Review of Red Creek Water Quality: Livestock, Irrigation and Protection of Aquatic Life

Prepared for the Milk River Watershed Council Canada

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1.0 INTRODUCTION

Red Creek is a small tributary of the Milk River in Alberta. The headwater tributaries of Red Creek originate southwest of the Town of Milk River in Alberta (Canada) and Montana (United States). The mainstem of Red Creek starts in Montana and flows in a northeast direction into Alberta for 49 km where it joins the Milk River (Figure 1). The confluence of Red Creek and the Milk River is approximately 34 km downstream of the Town of Milk River. Approximately 9 km of the mainstem Red Creek is in Montana and 40 km is located in Alberta.

Land use in the Red Creek watershed is characteristic of a rural, agricultural landscape, comprised of crop and pasture lands. Water from the creek is used for livestock water and irrigation. Streamflow is considered ephemeral/intermittent, with dry conditions observed frequently in mid-to-late summer at various locations. Baseflow in Red Creek is maintained by numerous springs that surface along the length of Red Creek. In many tributaries in the Milk River watershed, including Red Creek, groundwater is an important contributor to base streamflow.

Water quality monitoring has been conducted at Red Creek by Alberta Environment and Parks and the Milk River Watershed Council. Alberta Environment and Parks monitored the site Red Creek at Hwy 4 in the 1980s, but this data is limited to a few samples collected and a short list of water chemistry parameters analysed. In 2006, Alberta Environment and Parks began to regularly monitor water quality at Red Creek at a lower site, and the MRWCC established three sites at Red Creek to represent an upper, middle and lower reach.

Historically, landowners have expressed concern regarding water quality at Red Creek. The main concerns are related to potential pesticide use and their impact on amphibians, as well as heavy metals (e.g., mercury, cadmium and lead) and their potential impact on livestock health. In particular, landowners noted that they have not observed the same abundance of Leopard Frogs at the creek. The Red Creek Watershed Group (RCWG) established in 2013 to address concerns. The group is a collaboration of about 70 landowners, the County of Warner, the MRWCC and Cows and Fish. The RCWG worked with Cows and Fish to improve understanding of riparian health, and also with ACA to better understand the presence of amphibians in the watershed.

To support the Red Creek Watershed Group, a historical water quality review was recommended for Red Creek to better understand water quality conditions as it relates to aquatic life, livestock water and irrigation (PESL 2020). In 2021, the MRWCC initiated the water quality assessment. Palliser Environmental Services Ltd. was retained to review the data and compare water quality to relevant water quality guidelines.

2.0 METHODS

Historical water quality data from Red Creek was obtained from two sources: 1) the Milk River Watershed Council Canada (MRWCC) and 2) Alberta Environment and Parks (AEP). The data sets were not combined, but treated separately for ease of analysis.

The MRWCC provided the historical surface water quality data they have collected at Red Creek through the Council's annual water quality monitoring program. The MRWCC Excel database contained data from 2011 to 2019. The MRWCC did not collect data at Red Creek in 2020 due to Covid-19 restrictions.

Figure 1. Location of Red Creek water quality sampling sites.

The MRWCC water quality database contained **Ions and General** parameters (i.e., dissolved oxygen, pH, conductivity, total dissolved solids, total suspended sediment), **Nutrient** parameters (i.e., nitrogen and phosphorus) and **Biological** parameters (i.e., fecal coliforms). The MRWCC database did not contain **Metals, Pesticide** or **Trace Organic** parameters. The MRWCC has sampled three sites at Red Creek: 1) Red Creek - upper, 2) Red Creek - middle and 3) Red Creek - lower (Figure 1). Sampling represents the period April through October with two samples collected twice per month April-June, and once per month July through October.

The Red Creek water quality sample sites (Figure 1) are located at:

- Red Creek - upper site: Located near the Canada-United States border, 40 km upstream of the confluence with the Milk River at the end of Range Road 170 (lat. 48.999940, long. -112.145444)
- Red Creek - middle site: Located 17 km upstream of the confluence with the Milk River at Highway 4 (lat. 49.043421, long. -111.996272)
- Red Creek - lower site: Located 6 km upstream of the confluence with the Milk River at Range Road 152 bridge (lat. 49.067037, long. -111.922562)

A data request was made to AEP in July 2021 for the surface water quality data that the province has collected for Red Creek. The data was provided in an Excel spreadsheet format. The AEP database contained water quality data from 2006 to 2020 for the lower Red Creek site, specifically the years 2006-2010 and 2016-2020. Samples were generally collected monthly from April through October (2006-2016) or March through October (2017-2020). The AEP water quality database contained **Ions and General** parameters (e.g., chloride, fluoride, sulphate, total dissolved solids), **Nutrient** parameters (e.g., nitrogen and phosphorus), **Biological** parameters (e.g., fecal coliforms) and **Metal** parameters (e.g., total recoverable and dissolved). AEP collected metals data from 2016 to 2020. The AEP database did not contain **Pesticide** or **Trace Organic** parameters.

The Red Creek water quality data was compared to Livestock, Irrigation and Protection of Aquatic Life (PAL) guidelines to determine compliance and identify parameters of concern. The focus of the Red Creek water quality guideline compliance was in comparison to the "Environmental Quality Guidelines for Alberta Surface Waters" (GoA 2018).

In addition, the federal water quality guidelines summarized in the Canadian Council of Ministers of the Environment (CCME) website (https://www.ccme.ca/) were reviewed to determine if there were additional guidelines for Livestock, Irrigation or Protection of Aquatic Life that were not available in the Alberta provincial guidelines (GoA 2018). The only additional CCME guideline found was manganese (dissolved) for the Protection of Aquatic Life. The review of Protection of Aquatic Life guidelines also included the following parameters that currently do not have a guideline: total phosphorus, dissolved phosphorus, total nitrogen, total Kjeldahl nitrogen and total suspended sediment. Until 2014, Alberta had a chronic Protection of Aquatic Life guideline of 0.05 mg/L for total phosphorus and 1.0 mg/L for total nitrogen. Total suspended solids was included in the analysis as a parameter of interest as it relates to erosion, and the transport of other parameters in surface water including phosphorus, fecal coliform bacteria and metals.

Data Analysis

The Red Creek water quality data for each relevant Livestock, Irrigation or Protection of Aquatic Life guideline was summarized by site (upper, middle, lower) and year. Each site *x* year dataset was summarized into tables as a median (50^{th} percentile) and range (minimum – maximum).

3.0 RESULTS

3.1 Precipitation and Streamflow

Precipitation for the monitoring period (April to October) varied among years (Table 1). Years that had "high precipitation" or greater than 300 mm were 2008, 2010, 2012, 2013, and 2016. Years that were considered "dry" or had less than 200 mm of rainfall were 2009, 2015 and 2018. The years that had >263 mm of precipitation (2006, 2011 to 2014, 2020) had continuous flow from April to October at all sites or experienced one month of low flow conditions late in the year. The years that had <225 mm of precipitation (2007, 2009, 2015, 2018 and 2019) had multiple months of dry or no flow conditions from April to October. The years 2008, 2010 and 2016 were unusual in that they had >316 mm of precipitation from April to October but had multiple months of dry or no flow conditions (Table 1).

Table 1 - Total precipitation (mm) at the Town of Milk River and streamflow observations (dry, no flow or continuous flow) for water monitoring, April to October, 2006 to 2020.

Year	Precipitation (mm) at Milk River	Streamflow Observations Red Creek - upper	Streamflow Observations Red Creek - middle	Streamflow Observations Red Creek - lower
2006	263.0	--	--	No flow in September
2007	222.1	--	--	No flow July to October
2008	318.8	--	--	No flow July to October
2009	178.8	--	--	No flow June to October
2010	357.0	--	--	No flow August and September
2011	296.7	Continuous flow April to October	Continuous flow April to October	Continuous flow April to October
2012	326.8	Continuous flow April to October	Continuous flow April to October	Continuous flow April to October
2013	347.5	Continuous flow April to October	Continuous flow April to October	Continuous flow April to October
2014	290.1	Continuous flow April to October	No flow in September	No flow in September
2015	199.6	Dry in August and October	Dry in July and August	Dry July to October
2016	315.5	Continuous flow April to October	Dry in August and October	Dry June to October
2017	261.6	Dry in October	Dry in August and September	No flow August to October
2018	195.4	No flow in August and September	No flow July to October	No flow in September
2019	215.8	Continuous flow April to October	Dry August to October	No flow in March, August and September
2020	278.4	--	--	Continuous flow April to October

Data Source: Environment and Climate Change Canada - https://weather.gc.ca/canada_e.html

3.1 LIVESTOCK WATER QUALITY

3.1.1 Results

Upper, Middle and Lower Red Creek (2011 to 2019)
Table 2 summarizes water quality data collected by the MRWCC from 2011 to 2019 at the upper, middle and lower Red Creek sites and compared to applicable livestock water quality guidelines. The water quality parameters were limited to nitrate-nitrite, nitrite and total dissolved solids (TDS) and none exceeded the livestock water quality guidelines.

Median **nitrate-nitrite** concentrations at the three sites ranged from 0.036 to 0.644 mg/L and were 155 to 2778 times below the guideline of 100 mg/L for livestock water. Median **nitrite** concentrations at the three Red Creek sites ranged from 0.010 to 0.045 mg/L and were 222 to 1000 times below the guideline of 10 mg/L for livestock water. Median **TDS** concentrations at the three Red Creek sites ranged from 1715 to 2160 mg/L and were 1.4 to 1.8 times below the guideline of 3,000 mg/L for livestock water.

Lower Red Creek (2006 to 2020)
Table 3 summarizes water quality data collected by Alberta Environment and Parks (AEP) for 10 years from 2006 to 2020 at lower Red Creek site and compared to applicable livestock water quality guidelines. The AEP portion of the dataset from 2016 to 2020 includes 15 total metal parameters as well as 5 ions and general parameters (calcium, nitrate-nitrite, nitrite, sulphate and TDS). The AEP portion of the dataset from 2006 to 2010 contains 5 relevant Livestock guidelines from ions and general parameters (nitrate-nitrite, nitrite, sulphate, TDS and fluoride).

All of the total metal parameters were below the respective livestock water quality guidelines (Table 3). The metals with the highest concentrations relative to their respective guidelines were arsenic (8.9 to 20 times below the guideline), boron (9.8 to 21 times below the guideline) and selenium (4.8 to 20 times below the guideline). The metals with the lowest concentrations relative to their respective guidelines were beryllium (5,000 to 50,000 times below the guideline), cadmium (13,333 to 16,000 times below the guideline) and zinc (10,638 to 41,666 times below the guideline).

Of the ions and general parameters at lower Red Creek, **sulphate** concentrations sometimes exceeded the livestock water quality guideline (Table 3; Figure 2). Median sulphate concentrations (range: 828 to 1,100 mg/L) exceeded the livestock water quality guideline (1,000 mg/L) in 3 of 10 years (2016, 2018 and 2019). In 9 of 10 years, at least one sample (range: 1 to 4) exceeded the sulphate livestock guideline. The maximum sulphate concentration was 1,300 mg/L recorded in 2010, 2019 and 2020 (Table 3).

Table 2 - Water quality (median and range) at upper, middle and lower Red Creek sites (2011 to 2019) compared to Livestock Water Guidelines (GoA 2018). Exceedances are identified in red. Water quality data collected by MRWCC.

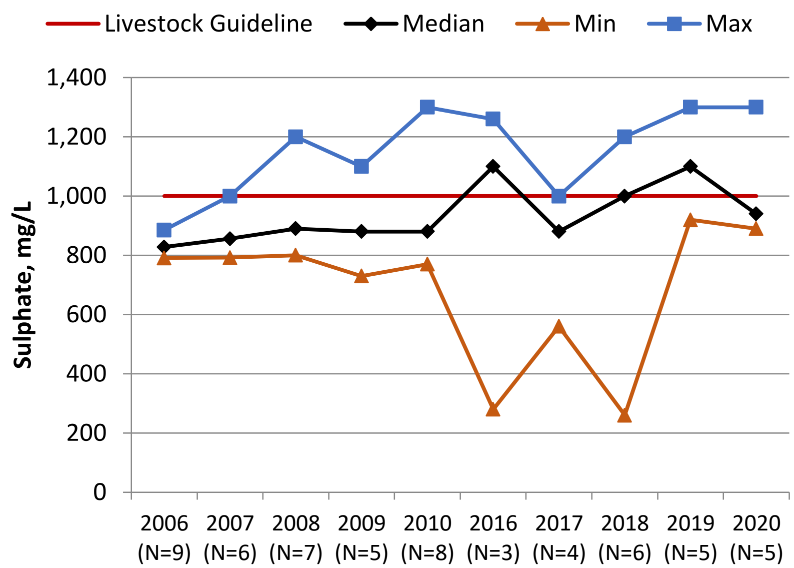
Red Creek - upper site										
Parameter	**Guideline**	**2019 (N=10)**	**2018 (N=8)**	**2017 (N=9)**	**2016 (N=10)**	**2015 (N=8)**	**2014 (N=10)**	**2013 (N=9)**	**2012 (N=10)**	**2011 (N=10)**
Nitrate-Nitrite (mg/L)	100	0.064 (0.050-2.680)	0.482 (0.050-4.19)	0.250 (0.005-1.6)	0.055 (0.025-1.85	0.185 (0.027-1.66)	0.316 (0.002-0.05)	0.036 (0.036-1.41)	0.127 (0.036-1.02)	0.036 (0.036-1.42)
Nitrite (mg/L)	10	0.025 (0.025-0.025)	0.025 (0.021-0.071	0.025 (0.005-0.074)	0.025 (0.005-0.083)	0.025 (0.005-0.025)	0.025 (0.010-0.060)	0.025 (0.025-0.060)	0.045 (0.025-0.125)	0.025 (0.025-0.057)
TDS (mg/L)	3,000	2,095 (1,410-2,690)	1,840 (366-2,220)	2,020 (1,590-2,240)	1,965 (1,790-2,130)	1,980 (1,830-2,130)	2,025 (1,470-2,320)	2,160 (2,040-2,420)	2,155 (2,000-2,510)	1,910 (1,150-2,110)
Red Creek - middle site										
Parameter	**Guideline**	**2019 (N=7)**	**2018 (N=6)**	**2017 (N=8)**	**2016 (N=7)**	**2015 (N=8)**	**2014 (N=9)**	**2013 (N=10)**	**2012 (N=10)**	**2011 (N=10)**
Nitrate-Nitrite (mg/L)	100	0.055 (0.050-0.870)	0.053 (0.050-0.495)	0.050 (0.050-0.050)	0.055 (0.055-0.140)	0.050 (0.010-0.280)	0.036 (0.027-0.135)	0.036 (0.036-0.036)	0.063 (0.036-0.175)	0.036 (0.036-0.685)
Nitrite (mg/L)	10	0.025 (0.025-0.025)	0.025 (0.018-0.025)	0.025 (0.025-0.025)	0.025 (0.025-0.025)	0.025 (0.025-0.025)	0.010 (0.010-0.050)	0.025 (0.025-0.025)	0.038 (0.025-0.125)	0.025 (0.025-0.025)
TDS (mg/L)	3,000	1,820 (1,110-1,870)	1,715 (343-1,900)	1,920 (1,180-2,270)	2,020 (1,720-2,320)	1,885 (1,820-2,370)	1,950 (1,610-2,310)	2,045 (1,660-2,510)	2,055 (1,780-2,430)	1,835 (1,310-2,230)
Red Creek - lower site										
Parameter	**Guideline**	**2019 (N=3)**	**2018 (N=9)**	**2017 (N=7)**	**2016 (N=4)**	**2015 (N=6)**	**2014 (N=9)**	**2013 (N=10)**	**2012 (N=10)**	**2011 (N=10)**
Nitrate-Nitrite (mg/L)	100	0.098 (0.055-0.920)	0.39 (0.025-0.85)	0.050 (0.021-0.017)	0.103 (0.055-0.17)	0.14 (0.05-0.32)	0.135 (0.027-0.839)	0.644 (0.258-1.52)	0.454 (0.175-2.16)	0.036 (0.036-2.290)
Nitrite (mg/L)	10	0.025 (0.005-0.025)	0.014 (0.004-0.027)	0.025 (0.0015-0.025)	0.025 (0.025-0.025)	0.025 (0.025-0.025)	0.025 (0.010-0.052)	0.025 (0.025-0.025)	0.039 (0.025-0.125)	0.025 (0.025-0.025)
TDS (mg/L)	3,000	1,900 (1,090-1,990)	1,900 (375-2,100)	1,870 (1,670-2,230)	1,885 (1,760-2,040)	2,030 (1,920-2,230)	1,960 (1,730-2,320)	1,915 (1,710-2,290)	1,955 (1,800-2,460)	1,955 (1,350-2,310)
Note: Water quality samples were not collected at Red Creek upper and middle sites in 2020 due to Covid-19 restrictions.										

Table 3 - Water quality (median and range) at lower Red Creek site (2006 to 2020) compared to Livestock Water Guidelines (GoA 2018). Exceedances are identified in red. Water quality data collected by Alberta Environment and Parks.

Parameter	Guideline	2020 (N=5)	2019 (N=5)	2018 (N=6)	2017 (N=4)	2016 (N=3)	2010 (N=8)	2009 (N=5)	2008 (N=7)	2007 (N=6)	2006 (N=9)
TOTAL METALS (total metals and guidelines are µg/L except total mercury (ng/L)											
Aluminum	5,000	18.8 (4.6-26.8)	11.9 (10.8-16.9)	24.3 (12.5-1,470)	75.6 (35-187)	269 (39-1,670)	--	--	--	--	--
Arsenic	25	1.25 (0.77-3.03)	2.39 (1.25-2.97)	2.35 (1.05-6.67)	2.80 (1.81-8.48)	1.30 (1.18-2.31)	--	--	--	--	--
Beryllium	100	0.002 (0.002-0.052)	0.005 (0.002-0.020)	0.003 (0.002-0.080)	0.004 (0.004-0.010)	0.020 (0.009-0.069)	--	--	--	--	--
Boron	5,000	512 (396-570)	300 (251-557)	312 (79.1-572)	238 (171-623)	265 (106-362)	--	--	--	--	--
Cadmium	80	0.005 (0.005-0.030)	0.005 (0.005-0.010)	0.005 (0.005-0.050)	0.006 (0.005-0.010)	0.006 (0.006-0.066)	--	--	--	--	--
Cobalt	1,000	0.080 (0.001-0.228)	0.202 (0.001-0.269)	0.246 (0.075-0.915)	0.378 (0.173-0.630)	0.286 (0.181-0.732)	--	--	--	--	--
Copper	500 to 5,000	0.03 (0.21-0.42)	0.61 (0.45-9.69)	0.65 (0.34-6.76)	2.09 (1.32-3.17)	2.81 (1.13-4.52)	--	--	--	--	--
Lead	100	0.047 (0.012-0.061)	0.032 (0.002-0.067)	0.049 (0.022-1.07)	0.130 (0.077-0.195)	0.180 (0.127-1.240)	--	--	--	--	--
Mercury (ng/L)	3,000	0. 59 (0.03-1.46)	1.37 (1.22-1.63)	1.2 (0.69-5.82)	1.52 (1.29-2.97)	0.94 (0.92-6.53)	--	--	--	--	--
Molybdenum	500	0.738 (0.675-1.22)	1.07 (0.954-1.57)	1.27 (0.946-1.94)	1.21 (0.794-1.56)	1.07 (0.981-1.28)	--	--	--	--	--
Nickel	1,000	0.44 (0.29-1.19)	1.32 (0.02-7.24)	1.96 (0.69-4.3)	6.43 (2.74-11.60)	0.643 (0.447-2.26)	--	--	--	--	--
Selenium	50	10.5 (6.2-14.5)	4.0 (2.5-12.4)	3.9 (3.3-16.8)	2.5 (2.26-8.3)	3.1 (0.77-3.43)	--	--	--	--	--
Uranium	200	3.05 (2.43-6.35)	5.91 (2.93-8.70)	4.81 (2.12-6.7)	4.19 (2.74-6.63)	5.36 (1.79-7.57)	--	--	--	--	--
Vanadium	100	0.74 (0.33-1.09)	0.61 (0.59-0.84)	0.906 (0.359-5.38)	1.26 (0.72-2.23)	0.97 (0.53-4.14)	--	--	--	--	--
Zinc	50,000	1.2 (1.0-1.8)	2.0 (1.1-2.2)	2.7 (2.3-7.3)	2.8 (2.5-2.8)	4.7 (1.4-8.0)	--	--	--	--	--
IONS & GENERAL (mg/L)											
Calcium	1,000	93.0 (73.3-125)	108 (88.2-165)	117 (57.8-164)	107 (78.2-137)	108 (36.8-129)	--	--	--	--	--

Table 3 - Water quality (median and range) at lower Red Creek site (2006 to 2020) compared to Livestock Water Guidelines (GoA 2018). Exceedances are identified in red. Water quality data collected by Alberta Environment and Parks.

Parameter	Guideline	2020 (N=5)	2019 (N=5)	2018 (N=6)	2017 (N=4)	2016 (N=3)	2010 (N=8)	2009 (N=5)	2008 (N=7)	2007 (N=6)	2006 (N=9)
Nitrate-Nitrite	100	0.260 (0.210-1.5)	0.094 (0.052-0.220)	0.325 (0.025-0.55)	0.010 (0.002-0.35)	0.083 (0.003-0.17)	0.072 (0.002-1.2)	0.017 (0.002-0.05)	0.031 (0.002-0.62)	0.083 (0.010-0.308)	0.005 (0.003-0.492)
Nitrite	10	0.024 (0.014-0.027)	0.002 (0.002-0.013)	0.007 (0.004-0.027)	0.002 (0.002-0.011)	0.002 (0.002-0.0039)	0.002 (0.002-0.067)	0.002 (0.002-0.003)	0.003 (0.002-0.014)	0.003 (0.002-0.009)	0.002 (0.002-0.019)
Sulphate	1,000	940 (890-**1,300**)	**1,100** (920-**1,300**)	**1,000** (260-**1,200**)	880 (560-**1,000**)	**1,100** (280-**1,260**)	880 (770-**1,300**)	880 (730-**1,100**)	890 (800-**1,200**)	856 (792-**1,000**)	828 (791-885)
TDS	3,000	1,900 (1,800-2,200)	1,900 (1,800-2,100)	1,900 (520-2,100)	1,650 (1,100-1,900)	1,900 (560-2,100)	1,725 (1,100-2,250)	1,800 (1,400-1,900)	1,700 (1,600-2,100)	1,675 (1,610-1,860)	1,680 (1,590-1,750)
Dissolved Flouride	1 to 2	--	--	--	--	--	--	0.12 (0.12-0.14)	0.14 (0.12-0.18)	0.14 (0.12-0.15)	0.11 (0.10-0.13)
Copper: Guideline is 500 µg/L for sheep, 1000 µg/L for cattle and 5000 µg/L for swine and poultry.											



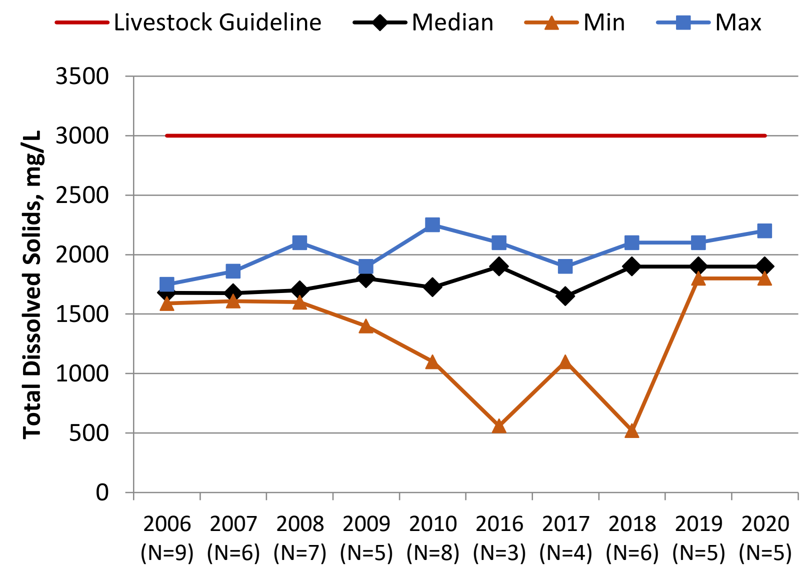


Figure 2. Sulphate concentrations compared to the Livestock water quality guideline (2006-2010, 2016-2020) (AEP 2021).

3.1.2 Discussion

Of the total metal, ion and general parameters with livestock water guidelines in Tables 2 and 3, only sulphate was identified to sometimes exceed the provincial livestock water quality guideline. Annual median sulphate concentrations ranged from 828 to 1,100 mg/L with maximum concentrations reaching 1,300 mg/L. Table 4 summarizes the Saskatchewan Ministry of Agriculture's sulphate interpretation for livestock use. Water with sulphate concentrations less than 500 mg/L is considered good for livestock use. Sulphate concentrations at Red Creek are only occasionally <500 mg/L. Median and individual sulphate concentrations at Red Creek are typically in the 500 to 1,000 mg/L range which is considered good for livestock water; however, livestock may develop scours or refuse to drink the water if not accustomed to it. These higher sulphate concentrations may contribute to trace mineral deficiency in calves which can cause depressed growth rate, fertility and immune response. Sulphate between 500 to 1,000 mg/L may result in decreased performance in feedlot cattle (Table 4). Sulphate concentrations at Red Creek are occasionally between 1,000 and 1,500 mg/L. Water with sulphate concentrations from 1,000 to 1,500 mg/L is considered acceptable for livestock use; however, it may cause laxative affects in livestock with reduced performance and can contribute to copper and trace mineral deficiencies.

Table 4 - Sulphate interpretation chart for livestock use (Saskatchewan Ministry of Agriculture, online link).

Sulphates (SO_4) (mg/L)	Livestock Suitability
<500	• Good
500-1,000	• Good • Diarrhea or refusal of water by animals not accustomed to it • 500-800 mg/L may affect calves, inducing a trace mineral deficiency • Trace mineral deficiencies can cause depressed growth rate, depressed fertility and depressed immune response • Decreased performance in feedlot cattle • 1,000 mg/L recommended maximum if feed level is high in sulphates or if ambient temperature is high
1,000-1,500 **Typical Red Creek range**	• Acceptable • Laxative • Performance reduced • High levels of sulphates can also contribute to copper and other trace mineral deficiencies
1,500-2,000	• Poor • Chelated or Hydroxy minerals may be required • High chance of trace mineral deficiency • Symptoms include: decreased gains, depressed immunity and reduced conception, etc. • Sporadic cases of polio possible • 2,000 mg/L > can cause diarrhea and reduced milk production in dairy cows
>2,000	• Unsuitable • Sporadic cases of polio are highly probable • Performance reduced • Scours likely • >4,000 mg/L dangerous health problems expected

3.2 IRRIGATION WATER QUALITY

3.2.1 Results

Upper, Middle and Lower Red Creek (2011 to 2019)

Table 5 summarizes water quality data collected by the MRWCC from 2011 to 2019 at the upper, middle and lower Red Creek sites and compared to applicable irrigation guidelines. The water quality parameters were limited to total dissolved solids (TDS), conductivity and fecal coliform bacteria and all exceeded the irrigation water quality guidelines.

The median **TDS** at each site exceeded the irrigation guideline (500 to 3,500 mg/L) in each of the nine years from 2011 to 2019 (Table 5). Median TDS at the three sites ranged from 1,715 to 2,160 mg/L with individual samples ranging between 343 and 2,690 mg/L. Ninety-nine percent (99%) of samples (N=227) from the three Red Creek sites (2011-2019) exceeded the irrigation guideline for TDS.

The median **conductivity** at each site exceeded the irrigation guideline (≤ 1000 µS/cm) in each of the nine years from 2011 to 2019 (Table 5). Median conductivity at the three sites ranged from 2,115 to 2,870 µS/cm with individual samples ranging between 426 and 3,450 µS/cm. The median conductivity at each site exceeded 2,000 µS/cm which classified the water as “hazardous” for irrigation. Ninety-eight percent (98%) of samples (N=227) from the three Red Creek sites (2011-2019) exceeded the irrigation guideline for conductivity.

The median **fecal coliform bacteria** count at the upper and middles sites (range: 2 to 400 cfu/100 mL) occasionally exceeded (1 in 9 years) the irrigation guideline (100 cfu/100 mL). Fecal coliform counts at the upper and middle sites ranged from 0 to 49,000 cfu/100 mL. Thirty-two percent (32%) of samples (N=159) from the upper and middle Red Creek sites (2011-2019) exceeded the irrigation guideline for fecal coliform bacteria (Table 5).

The median fecal coliform bacteria counts at the lower site (range: 44 to 315 cfu/100 mL) often exceeded (7 of 9 years) the irrigation guideline (Table 5). Fecal coliform counts at the lower site ranged from 1 to 17,800 cfu/100 mL. Fifty-four percent (54%) of samples (N=68) from the lower Red Creek site (2011-2019) exceeded the irrigation guideline for fecal coliform bacteria.

Lower Red Creek (2006 to 2020)

Table 6 summarizes water quality data collected by Alberta Environment and Parks (AEP) for 10 years from 2006 to 2020 at lower Red Creek site and compared to applicable irrigation water quality guidelines. The AEP dataset from 2016 to 2020 is more comprehensive as it includes 17 total metal parameters as well as 4 ions and general parameters (TDS, conductivity, chloride and fecal coliform bacteria). The AEP dataset from 2006 to 2010 is less comprehensive and only includes 5 ions and general parameters (TDS, conductivity, fluoride, chloride and fecal coliform bacteria).

Of the 17 total metal parameters at lower Red Creek, **boron** concentrations sometimes exceeded the irrigation guideline (Table 6; Figure 3). Median boron concentrations (range: 238 to 512 µg/L) exceeded the irrigation guideline (500 to 6,000 µg/L) in 1 of 5 years (2020). In 4 of 5 years, at least one sample (range: 1 to 3) exceeded the boron irrigation guideline. The maximum boron concentration was 623 µg/L recorded in 2017.

Table 5 - Water quality (median and range) at upper, middle and lower Red Creek (2011 to 2019) compared to Irrigation Water Guidelines (GoA 2018). Exceedances shown in red or orange. Data collected by the MRWCC.

Red Creek - upper site										
Parameter	**Guideline**	**2019 (N=10)**	**2018 (N=8)**	**2017 (N=9)**	**2016 (N=10)**	**2015 (N=8)**	**2014 (N=10)**	**2013 (N=9)**	**2012 (N=10)**	**2011 (N=10)**
TDS (mg/L)	500 to 3,500	**2,095** (1,410-2,690)	**1,840** (366-2,220)	**2,020** (1,590-2,240)	**1,965** (1,790-2,130)	**1,980** (1,830-2,130)	**2,025** (1,470-2,320)	**2,160** (2,040-2,420)	**2,155** (2,000-2,510)	**1,910** (1,150-2,110)
Conductivity (µS/cm)	1,000	**2,690** (1,920-3,140)	**2,345** (506-2,796)	**2,540** (2,130-2,690)	**2,610** (2,290-2,760)	**2,350** (2,030-2,700)	**2,415** (1,880-2,760)	**2,550** (2,500-2,700)	**2,555** (2,160-2,880)	**2,445** (1,570-2,690)
Fecal Coliform (#/100 mL)	100	4 (1-300)	61 (1-200)	19 (1-400)	47 (1-8,900)	**122** (1-900)	46 (1-900)	18 (1-400)	41 (1-11,800)	39 (0-900)
Red Creek - middle site										
Parameter	**Guideline**	**2019 (N=7)**	**2018 (N=6)**	**2017 (N=8)**	**2016 (N=7)**	**2015 (N=8)**	**2014 (N=9)**	**2013 (N=10)**	**2012 (N=10)**	**2011 (N=10)**
TDS (mg/L)	500 to 3,500	**1,820** (1,110-1,870)	**1,715** (343-1,900)	**1,920** (1,180-2,270)	**2,020** (1,720-2,320)	**1,885** (1,820-2,370)	**1,950** (1,610-2,310)	**2,045** (1,660-2,510)	**2,055** (1,780-2,430)	**1,835** (1,310-2,230)
Conductivity (µS/cm)	1,000	**2,390** (1,580-2,580)	**2,115** (426-2,440)	**2,560** (1,610-3,080)	**2,870** (2,420-3,450)	**2,335** (2,040-3,020)	**2,590** (2,110-2,880)	**2,665** (2,220-2,860)	**2,620** (2,300-2,970)	**2,455** (1,830-3,020)
Fecal Coliform (#/100 mL)	100	2 (1-300)	57 (1-83)	48 (1-600)	21 (1-1,300)	49 (1-92)	**400** (2-49,000)	14 (1-74)	42 (1-3,800)	19 (2-1,300)
Red Creek - lower site										
Parameter	**Guideline**	**2019 (N=3)**	**2018 (N=9)**	**2017 (N=7)**	**2016 (N=4)**	**2015 (N=6)**	**2014 (N=9)**	**2013 (N=10)**	**2012 (N=10)**	**2011 (N=10)**
TDS (mg/L)	500 to 3,500	**1,900** (1,090-1,990)	**1,900** (375-2,100)	**1,870** (1,670-2,230)	**1,885** (1,760-2,040)	**2,030** (1,920-2,230)	**1,960** (1,730-2,320)	**1,915** (1,710-2,290)	**1,955** (1,800-2,460)	**1,955** (1,350-2,310)
Conductivity (µS/cm)	1,000	**2,600** (1,560-2,880)	**2,489** (510-2,796)	**2,630** (1,530-2,920)	**2,615** (2,500-2,880)	**2,665** (2,440-2,890)	**2,620** (2,250-2,830)	**2,500** (2,230-2,960)	**2,505** (2,380-2,840)	**2,675** (1,870-2,990)
Fecal Coliform (#/100 mL)	100	82 (1->200)	**100** (6-3,600)	**118** (1-700)	**215** (2-700)	**315** (9-6,000)	**300** (1-4,600)	44 (1-17,800)	**178** (4-800)	**123** (12-1,870)

TDS: The irrigation guideline (500 to 3,500 mg/L) for total dissolved solids (TDS) is crop-specific (AEP 2018):

- 500 mg/L: strawberries, raspberries, bean and carrots
- 500 to 800 mg/L: Boysenberries, currants, blackberries, gooseberries, plums, grapes, apricots, peaches, pears, cherries, apples, onions, parsnips, radishes, peas, pumpkins, lettuce, peppers, muskmelons, sweet potatoes, sweet corn, potatoes, celery, cabbage, kohlrabi, cauliflower, cowpeas, broadbeans, flax, sunflower and corn
- 800 to 1,500 mg/L: spinach, cantaloupe, cucumbers, tomatoes, squash, Brussel sprouts, broccoli, turnips, smooth brome, alfalfa, big trefoil, beardless wild rye, vetch, timothy, and crested wheat grass
- 1,500 to 2,500 mg/L: beets, zucchini, canola, sorghum, oat hay, wheat hay, mountain brome, tall fescue, sweet clover, reed canary grass, birdsfoot trefoil, and perennial ryegrass
- 2,500 to 3,500 mg/L: asparagus, soybeans, safflower, oats, rye, wheat, sugar beets, barley, barley hay and tall wheat grass

Conductivity: Irrigation water quality guidelines for conductivity (µS/cm) (AEP 2018):

- ≤ 1,000 (safe)
- > 1,000 to ≤ 2,000 (possibly safe)
- ≥ **2,000** (hazardous)

Table 6 - Water quality (median and range) at lower Red Creek site (2006 to 2020) compared to Irrigation Water Guidelines (GoA 2018). Exceedances are identified in red or orange. Water quality data collected by Alberta Environment and Parks.

Parameter	Guideline	2020 (N=5)	2019 (N=5)	2018 (N=6)	2017 (N=4)	2016 (N=3)	2010 (N=8)	2009 (N=5)	2008 (N=7)	2007 (N=6)	2006 (N=9)
TOTAL METALS (total metals and guidelines are µg/L)											
Aluminum	5,000	18.8 (4.6-26.8)	11.9 (10.8-16.9)	24.3 (12.5-1,470)	75.6 (35-187)	269 (39-1,670)	--	--	--	--	--
Arsenic	160	1.25 (0.77-3.03)	2.39 (1.25-2.97)	2.35 (1.05-6.67)	2.80 (1.81-8.48)	1.30 (1.18-2.31)	--	--	--	--	--
Beryllium	100	0.002 (0.002-0.052)	0.005 (0.002-0.020)	0.003 (0.002-0.080)	0.004 (0.004-0.010)	0.020 (0.009-0.069)	--	--	--	--	--
Boron	500 to 6,000	**512** (396-**570**)	300 (251-**557**)	312 (79.1-**572**)	238 (171-**623**)	265 (106-362)	--	--	--	--	--
Cadmium	8.2	0.005 (0.005-0.030)	0.005 (0.005-0.010)	0.005 (0.005-0.050)	0.006 (0.005-0.010)	0.006 (0.006-0.066)	--	--	--	--	--
Cobalt	50	0.080 (0.001-0.228)	0.202 (0.001-0.269)	0.246 (0.075-0.915)	0.378 (0.173-0.630)	0.286 (0.181-0.732)	--	--	--	--	--
Copper	200 to 1,000	0.03 (0.21-0.42)	0.61 (0.45-9.69)	0.65 (0.34-6.76)	2.09 (1.32-3.17)	2.81 (1.13-4.52)	--	--	--	--	--
Iron	5,000	60.7 (12.5-139)	68.3 (39.3-140)	100 (36.6-1,760)	302 (121-671)	341 (256-1,980)					
Lead	200	0.047 (0.012-0.061)	0.032 (0.002-0.067)	0.049 (0.022-1.07)	0.130 (0.077-0.195)	0.180 (0.127-1.240)	--	--	--	--	--
Lithium	2,500	32.7 (32.1-44.3)	35.9 (34.1-55.6)	35.3 (14.5-41.4)	37.9 (27.1-39.6)	36.9 (12.3-40.8)					
Manganese	200	--	--	2.70 (0.52-52.4)	3.81 (0.54-65.6)	1.68 (1.65-1.72)					
Molybdenum	10	0.738 (0.675-1.22)	1.07 (0.954-1.57)	1.27 (0.946-1.94)	1.21 (0.794-1.56)	1.07 (0.981-1.28)	--	--	--	--	--
Nickel	200	0.44 (0.29-1.19)	1.32 (0.02-7.24)	1.96 (0.69-4.3)	6.43 (2.74-11.60)	0.643 (0.447-2.26)	--	--	--	--	--
Selenium	20 or 50	10.5 (6.2-14.5)	4.0 (2.5-12.4)	3.9 (3.3-16.8)	2.5 (2.26-8.3)	3.1 (0.77-3.43)	--	--	--	--	--
Uranium	10	3.05 (2.43-6.35)	5.91 (2.93-8.70)	4.81 (2.12-6.7)	4.19 (2.74-6.63)	5.36 (1.79-7.57)	--	--	--	--	--
Vanadium	100	0.74 (0.33-1.09)	0.61 (0.59-0.84)	0.906 (0.359-5.38)	1.26 (0.72-2.23)	0.97 (0.53-4.14)	--	--	--	--	--
Zinc	1,000 or 5,000	1.2 (1.0-1.8)	2.0 (1.1-2.2)	2.7 (2.3-7.3)	2.8 (2.5-2.8)	4.7 (1.4-8.0)	--	--	--	--	--

Table 6 - Water quality (median and range) at lower Red Creek site (2006 to 2020) compared to Irrigation Water Guidelines (GoA 2018). Exceedances are identified in red or orange. Water quality data collected by Alberta Environment and Parks.

Parameter	Guideline	2020 (N=5)	2019 (N=5)	2018 (N=6)	2017 (N=4)	2016 (N=3)	2010 (N=8)	2009 (N=5)	2008 (N=7)	2007 (N=6)	2006 (N=9)
IONS & GENERAL (parameter and guideline are mg/L unless otherwise noted)											
TDS	500 to 3,000	1,900 (1,800-2,200)	1,900 (1,800-2,100)	1,900 (520-2,100)	1,650 (1,100-1,900)	1,900 (560-2,100)	1,725 (1,100-2,250)	1,800 (1,400-1,900)	1,700 (1,600-2,100)	1,675 (1,610-1,860)	1,680 (1,590-1,750)
Conductivity (µS/cm)	1,000	2,700 (2,500-3,000)	2,700 (2,600-2,900)	2,600 (820-2,800)	2,400 (1,600-2,500)	2,700 (880-2,800)	2,400 (1,600-3,100)	2,500 (2,000-2,700)	2,500 (2,280-2,800)	2,365 (2,280-2,630)	2,370 (2,150-2,420)
Dissolved Flouride	1	--	--	--	--	--	--	0.12 (0.12-0.14)	0.14 (0.12-0.18)	0.14 (0.12-0.15)	0.11 (0.10-0.13)
Chloride	100 to 700	30 (29-41)	37 (32-40)	35 (13-41)	31 (25-36)	37 (13-39)	32 (28-39)	28 (26-35)	29.5 (26-35)	27.1 (24.4-32.4)	27.3 (25.4-30.4)
Fecal Coliform (#/100 mL)	100	20 (6-1,091)	160 (67-2,000)	70 (6-3,600)	72 (2-700)	280 (1-290)	100 (1-1,727)	3 (1-2,500)	350 (1-5,300)	415 (1-730)	100 (18-5,100)

Boron: The irrigation guideline (500 to 6,000 µg/L) for Boron is crop-specific:
- 500 µg/L: blackberries
- 500 to 1,000 µg/L: plums, grapes, cowpeas, peaches, cherries, onions, sweet potatoes, sunflower, garlic, wheat, barley, mung beans, sesame, lupins, strawberries, Jerusalem artichokes, kidney beans and lima beans
- 1,000 to 2,000 µg/L: red peppers, peas, carrots, radishes, potatoes and cucumbers
- 2,000 to 4,000 µg/L: lettuce, cabbage, celery, turnips, Kentucky bluegrass, corn, artichokes, tobacco, mustard, clover, squash, muskmelons and oats
- 4,000 to 6,000 µg/L: sugar beets, alfalfa, sorghum, tomatoes, purple vetch, parsley and red beets
- 6,000 µg/L: asparagus

TDS: The irrigation guideline (500 to 3,500 mg/L) for Total Dissolved Solids (TDS) is crop-specific:
- 500 mg/L: strawberries, raspberries, bean and carrots
- 500 to 800 mg/L: Boysenberries, currants, blackberries, gooseberries, plums, grapes, apricots, peaches, pears, cherries, apples, onions, parsnips, radishes, peas, pumpkins, lettuce, peppers, muskmelons, sweet potatoes, sweet corn, potatoes, celery, cabbage, kohlrabi, cauliflower, cowpeas, broadbeans, flax, sunflower and corn
- 800 to 1,500 mg/L: spinach, cantaloupe, cucumbers, tomatoes, squash, Brussel sprouts, broccoli, turnips, smooth brome, alfalfa, big trefoil, beardless wild rye, vetch, timothy, and crested wheat grass
- 1,500 to 2,500 mg/L: beets, zucchini, canola, sorghum, oat hay, wheat hay, mountain brome, tall fescue, sweet clover, reed canary grass, birdsfoot trefoil, and perennial ryegrass
- 2,500 to 3,500 mg/L: asparagus, soybeans, safflower, oats, rye, wheat, sugar beets, barley, barley hay and tall wheat grass

Conductivity: Irrigation water quality guidelines for conductivity (µS/cm):
- ≤ 1,000 (safe)
- > 1,000 to ≤ 2,000 (possibly safe)
- ≥ 2,000 (hazardous)

The median **TDS** at the lower Red Creek site exceeded the irrigation guideline (500 to 3,500 mg/L) in each of the ten years from 2006 to 2020 (Table 6; Figure 4). Median TDS at the lower site ranged from 1,650 to 1,900 mg/L with individual samples ranging between 520 and 2,250 mg/L. One hundred percent (100%) of samples (N=58) from lower Red Creek (2006-2020) exceeded the irrigation guideline for TDS.

The median **conductivity** at the lower Red Creek site exceeded the irrigation guideline (≤ 1000 µS/cm) in each of the ten years from 2006 to 2020 (Table 6). Median conductivity at the lower site ranged from 2,365 to 2,700 µS/cm with individual samples ranging between 820 and 3,100 µS/cm. The median conductivity at each site exceeded 2,000 µS/cm which classified the water as "hazardous" for irrigation. Ninety-seven percent (97%) of samples (N=58) from lower Red Creek (2006-2020) exceeded the irrigation guideline for conductivity.

The median **fecal coliform bacteria** count at the lower site (range: 20 to 415 cfu/100 mL) often exceeded (6 of 10 years) the irrigation guideline (Table 6). Fecal coliform counts at the lower site ranged from 1 to 5,300 cfu/100 mL. Fifty percent (50%) of samples (N=58) from the lower Red Creek site (2006-2020) exceeded the irrigation guideline for fecal coliform bacteria.

3.2.2 Discussion

Boron

Boron is an essential micronutrient for normal plant growth and is involved in many important processes in plants particularly in a primary role as a structural component conferring stability to cell walls and plasma membranes. In excess, boron can have a significant toxicity that affects crop yield and quality. Typical visible symptoms of boron toxicity include leaf discolouration, as well as reduced plant vigour, delayed plant development, and decreased number, size and weight of fruits (Princi *et al.* 2015).

Concerns with boron toxicity from Red Creek irrigation water are likely minor. The median boron concentration marginally exceeded the lower range of the guideline once in five years (2020: median boron 512 µg/L, Guideline 500 to 6,000 µg/L) (Figure 3). In 5 years, 6 of 23 samples exceeded the guideline with boron concentrations ranging from 512 to 623 µg/L. Crop-specific guidelines for boron indicate that Red Creek irrigation water may have limitations for irrigating blackberries (Table 6: footnotes). Berry production in the Red Creek watershed is likely limited to home use and would not be commercially important. Economically more important crops and plants in the Red Creek watershed such as wheat, barley, oats and alfalfa have boron tolerances >500 µg/L.

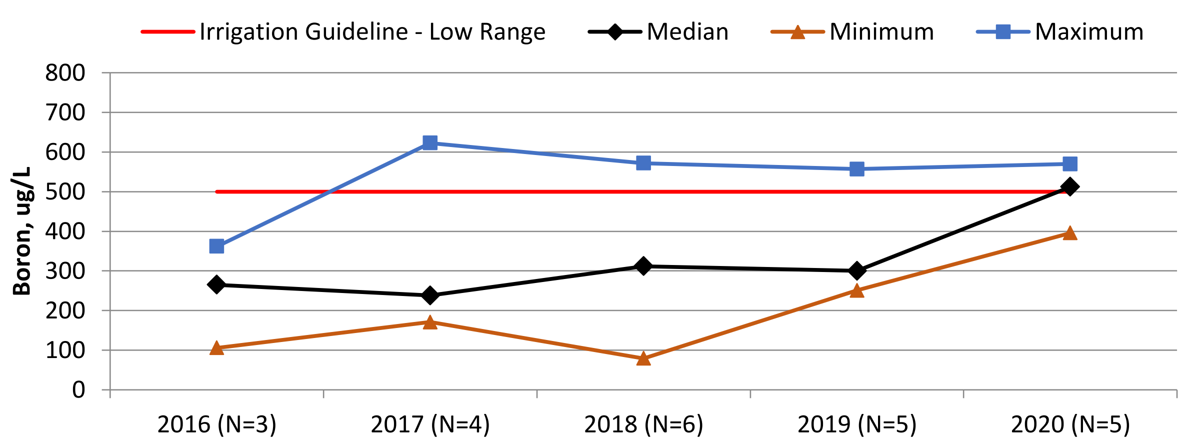


Figure 3. Boron concentrations at the Lower Red Creek site (2016-2020).

Salinity

Plant responses to excess salinity have been divided into two main phases. First, a short-term phase of ion-independent growth reduction, causing stomatal closure and inhibition of cell expansion mainly in the shoot. A second longer-term phase and relates to the build-up of cytotoxic ion levels, which slows down metabolic processes, causes premature senescence, and ultimately cell death (Isayenkov and Maathuis 2019). The general effect of salinity is to reduce the growth rate resulting in smaller leaves, shorter stature, and sometimes fewer leaves. The initial and primary effect of salinity, especially at low to moderate concentrations, is due to its osmotic effects. Roots are also reduced in length and mass but may become thinner or thicker. Maturity rate may be delayed or advanced depending on species. Ionic effects are manifested more generally in leaf and meristem damage or as symptoms typical of nutritional disorders.

Water used from Red Creek for irrigation may have limitations due to salinity. The median TDS and conductivity values exceeded guidelines for irrigation (Figure 4). With typical median TDS values ranging between 1,800 and 2,000 mg/L, the irrigation of several fruit and vegetables (e.g., strawberries, raspberries, beans, carrots, cantaloupe, apples, onions, peas, pumpkins, lettuce, peppers, potatoes, cabbage, cucumbers, tomatoes) and some pasture and hay crops (alfalfa, wild rye, smooth brome, vetch, timothy and crested wheat grass) may have limitations (Table 5: footnotes). Water from Red Creek may be suitable to irrigate vegetables more tolerant of salinity (e.g., beets, zucchini, asparagus) and hay and crop species (e.g., canola, oat hay, wheat hay, mountain brome, tall fescue, sweet clover, perennial ryegrass, oats, rye and barley).

Groundwater is an important contributor to streamflow at Red Creek. Local groundwater tends to be high in total dissolved solids. In the groundwater investigation of 40 wells, total dissolved solids concentrations ranged from 270 to 3,400 mg/L in wells located in the County of Warner (MRWCC 2013).

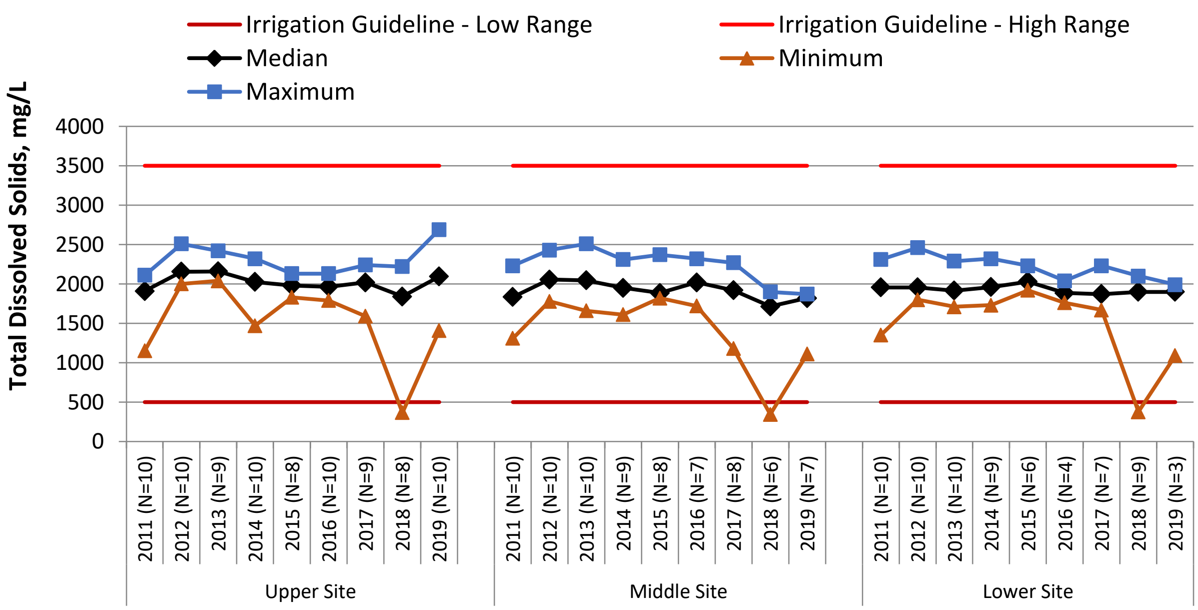


Figure 4. Total Dissolved Solids concentrations compared to the Irrigation guidelines at Upper, Middle and Lower Red Creek (2011-2019).

Fecal Coliform Bacteria

Exceedance of irrigation guidelines for fecal coliform bacteria occurs at the three Red Creek sites. The lower Red Creek site in particular has high median annual fecal coliform bacteria counts that often exceed the irrigation guideline of 100 cfu/100 mL (Figure 5). Single sample counts have reached as high as 17,800 cfu/100 mL at the lower site. Although fecal coliform bacteria counts are high at Red Creek, the concern for irrigation use is lower as the irrigation guideline has been developed largely to address potential human health risks of consuming irrigated raw produce that may be consumed soon after irrigation (e.g., lettuce, cabbage etc.). There are no commercial vegetable or fruit operations in the Red Creek watershed that would use irrigation; however, Red Creek watershed residents should be aware of fecal coliform bacteria concerns for irrigation water from Red Creek for home garden use.

The source of fecal coliform bacteria at Red Creek is not known. Fecal coliform bacteria are specific to the intestinal tracts of warm-blooded animals (e.g., cattle, birds, deer, muskrats, pets etc.) and humans. More specific tests could be conducted using microbial source tracking to identify potential sources of fecal coliform bacteria at Red Creek. If cattle are determined to be a source of fecal coliform bacteria to Red Creek, measures such as offstream watering and fencing to prevent direct cattle access to streams may be beneficial in reducing bacteria counts. Riparian fencing can have additional benefits such as increasing bank stability, reducing bank erosion and sediment, reducing transport of nutrients and metals by way of sediment adsorption and increasing habitat diversity for wildlife.

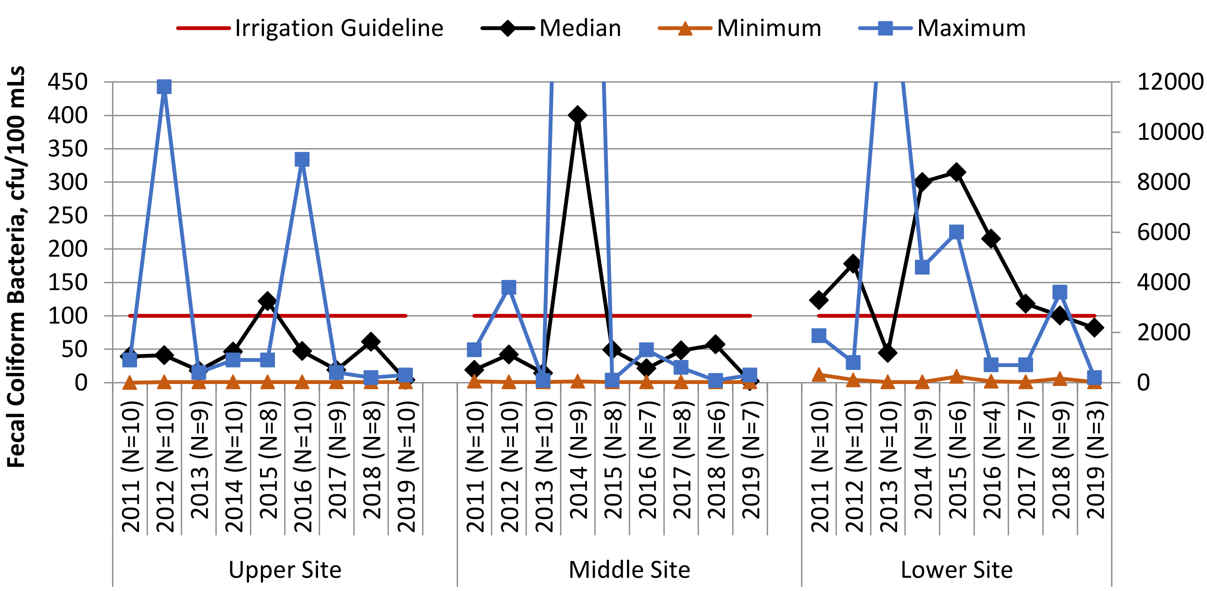


Figure 5. Fecal coliform bacteria counts at Red Creek compared to the Irrigation guideline. The secondary scale on the right-side of the graph (scale 0 to 12,000) is for the maximum fecal coliform bacteria count only.

3.3 AQUATIC LIFE WATER QUALITY

3.3.1 Results

Upper, Middle and Lower Red Creek (2011 to 2019)
Table 7 summarizes water quality data collected by the MRWCC from 2011 to 2019 at the upper, middle and lower Red Creek sites and compared to applicable protection of aquatic life (PAL) guidelines. The relevant PAL water quality parameters were limited to nitrate, nitrite, dissolved oxygen and pH. **Nitrite** and **pH** (median and individual samples) were always in compliance at all Red Creek sites in all years (Table 7).

A single exceedance (4.26 mg/L) of the chronic **nitrate** PAL guideline (3 mg/L) occurred in October 2018 at the upper Red Creek site and was 1.4 times the guideline. Ninety-nine percent (99%) of the nitrate results at the upper site and 100% of the nitrate results at the middle and lower site met the PAL guideline.

Dissolved oxygen concentrations at the upper and middle Red Creek sites occasionally exceeded the PAL guidelines. Dissolved oxygen concentrations at the lower Red Creek site were always in compliance with the PAL guidelines (Tables 7 and 8; Figure 6). The 2014 median dissolved oxygen concentration (5.95 mg/L) at upper Red Creek did not meet the chronic PAL guideline (>6.5 mg/L) (Table 7). The annual median dissolved oxygen in all other years and sites (range: 7.56 to 11.46 mg/L) met the chronic PAL guideline. Individual samples occasionally did not meet the acute dissolved oxygen PAL guideline (>5 mg/L) at the upper and middle Red Creek sites. At upper Red Creek there were seven acute exceedances (2.61 to 4.97 mg/L) within the years 2013(1), 2014(3), 2016(1) and 2017(2). At middle Red Creek there were six acute exceedances (2.55 to 4.92 mg/L) within the years 2013(1), 2014(3), 2016(1) and 2018(1).

The **total phosphorus** was high at the upper and middle sites. Annual median total phosphorus ranged from 0.0223 to 0.1765 mg/L, and 14 of 18 annual median total phosphorus concentrations exceeded the historic guideline of 0.5 mg/L at the upper and middle sites. Total phosphorus at the lower site was low. Annual median total phosphorus ranged from 0.0241 to 0.0511 mg/L at the lower site, and 1 of 9 annual median total phosphorus concentrations marginally exceeded the historic guideline of 0.5 mg/L (Table 7). The maximum total phosphorus was 0.6150 mg/L which occurred at the upper site on June 22, 2017 during moderate but increasing flow. The annual median **dissolved phosphorus** ranged from 0.0055 to 0.067 mg/L at the upper, middle and lower sites and comprised approximately 48% of the total phosphorus.

The **total nitrogen** was high at the upper, middle and lower sites. Annual median total nitrogen ranged from 0.778 to 2.052 mg/L, and 24 of 27 annual median total nitrogen concentrations exceeded the historic guideline of 1.0 mg/L at the upper and middle sites (Table 7). The maximum total nitrogen was 5.74 mg/L which occurred at the upper site on October 24, 2018 during low flow. The annual median

Table 7 - Water quality (median and range) at upper, middle and lower Red Creek sites (2011 to 2019) compared to Protection of Aquatic Life Guidelines (GoA 2018). Exceedances are identified in red (acute) or orange (chronic). Water quality data collected by the MRWCC.

Red Creek - upper site (all parameters are mg/L except pH [units])										
Parameter	**Guideline**	**2019 (N=10)**	**2018 (N=8)**	**2017 (N=9)**	**2016 (N=10)**	**2015 (N=8)**	**2014 (N=10)**	**2013 (N=9)**	**2012 (N=10)**	**2011 (N=10)**
Nitrate	3 c 124 a	0.064 (0.050-2.680)	0.492 (0.055-4.26)	0.25 (0.025-1.6)	0.05 (0.05-1.76)	0.188 (0.055-1.43)	0.296 (0.025-1.6)	0.025 (0.025-1.41)	0.102 (0.025-0.952)	0.025 (0.025-1.420)
Nitrite	0.20 c 0.60 a	0.025 (0.025-0.025)	0.025 (0.021-0.071	0.025 (0.005-0.074)	0.025 (0.005-0.083)	0.025 (0.005-0.025)	0.025 (0.010-0.060)	0.025 (0.025-0.060)	0.045 (0.025-0.125)	0.025 (0.025-0.057)
Oxygen (dissolved)	6.5 c 5 a	8.28 (5.53-13.01)	9.09 (5.68-12.62)	7.98 (4.51-12.41)	10.06 (4.34-13.53)	9.50 (6.61-12.24)	5.95 (2.61-10.70)	8.97 (4.61-10.37)	7.51 (5.08-10.94)	--
pH (units)	6.5 to 9.0 c	8.19 (7.99-8.33)	8.44 (7.99-8.55)	8.24 (7.98-8.34)	8.15 (7.69-8.58)	8.28 (7.95-8.37)	8.22 (8.11-8.42)	8.24 (7.94-8.32)	8.20 (8.00-8.32)	--
Other Parameters (mg/L, no guidelines)										
Total Phosphorus	--	0.053 (0.016-0.212)	0.0810 (0.0122-0.4880)	0.0450 (0.0251-0.6150)	0.0225 (0.0152-0.0466)	0.0351 (0.025-0.0528)	0.0734 (0.0152-0.4570)	0.0223 (0.0146-0.0345)	0.0552 (0.0025-0.0770)	0.108 (0.052-0.700)
Dissolved Phosphorus	--	0.017 (0.008-0.111)	0.067 (0.003-0.413)	0.0214 (0.0082-0.447)	0.0159 (0.0116-0.0329)	0.0174 (0.0103-0.0313)	0.0298 (0.0061-0.426)	0.01 (0.0025-0.0139)	0.0201 (0.0025-0.028)	0.045 (0.015-0.604)
Total Nitrogen	--	2.052 (0.725-4.100)	1.96 (0.85-5.74)	1.81 (0.85-2.54)	1.10 (0.635-2.81)	1.15 (0.42-2.39)	1.638 (0.787-2.23)	1.066 (0.7455-2.1)	1.10 (0.8655-1.87)	1.358 (0.766-3.900)
Total Kjeldahl Nitrogen	--	1.165 (0.670-3.010)	1.33 (0.73-1.68)	1.00 (0.84-2.12)	0.93 (0.58-1.1)	0.85 (0.10-1.10)	0.99 (0.57-1.71)	0.76 (0.69-1.08)	0.90 (0.76-1.44)	1.255 (0.730-2.500)
Total Suspended Solids	--	12 (5-106)	9.15 (1.5-33.3)	12 (4-61)	2.3 (1.5-8)	4.3 (1.5-6)	6.2 (2-26.1)	2 (2-13)	10 (6.3-40)	11 (2-27)
Red Creek - middle site (all parameters are mg/L except pH [units])										
Parameter	**Guideline**	**2019 (N=7)**	**2018 (N=6)**	**2017 (N=8)**	**2016 (N=7)**	**2015 (N=8)**	**2014 (N=9)**	**2013 (N=10)**	**2012 (N=10)**	**2011 (N=10)**
Nitrate	3 c 124 a	0.050 (0.050-0.870)	0.055 (0.05-0.512)	0.055 (0.055-0.055)	0.05 (0.05-0.14)	0.055 (0.055-0.28)	0.025 (0.025-0.125)	0.025 (0.025-0.025)	0.058 (0.025-0.125)	0.025 (0.025-0.685)
Nitrite	0.20 c 0.60 a	0.025 (0.025-0.025)	0.025 (0.018-0.025)	0.025 (0.025-0.025)	0.025 (0.025-0.025)	0.025 (0.025-0.025)	0.010 (0.010-0.050)	0.025 (0.025-0.025)	0.038 (0.025-0.125)	0.025 (0.025-0.025)
Oxygen (dissolved)	6.5 c 5 a	8.06 (6.49-9.98)	8.00 (4.07-10.92)	9.19 (8.39-11.87)	8.85 (2.55-14.33)	8.63 (5.60-11.90)	7.66 (4.41-8.91)	7.61 (4.14-11.60)	7.96 (5.96-11.08)	--
pH (units)	6.5 to 9.0 c	8.33 (7.94-8.40)	8.49 (8.12-8.64)	8.42 (8.18-8.61)	8.45 (7.98-8.92)	8.39 (7.89-8.67)	8.33 (8.26-8.64)	8.29 (8.01-8.79)	8.25 (8.09-8.33)	--
Other Parameters (mg/L, no guidelines)										
Total Phosphorus	--	0.075 (0.072-0.172)	0.1765 (0.0560-0.3620)	0.0982 (0.0450-0.3410)	0.0799 (0.0407-0.0969)	0.077 (0.063-0.111)	0.151 (0.031-0.178)	0.081 (0.038-0.16)	0.101 (0.009-0.23)	0.116 (0.059-0.566)
Dissolved Phosphorus	--	0.045 (0.039-0.094)	0.081 (0.036-0.174)	0.0473 (0.0240-0.3100)	0.0466 (0.0260-0.0770)	0.0382 (0.021-0.0527)	0.0481 (0.0276-0.139)	0.030 (0.01-0.0468)	0.0331 (0.0025-0.0522)	0.072 (0.007-0.410)

Table 7 - Water quality (median and range) at upper, middle and lower Red Creek sites (2011 to 2019) compared to Protection of Aquatic Life Guidelines (GoA 2018). Exceedances are identified in red (acute) or orange (chronic). Water quality data collected by the MRWCC.

Total Nitrogen	--	1.080 (0.705-2.510)	1.275 (0.65-1.815)	1.33 (1.13-1.94)	1.325 (0.845-2.005)	0.93 (0.32-1.58)	1.367 (0.487-1.695)	1.2505 (0.9155-1.4555)	1.45 (0.8855-1.335)	1.271 (0.906-3.385)
Total Kjeldahl Nitrogen	--	0.920 (0.650-1.640)	1.18 (0.60-1.58)	1.28 (1.08-1.89)	1.27 (0.79-1.95)	0.88 (0.31-1.53)	1.31 (0.46-1.56)	1.215 (0.880-1.420)	1.035 (0.850-1.270)	1.235 (0.870-2.700)
Total Suspended Solids	--	9 (7-12)	14.0 (3.7-91.3)	12 (6-26)	3.7 (1.5-12.7)	6.7 (3.3-10.7)	16 (4.1-39.9)	5 (2-21)	13 (2-22.9)	12 (2-77)
Red Creek - lower site (all parameters are mg/L except pH [units])										
Parameter	**Guideline**	**2019 (N=3)**	**2018 (N=9)**	**2017 (N=7)**	**2016 (N=4)**	**2015 (N=6)**	**2014 (N=9)**	**2013 (N=10)**	**2012 (N=10)**	**2011 (N=10)**
Nitrate	3 c 124 a	0.098 (0.050-0.920)	0.38 (0.02-0.85)	0.055 (0.002-0.017)	0.10 (0.05-0.17)	0.135 (0.055-0.32)	0.130 (0.025-0.812)	0.644 (0.025-1.52)	0.454 (0.125-2.16)	0.058 (0.025-2.290)
Nitrite	0.20 c 0.60 a	0.025 (0.005-0.025)	0.014 (0.004-0.027)	0.025 (0.002-0.025)	0.025 (0.025-0.025)	0.025 (0.025-0.025)	0.025 (0.010-0.052)	0.025 (0.025-0.025)	0.039 (0.025-0.125)	0.025 (0.025-0.025)
Oxygen (dissolved)	6.5 c 5 a	10.86 (10.64-11.08)	10.64 (10.18-11.58)	10.75 (9.50-13.47)	10.22 (10.16-11.84)	11.46 (6.84-18.30)	9.38 (5.48-12.84)	9.33 (7.84-10.91)	10.08 (8.83-12.09)	--
pH (units)	6.5 to 9.0 c	8.39 (8.35-8.48)	8.17 (8.06-8.56)	8.35 (7.97-8.50)	8.39 (8.29-8.43)	8.41 (8.33-8.52)	8.34 (8.24-8.58)	8.29 (8.04-8.40)	8.30 (8.14-8.37)	--
Other Parameters (mg/L, no guidelines)										
Total Phosphorus	--	0.028 (0.024-0.121)	0.0260 (0.0093-0.4000)	0.0364 (0.019-0.18)	0.0298 (0.0212-0.0412)	0.0511 (0.036-0.0703)	0.0320 (0.0161-0.098)	0.0241 (0.0055-0.081)	0.0307 (0.0025-0.0525)	0.050 (0.007-0.486)
Dissolved Phosphorus	--	0.015 (0.015-0.068)	0.020 (0.003-0.320)	0.0192 (0.007-0.16)	0.0176 (0.0139-0.0292)	0.0194 (0.0123-0.0307)	0.0094 (0.0053-0.0475)	0.0055 (0.0025-0.113)	0.0089 (0.0025-0.0181)	0.031 (0.001-0.322)
Total Nitrogen	--	0.778 (0.665-2.470)	1.05 (0.64-2.04)	1.07 (0.51-1.3)	0.82 (0.685-1.11)	1.02 (0.64-2.93)	1.23 (0.717-1.725)	1.244 (0.898-3.78)	1.253 (0.83-2.59)	1.821 (0.916-2.776)
Total Kjeldahl Nitrogen	--	0.680 (0.610-1.550)	0.82 (0.25-1.4)	1.02 (0.51-1.3)	0.73 (0.59-0.96)	0.82 (0.52-2.76)	0.79 (0.53-1.59)	0.66 (0.38-2.48)	0.60 (0.2-0.96)	1.060 (0.250-2.740)
Total Suspended Solids	--	6 (4-6)	1.60 (0.5-135)	3.7 (1-9)	6.3 (1.5-10)	16.7 (5.3-42)	8.5 (3.3-25.3)	6 (2-32)	8 (5-21)	9 (4-117)

Notes:
Water quality samples were not collected at Red Creek sites in 2020 due to Covid-19 restrictions.
Guideline: 'c' denotes chronic guideline, 'a' denotes acute guideline
Total Phosphorus and Total Nitrogen – Until 2014, Alberta used a chronic guideline of 0.5 mg/L and 1.0 mg/L, respectively.

Total Kjeldahl nitrogen ranged from 0.60 to 1.33 mg/L at the upper, middle and lower sites and comprised approximately 79% of the total nitrogen.

Total suspended solids at the upper, middle and lower sites of Red Creek were relatively low with the annual median ranging from 1.6 to 26.6 mg/L with maximum concentrations ranging from 6 to 135 mg/L (Table 7). Two of the TSS concentrations over 100 mg/L occurred in April (2018) or June (2011) during high flows from either snowmelt or heavy precipitation; however, a high TSS concentration in September 2019 occurred during very low flow and may have been related to a nearby local event (e.g., cattle or waterfowl instream, bank sloughing).

Lower Red Creek (2006 to 2020)

Table 8 summarizes water quality data collected by Alberta Environment and Parks (AEP) for 10 years from 2006 to 2020 at lower Red Creek site and compared to applicable protection of aquatic life (PAL) water quality guidelines. The AEP dataset from 2016 to 2020 is more comprehensive as it includes 17 metal parameters as well as 8 ions and general parameters (alkalinity, ammonia, chloride, nitrate, nitrite, dissolved oxygen, pH and sulphate) relevant to PAL guidelines. The AEP dataset from 2006 to 2010 is less comprehensive and only includes 7 ions and general parameters (the above parameters minus dissolved oxygen).

Individual samples of four total and dissolved metals infrequently exceeded the chronic PAL guideline in the years from 2016 to 2020 (Table 8). The median concentration of these four metals was less than the chronic PAL guideline in each year. A single sample analysed for **dissolved aluminum** (77.8 µg/L) exceeded the chronic guideline (guideline: 50 µg/L) in 2016 at lower Red Creek and was 1.6 times above the guideline. Two samples analysed for **total arsenic** (6.67 and 8.48 µg/L) exceeded the chronic guideline (guideline: 5 µg/L) in 2018 and 2017 at lower Red Creek and were 1.3 and 1.7 times above the guideline, respectively. A single sample analysed for **total copper** (9.69 µg/L) exceeded the chronic guideline (guideline: 7 µg/L) in 2019 at lower Red Creek and was 1.4 times above the guideline. Two samples analysed for **total mercury** (5.82 and 6.53 ng/L) exceeded the chronic guideline (guideline: 5 ng/L) in 2018 and 2016 at lower Red Creek and were 1.2 and 1.3 times above the guideline, respectively.

Total selenium frequently exceeded the chronic PAL guideline. Ninety-six percent (96%) of samples (N=23) from 2016 to 2020 (range: 0.77 to 16.8 µg/L) exceeded the chronic guideline (2 µg/L) for total selenium (Table 8). The median total selenium in each of the 5 years (range: 2.5 to 10.5 µg/L) exceeded the chronic guideline by 1.3 to 5.3 times. The maximum total selenium concentration at lower Red Creek was 16.8 µg/L on August 20, 2018 and exceeded the chronic guideline by 8.4 times.

Total phosphorus at the lower site from 2006 to 2020 was low. Annual median total phosphorus ranged from 0.0063 to 0.038 mg/L at the lower site, and 0 of 10 exceeded the historic guideline of 0.5 mg/L (Table 8). The maximum total phosphorus was 0.4 mg/L which occurred on April 23, 2018 during moderately high flow and a TSS of 22 mg/L. The annual median **dissolved phosphorus** ranged from 0.0032 to 0.019 mg/L at the lower site and comprised approximately 46% of the total phosphorus.

The **total nitrogen** was moderately high at the lower site from 2006 to 2020. Annual median total nitrogen ranged from 0.50 to 1.15 mg/L, and 3 of 10 annual median concentrations exceeded the historic guideline of 1.0 mg/L (Table 8). The maximum total nitrogen was 2.93 mg/L which occurred on June 2, 2010 after 76 mm of rain the previous week. The annual median **total Kjeldahl nitrogen** ranged from 0.44 to 0.99 mg/L at the lower site and comprised approximately 85% of the total nitrogen.

Total suspended solids at the lower site of Red Creek were relatively low with the annual median ranging from 1 to 20 mg/L with maximum concentrations ranging from 3 to 36 mg/L (Table 8).

Table 8 - Water quality (median and range) at lower Red Creek site (2006 to 2020) compared to Protection of Aquatic Life guidelines (GoA 2018). Chronic exceedances are identified in orange. Water quality data collected by Alberta Environment and Parks.

Parameter	Guideline c-chronic a-acute	2020 (N=5)	2019 (N=5)	2018 (N=6)	2017 (N=4)	2016 (N=3)	2010 (N=8)	2009 (N=5)	2008 (N=7)	2007 (N=6)	2006 (N=9)
TOTAL METALS (metals and guidelines are µg/L except total mercury [ng/L])											
Aluminum (dissolved)	50 c 100 a	--	--	1.4 (0.7-1.9)	7.9 (1.9-12.5)	2.16 (1.19-77.8)	--	--	--	--	--
Arsenic	5 c	1.25 (0.77-3.03)	2.39 (1.25-2.97)	2.35 (1.05-6.67)	2.80 (1.81-8.48)	1.30 (1.18-2.31)	--	--	--	--	--
Boron	1,500 c 29,000 a	512 (396-570)	300 (251-557)	312 (79.1-572)	238 (171-623)	265 (106-362)	--	--	--	--	--
Cadmium	0.30 to >0.37 c 4.7 to >7.7 a	0.005 (0.005-0.030)	0.005 (0.005-0.010)	0.005 (0.005-0.050)	0.006 (0.005-0.010)	0.006 (0.006-0.066)	--	--	--	--	--
Cobalt	1.4 to >1.8 c	0.080 (0.001-0.228)	0.202 (0.001-0.269)	0.246 (0.075-0.915)	0.378 (0.173-0.630)	0.286 (0.181-0.732)	--	--	--	--	--
Copper	7 c 35 to >62 a	0.03 (0.21-0.42)	0.61 (0.45-9.69)	0.65 (0.34-6.76)	2.09 (1.32-3.17)	2.81 (1.13-4.52)	--	--	--	--	--
Iron (dissolved)	300 a			14 (8-53)	80 (13-162)	65 (30.9-102)					
Lead	7 c	0.047 (0.012-0.061)	0.032 (0.002-0.067)	0.049 (0.022-1.07)	0.130 (0.077-0.195)	0.180 (0.127-1.240)	--	--	--	--	--
Manganese (dissolved)	290 to 300 c	5 (2-43)	6 (2-66)	11 (2-64)	21 (2-86)	15 (2-15)	32 (2-67)	5 (2-20)	6 (2-19)	11 (5-29)	2 (2-7)
Mercury (ng/L)	5 c 13 a	0.59 (0.03-1.46)	1.37 (1.22-1.63)	1.2 (0.69-5.82)	1.52 (1.29-2.97)	0.94 (0.92-6.53)	--	--	--	--	--
Molybdenum	73 c	0.738 (0.675-1.22)	1.07 (0.954-1.57)	1.27 (0.946-1.94)	1.21 (0.794-1.56)	1.07 (0.981-1.28)	--	--	--	--	--
Nickel	100 to >170 c 910 to >1,520 a	0.44 (0.29-1.19)	1.32 (0.02-7.24)	1.96 (0.69-4.3)	6.43 (2.74-11.60)	0.643 (0.447-2.26)	--	--	--	--	--
Selenium	2 c	10.5 (6.2-14.5)	4.0 (2.5-12.4)	3.9 (3.3-16.8)	2.5 (2.26-8.3)	3.1 (0.77-3.43)	--	--	--	--	--
Silver	0.25 c	0.001 (0.005-0.010)	0.004 (0.001-0.011)	0.005 (0.002-0.017)	0.005 (0.003-0.006)	0.010 (0.004-0.013)	--	--	--	--	--
Thallium	0.8 c	0.003 (0.001-0.005)	0.003 (0.001-0.010)	0.003 (0.003-0.022)	0.0085 (0.0031-0.0155)	0.0061 (0.005-0.0244)	--	--	--	--	--
Uranium	15 c 33 a	3.05 (2.43-6.35)	5.91 (2.93-8.70)	4.81 (2.12-6.7)	4.19 (2.74-6.63)	5.36 (1.79-7.57)	--	--	--	--	--
Zinc	30 c	1.2 (1.0-1.8)	2.0 (1.1-2.2)	2.7 (2.3-7.3)	2.8 (2.5-2.8)	4.7 (1.4-8.0)	--	--	--	--	--

Table 8 - Water quality (median and range) at lower Red Creek site (2006 to 2020) compared to Protection of Aquatic Life guidelines (GoA 2018). Chronic exceedances are identified in orange. Water quality data collected by Alberta Environment and Parks.

Parameter	Guideline c-chronic a-acute	2020 (N=5)	2019 (N=5)	2018 (N=6)	2017 (N=4)	2016 (N=3)	2010 (N=8)	2009 (N=5)	2008 (N=7)	2007 (N=6)	2006 (N=9)
IONS & GENERAL (all parameters are mg/L except pH [units])											
Alkalinity	>20	430 (340-550)	360 (270-420)	360 (130-450)	360 (270-460)	340 (140-370)	395 (250-520)	430 (340-520)	470 (375-500)	450 (383-496)	440 (386-487)
Ammonia (total)	0.109 to 1.91 c	0.073 (0.038-0.15)	0.059 (0.021-0.2)	0.041 (0.033-0.099)	0.032 (0.025-0.23)	0.067 (0.025-0.069)	--	0.06 (0.025-0.08)	0.05 (0.025-0.15)	0.035 (0.025-0.09)	0.05 (0.005-0.11)
Chloride	120 c 640 a	30 (29-41)	37 (32-40)	35 (13-41)	31 (25-36)	37 (13-39)	32 (28-39)	28 (26-35)	29.5 (26-35)	27.1 (24.4-32.4)	27.3 (25.4-30.4)
Nitrate	3 c 124 a	0.23 (0.2-1.4)	0.094 (0.052-0.21)	0.32 (0.02-0.53)	0.010 (0.002-0.34)	0.079 (0.002-0.17)	0.072 (0.002-1.1)	0.017 (0.014-0.05)	0.028 (0.002-0.61)	0.083 (0.01-0.299)	0.005 (0.003-0.473)
Nitrite	0.20 c 0.60 a	0.024 (0.014-0.027)	0.002 (0.002-0.013)	0.007 (0.004-0.027)	0.002 (0.002-0.011)	0.002 (0.002-0.0039)	0.002 (0.002-0.067)	0.002 (0.002-0.003)	0.003 (0.002-0.014)	0.003 (0.002-0.009)	0.002 (0.002-0.019)
Oxygen (dissolved)	6.5 c 5 a	12.64 (10.31-15.10)	10.26 (9.62-11.26)	10.63 (10.18-11.58)	10.19 (10.02-12.78)	10.03 (7.02-10.98)	--	--	--	--	--
pH (units)	6.5 to 9.0 c	8.29 (8.19-8.39)	8.26 (8.22-8.38)	8.34 (8.10-8.37)	8.30 (8.03-8.42)	8.31 (8.06-8.38)	8.26 (8.08-8.39)	8.38 (8.25-8.48)	8.3 (8.1-8.4)	8.29 (8.14-8.35)	8.45 (8.35-8.56)
Sulphate	see note	940 (890-1,300)	1,100 (920-1,300)	1,000 (260-1,200)	880 (560-1,000)	1,100 (280-1,260)	880 (770-1,300)	880 (730-1,100)	890 (800-1,200)	856 (792-1,000)	828 (791-885)
OTHER PARAMETERS (mg/L, no guidelines)											
Total Phosphorus	--	0.0063 (0.0044-0.017)	0.022 (0.011-0.031)	0.016 (0.0093-0.4)	0.038 (0.019-0.042)	0.025 (0.22-0.038)	0.023 (0.002-0.094)	0.019 (0.017-0.360)	0.015 (0.01-0.031)	0.021 (0.01-0.037)	0.009 (0.004-0.01)
Dissolved Phosphorus	--	0.0032 (0.002-0.0089)	0.0081 (0.0066-0.013)	0.010 (0.0031-0.32)	0.019 (0.007-0.16)	0.011 (0.01-0.025)	0.014 (0.002-0.17)	0.007 (0.005-0.009)	0.007 (0.004-0.025)	0.005 (0.002-0.008)	0.004 (0.002-0.005)
Total Nitrogen	--	1.1 (0.71-1.9)	0.85 (0.54-0.97)	0.85 (0.7-1.8)	1.15 (0.51-1.3)	0.71 (0.70-1)	1.2 (0.46-2.93)	0.58 (0.09-0.74)	0.60 (0.35-1.21)	0.70 (0.24-0.91)	0.50 (0.3-0.86)
Total Kjeldahl Nitrogen	--	0.63 (0.49-0.970)	0.74 (0.44-0.84)	0.73 (0.25-1.3)	0.99 (0.51-1.3)	0.7 (0.54-0.97)	0.93 (0.45-1.8)	0.55 (0.08-0.69)	0.55 (0.35-1.2)	0.59 (0.23-0.77)	0.44 (0.29-0.63)
Total Suspended Solids	--	4.3 (2.7-7.9)	4.2 (1.2-16)	1.5 (0.5-22)	2.3 (0.5-5.3)	3.5 (3.3-17)	2 (0.5-15)	6 (3-12)	2 (0.5-6)	20 (2-36)	1 (0.5-3)

All guidelines are from (GoA 2018) except dissolved manganese (CCME 2019)
Sulphate – Guideline could not be calculated as Red Creek hardness ($CaCO_3$) was >250 mg/L
Ammonia (total) – Guideline varies and is determined by site-specific water temperature and pH
Nitrite - Guideline varies and is determined by site-specific chloride
Cadmium, Cobalt, Copper, Lead, Nickel (total) - Guideline varies and is determined by site-specific hardness ($CaCo_3$).
Total Phosphorus and Total Nitrogen – Until 2014, Alberta used a chronic guideline of 0.5 mg/L and 1.0 mg/L, respectively.

3.3.2 Discussion

Based on the current data available, there are no concerns with nitrate concentrations at Red Creek. Only a single chronic **nitrate** PAL exceedance has occurred at the upper Red Creek site from 2011 to 2019 (Table 7) and no nitrate exceedances have occurred at the middle and lower Red Creek sites from 2011 to 2019 and 2006 to 2020, respectively (Table 7 and 8).

Dissolved oxygen concentrations at the upper and middle Red Creek sites occasionally exceeded the PAL guidelines (Figure 6). The majority of the PAL exceedances were acute dissolved oxygen concentrations <5 mg/L. There was an exceedance of the chronic PAL guideline (<6.5 mg/L) at the upper Red Creek site in 2014. Dissolved oxygen concentrations <5 mg/L at Red Creek may result in the mortality of some fish. Fish species captured at Red Creek include Yellow Perch, White Sucker, Longnose Sucker, Northern Redbelly Dace, Lake Chub, Brassy Minnow, Fathead Minnow, Brook Stickleback and Iowa Darter (MRWCC 2013). Yellow Perch, Fathead Minnow and Iowa Darter have been classified as tolerant (not sensitive) to low dissolved oxygen concentrations with an acute lethal dissolved oxygen concentration of <1 mg/L (Barton and Taylor 1996, Eakins 2021). Barton and Taylor (1996) classified White Sucker, Brook Stickleback and the minnow species Lake Chub, Northern Redbelly Dace and Brassy Minnow as having intermediate acute dissolved oxygen sensitivity (1-2 mg/L). In a Colorado river, Scheurer et al. (2003) found that Brassy Minnows could survive in isolated pools with water temperatures and high as 35.5°C and dissolved oxygen between 0.03 and 1.52 mg/L. The authors found that main mechanism of mortality in Brassy Minnows was pool drying (Scheurer et al. 2003). Longnose Sucker are classified as sensitive to low dissolved oxygen concentrations (acute lethal oxygen >2 mg/L). With the exception of Longnose Sucker, the fish community at Red Creek is tolerant or moderately tolerant of low dissolved oxygen concentrations which suggests the acute and chronic effects of low dissolved oxygen has likely been a factor in determining the fish community structure. Fish populations and communities integrate and sum all biochemical, physiological and behavioural changes induced by low oxygen and at this level the long-term effects of suboptimal oxygen regimes will be most evident. Studies have shown the numbers of fish species and sport fishes and percent sport fish in the fish community are reduced in areas where average summer oxygen was <5 mg/L (Barton and Taylor 1996).

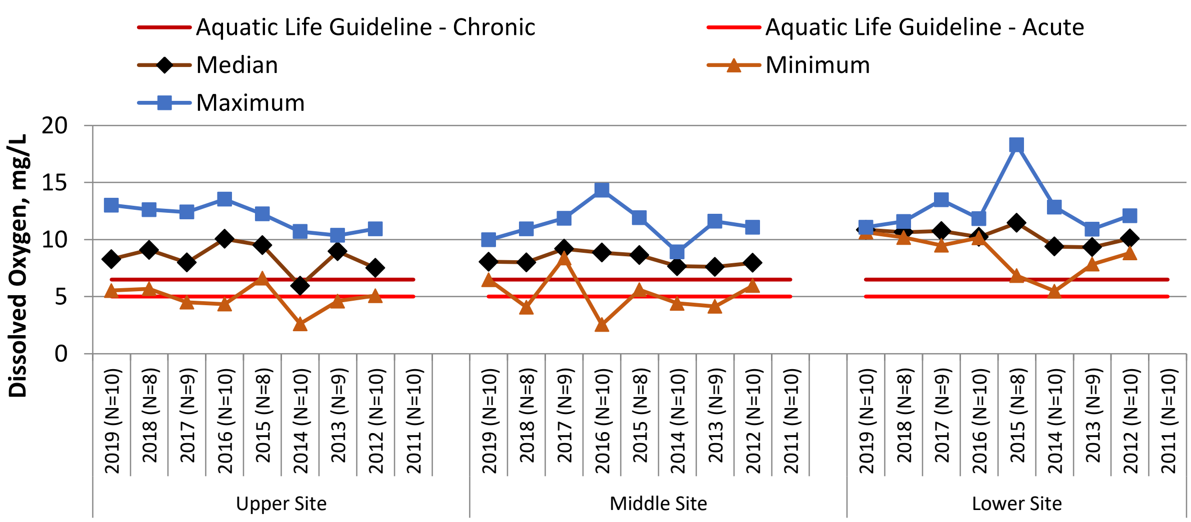


Figure 6. Dissolved oxygen concentrations compared to Aquatic Life guidelines at Upper, Middle and Lower Red Creek (2011-2019).

Concerns with the exceedance of **dissolved aluminum**, **total arsenic**, **total copper** and **total mercury** chronic guidelines are minor (Figure 7). No more than a single metal exceedance has occurred in a year for any of the metals and the median metal concentration of the four metals has always been below guidelines. The concentrations of these four metals are probably not elevated for long enough periods to result in chronic affects. As an example, in a study of Chiricahua Leopard Frogs (*Lithobates chiricahuensis*), exposure of tadpoles in water with 7 µg/L of copper for 8 weeks did not result in any mortality; however, at 46.5 µg/L of copper there was 11% mortality of tadpoles at 2 weeks and 22% mortality at 6 weeks. A concentration of 165 µg/L of copper caused 100% mortality in tadpoles at 2 weeks (Calfee and Little 2017). Calfee and Little (2017) found after 60 days exposure, chronic negative affects on tadpole weight occurred at 7 µg/L of copper and negative affects on tadpole length and development stage occurred at 46.5 µg/L of copper. At Red Creek, median copper concentrations ranged from 0.03 to 2.81 µg/L and the highest concentration recorded was 9.69 µg/L on July 24, 2019 at lower Red Creek. Ninety-six percent (96%) of samples at lower Red Creek had total copper concentrations less than the guideline of 7 µg/L (Table 8).

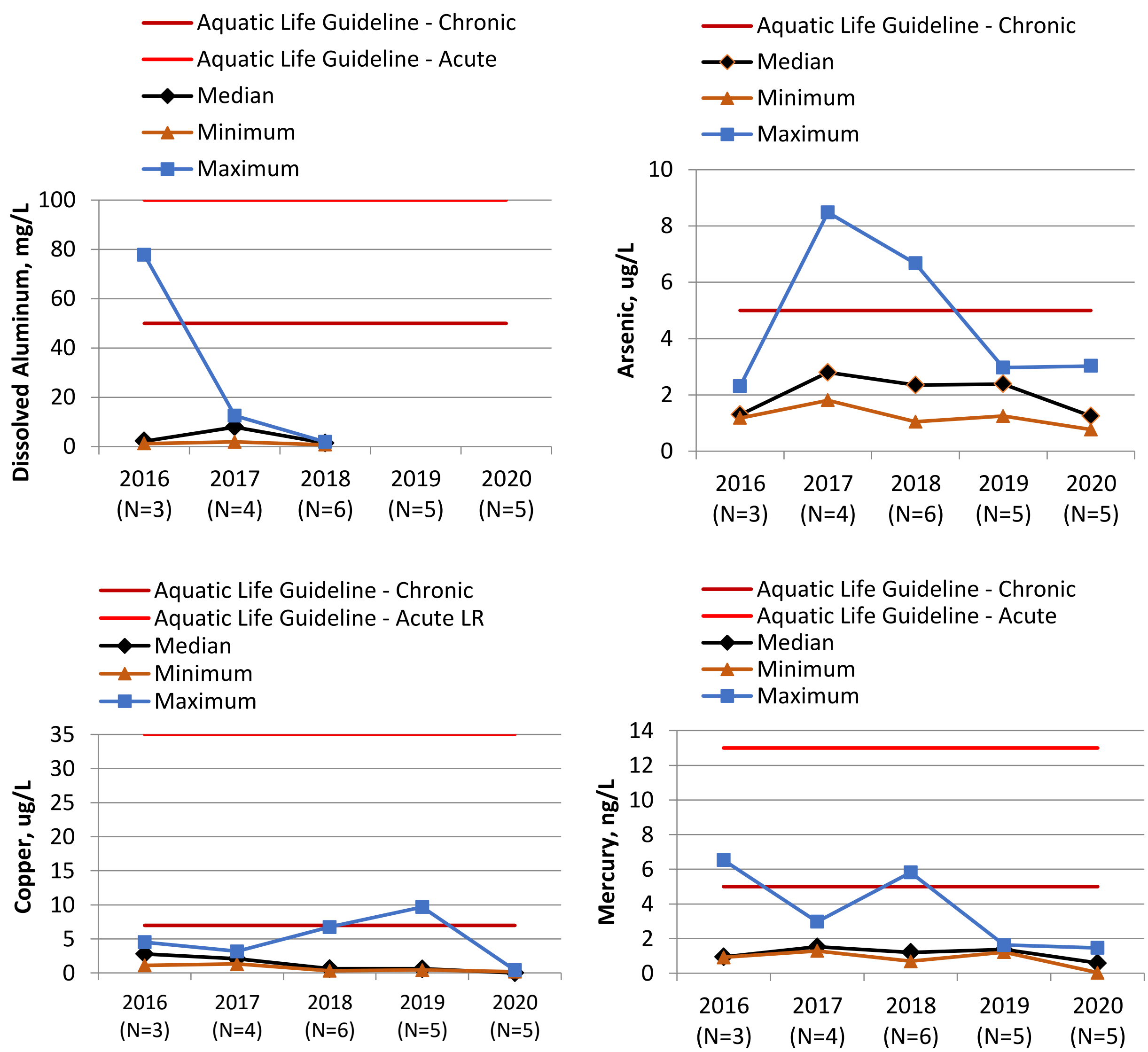


Figure 7. Select metal species concentration compared to Aquatic Life guidelines at Lower Red Creek (2006 to 2020).

Total selenium concentrations at lower Red Creek are persistently elevated and exceed the chronic guideline of 2 µg/L (Table 8; Figure 8). Anthropogenic sources of selenium include coal mining, coal-fired power plants, smelter emissions, oil and gas refining, wastewater discharges and landfills (BC MoE 2014). None of these anthropogenic sources are likely to contribute to Red Creek; therefore, selenium in Red Creek is likely naturally occurring. Soils naturally high in selenium are found in arid and semi-arid areas where soil is alkaline including some areas of the Prairie Provinces (BC MoE 2014).

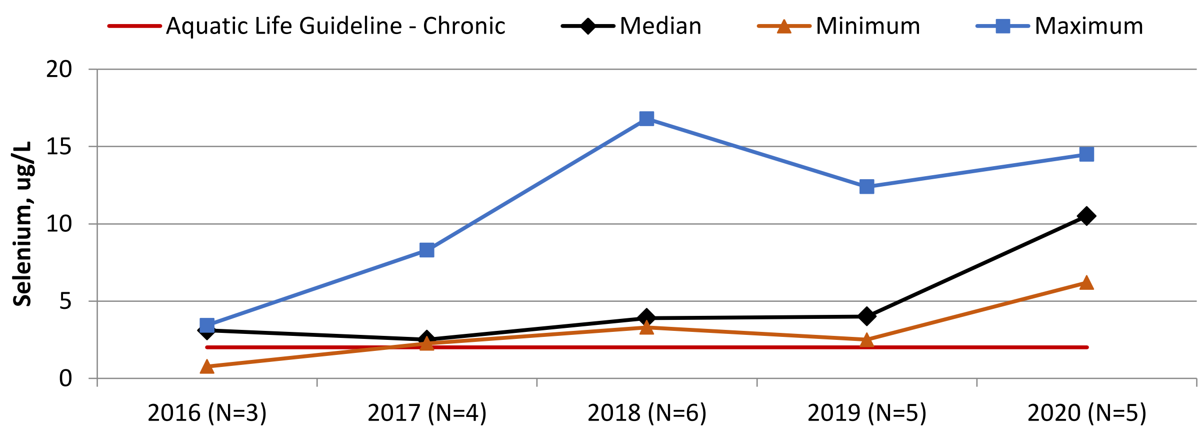


Figure 8. Selenium concentrations compared to the chronic Aquatic Life guideline at Lower Red Creek (2016-2020).

Data collected from 19 stations on major Alberta rivers between 2005 to 2007 showed an average total selenium concentration between 0.3 and 0.7 µg/L. These concentrations represented background levels, but in some other Alberta locations, anthropogenic sources of selenium are known to elevate background concentrations. Data collected from the mid-1980s to 2003, documented selenium increases near open-pit coal mining areas in Alberta. Upstream of mining influences, waters had a median selenium concentration of 0.7 µg/L, while in closest proximity to the mines, selenium concentrations ranged between 12.7 and 29.2 µg/L. Another study conducted between 1998 and 1999 on Alberta streams influenced by large-scale open-pit coal mining showed that selenium concentrations were as high as 48 µg/L (BC MoE 2014). Therefore, selenium concentrations at lower Red Creek appear to fall between natural background levels and coal mine impacted waters.

Ambient selenium concentrations rarely reach levels that result in acute effects. The concentration of selenium resulting in acute endpoints in invertebrates (cladocerans to mussels) has ranged from 9.9 to 203,000 µg/L. Acute toxicity concentrations of selenium for fish has ranged from 600 to 23,400 µg/L (BC MoE 2014).

The more common route for selenium toxicity is through chronic exposure at lower concentrations. Environmental guidelines focus on chronic exposure concentrations to protect against sublethal effects. Research supports an effect threshold for fish of approximately 2 µg/L in water. However, some studies have indicated a water concentration of 2 µg/L may not be sufficiently protective when bioaccumulation of selenium in the food web is considered. Some researchers have found negative effects on biota in ecosystems with very low water selenium concentrations, at or below 2 µg/L (BC MoE 2014).

Bacteria, fungi, algae, and invertebrates are considered to be fairly tolerant to elevated selenium concentrations, and the more important role these organisms play is in the rapid transformation and transfer of selenium into the aquatic food web. Selenium toxicity in fish results in many adverse effects including: reductions in growth; behavioural changes; increased deformity; and increased mortality in early life stages. Other reported effects on early life stage and juvenile fish from chronic selenium exposure at relatively low water selenium concentrations (3–8 µg/L) include reduced condition factor, growth and survival. Sublethal effects may occur at low selenium concentrations, for example reduction in calcium concentrations in the vertebrae of rainbow trout fry, eye cataracts, and changes in gill and organ histopathology and blood characteristics. Adult organisms may appear unaffected by selenium toxicity; however, overall reproductive success and productivity may be negatively impacted. While research has demonstrated the range of observed reproductive and non-reproductive effects in fish may be very broad, the literature also suggests that chronic effects observed in the early life and juvenile stages of fish are not consistent, likely as a result of differential rates of selenium accumulation and/or different species sensitivity (BC MoE 2014).

Selenium bioaccumulation in aquatic environments is complex and can vary widely within and between species and is dependent on many biotic and abiotic factors, including the amount and form of selenium, the presence of other elements and compounds, food preferences, temperature, type of habitat, species sensitivity, life stage, and trophic position or food web structure. Some constituents may reduce selenium toxicity and include arsenic, antimony, bismuth, cadmium, copper, lead, germanium, mercury, silver, thallium, tungsten and zinc. However, interactions between selenium and other compounds are often unclear and inconsistent. Selenium is also thought to be taken up into cells via the sulphate uptake mechanisms, due to the similarity of selenate and sulphate. In the presence of elevated sulphate concentrations, the bioaccumulation and toxicity of selenate can be reduced. Red Creek has elevated concentrations of sulphate; however, the relationship between the reduction of selenium bioaccumulation and toxicity in the presence of sulphate is again not consistent (BC MoE 2014).

Total phosphorus and **total nitrogen** are high at Red Creek (Figure 9). Both nutrients are required for plant growth; however, excessive concentrations of both can result in dense algae and aquatic plant growth. Bain and Stevenson (1999) report that total phosphorus > 0.1 mg/L may result in problematic algae and plant growth. At the three Red Creek sites, aquatic plant coverage >75% (and often 100%) and algae coverage >50% are commonly estimated during site visits which may be indicative of excessive nutrients. Nutrients can be stored in decaying plant material and bottom sediments and can be a continual internal source of nutrients in freshwater systems.

Total suspended sediment concentrations are not a major concern for aquatic life at Red Creek (Figure 9); although, suspended sediment can play a large role in the transport and sequestering of nutrients and metals. Researchers have observed concentrations of suspended sediment 500 to 6,000 mg/L may be fatal or result in lowered survival for fish. Very young trout may experience mortality at 500 to 1,500 mg/L (Waters 1995). Fish have evolved behavioural of physiological adaptations to temporarily high concentrations of suspended sediment in order to survive short-term conditions caused by floods and precipitation. Chronic high suspended sediment caused by anthropogenic sources may not be tolerated by aquatic life; however suspended sediment concentrations at Red Creek are not likely to reach levels that would cause chronic issues in fish. Studies have noted fin rot and gill damage in fish at suspended sediment concentrations between 230 and 270 mg/L, changes to blood chemistry (stress indicators) at 500 to 1,500 mg/L and evidence of growth impairment in fish at 84 to 120 mg/L of suspended sediment (Waters 1995, Anderson et al. 1996).

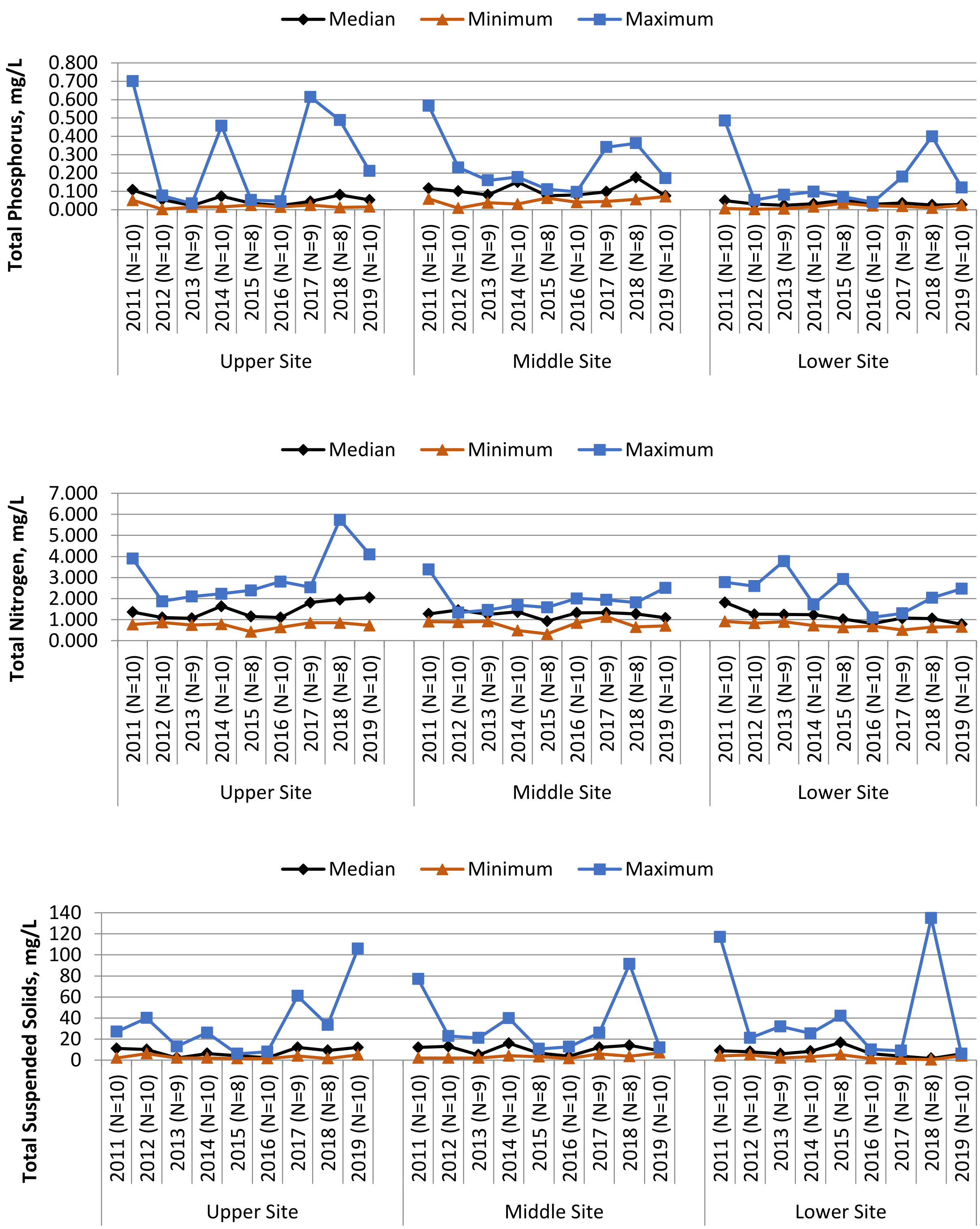


Figure 9. Total phosphorus, total nitrogen and total suspended solids concentrations at Upper, Middle and Lower Red Creek (2011-2019)

4.0 SUMMARY

- Landowners at Red Creek have been concerned about water quality for livestock, irrigation activity and aquatic life. Although water quality has been collected by the MRWCC and reported annually since 2006, additional water chemistry data (e.g., ions and metals data) were not typically included in the annual reports. This review of water quality aimed to address landowner concerns by assessing additional water quality data in comparison to available water quality guidelines.

- Water quality is influenced by a number of factors including surficial geology, soils, weather and climate, and groundwater influence. Generally, water quality tends to degrade in wet years compared to dry years, as contaminants leach from soils and are transported to surface water. This mobilization is typical and is observed in the Red Creek data. Wet years were experienced in 2008, 2010, 2012, 2013 and 2016.

- The following parameters did not meet guidelines

Water Quality Guidelines	Parameters Exceeding Guidelines	Sites
For Livestock	Sulphate	Data only available for Lower Red Creek
For Irrigation	Boron (minor)	Data only available for Lower Red Creek
	Salinity (as indicated by Total Dissolved Solids and Conductivity)	All sites
	Fecal coliform bacteria (minor – frequent)	Lower Red Creek median and maximum values typically exceed guidelines; Upper and Middle Red Creek maximum values regularly exceed guidelines
For Aquatic Life	Dissolved oxygen (min <5.0 mg/L)	Upper and middle sites
	Aluminum (dissolved); Arsenic; Copper; Mercury (chronic - occasional)	Data only available for lower Red Creek
	Selenium (chronic – persistent)	Data only available for lower Red Creek

Recommendations

- While there are currently no guidelines in place for nutrients and total suspended solids, the Environmental Quality Guidelines for Alberta Surface Waters (GoA 2018) indicates that site-specific water quality objectives may be established where there is sufficient data. Although beyond the scope of this report, establishing these objectives for Red Creek is recommended.

- Metals data could be collected at the upper and middle Red Creek sites to determine the extent of these metals in Red Creek, as well as confirm sources of selenium in the watershed.

- Microbial source tracking could be undertaken at Red Creek to determine the major sources of fecal coliform bacteria (e.g., waterfowl, wildlife and/or livestock). The results of this investigation could help to inform and focus remediation efforts.

5.0 REFERENCES

Anderson, P.G., B.R. Taylor and G.C. Balch. Quantifying the effects of sediment release on fish and their habitats. Canadian Manuscript Report of Fisheries and Aquatic Sciences No. 2346. 110 pp.

Bain, M.B. and N.J. Stevenson. 1999. Aquatic habitat assessment: common methods. American Fisheries Society, Bethesda, Maryland. 216 pp.

Barton, B.A. and B. R. Taylor. 1996. Oxygen requirements of fishes in northern Alberta rivers with a general review of the adverse effects of low dissolved oxygen. Water Quality Research Journal of Canada 31:361-409.

British Columbia Ministry of Environment (BC MoE). 2014. Ambient Water Quality Guidelines for Selenium Technical Report Update. Prepared by: J.M. Beatty and G.A. Russo. Water Protection and Sustainability Branch, Environmental Sustainability and Strategic Policy Division. 257 pp.

Calfee, R.D. and E.E. Little. 2017. Toxicity of cadmium, copper and zinc to Chiricahua Leopard Frog (*Lithobates [Rana] chiricahuensis*). Bulletin of Environmental Contamination and Toxicology 99:679-683.

Canadian Council of the Ministers of the Environment (CCME). 2019. Scientific criteria document for the development of the Canadian water quality guidelines for the protection of aquatic life: manganese. Canadian Council of the Ministers of the Environment. ISBN 978-1-77202-058-8 PDF. Winnipeg, MB. 57 pp.

Eakins, R.J. 2021. Ontario Freshwater Fishes Life History Database. Version 5.11. Online database. (https://www.ontariofishes.ca), accessed 05 October 2021

Government of Alberta (GoA). 2018. Environmental Quality Guidelines for Alberta Surface Waters. Water Policy Branch, Alberta Environment and Parks. Edmonton, Alberta. 53 pp.

Isayenkov, S.A., and F.J.M. Maatthuis. 2019. Plant Salinity Stress: Many Unanswered Questions Remain. Frontiers in Plant Science. Volume 10, Article 80:1-11.

Milk River Watershed Council Canada (MRWCC). 2013. Milk River Transboundary State of the Watershed Report, 2nd edition. Compiled by Palliser Environmental Services Ltd. And prepared for Milk River Watershed Council Canada (Alberta) in collaboration with the Milk River Watershed Alliance (Montana). Milk River, Alberta. 238 pp.

Palliser Environmental Services Ltd. 2021. Milk River Water Monitoring Report 2020. Prepared for Milk River Watershed Council Canada. 22 pp + appendix.

Princi, M. P., A. Lupini, A. Fabrizio, C. Longo, A. Mauceri, F. Sunseri and M. R. Abenavoli. 2015. Chapter 5: Boron toxicity and tolerance in plants: Recent advances and future perspectives. Pages 115-147 *in* P. Ahmad, editor. Plant Metal Interaction: Emerging Remediation Techniques. Elsevier Inc. 652 pp.

Scheurer, J.A., K.D. Fausch and K.R. Bestgen. 2003. Multiscale processes regulate Brassy Minnow persistence in a Great Plains river. Transaction of the American Fisheries Society 132(5): 840-855.

Waters, T.F. 1995. Sediment in streams: sources, biological effects and control. American Fisheries Society Monograph 7. 251 pp.