, which would generate 7E-5 mol/L of carbon according to Equation 1 (see Section 5.5.1). Therefore, the updated carbon value was also input into the model as a part of the reduced leachate. Figure 5-9 shows the iron generation by the oxidation of organic matter simulated by the PHREEQC model. The results affirm that iron concentration increases (or decreases) along with the available organic matter to be oxidized.

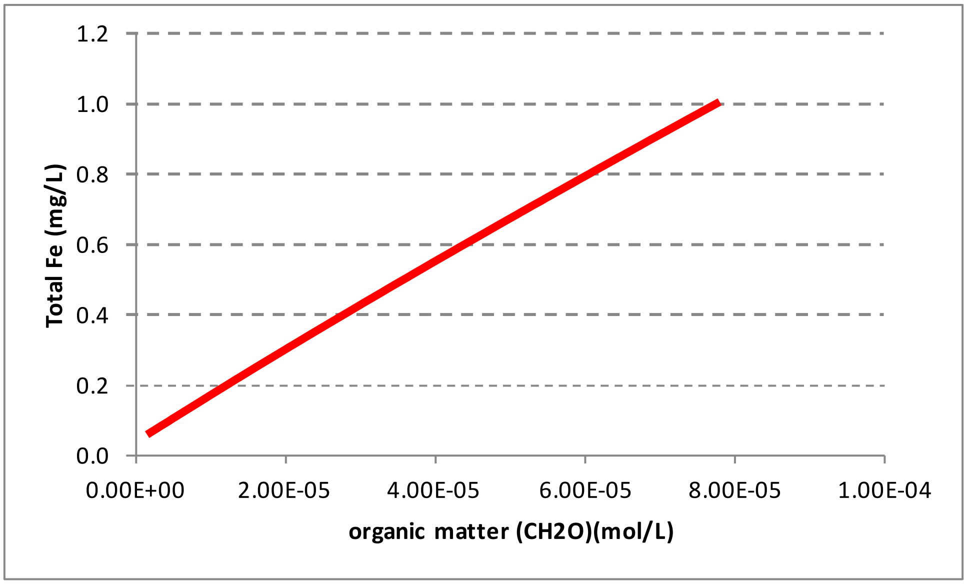

Figure 5-9: Iron dissolution through organic matter oxidation

The mixing ratio scenario model results indicated that the ratio of 0.75 and 0.25, respectively, for the reduced-concentrations inflows and the sediment affected upwelling solution could meet the water quality standard (Table 5-6). However, once the upwelling solution exceeded the specified ratio (0.25), the water column solution for Red Lake and Anton Road Pond violated the water quality criteria (Section 3.1).

Table 5-6: Modeled total iron and manganese concentrations at the bottom of Red Lake and Anton Road Pond based on reduced inflows and current sediment concentrations.

Waterbody	Total Iron (µg/L)	Total Manganese (µg/L)
Red Lake	984	50.0
Anton Road Pond	974	49.5

Reduced Inflows and Reduced Sediment Concentrations

In the second scenario, the current sediment concentrations were reduced to the sediment LELs and SELs discussed in Section 4.2.2. All inflow concentrations (groundwater and leachate) of iron and manganese were set to the water quality criteria of 1,000 µg/L and 50 µg/L, respectively, but were assumed to recharge through the bottom of the lake/pond through the sediments. In addition, the carbon input was updated consistent with Figure 5-9 above. This simulates a worst case scenario where the water table is low, potentially during a dry period, and the hydrologic connectivity between the recharge area and the lake/pond bottom sustains the water level in the water body. Table 5-7 shows the reduction results based on the sediment concentrations for total iron and manganese. The results indicate that LEL sediment concentrations ensure the water quality conditions of the overlying water will meet the water quality criteria (Section 3.1). This scenario represents the most stringent approach to achieve water quality criteria under all conditions.

Table 5-7: Modeled total iron and manganese concentrations at the bottom of Red Lake and Anton Road Pond based on reduced inflows and reduced sediment concentrations.

Waterbody	Sediment Reduction Type	Total Iron (µg/L)	Total Manganese (µg/L)
Red Lake	**LEL**	***988***	***50.0***
	SEL	1,052	53.5
Anton Road Pond	**LEL**	***953***	***48.3***
	SEL	1,008	51.2

Based on the available observed data collected at various depths, the concentrations at the shallower depths should also meet the water quality criteria. An additional model run was conducted by only mixing the leachate and groundwater, without the sediment interactions. The results were below the water quality criteria: 132 µg total iron/L and 8.73 µg total manganese/L. Therefore, any mixing between the sediment influenced solution and the solution without the bottom sediment influences (inflows from the surface or the subsurface flow with no flow path through the bottom sediments) can meet the water quality criteria. Section 7 discusses the effects this modeling effort has on the TMDL implementation for Red Lake and Anton Road Pond.

5.5.6. Potential Use of Dissolved Oxygen to Aid Iron and Manganese Reductions

Dissolved oxygen in the water column could facilitate iron oxidation, and eventually lead to the formation of amorphous iron oxide (particulate) within the natural pH range. The newly formed iron particulate could go through flocculation/coagulation and subsequent larger colloidal formation to be more susceptible to the deposition processes. Thus, supplying more dissolved oxygen would create a favorable condition for iron to be eliminated from the water column. However, the high total iron concentrations could persist and continue to exceed the criterion if the particulate iron stays in the solution.

Figure 5-10 shows the kinetic reaction of iron oxidation and iron particulate formation through the PHREEQC model using dissolved iron concentrations observed at the bottom of Red Lake. The kinetic equation and all reaction rates were based on literature values (Stumm and Morgan 1997). Assuming the iron (III) concentration was saturated with respect to amorphous iron oxide, dissolved iron (III) could be precipitated as the form of iron oxide. The results indicate that dissolved iron (II) was relatively sensitive to dissolved oxygen content in the solution. Figure 5-10 shows that higher dissolved oxygen (10 mg/L) oxidized ferrous iron (II) to ferric iron (III) faster, thus, created the iron particulate quicker than lower dissolved oxygen (8.5 mg/L).

Based on the kinetic results here and the loading reduction conditions described in the Section 5.5.5, the optimal condition for iron to be eliminated would be to reduce both the incoming solutions and the existing sediment concentrations and to add a constant dissolved oxygen supply to keep dissolved oxygen high enough to create the favorable conditions for iron mineral formation and subsequent deposition. As previously described, manganese oxidation by oxygen alone is very slow but manganese reduction could be facilitated by oxidation and co-precipitation on the surface of the iron oxide, which could lead to manganese's swift elimination from the water column. Bacterial oxidation of iron that could result in a faster oxidation reaction is not considered here.

5.5.7. Summary of Modeling Results

The PHREEQC modeling results indicate that internal loading is a potential source of metals loading to both Red Lake and Anton Road Pond. The two scenarios performed suggest reductions are required in either sediment concentrations (to LEL levels) or a balance must be achieved between the inflows and upwelling solutions (0.75 to 0.25 ratio, respectively) when considering current sediment concentrations. The addition of dissolved oxygen can also facilitate the elimination of iron from the water column. Ultimately, these results suggest that additional reductions are required to meet water quality criteria. Alternative reductions are described in Section 6.4.

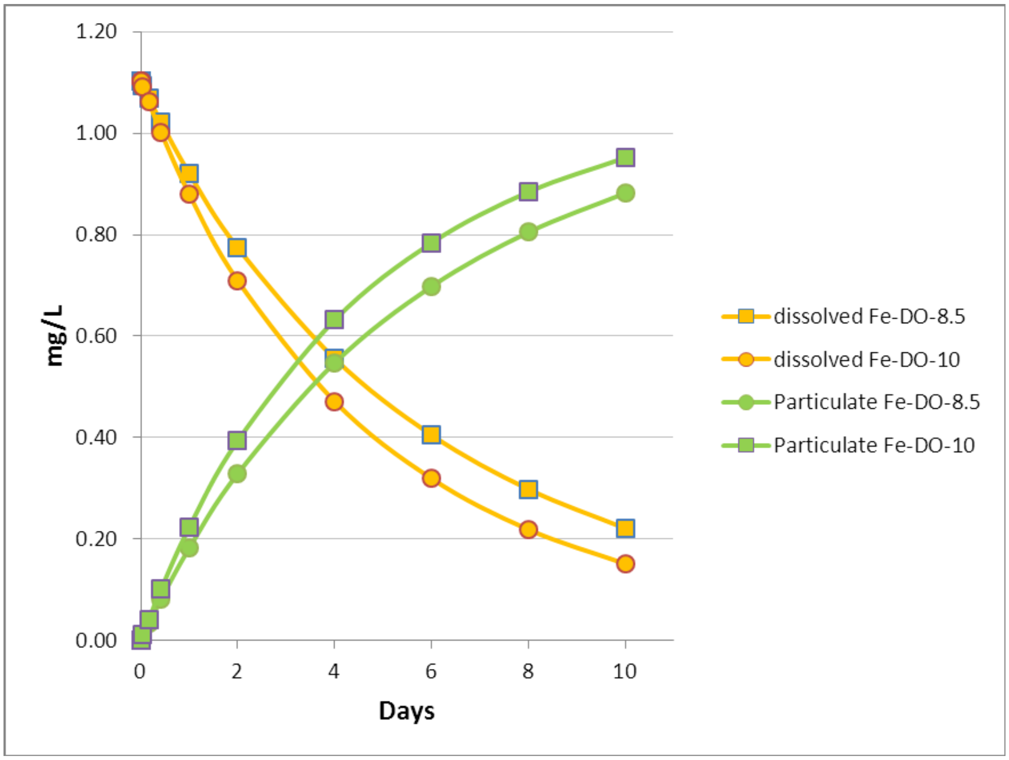

Figure 5-10: Kinetic iron oxidation results (DO–8.5: dissolved oxygen 8.5mg/L, DO–10: dissolved oxygen 10 mg/L)

5.5.8. Model Utility and Assumptions

Because of the limited data available, it was necessary to make assumptions during the model setup process, leading to uncertainties in the modeling effort. In addition to the detailed assumptions described in Sections 5.5.1 and 5.5.2, the following assumptions should also be recognized or reiterated:

- The elevated bottom iron concentrations (at 4.5 feet) shown in the data sets were assumed to originate from diffusion of dissolved iron existing in the pore solution, not from disturbances by the bottom sampling efforts.
- The available water column data collected at Red Lake (three data sets) and Anton Road Pond (one data set) were assumed to be showing representative typical conditions of the waterbodies.
- The solution data collected at the downgradient diversion ditch station was assumed to represent the subsurface leachate solution because of the lack of subsurface chemical data collected along the potential groundwater pathways from the landfill to Red Lake.
- Iron was assumed to be the major oxidant for organic matter existing in the landfill. Potential organic matter oxidation processes by nitrate and sulfate were not considered due to the lack of data.
- Historical chloride data used to derive the mixing of the groundwater and the leachate was assumed to be representative of the current/recent chloride conditions.
- The literature-based reactive metal oxide (Fe and Mn) fractions were assumed for total heavy metals concentrations in sediments; 10% of the total iron sediment concentrations and 30% of the total manganese sediment concentrations were used.

The model was constructed based on the assumptions described above to evaluate iron and manganese concentrations in Red Lake and Anton Road Pond. Validation of the model for simulating both the geochemical interactions at the water/sediment interface and the leachate loading effects on water quality conditions was demonstrated through comparison with observed data (see Section 5.5.4). The model also confirms the current lake bottom sediments to be the likely cause of elevated in-lake metal concentrations. Since the model was constructed with limited available data, the quantitative results for the remediation scenarios should be evaluated with caution. It is recommended that all potential loading sources should be reduced to the water quality criteria levels first, as the reductions were also assumed in the model. Then, subsequent in-lake water quality and sediment quality data should be collected and assessed to determine the additional level of remediation necessary, especially in the sediments. Further remedial actions may be necessary, such as the level of mixing and/or sediment removal, if iron and manganese levels are still not meeting TMDL targets (see Section 6).

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6. Technical Approach

A TMDL represents the total amount of a pollutant that can be assimilated by a receiving water while still achieving water quality standards—also called the *loading capacity*. A TMDL is composed of individual waste load allocations (WLAs) for point sources and load allocations (LAs) for nonpoint sources 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.

The analytical approach used to estimate the loading capacity and allocations for Red Lake and Anton Road Pond is based on the best available information to represent the impairment and expected sources.

6.1. Loading Capacity

The loading capacity is equivalent to the TMDL and is the greatest amount of a given pollutant that a waterbody can receive without exceeding the applicable water quality standards, as represented by the TMDL water quality target. Almost all iron and manganese loads entering Red Lake and Anton Road Pond are by groundwater pathways from the landfill and are not precisely known; however, the resulting concentrations in surface water are measured. Recent modeling analyses also indicate that internal loadings impact the water column concentrations. The TMDL expresses the loading capacity for iron and manganese in Red Lake and Anton Road Pond as concentrations, equivalent to Alaska's numeric water quality criteria of 1,000 µg/L for iron and 50 µg/L for manganese. These targets are protective of all freshwater designated uses[1]. A concentration-based TMDL is directly comparable to the applicable water quality criteria and as such, is easily communicated.

A concentration-based TMDL is appropriate because using a more complicated analysis to estimate iron and manganese loads from landfill drainage would require additional data collection 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 water. Therefore, if the loading capacity is expressed as a concentration in Red Lake and Anton Road Pond, all allocations are equivalent to, rather than a portion of, the loading capacity. In other words, the target concentration implicitly represents an acceptable (but undefined) loading rate.

Necessary reductions in existing concentration were calculated for Red Lake and Anton Road Pond to identify the reductions needed to meet the loading capacity and corresponding water quality standards. Reductions were calculated based on the maximum observed iron and manganese concentration (since the 1999 site improvements) relative to the load allocation that is equal to the water quality criterion:

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

[1] TMDLs are typically based on *loads* of pollutants—some allowable mass of a pollutant over a specified time period such as kilograms per day. The loading capacity is then divided among WLAs for point sources and LAs for nonpoint sources, minus a MOS. Conceptually, this definition is denoted by the equation

$$\text{TMDL} = \Sigma\,\text{WLAs} + \Sigma\,\text{LAs} + \text{MOS}$$

6.2. 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. An implicit MOS was included in this TMDL.

Meeting the Alaska water quality criteria for iron and manganese results in the inclusion of an implicit margin of safety. Determination of an explicit margin of safety is not necessary for this particular TMDL because in presenting the allocations as a concentration at the water quality criteria for iron and manganese, the sources will comply with the water quality standards and there will be no uncertainty involved.

In addition to the use of water quality criteria for the loading capacity, other conservative assumptions were included that contribute to the implicit MOS. These assumptions include the determination of existing concentrations and assumptions made during the internal loading modeling. Specifically, by using the maximum (as opposed to average or median) observed iron and manganese concentrations in the waterbodies to represent existing conditions, the necessary reductions reflect the worst case scenario. During the internal loading model, water quality concentrations were higher at lower depths for Red Lake; however, the scenarios ensured that water quality criteria were met at all depths.

6.3. Wasteload Allocation

There are currently no known active permitted discharges of iron and manganese to Red Lake and Anton Road Pond. Therefore, no WLA is required for this TMDL.

6.4. Load Allocation

The LA is the portion of the loading capacity allocated to nonpoint source discharges to the waterbody. As discussed in Section 5, landfill drainage is the primary source and the only nonpoint source documented to impact iron and manganese levels in Red Lake and Anton Road Pond. The concentration-based LAs for the landfill are equal to the loading capacities for iron and manganese.

Table 6-1 and Table 6-2 summarize the water column LA for each waterbody along with the necessary percent reductions of iron and manganese concentrations from the maximum observed iron and manganese concentration in each waterbody following 1999 site improvements while considering an implicit margin of safety (note: the maximum observed concentrations represent the worst case scenario). The reductions in existing concentrations are provided to illustrate the relative magnitude of impairment and associated reductions needed to meet the loading capacity and water quality numeric targets. Using the highest observed concentration to calculate reductions reflects the worst case scenario. Therefore, the reductions represent the levels needed to ensure that water quality standards are met during all conditions.

Table 6-1: TMDL allocation summary for iron in the water column.

Total Recoverable Iron (µg/L)							
Waterbody	Loading Capacity	WLA	LA	Margin of Safety	Future Growth	Maximum Observed since 1999	Percent Reduction to Meet LA
Red Lake	1,000	NA	1,000	Implicit	1,000	3,160	68%
Anton Road Pond	1,000	NA	1,000	Implicit	1,000	12,600	92%

Table 6-2: TMDL allocation summary for manganese in the water column.

Waterbody	Total Recoverable Manganese (µg/L)						Percent Reduction to Meet LA
	Loading Capacity	WLA	LA	Margin of Safety	Future Growth	Maximum Observed since 1999	
Red Lake	50	NA	50	Implicit	50	1,030	95%
Anton Road Pond	50	NA	50	Implicit	50	728	93%

6.5. 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 with consideration of seasonal variation and critical conditions to ensure the waterbody will maintain water quality standards under all expected conditions.

The times of highest loading and worst impairment for Red Lake and Anton Road Pond are expected to be during the summer months when the highest temperatures occur. Higher temperatures decrease the solubility of oxygen in water, promote bacterial activity, and lead to more reducing conditions. These conditions would decrease the iron and manganese load that oxidizes and precipitates from the water column, thus increasing the dissolved fraction. Data were not available to compare concentration and temperature variation across spring, summer, and fall conditions. However, the seasonal comparison in SAIC (1997a) suggested that higher dissolved iron concentrations, and possibly higher manganese concentrations, occur in the fall compared to the spring. During this study, spring water temperatures were slightly higher than fall temperatures. While these results do not rule out the influence of temperature, they do support the potential for higher loading occurring during the fall compared to the spring. Leaching from the landfill is expected to occur year-round due to the relatively warm temperatures in the winter months (average minimum temperature of 26 degrees Fahrenheit).

Applicable water quality criteria for iron and manganese apply year round in Red Lake and Anton Road Pond. However, impairment has only been observed recently during summer months. No known data are available during the 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.

It is important to consider downstream conditions when addressing seasonal variation and critical conditions in Red Lake and Anton Road Pond because the Buskin River downstream from the confluence with the drainage ditch is a pink salmon spawning area. The critical season for the pink salmon spawning area in the Buskin River is the spring when the eggs hatch and juveniles outmigrate to marine waters. Loading from the drainage ditch to the Buskin River could affect other salmonid populations and aquatic life throughout the year. For example, coho salmon have been observed to use the Buskin River for rearing over a year's time after spawning occurs in Buskin Lake. Review of the data, however, does not indicate that the high iron and manganese levels in the drainage ditch are observed in the Buskin River (see Section 4.1).

In summary, available data on iron and manganese as well as aquatic life suggest that iron and manganese loading to Red Lake and Anton Road Pond during the spring through the 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.

6.6. Reasonable Assurance

USEPA 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 USEPA. There are no point sources contributing to the impairments in Red Lake and Anton Road Pond, therefore, reasonable assurance does not apply to the Red Lake/Anton Road Pond TMDLs.

6.7. Future Growth

Current impairments in Red Lake and Anton Road Pond are thought to be the result of historical contamination of surface water and sediments caused by leaching from the adjacent Navy landfill. The landfill was closed in 1972; however, no engineering or access controls, including a liner, cover, or leachate controls were implemented. The landfill was re-graded in 1999 to improve vegetative cover and surface water drainage with the purpose of reducing potential offsite migration of contaminants. The site is currently located within US Coast Guard (USCG) Base Kodiak in Kodiak, Alaska.

Total iron and total manganese in Red Lake and Anton Road Pond appear to have decreased in recent years although they remain above the TMDL target (see Section 4.1). While future sources are not anticipated to affect impairment in Red Lake and Anton Road Pond, it is possible that future sources, such as facilities that will apply for coverage under an APDES permit, will have the potential to deliver metals to the waterbodies. To address future growth, the TMDLs establish allocations for future sources equivalent to the following respective LAs to ensure that any future sources also meet established water quality targets:

Total Iron: 1,000 µg/L
Total Manganese: 50 µg/L

6.8. 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 water quality standards. The TMDLs for iron and manganese are presented as maximum concentrations allowed in the water column. The allowable concentrations are applicable at all times and can therefore be applied on a daily basis.

7. Implementation and Future Monitoring Recommendations

To date, the landfill has been regraded to improve the vegetative cover and surface water drainage with the purpose of reducing potential offsite migration of contaminants. The regrading was completed based on recommendations made in USEPA's RFI/CMS and included the construction of diversion ditches. The Coast Guard and the USACE are continuing systematic investigations, monitoring programs and cleanup at sites throughout Base Kodiak under RCRA and the ADEC Contaminated Sites Program.

This section of the report presents recommendations for future monitoring and implementation to assist in meeting the iron and manganese TMDLs presented for Red Lake and Anton Road Pond.

7.1. Future Monitoring

The internal loading simulation conducted for this TMDL effort (see Section 5.5) presents results that can be used to inform any future implementation and monitoring for Red Lake and Anton Road Pond. While the model results show that reducing the Red Lake and Anton Road bottom sediments to the LELs for iron and manganese and increased levels of dissolved oxygen in the water column could facilitate the reduction of iron in the water column, it should be noted that there is much uncertainty surrounding the internal loading model due to limited data. The amount of available data to use as input to the PHREEQC model was very limited, which resulted in the necessity to make assumptions and use estimates and literature values rather than site-specific data. This can lead to uncertainty in the results.

Additional monitoring could support future model development using site-specific data to more accurately represent Red Lake and Anton Road Pond. Specifically, in addition to the list of the parameters already collected in and around the lake, additional chemical data would be helpful. These additional data would provide more confidence in evaluating the site conditions, the fate of the leachate, and the resulting water column/sediment conditions.

In addition, the sediment screening levels (LELs) applied in the model are below the current background sediment concentrations of iron and manganese observed in the vicinity of Red Lake and Anton Road Pond. Additional background monitoring should be conducted to confirm that these higher background levels truly exist.

The following monitoring activities are recommended to support TMDL implementation for Red Lake and Anton Road Pond:

- Monitor elevations and develop a water balance to estimate seasonal inflow from groundwater into Red Lake and Anton Road Pond to support estimates of pollutant load inputs
- Measure iron and manganese concentrations during each season in groundwater, surface water, and sediment
- Collect additional iron and manganese concentrations in Anton Road Pond to verify current conclusions from the limited dataset
- Collect groundwater background concentrations of iron and manganese to compare to previous background concentration estimates from historic data
- Collect sediment background concentrations of iron and manganese for comparison to historic background concentrations
- Collect additional water column, lake bottom sediment, groundwater, and landfill leachate (subsurface) data to support model refinement using site-specific data including: total organic carbon/dissolved organic carbon, total inorganic carbon, alkalinity, calcium, magnesium, sodium, ammonium, sulfate, chloride, cation exchange capacity (soils and lake bottom sediment), and sediment iron and manganese

concentrations from lake bottom using sequential extraction method to identify different metal conditions (exchangeable, carbonate, oxides, etc.).

7.2. Implementation Recommendations

To meet water quality criteria, one implementation option would be to create conditions in which the metals are precipitated out in insoluble form, perhaps through aggressive oxygen addition that keeps low reduction potential at the sediment surface. This could also be enhanced by reduction in the organic matter load. Controlling the organic matter is important because bacteria in/on the sediment are likely reducing insoluble ferric oxide to soluble ferrous hydroxide to release oxygen that is used for respiration of organic material. It should be noted that such an approach would *increase* the iron concentration in the sediment at the same time that it decreases release of soluble iron to the water column.

Another option would be to implement the modeling scenario described in Section 5.5.5, which reduces upwelling groundwater and leachate. The alternative scenario uses current sediment concentrations, but holds the inflow:upwelling solution concentration ratio to 0.75:0.25.

If as presented in the worst case modeled scenario, the water quality TMDL cannot be met through reductions in the inflow alone, steps will need to be taken to reduce iron and manganese in the sediment as well as in the water column. Iron and manganese would have to be removed from the bottoms of Red Lake and Anton Road Pond through dredging of the sediments. Modeling results predict that reducing sediment concentrations to the LELs will result in meeting the water column targets.

The Department of Environmental Conservation Contaminated Sites Program is currently leading a coordinated effort with the U.S. Coast Guard and the U.S. Army Corps of Engineers to develop a comprehensive remedy to appropriately address Red Lake/ Anton Road Pond water quality.

8. Public Comments

Federal regulations require USEPA to notify the public and seek comment concerning TMDLs it prepares. This TMDL was developed under contract to USEPA, and a public review period was held seeking comments, information, and data from the public and any other interested party. A pre-public draft of the TMDL was sent to agencies and interested stakeholders on February 6th, 2013. The notice for the public review period was posted on April 1th 2013, and the review period closed on May 13th, 2013. The notice was posted in the local news paper, the Kodiak , and in the Anchorage Daily News, on DEC's website, and on the State of Alaska's Public Notice Web Site. A fact sheet and this TMDL was also available on DEC's website. A public meeting regarding the Red Lake and Anton Road Pond iron and manganese TMDLs was also held on April 24th, 2013 at the Kodiak Public Library.

Comments on the TMDL were received from the U.S. Coast Guard, and the U.S. Corps of Engineers. Comments and additional information submitted during this public comment period were used to inform or revise this TMDL document. See Appendix A for detailed information on the response to comments.

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