Technical Report No. 20-03

Fish and Water Quality Monitoring at the Fort Knox Mine, 2019

by

Chad E. Bear and Alvin G. Ott

March 2020

Alaska Department of Fish and Game **Habitat Section**

Symbols and Abbreviations

The following symbols and abbreviations, and others approved for the Système International d'Unités (SI), are used without definition in the following reports by the Divisions of Habitat, Sport Fish, and Commercial Fisheries: Fishery Manuscripts, Fishery Data Series Reports, Fishery Management Reports, Technical Reports and Special Publications. All others, including deviations from definitions listed below, are noted in the text at first mention, as well as in the titles or footnotes of tables, and in figure or figure captions.

Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
nautical mile	nmi
ounce	oz
pound	lb
quart	qt
yard	yd

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
degrees kelvin	K
hour	h
minute	min
second	s

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity (negative log of)	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

Alaska Administrative Code	AAC
all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.
all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.
at	@
compass directions:	
east	E
north	N
south	S
west	W
copyright	©
corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
District of Columbia	D.C.
et alii (and others)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.
Federal Information Code	FIC
id est (that is)	i.e.
latitude or longitude	lat or long
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S.C.	United States Code
U.S. state	use two-letter abbreviations (e.g., AK, WA)

Mathematics, statistics

all standard mathematical signs, symbols and abbreviations	
alternate hypothesis	H_A
base of natural logarithm	e
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	(F, t, χ^2, etc.)
confidence interval	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	E
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	$\log_2$, etc.
minute (angular)	'
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
variance	
population	Var
sample	var

TECHNICAL REPORT NO. 20-03

FISH AND WATER QUALITY MONITORING AT THE FORT KNOX MINE, 2019

By

Chad E. Bear and Alvin G. Ott
Habitat Section, Fairbanks

Alaska Department of Fish and Game
Habitat Section
1300 College Rd, Fairbanks, Alaska, 99701

March 2020

Cover: Burbot with atypical mottling and color pigmentation, Fort Knox Water Supply Reservoir, October 1, 2019. Photograph by Chad Bear.

Technical Reports are available through the Alaska State Library, Alaska Resources Library and Information Services (ARLIS) and on the Internet: http://www.adfg.alaska.gov/index.cfm?adfg=habitat_publications.main. This publication has undergone editorial and peer review.

Note: Product names used in the publication are included for completeness but do not constitute product endorsement. The Alaska Department of Fish and Game does not endorse or recommend any specific company or their products.

Chad E. Bear and Alvin G. Ott
Alaska Department of Fish and Game, Habitat Section
1300 College Rd., Fairbanks, AK 99701-1599, USA

This document should be cited as:
Bear, C.E. and A.G. Ott. 2020. Fish and Water Quality Monitoring at the Fort Knox Mine, 2019. Alaska Department of Fish and Game, Technical Report No. 20-03, Fairbanks, Alaska.

Table of Contents

List of Tables ii
List of Figures ii
Acknowledgements ii
Executive Summary iv
Water Quality iv
Arctic Grayling in the Water Supply Reservoir iv
Burbot in the Water Supply Reservoir iv
Introduction 1
Methods 7
Water Quality 7
Fish 8
Results and Discussion 9
Water Quality, Water Supply Reservoir 9
Water Quality, Fish Creek 18
Water Supply Reservoir, Arctic Grayling 20
Arctic Grayling Spawning (Timing, Temperature, and Fry Presence) 21
Arctic Grayling Catches and Metrics 27
Water Supply Reservoir, Burbot 31
Stilling Basin, Arctic Grayling 35
Stilling Basin, Burbot 36
Stilling Basin Observations, 2019 37
Conclusion 38
Literature Cited 39
References 39
Appendix 1. A Summary of Mine Development with Emphasis on Biological Factors ..42
Appendix 2. Water Quality Data, from the Fort Knox Water Supply Reservoir (WSR), April 10, 2018. 49
Appendix 3. Population estimates of Arctic Grayling > 200 mm in the Fort Knox Water Supply Reservoir (WSR), 1995-2018. 51
Appendix 4. Arctic Grayling Growth in the WSR, 2018-2019. 52
Appendix 5. Population Estimate of Burbot (≥ 400mm) in the Fort Knox Water Supply Reservoir (WSR), 2001-2018. 52

List of Tables

Table 1. Winter (October 1 to April 30) water use from the WSR, 1997 to 2019..... 3
Table 2. Total Reverse Osmosis (RO) water discharge from Outfall 001 and 002 into Fish Creek, 2015 - 2019..... 4

List of Figures

Figure 1. Fort Knox gold mine and associated facilities. 1
Figure 2. Fort Knox Water Supply Reservoir (WSR) October 2019..... 2
Figure 3. RO Discharge at Outfall 002 on April 10, 2019..... 4
Figure 4. Spillway at outlet of water supply reservoir (WSR) on April 10, 2019. 5
Figure 5. Pond F outlet channel in 2000 (left photo) and in 2010 (right photo)..... 5
Figure 6. Map of Fort Knox WSR water quality sample sites, Arctic grayling fyke net, and RO water outfalls..... 7
Figure 7. 2019 WSR Burbot hoop trap locations..... 8
Figure 8. WSR on April 10, 2019. About 1-meter thick ice with 1 – 2 inches snow. 9
Figure 9. Fish Creek and Pond D open water on April 10, 2019..... 10
Figure 10. WSR water temperature profiles, April 10, 2019..... 11
Figure 11. WSR dissolved oxygen (mg/L) profiles, April 10, 2019..... 12
Figure 12. WSR dissolved oxygen saturation (%) profiles, April 10, 2019. 13
Figure 13. Average winter water column DO concentrations at Site 2 in the WSR, 1998-2019 (excluding 2000, 2011, 2012, and 2014). 14
Figure 14. Average, minimum and maximum levels of dissolved oxygen in Polar Bay, winter 2001-2019. 15
Figure 15. WSR pH profiles, April 10, 2019..... 15
Figure 16. WSR specific conductance (µS/cm) profiles, April 10, 2019. 16
Figure 17. WSR oxidation reduction potential (mV) profiles, April 10, 2019..... 17
Figure 18. WSR and Fish Creek total water column average water temperature, April 2019. ... 18
Figure 19. WSR and Fish Creek total water column average DO in mg/L, April 2019..... 19
Figure 20. WSR and Fish Creek total water column average specific conductance µS/cm, April 2019..... 20
Figure 21. Arctic Grayling with Floy brand T-Tag. 21
Figure 22. A hydraulic jump (about 1 m high) formed in the channel connecting Ponds D and E that was a limiting obstacle to the upstream movement of fish, April 12, 2019. 22
Figure 23. Pond F open water April 12, 2019 (left) and May 10, 2018 (right). 23
Figure 24. Open water at Pond D on April 10, 2019. 24
Figure 25. Pond F outlet daily water temperature maximums; 2013 to 2019..... 25
Figure 26. Pond F outlet peak daily water temperature April 11-May 23, 2019..... 25
Figure 27. Catch per unit of effort (CPUE) in #fish/hr at the Pond F fyke net in the wetlands complex..... 26
Figure 28. Spawning condition of Arctic grayling females categorized as: Not Ripe, Ripe or Spent, 2019. 27
Figure 29. Estimates of the Arctic grayling population (fish ≥200 mm) in the WSR, with 95% Confidence Intervals, 1998-2018..... 28

Figure 30. Number of new fish ≥ 200 mm that entered the population but would have been too small to mark in the previous year (based on growth of marked fish), 2002-2019. 29
Figure 31. Average annual growth of Arctic grayling by size group in the WSR in selected years including baseline (before WSR) in 1994. 30
Figure 32. Length frequency distribution of Arctic grayling in spring 1995 and 2019. 31
Figure 33. Population estimates of burbot (>400 mm) in the Fort Knox WSR, 2001 –2018 with 95% confidence intervals shown (no population estimates were produced from 2006-2011). 32
Figure 34. WSR burbot Catch Per Unit Effort (CPUE) in fish per day per trap (#fish/day), 1996-2019. 32
Figure 35. Length frequency of burbot caught in hoop traps in the Fort Knox WSR, 2019. 33
Figure 36. Growth (median, maximum, and minimum) of marked burbot (≥ 400 mm) in the WSR, 2000-2004 and 2012-2017. 33
Figure 37. Burbot with unusual coloration, Fort Knox WSR, October 2019. 34
Figure 38. Burbot with typical coloration, Fort Knox WSR, October 2019. 34
Figure 39. Fort Knox Stilling Basin and WSR Seepage Pond sampling and bathymetries (depth in feet). 35
Figure 40. Length frequency distribution of Arctic grayling in the stilling basin, June 2019. 36
Figure 41. Comparison of Fort Knox Stilling basin water level, June and September 2019. 37
Figure 42. Fort Knox Stilling Basin outlet after part of the beaver dam was washed out, which lowered the water level by about two vertical feet. 38

Acknowledgements

We thank Fairbanks Gold Mining Inc. (FGMI) Bartly Kleven, Mark Huffington, Dave Stewart and William Collingwood for their continued support of our work to monitor fish and wildlife resources in the water supply reservoir, tributaries, and developed wetlands.

We would also like to thank Justin Burrows, Nik Nichols, Amber Payton, and Haley Sorensen for their assistance with 2019 fieldwork: and Audra Brase (ADF&G) and Mark Huffington (FGMI) for constructive review of this report.

Executive Summary

Water Quality

Dissolved oxygen (DO) concentrations were measured in the water supply reservoir (WSR) in early April 2019. For the fifth consecutive year, DO concentrations were some of the highest since sampling began in 1998. Higher DO concentrations appear to be directly related to the discharge of reverse osmosis (RO) water from mine operations into the wetland complex downstream of the tailings dam.

Fort Knox began the discharge of up to 3000 gallons per minute (gpm) of RO water into Fish Creek on January 15, 2019, from Outfall 002. The input of warm (6.0°C) RO water raised Fish Creek water temperature to 3.3°C at the Pond F outlet on April 10, 2019.

Arctic Grayling in the Water Supply Reservoir

Sampling for Arctic graying was conducted from April 12 – May 3, 2019 as fish moved from the WSR into the developed wetlands for spawning. This was 21 days earlier than sampling was conducted in 2018 as Fish Creek was approaching the ideal spawning temperature of 4.0°C from the warm RO water input. Spawning began around April 27 and peaked on May 3 when 92% of the fish handled were classified as spent. This is three weeks earlier than in 2018 when sampling began on May 4 and 93% of females were classified as not ripe.

Recruitment (defined as those fish entering the population ≥ 200 mm but based on actual growth would have been too small to mark in the previous year) is variable among the sampling years but was highest in 2017 (406) and declined in 2018 (241) and 2019 (127).

The spring 2018 population estimate for Arctic grayling ≥ 200 mm fork length (FL) was 6,045 fish (95% CI 5,461 to 6,629 fish).

Burbot in the Water Supply Reservoir

Burbot sampling was conducted during the Arctic grayling sampling event from April 12 to May 3, 2019, and again from September 25 to October 9, 2019. During the two sampling events, 124 burbot were captured in the developed wetlands and WSR. These fish ranged in size from 166 to 735 mm TL. Forty eighty of the captured burbot were ≥ 400 mm TL with eight having been previously captured and used for the 2018 population estimate.

The spring/fall 2018 population estimate of burbot (≥ 400 mm TL) was 402 fish (95% CI 190 – 613). This is the highest population estimate of burbot >400 mm since sampling began at Fort Knox in 1996.

Introduction

Fairbanks Gold Mining Incorporated (FGMI) began construction of the Fort Knox hard-rock gold mine in March 1995. The mine is in the headwaters of the Fish Creek drainage about 25 km northeast of Fairbanks, Alaska. The project includes an open pit mine, mill, tailings impoundment, water supply reservoir (WSR), and related facilities (Figure 1). Construction of the WSR dam and spillway was completed in July 1996. In 2007, permits were issued for the construction, operation, and closure of a valley fill heap leach facility located in Walter Creek upstream of the tailings pond. In 2019, ore continued to be processed through the mill and through the Walter Creek valley fill heap leach. Pit mining continued expansion west into land leased from the State of Alaska in 2018.

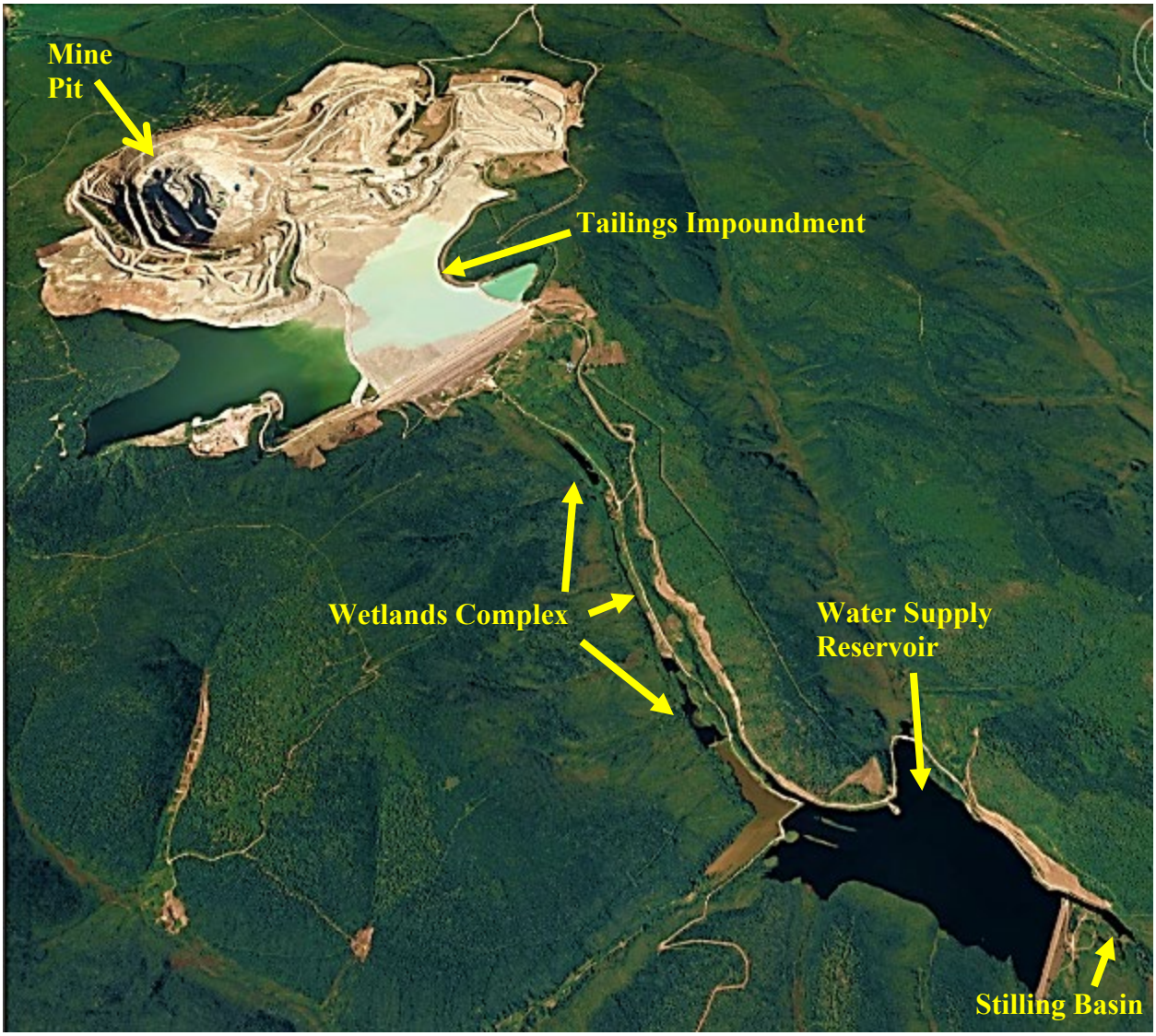

Figure 1. Fort Knox gold mine and associated facilities.

The WSR was constructed to be the primary water supply for mining activities and mill operations at Fort Knox. When full, the WSR contains about 3,363 acre-feet (1.1 billion gallons) of water (Figure 2). Water levels have remained mostly constant since 1998, except during the winter in certain years when large amounts were removed for mining processes. Since 2015, operational water needs have been satisfied from mine pit and tailings impoundment dewatering wells and no water was utilized from the WSR (Table 1). From August 27 to 29, 2019, the WSR water level was lowered 1.70 feet for a required spillway inspection for structural and performance adequacy. Water was discharged onto the spillway and passed through the stilling basin before flowing down Fish Creek.

Figure 2. Fort Knox Water Supply Reservoir (WSR) October 2019.

Spawning populations of Arctic grayling (*Thymallus arcticus*) and burbot (*Lota lota*) exist in the WSR, and smaller populations of both Arctic grayling and burbot inhabit the Stilling Basin below the WSR outlet spillway. Arctic grayling spawning occurs predominantly in the wetland complex between the WSR and the tailings dam. Burbot spawning, as documented by radio telemetry, likely occurs in Solo Bay where Solo Creek enters the WSR (Figure 6). Arctic grayling recruit into the stilling basin by going over the WSR spillway when the water is high. Burbot recruitment into the stilling basin by passage over the spillway was newly documented in June 2019 when two burbot tagged in the WSR were captured in stilling basin hoop traps.

Table 1. Winter (October 1 to April 30) water use from the WSR, 1997 to 2019.

Year (October 1 to April 30)	Acre-Feet of Water Removed	Percent of Water Removed
1997/1998	660	19.6
1998/1999	605	18.0
1999/2000	577	17.2
2000/2001	1,464	43.5
2001/2002	320	9.5
2002/2003	337	10.0
2003/2004	279	8.3
2004/2005	716	21.3
2005/2006	659	19.6
2006/2007	299	8.9
2007/2008	1,176	35.0
2008/2009	817	24.3
2009/2010	1,167	34.7
2010/2011	187	5.6
2011/2012	59	1.8
2012/2013	1,837	54.6
2013/2014	1,399	41.6
2014/2015	104	3.1
2015/2016	0	0
2016/2017	0	0
2017/2018	0	0
2018/2019	0	0

In spring 2015, FGMI initiated the discharge of non-contact water from dewatering wells around the open pit combined with mine operations water treated by Reverse Osmosis (RO) filtration into upper Fish Creek. The discharge was authorized by permits issued by the Alaska Department of Environmental Conservation (ADEC). During 2019 FGMI brought two additional RO facilities (RO2 and RO3) online and began discharging from Outfall 002 on January 15 (Figure 3). Water discharge through the RO systems has been increasing since 2015. The total 2018 discharge was 806 acre-feet. The addition of the two new RO facilities in 2019 increased the total discharge to 6,681 acre-feet of water (Table 2). The discharge water seems to be the key reason for increasing the dissolved oxygen (DO) concentrations in the WSR in late winter.

Table 2. Total Reverse Osmosis (RO) water discharge from Outfall 001 and 002 into Fish Creek, 2015 - 2019.

Year (January 1 to December 31)	Acre-Feet of RO Water Discharged from Outfall 001 and 002
2015	163
2016	461
2017	618
2018	806
2019	6,681

Figure 3. RO Discharge at Outfall 002 on April 10, 2019.

In early April 2019, there was relatively high-water flow over the spillway at the WSR outlet partly due to increased discharge of RO water into upper Fish Creek from Outfall 001 and 002 (Figure 4). Normally, flow would be confined to the low flow channel in the spillway.

Figure 4. Spillway at outlet of water supply reservoir (WSR) on April 10, 2019.

Fort Knox's rehabilitation of the fish and wildlife habitats disturbed during mine operations has been concurrent with permit requirements, to the extent practicable, and natural revegetation of some areas has been rapid (Figure 5).

Figure 5. Pond F outlet channel in 2000 (left photo) and in 2010 (right photo).

Fish monitoring has been performed annually at the Fort Knox mine and related facilities since 1992 and water quality sampling since 1997. This report summarizes fish and water quality data collected during 2019 and discusses these findings in relation to previous work. A chronology of events from 2011 to 2019, with emphasis on biological factors, is presented in Appendix 1. The chronology for the previous years 1992 to 2010 can be found in ADF&G Technical Report No. 10-5, *Arctic grayling and burbot studies at the Fort Knox Mine, 2010* (Ott and Morris, 2010). The References section contains a comprehensive list of all technical biological reports for Fort Knox.

Methods

Water Quality

Water quality sampling was conducted on April 10, 2019, when the WSR was ice covered. Six sites in the WSR have been sampled annually since 1998 with three new sites in the wetland complex included during 2019 (Figure 6). Measurements of Fish and North creeks were taken to document the effect of increased RO water discharged from Outfall 001 and 002 into the wetlands complex. Temperature (°C), dissolved oxygen (DO) concentration (mg/L), DO percent saturation (barometrically corrected), pH, specific conductance (*u*S/cm), oxidation reduction potential (ORP), and depth (m) were measured with a Hydrolab® Minisonde®5 water quality multiprobe connected to a Surveyor® 4 digital display unit. The multiprobe sensors were calibrated to suggested specifications prior to use. The DO sensor was calibrated using a saturated air method. Conductivity, ORP, and pH sensors were calibrated with fresh standard solutions. Winter water quality measurements were made at 1 m depth intervals from the surface to the bottom.

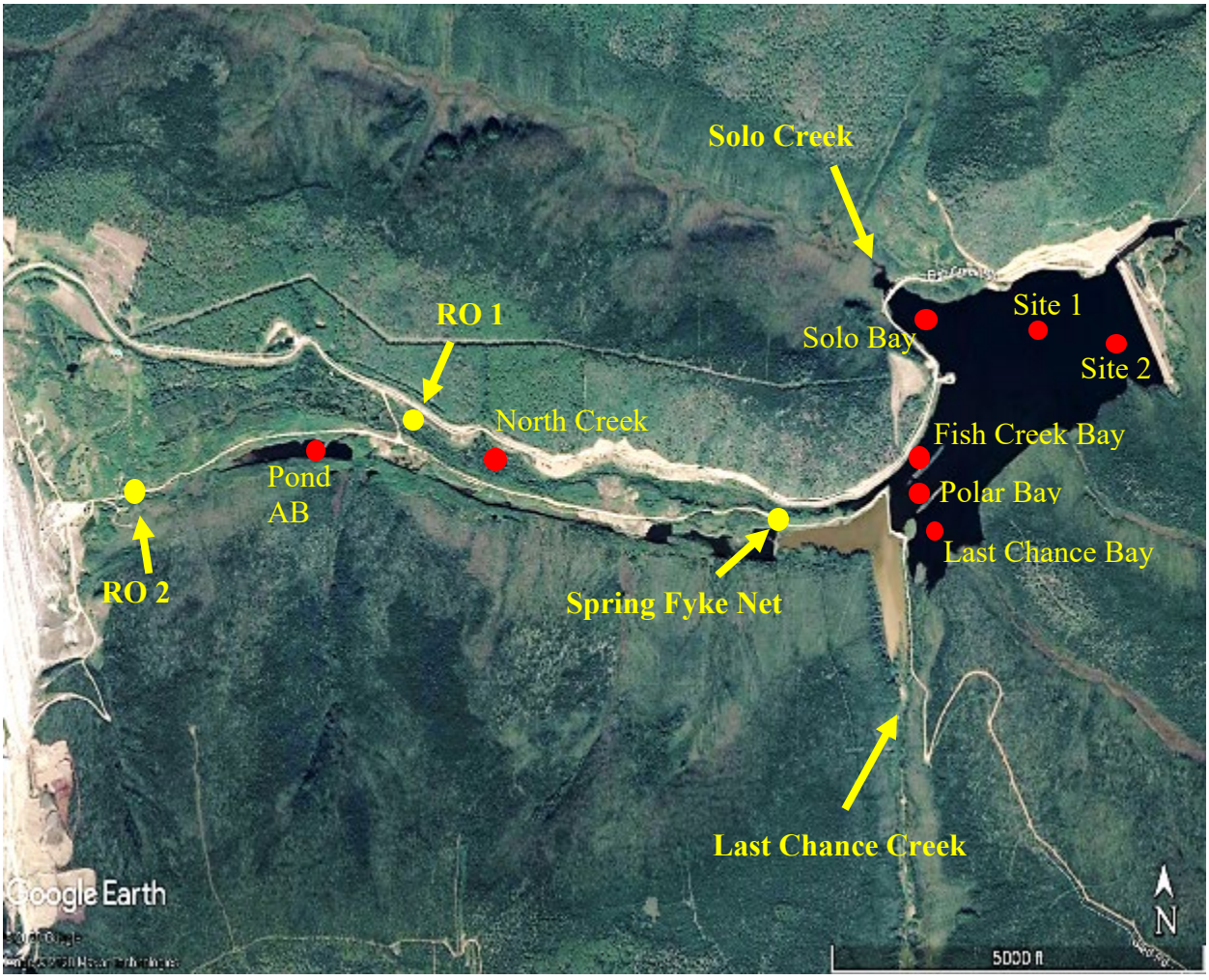

Figure 6. Map of Fort Knox WSR water quality sample sites, Arctic grayling fyke net, and RO water outfalls.

Fish

Fish sampling methods included fyke nets, hoop traps, angling, and visual observations. On April 12, 2019, one fyke net was set in the developed wetlands near the Pond F outlet (Figure 6). Traditionally two fyke nets have been used with one being in the lowest portion of Fish Creek directly adjacent to the WSR. In 2019, only one fyke net was set to determine if it could capture enough Arctic grayling for a population estimate with less recaptures and handling of the fish. The Pond F fyke was able to fish the same location without being moved for the duration of the sample period. The net was checked every 1 to 2 days (except for one five-day period due to heavy snow and bad road conditions) until the net was pulled on May 3.

Figure 7. 2019 WSR Burbot hoop trap locations.

Burbot were caught in the Pond F fyke net during April and May and in hoop traps in the WSR in late fall. Twenty-three hoop traps baited with herring were used to capture burbot from September 25 to October 9, 2019 in the WSR (Figure 7).

Arctic grayling was measured to fork length (FL, nearest mm), inspected for tags and spawning condition, and released. Burbot were measured to total length (nearest mm), inspected for tags, and released. Un-tagged Arctic grayling ≥ 200 mm and burbot ≥ 300 mm were marked with a numbered Floy® T-bar internal anchor tag. Abundance of Arctic grayling and burbot was estimated using Chapman's modification of the Lincoln-Petersen two-sample mark-recapture model (Chapman 1951) and variance was estimated (Seber 1982

Results and Discussion

Water Quality, Water Supply Reservoir

Water quality data were collected on April 10, 2019 (Appendix 2). Ice thickness on the WSR was slightly less than 1 m at each sampling location. There was 1 to 2 inches of slushy snow and very little overflow on top of the WSR ice (Figure 8). This overflow water did not influence the water quality sampling below the ice. The flowing water of Fish Creek was open with no surface ice (Figure 9). North Creek had sections of open water, but also sections with overflow and glaciated ice in the riverbed. The winter of 2018/19 had slightly below average snowfall and warm air temperatures in March, which melted most of the accumulated snow from the WSR before the April 10 sampling event. The annual cumulative snowfall on February 28, 2019, at the Fairbanks International Airport was ~127 cm compared to ~199 cm in 2018. The below average snow depth and mild air temperatures likely contributed to the normal ice thickness with reduced overflow as compared to the April 5, 2018, sampling event where ice was less than 1 meter thick with about 15 cm of overflow.

Figure 8. WSR on April 10, 2019. About 1-meter thick ice with 1 – 2 inches snow.

Figure 9. Fish Creek and Pond D open water on April 10, 2019.

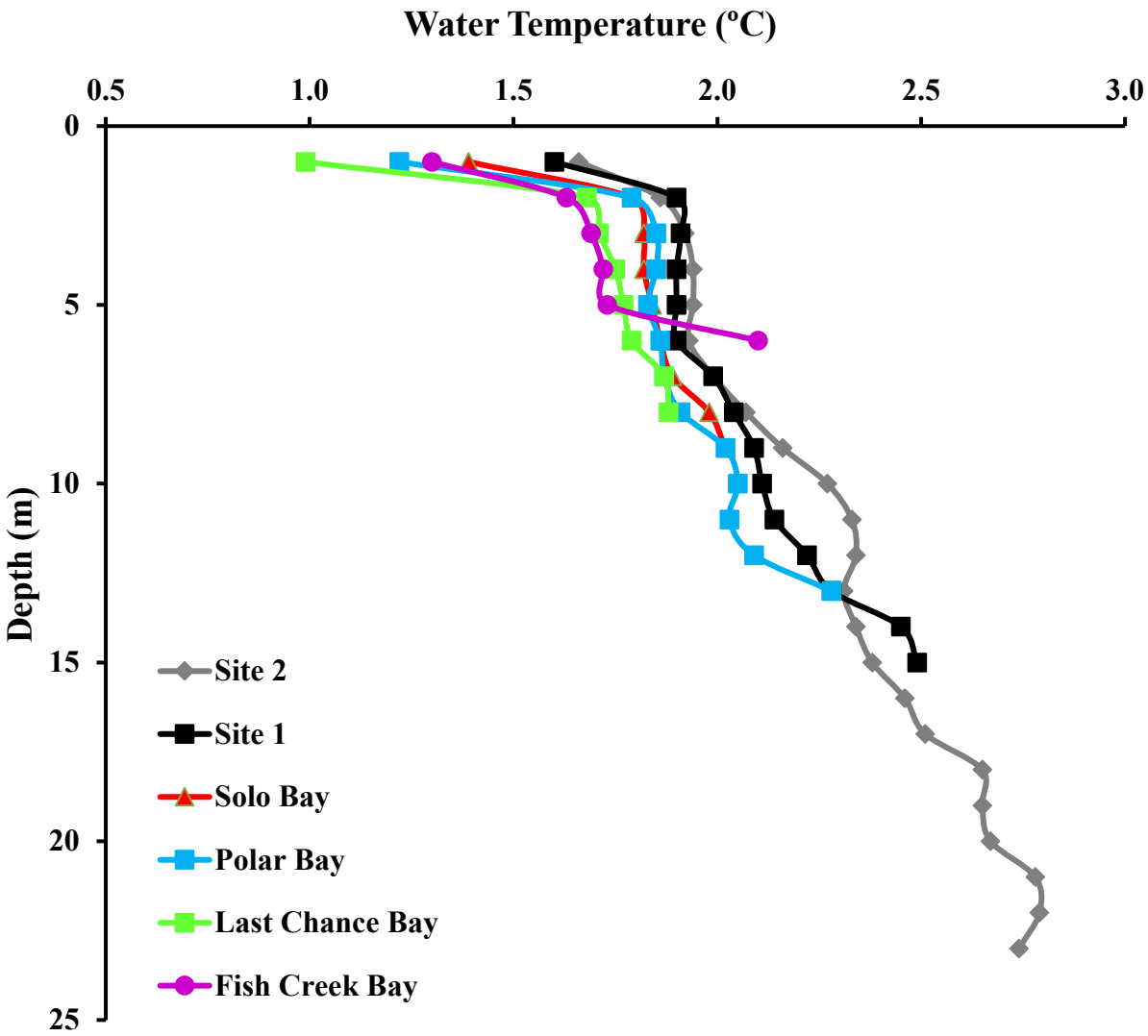

Figure 10. WSR water temperature profiles, April 10, 2019.

WSR water temperatures recorded in 2019 ranged from 0.99°C to 2.79°C (Figure 10). The minimum temperature was recorded in Last Chance Bay just below the ice surface. The maximum temperature was recorded in Site 2 at 22 meters deep just above the reservoir bottom. The temperature range of 0.99°C to 2.79°C is narrower than the 2018 range of 0.24°C to 3.51°C. Temperature at all six WSR sample sites steadily increased with water depth. The water temperature profiles at each site are similar when compared to previous years starting in 2015 with the introduction of RO discharge water into Fish Creek.

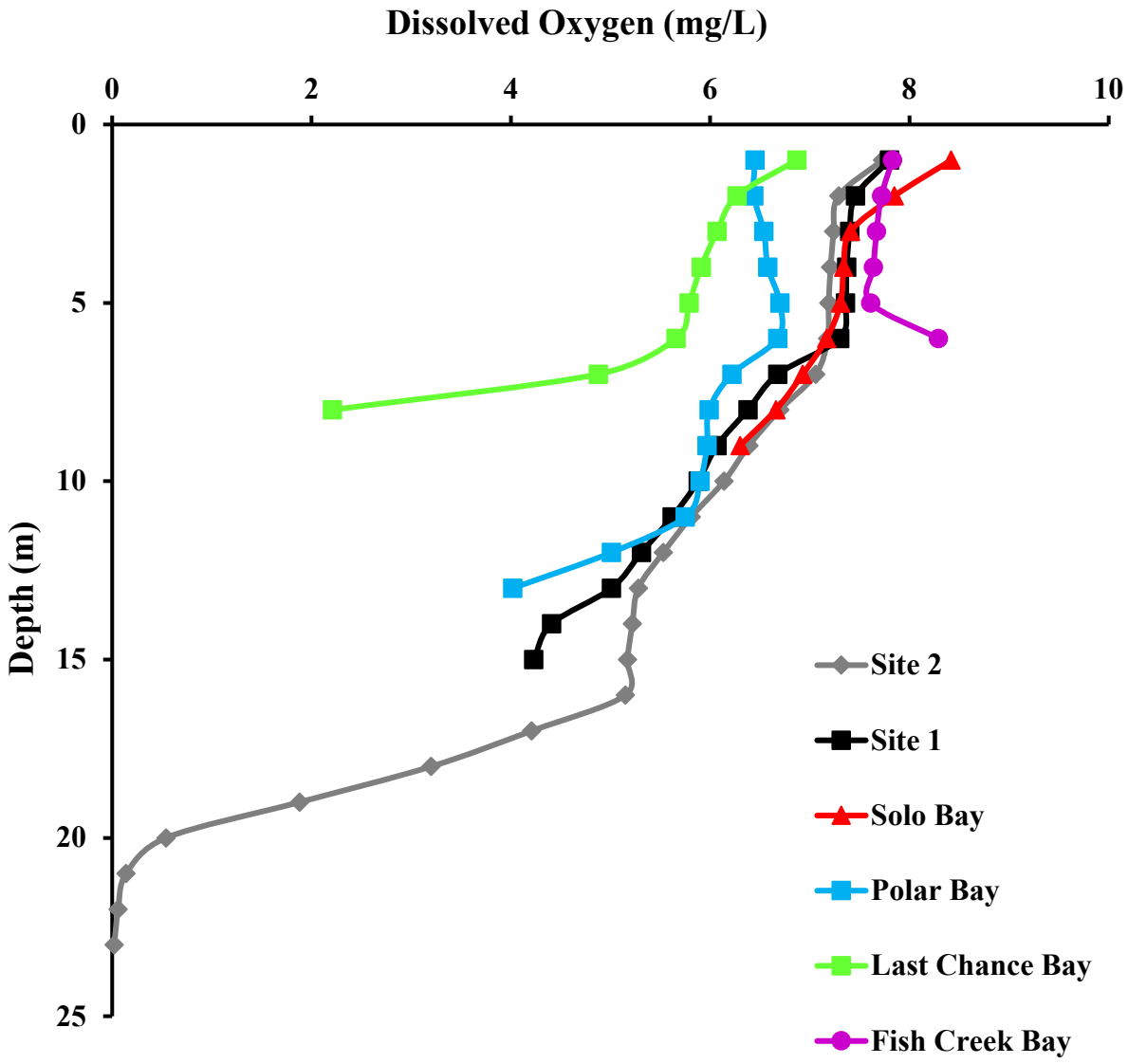

Figure 11. WSR dissolved oxygen (mg/L) profiles, April 10, 2019.

Dissolved oxygen (DO) is essential for the survival of fish, aquatic invertebrates, and aquatic plants. Solo Bay and Fish Creek Bay had the highest recorded DO at 8.42 mg/L and 7.83 mg/L of the six WSR sample sites (Figure 11). These maximums are higher than years prior to 2015 where the average DO record at Fish Creek Bay was 0.195 mg/L. Increased DO is primarily a result of the non-contact water discharge that began in March 2015 at Outfall 001 - 1.6 km upstream from the Pond F outlet. On January 15, 2019 Fort Knox began discharging up to 3000 gpm from RO2 and RO3 into Fish Creek at Outfall 002. Outfall 002 discharges RO water upstream of Pond AB and flows downgradient into the WSR. Fish Creek Bay had the highest average DO concentration for the fifth year in a row of 7.79 mg/L followed by Solo Bay at 7.49 mg/L. Similar results were found from 2015 to 2018.

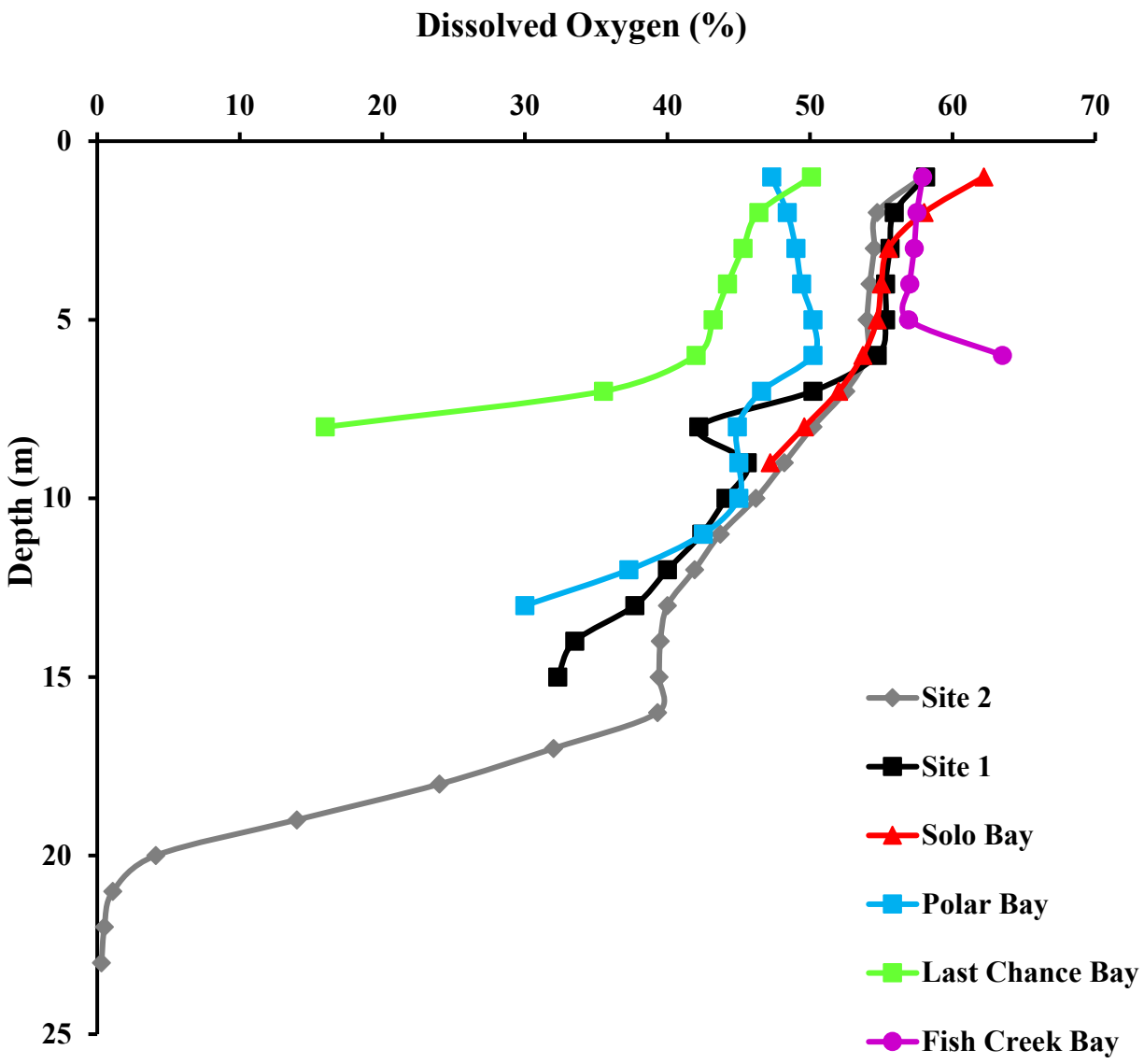

Figure 12. WSR dissolved oxygen saturation (%) profiles, April 10, 2019.

Dissolved oxygen (DO) saturation generally decreased with depth at all sites measured. Temperature specific DO saturation (%) followed the same pattern with higher values in the upper WSR near the inlet of Fish Creek and Solo Creek and lower values near the outlet end of the WSR near the spillway, furthest from the fresh water sources (Figure 12). With the increased water volume entering the WSR from the combined RO discharges into Fish Creek the water is mixed with more consistent DO concentrations among the six sites averaging from 4.88 mg/L to 7.79 mg/L. The Polar and Last Chance Bays sites had the lowest DOs and these sites are not directly influenced by the water entering the WSR from Fish Creek.

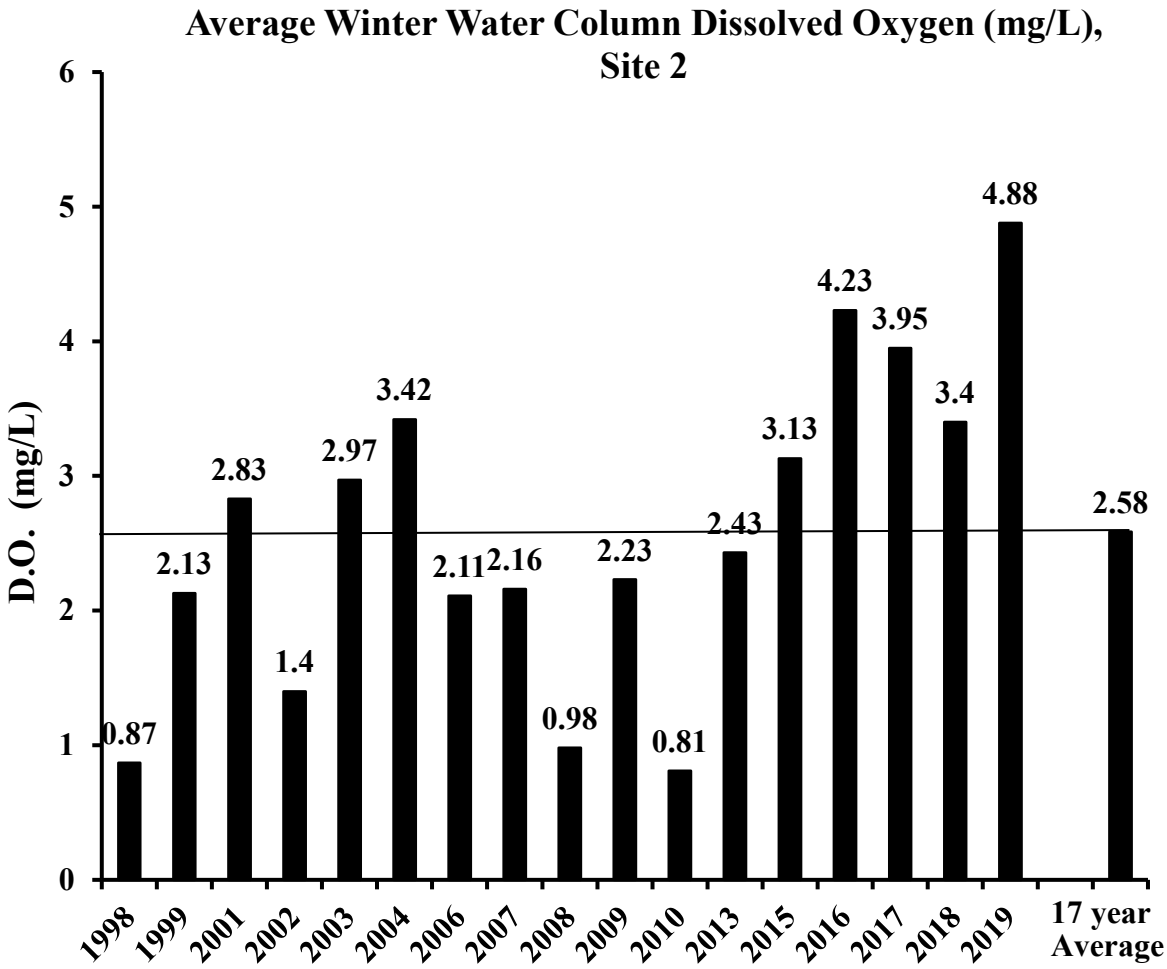

Figure 13. Average winter water column DO concentrations at Site 2 in the WSR, 1998-2019 (excluding 2000, 2011, 2012, and 2014).

Average winter water column DO at Site 2, in the WSR, was above the 17-year running average for the fifth year in a row and the highest on record (Figure 13). Similarly, the DO concentrations during late winter of 2015 through 2019, at Polar Bay were much higher than those previously recorded starting in 2001. (Figure 14). The range between the minimum and maximum values in 2019 was larger than the previous three years with highest concentrations of DO near the surface and the lowest DO near the bottom. This is likely a result of the continual discharge of RO water into Fish Creek upstream from WSR. The 2019 total input of 6,681 acre-feet of RO water is twice the total volume of the WSR water of about 3,363 acre-feet.

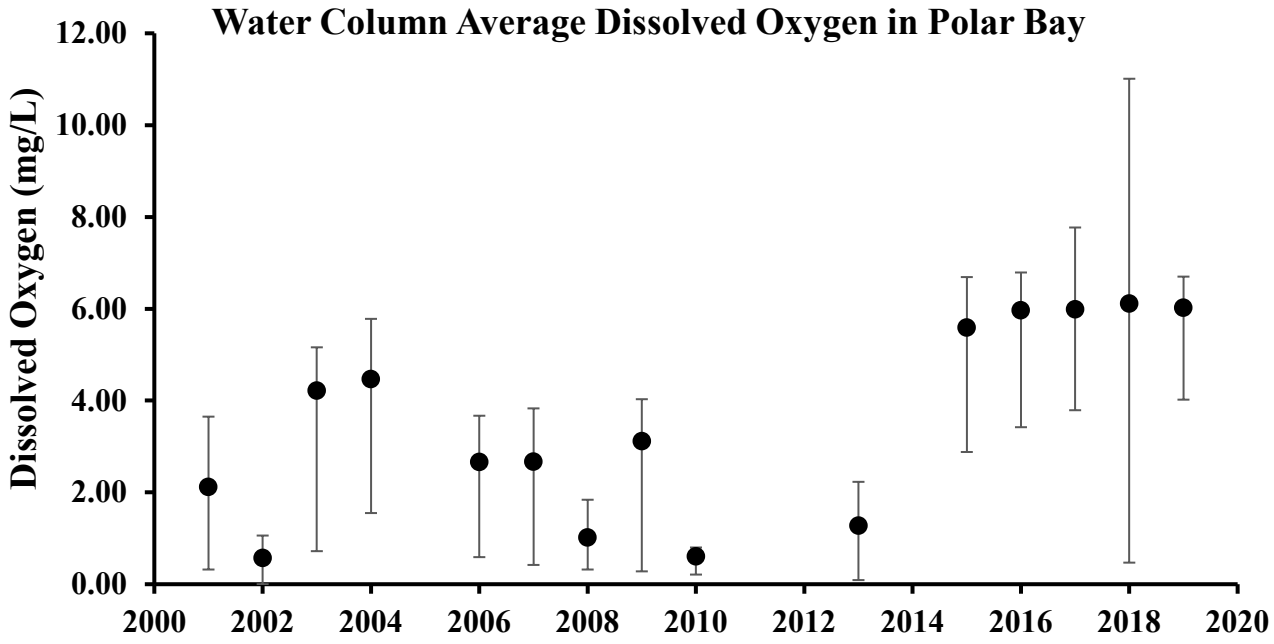

Figure 14. Average, minimum and maximum levels of dissolved oxygen in Polar Bay, winter 2001-2019.

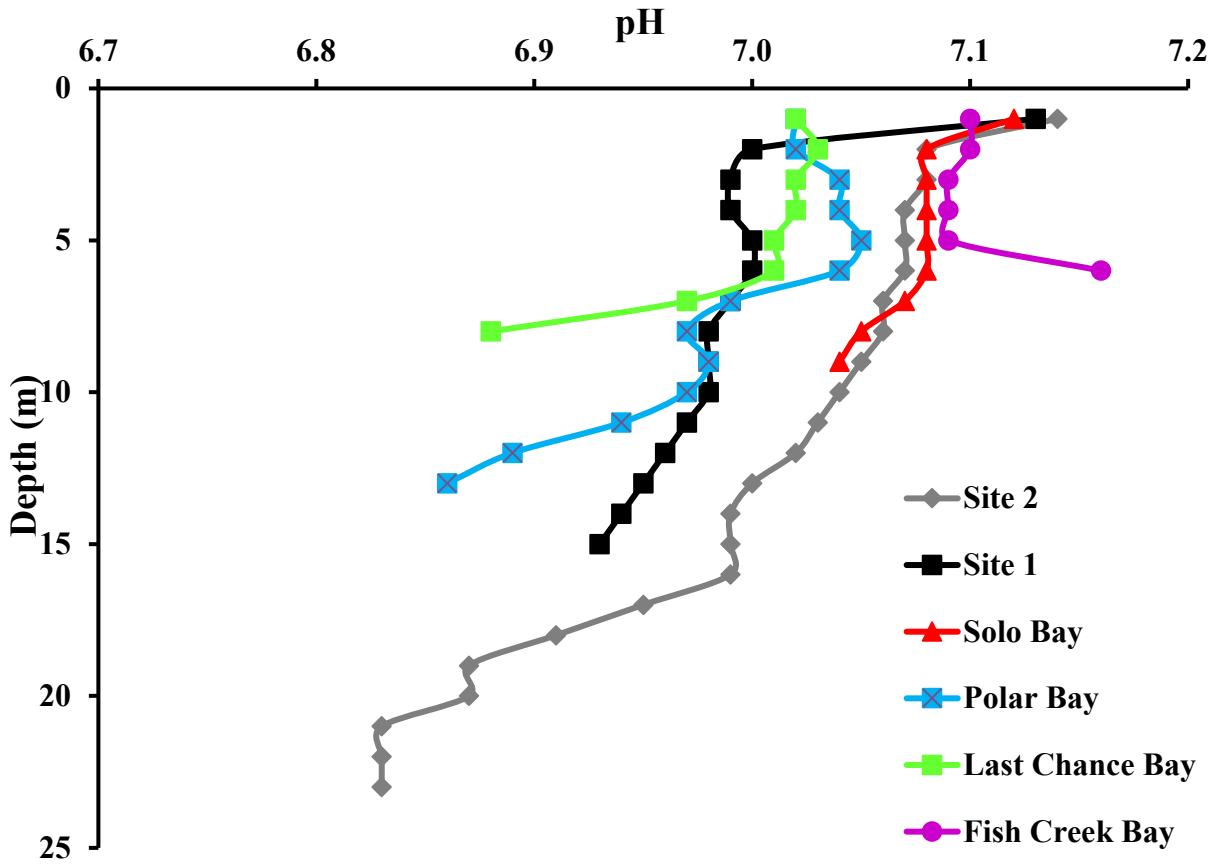

Figure 15. WSR pH profiles, April 10, 2019.

The pH of water has many effects on the plants, invertebrates, and fish in a water body, and has the potential to affect reproduction, recruitment, growth rates. and general health of fish. The pH levels of the water in the WSR in 2019 were relatively similar compared to prior years (Figure 15) at all six sample sites. At most sites the pH just below the ice surface was slightly above 7.0 then dropped with increased depth. All WSR pH readings were in the accepted range for freshwater fish, ranging between 5.5 and 7.5.

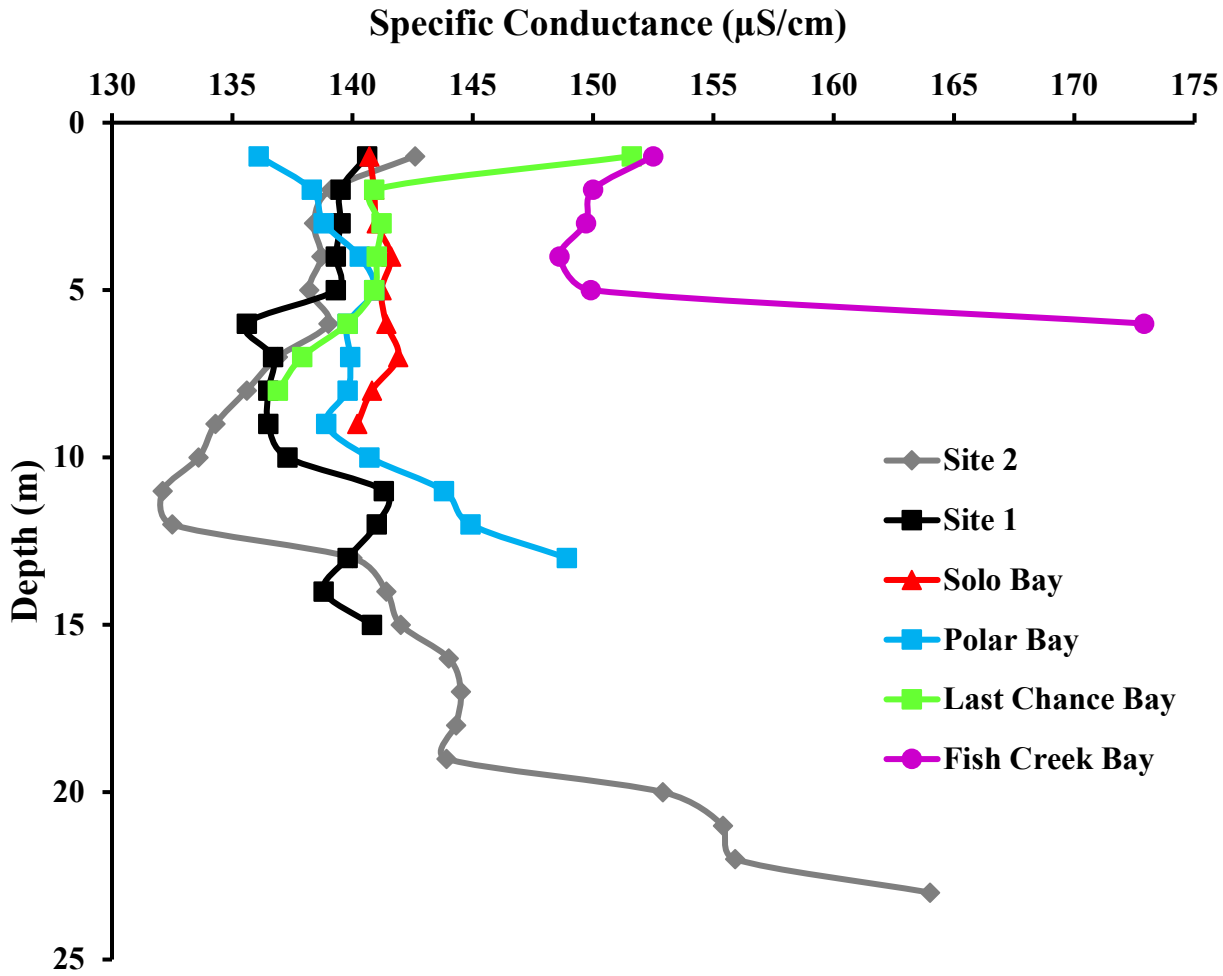

Figure 16. WSR specific conductance (µS/cm) profiles, April 10, 2019.

Specific conductance is a measure of the conductivity of water (the ability to conduct electrical current) and is a general indicator for the concentration of dissolved ions in the water, which can be affected by the mineralization surrounding a waterbody, or by runoff. Specific conductance was similar among all six sites throughout the reservoir (Figure 16). Values generally increased with water depth. The water column in the WSR appears to be mixed with little stratification. Specific conductance readings were more uniform between five of the sample sites compared to previous year's average range. Fish Creek Bay's average reading was higher at 153.9 µS/cm compared to the other five samples sites with a combined average of 140.9 µS/cm.

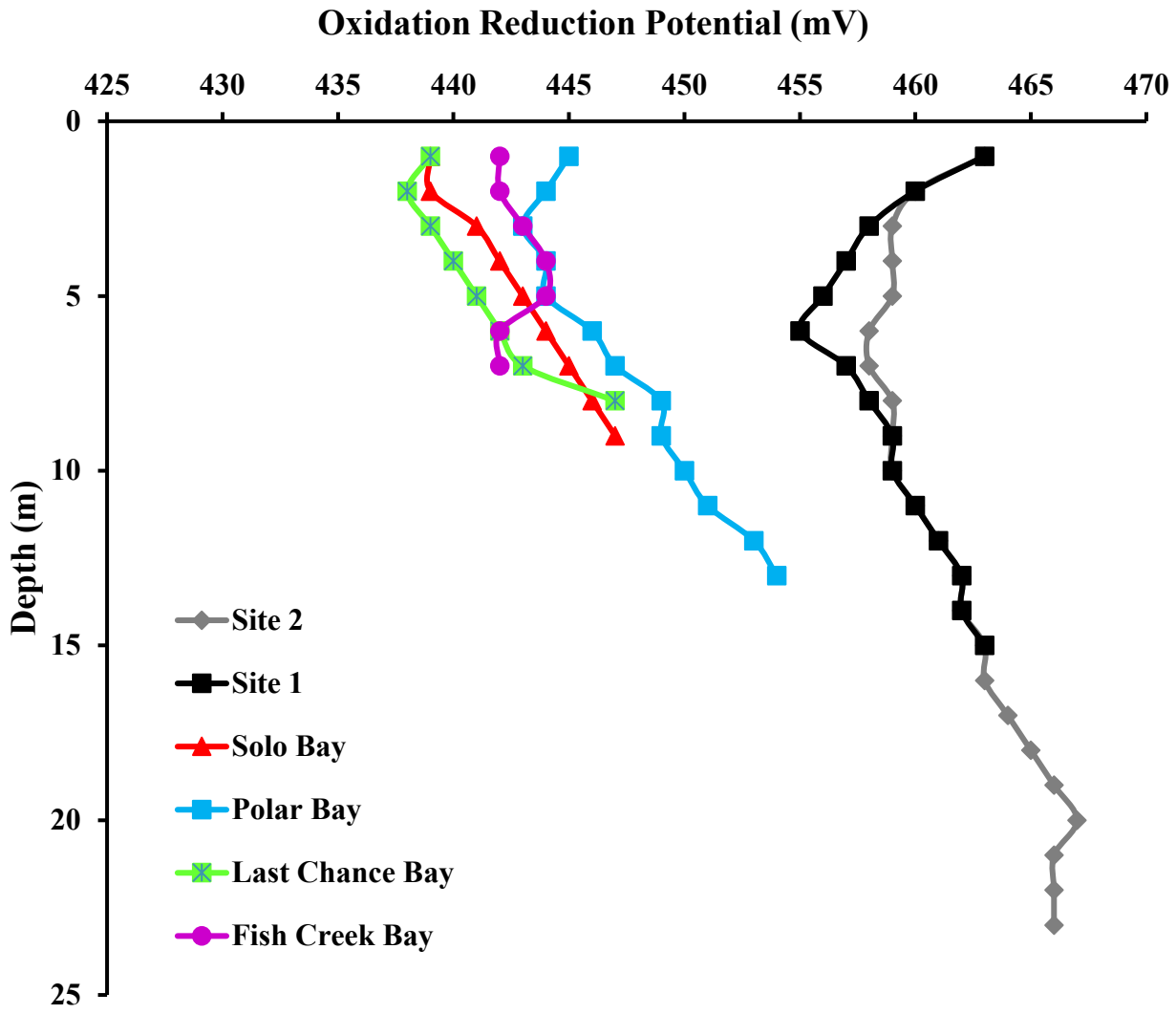

Figure 17. WSR oxidation reduction potential (mV) profiles, April 10, 2019.

Oxidation reduction potential (ORP) measures the ability of a lake or river system to break down waste products, such as contaminants and/or dead biological material. The more oxygen is present in the water, the higher the ORP value. ORP was highest in Site 1 and Site 2 and lowest in Last Chance Bay and Solo Bay (Figure 17). This is similar to previous years except the average value has shifted higher to 452 mV from 422 mV in 2018. Values were uniform throughout the water column except for Site 2 where ORP decreased below 19 m as water became anoxic.

Water Quality, Fish Creek

In 2019, three new sites were sampled for temperature, DO and specific conductance. Two of the sites were in Fish Creek ("Pond F" and "Pond AB") and one in North Creek (Figure 6). Water temperatures at the three new sites were higher compared to water temperatures in the WSR on April 10, 2019 (Figure 18). Typically, the WSR and Fish Creek water temperatures would be similar in April. The influence of warmer RO water discharged from Outfalls 001 and 002 raised the water temperature in Fish Creek. Arctic grayling use in-river water temperature as an indicator for spawning timing and typically spawn as water approaches 4.0°C. Water temperature measured near the discharge point of Outfall 001 was 6.9°C and Outfall 002 was 5.2°C. The water naturally cooled by the time it reached Pond F, one of the primary spawning locations, to 3.3°C, but this was still warmer than the WSR water temperature average range of 0.99 – 1.66 °C.

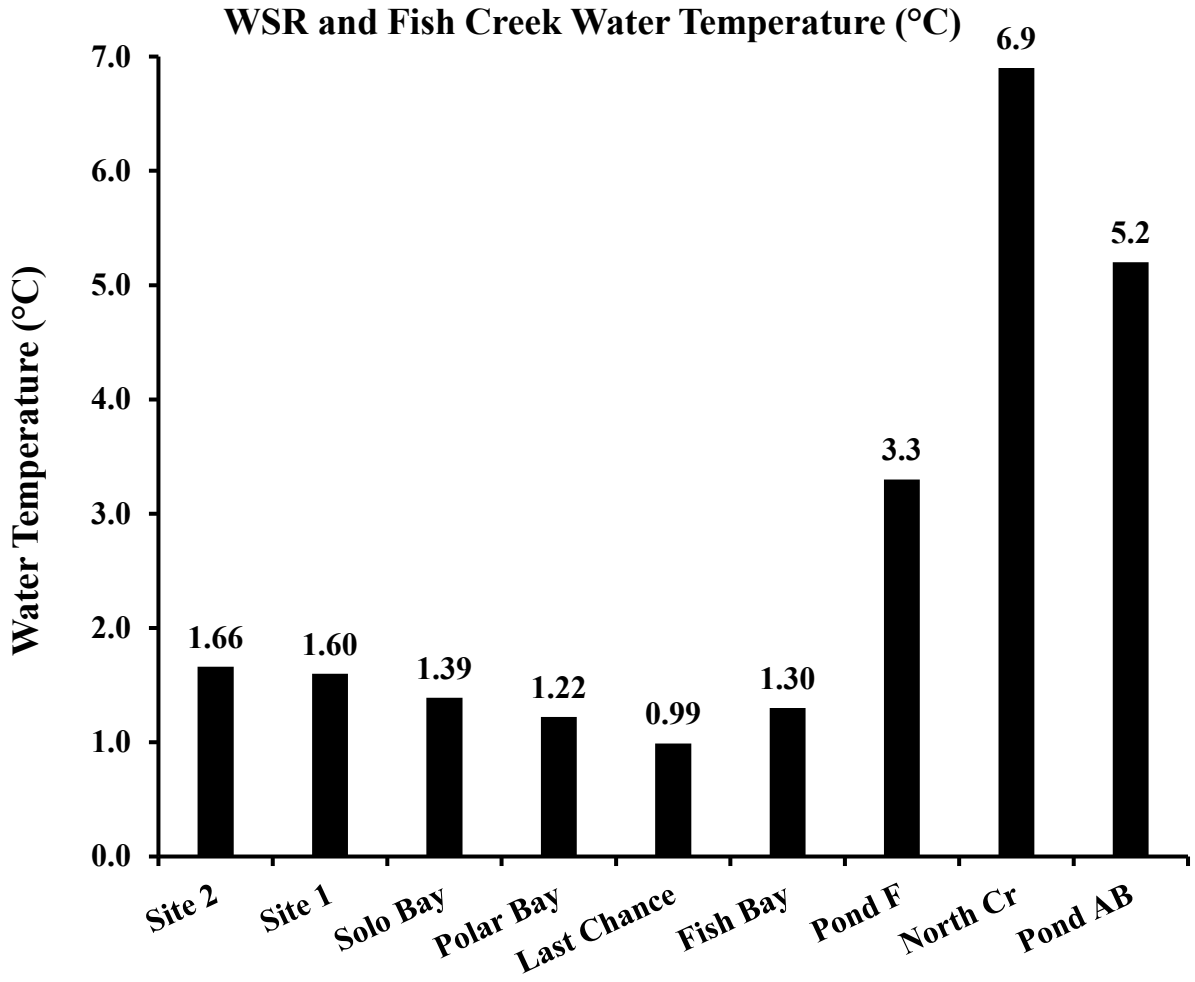

Figure 18. WSR and Fish Creek total water column average water temperature, April 2019.

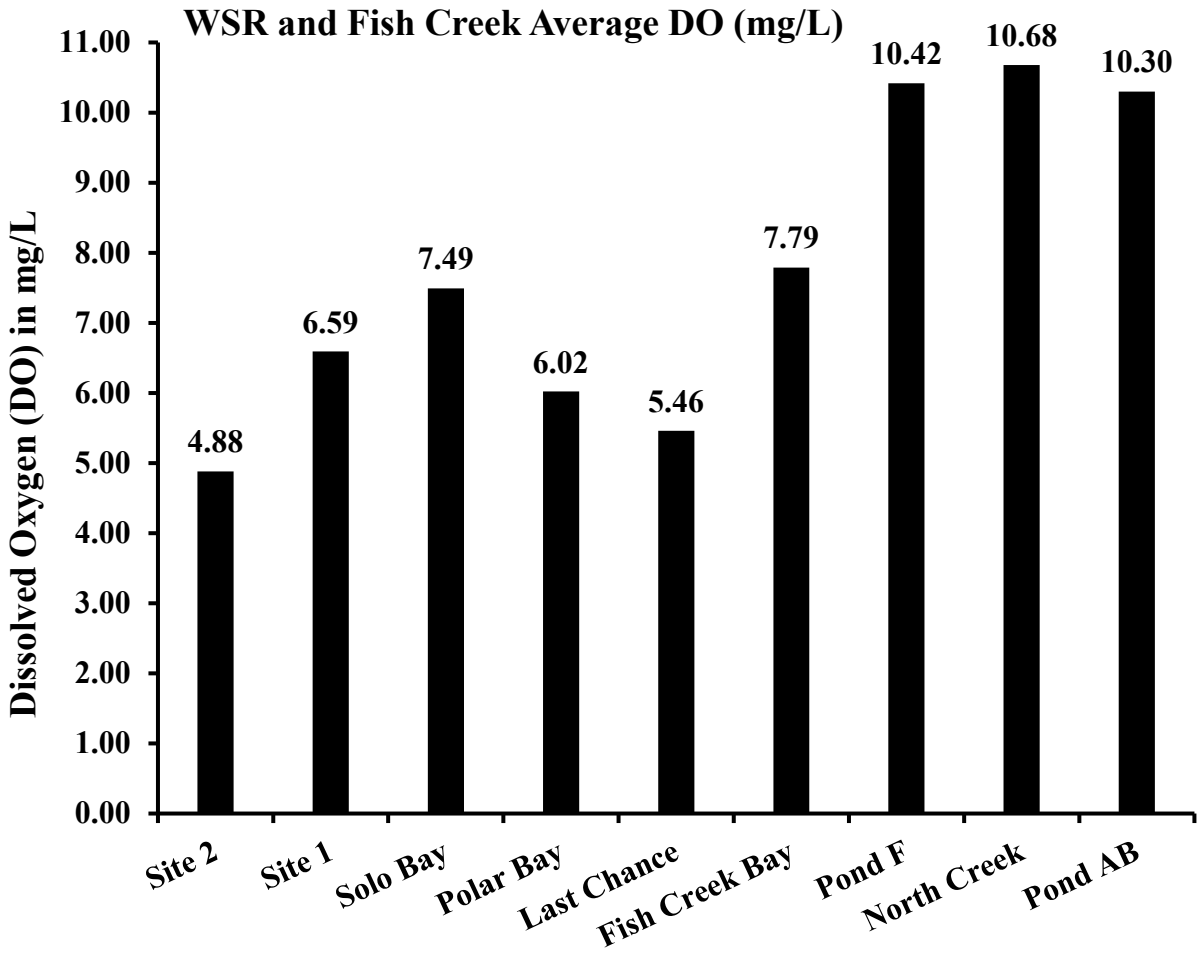

Figure 19. WSR and Fish Creek total water column average DO in mg/L, April 2019.

The average DO in mg/L at the three new sites were higher when compared to the average DO in the WSR sample sites (Figure 19). RO water discharged from Outfalls 001 and 002 is high in DO and has contributed to the rise in measured WSR DO since 2015.

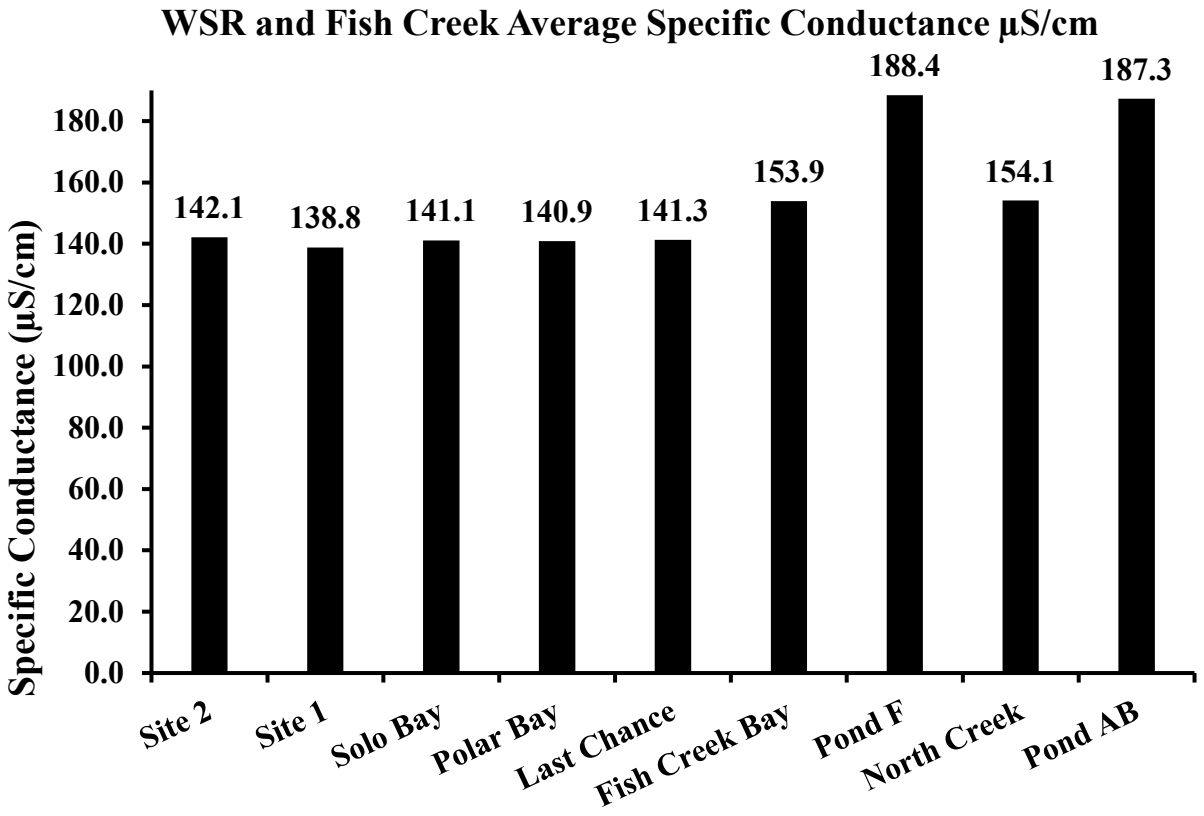

Figure 20. WSR and Fish Creek total water column average specific conductance µS/cm, April 2019.

The RO water discharged from Outfall 002 is mixed with non-contact ground water from de-watering wells that adds minerals and raises the specific conductance before it is discharged into Fish Creek. Pond AB and Pond F Specific Conductance measurements were taken downstream of Outfall 002 and had the highest recoded values for the WSR and Fish Creek (Figure 20).

Water Supply Reservoir, Arctic Grayling

Arctic grayling were found throughout the Fish Creek drainage prior to construction of the WSR. However, fish were concentrated in flooded mine cuts in Last Chance Creek. The population appeared stunted: fish larger than 220 mm were rare, average annual growth was 9 mm, and size at maturity was small averaging 148 mm for males and 165 mm for females (Al Ott, Unpublished Data). Successful spawning was limited to inlets and outlets of the flooded mine cuts and upper Last Chance Creek. Flooding of the WSR inundated the inlets and outlets of mine cuts, thus eliminating this spawning habitat. Since flooding of the WSR, aufeis in Last Chance Creek has been substantial. Since 1998, successful spawning by Arctic grayling in Last Chance Creek has only been observed in 2004 and 2005.

After completion of the freshwater dam, very few Arctic grayling fry were captured or observed (< 10 fish) from 1996 through 1998 in the WSR and Last Chance Creek. In spring 1999, FGMI

constructed an outlet channel to connect the developed wetland complex with the WSR. The outlet channel was constructed to bypass a perched pipe and provide fish access to potential spawning and rearing habitat in the wetland complex.

Arctic grayling have successfully spawned in the wetland complex every year since 1999 (Figure 21). However, in 2002, 2006, and 2007, substantial aufeis and resultant cold-water temperatures in the wetland complex, in addition to beaver dams, limited the access and availability of spawning habitat. In recent years, aufeis buildup has been relatively minor and more effective beaver management has been implemented, including the annual removal of dams throughout the wetland complex.

Figure 21. Arctic Grayling with Floy brand T-Tag.

Arctic Grayling Spawning (Timing, Temperature, and Fry Presence)

In winter 2019, aufeis in Fish Creek was minimal. North Creek had substantial aufeis and formed a glacier across Centerline Road above Pond F. Beaver dams in Pond D and F outlets and in the lower wetland complex had been rebuilt during winter of 2018/2019. Two dams were breached by ADF&G staff on April 15 and June 25, 2019, to allow fish passage. Fort Knox was successful in removing resident beavers from Fish Creek during the spring of 2019 to maintain fish passage for successful spawning and rearing. Arctic grayling had access to the wetland complex (Ponds E and F) for most of the summer, but access was reduced further upstream by a 1 m high natural barrier in the channel connecting Ponds D and E (Figure 22). Several Arctic grayling were observed upstream of the vertical obstruction between Pond E and Horseshoe ponds on May 23, 2018, but no survey was conducted during the summer of 2019. With the increase of up to 3000

gpm of water from Outfall 002 into Fish Creek, substantially more water was flowing over the 1-meter barrier during 2019, which may impacted the number of fish utilizing this stretch of the wetlands complex.

Figure 22. A hydraulic jump (about 1 m high) formed in the channel connecting Ponds D and E that was a limiting obstacle to the upstream movement of fish, April 12, 2019.

On April 10, during the late winter WSR water quality sampling, water temperature at the Pond F outlet was 3.3 °C and approaching the ideal spawning conditions for Arctic grayling (4.0 ºC). Fish Creek was open and flowing and most of the Pond F ice was melted (Figure 23). Conditions were determined to be appropriate to begin fyke netting Arctic grayling on April 12. This was 21 days earlier than sampling began in 2018 (Figure 23). More open water was present in Fish Creek than previously seen (Figure 24) from the increased discharge of warm (RO) water from the new treatment plant brought online January 15, 2019. Snow melt was slow and water levels remained consistent with no high flow events during the sampling period.

Figure 23. Pond F open water April 12, 2019 (left) and May 10, 2018 (right).

Figure 24. Open water at Pond D on April 10, 2019.

The daily peak water temperatures taken at the Pond F outlet in 2019 were more constant over the first three weeks of monitoring when compared to previous years (Figure 25). The temperature of Fish Creek water remained more consistent into May even as snow melt occurred and cold water entered the system. The more consistent water temperature likely resulted from the approximate 3000 gpm discharge of warm RO water (5.2 ºC) from Outfall 002 that started entering the system on January 15. This large volume of warm moving water buffered the influx of cold spring melt water, keeping the average water temperature more stable and consistent. The daily peak water temperature timing was slightly later than average but not as late as 2013, which was the year with the latest spring peak in recent records (June 1). Arctic grayling spawning normally takes place when water temperature is near 4 °C and above, this response can be seen in the Catch Per Unit of Effort (CPUE) and spent condition of Arctic grayling increasing from April 27 to May 3 as water temperature rose above 4 °C (Figure 26 and 27).

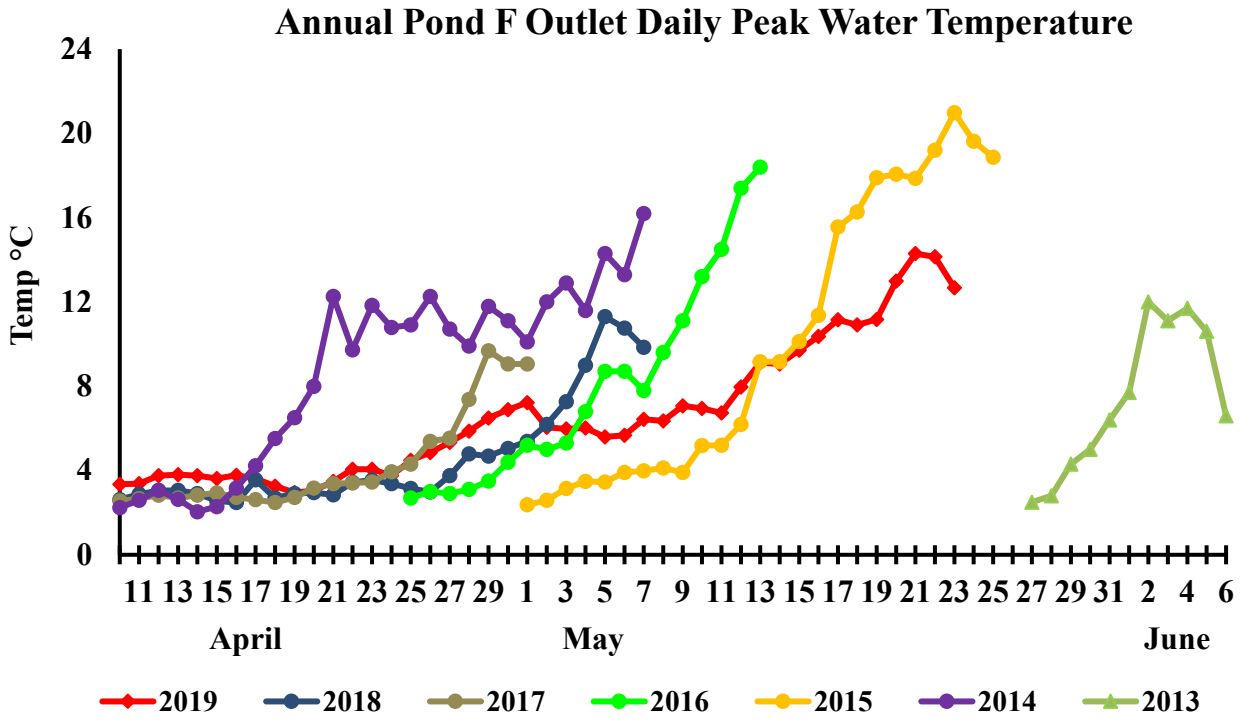

Figure 25. Pond F outlet daily water temperature maximums; 2013 to 2019.

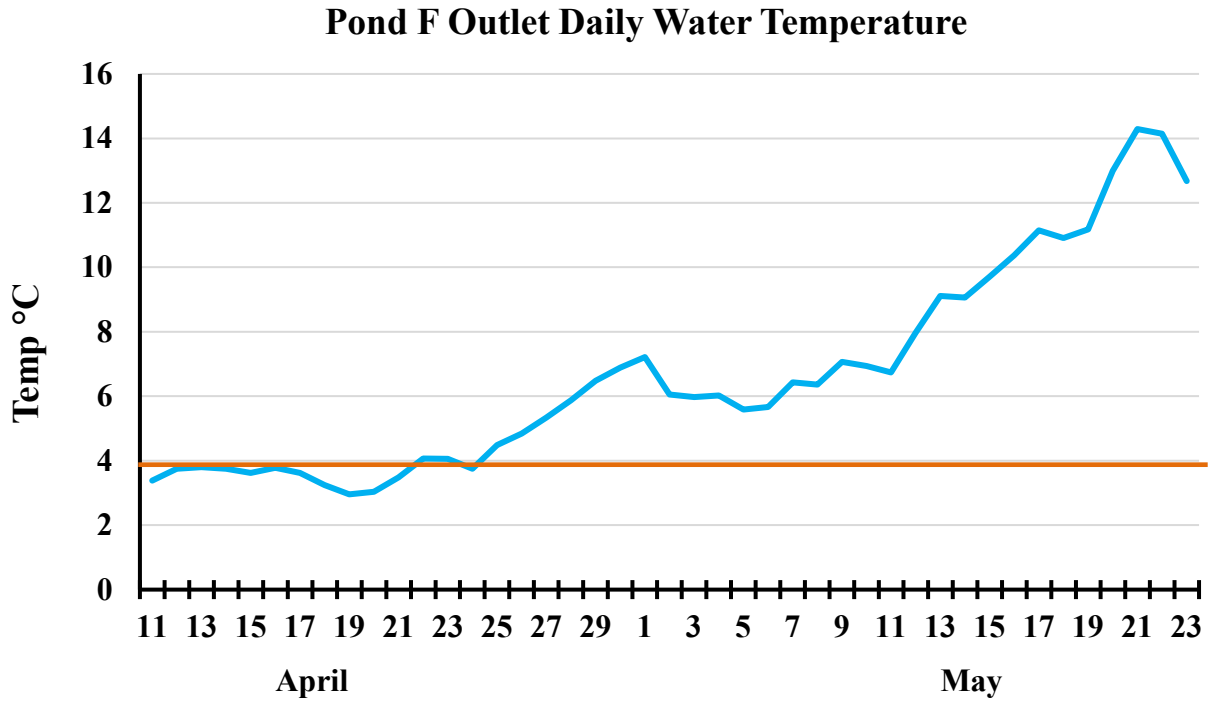

Figure 26. Pond F outlet peak daily water temperature April 11-May 23, 2019.

From April 15 to May 3 all fish caught in the Pond F fyke net were sampled with the majority being Arctic grayling. Burbot were also caught and these data are reported in the WSR burbot section of this report. The Arctic grayling CPUE was low during the first few days of sampling and picked up on April 27 after the first week. The CPUE reached a high of 7.5 Arctic grayling per hour at Pond F on May 2 before beginning to decline (Figure 27). The fyke was pulled on May 3 as the approximate target sample size of 1,200 grayling had been reached and most of the Arctic grayling had spawned.

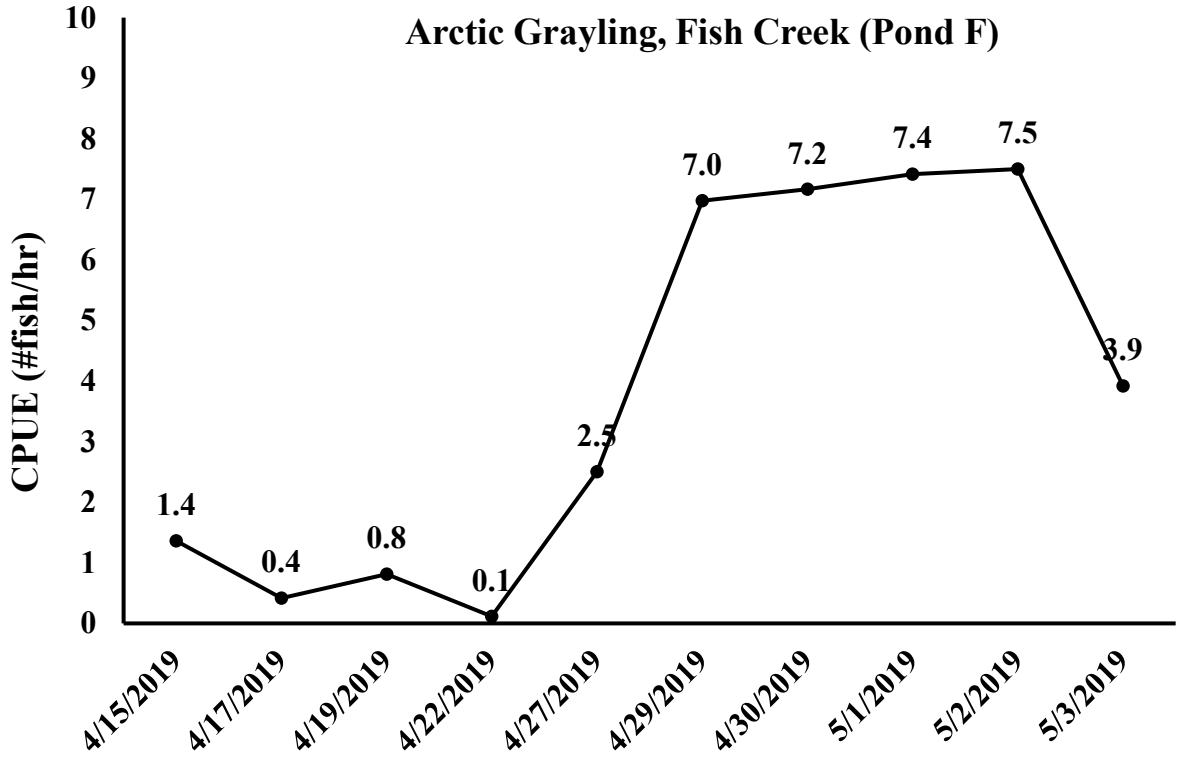

Figure 27. Catch per unit of effort (CPUE) in #fish/hr at the Pond F fyke net in the wetlands complex.

Female Arctic grayling were categorized as not ripe, ripe or spent, based on their spawning condition (Figure 28). On the first day of fish capture (April 15), 63% of the female Arctic grayling were categorized as not ripe. The number of not ripe fish steadily decreased throughout the sampling period to 6% on April 29, then slightly increased to 10% as new Arctic grayling moved from the WSR into the Fish Creek wetlands complex. On April 15, 38% of the Arctic graying were classified as ripe. The number of ripe fish steadily increased to 89% on April 29 before declining as most of the fish began to spawn. No fish were classified as spent during the first twelve days of the sampling period, then spent fish peaked at 92% on May 3. The 2019 spawning

condition and timing was 21 days earlier than in 2018 where sampling began on May 4 and 93% of the females were categorized as not ripe.

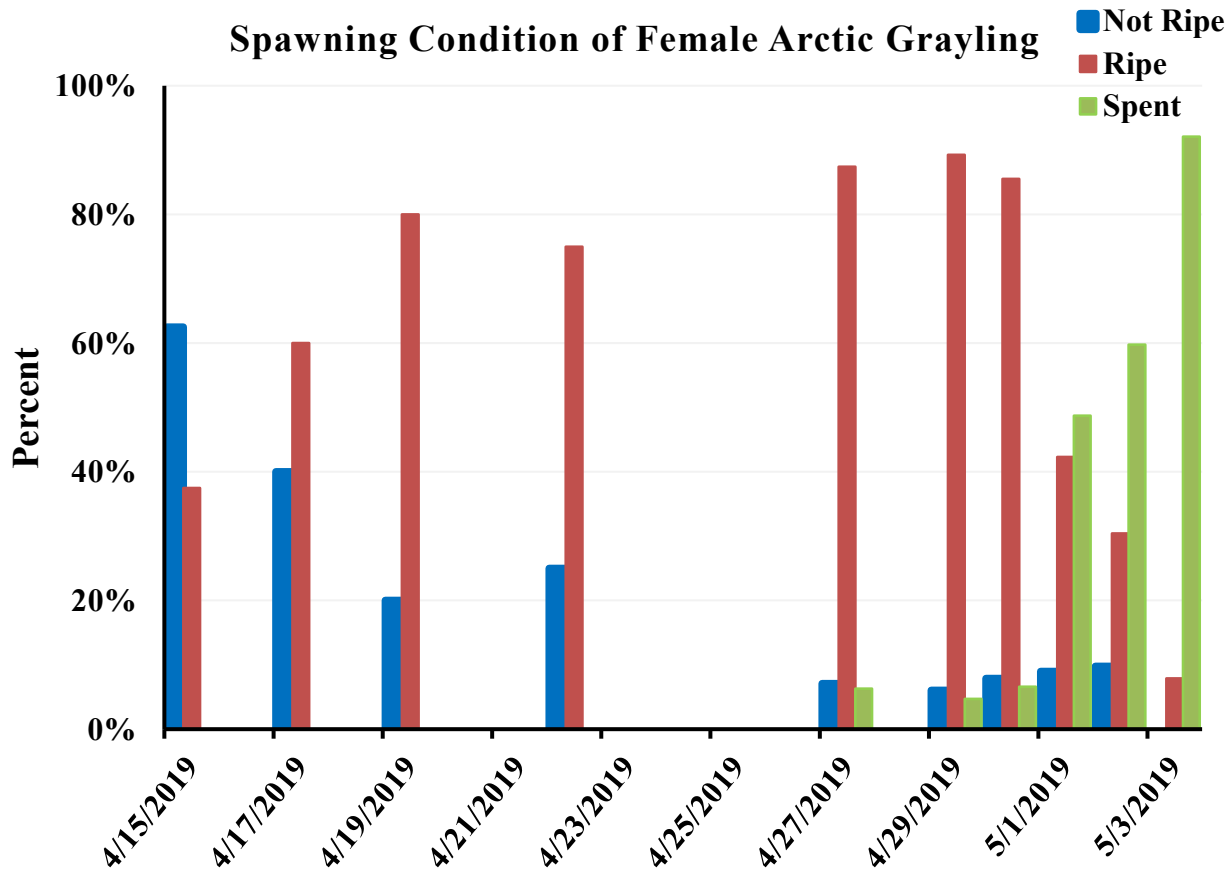

Figure 28. Spawning condition of Arctic grayling females categorized as: Not Ripe, Ripe or Spent, 2019.

Arctic Grayling Catches and Metrics

The spring 2018 population abundance estimate for Arctic grayling ≥ 200 mm was 6,045 fish with a 95% CI of 5,461 to 6,629 fish (Figure 29). The population has been declining but relatively stable for six years since 2011 but showed a sharp increase in 2017. The 2018 population estimate is 1,096 fish lower than the 2017 estimate.

The 2018 population abundance estimate of Arctic grayling in the WSR was calculated using spring 2018 as the mark event and spring 2019 as the recapture event. During the spring of 2019 there were 1,382 Arctic grayling captured ≥ 230 mm, of those 257 were recaptures from the spring 2018 tagging event. For the 2018 population estimate, Arctic grayling population length frequency distributions from 2018 and 2019 were compared to eliminate those fish handled in 2018 that

would have been too small (<200 mm) to mark in spring 2018, 127 fish met these criteria and were not included in the population estimate.

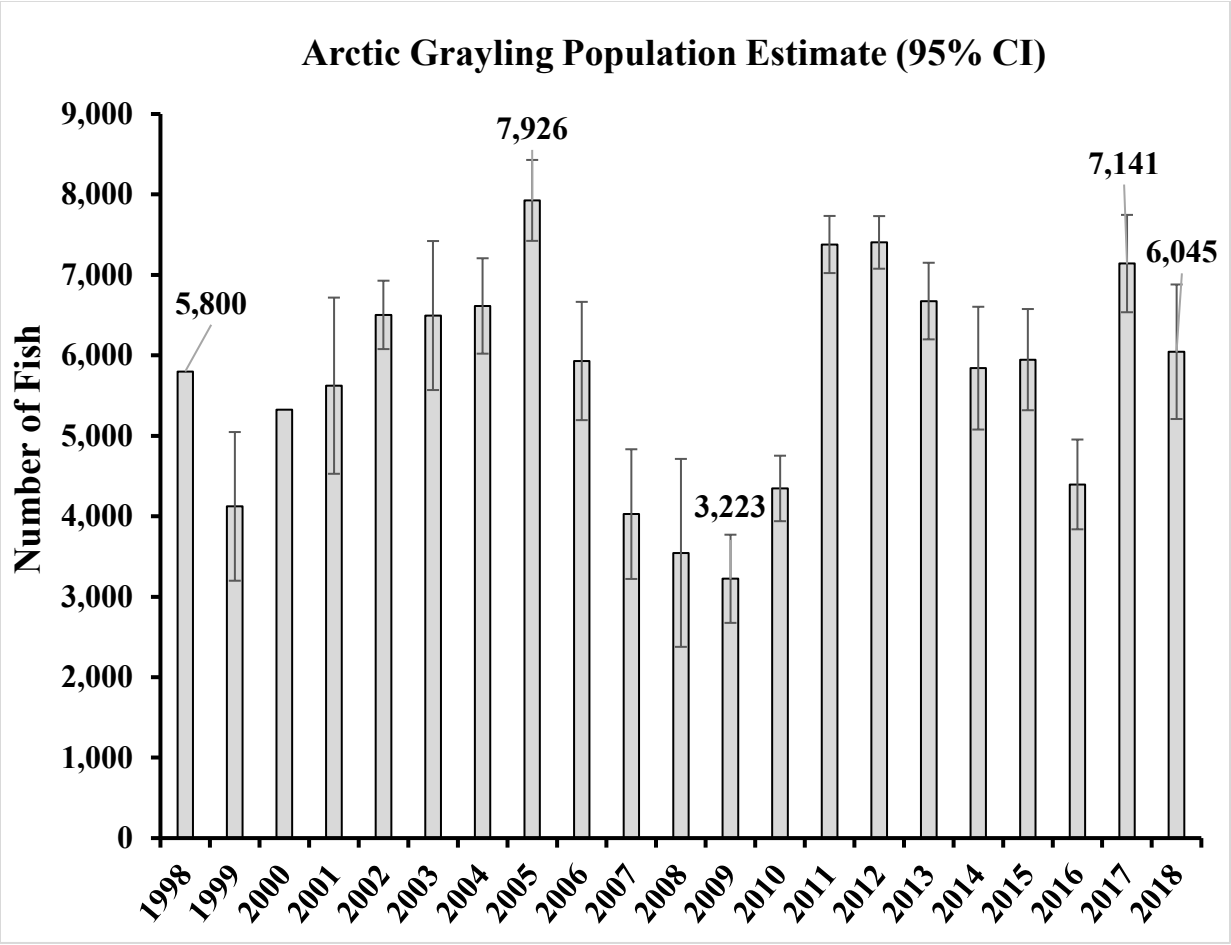

Figure 29. Estimates of the Arctic grayling population (fish ≥200 mm) in the WSR, with 95% Confidence Intervals, 1998-2018.

Recruitment (defined as those fish entering the population ≥ 200 mm, but based on actual growth would have been too small to mark in the previous year) is variable among the sampling years, but was highest in 2017 and declined in 2018 and 2019 (Figure 30). Substantial recruitment was most recently observed in the spring of 2017. A substantial recruitment event was defined as >300 fish encountered during a recapture sampling event that were not available for tagging based on size during the mark sampling event (typically fish between 200 and 240 mm).

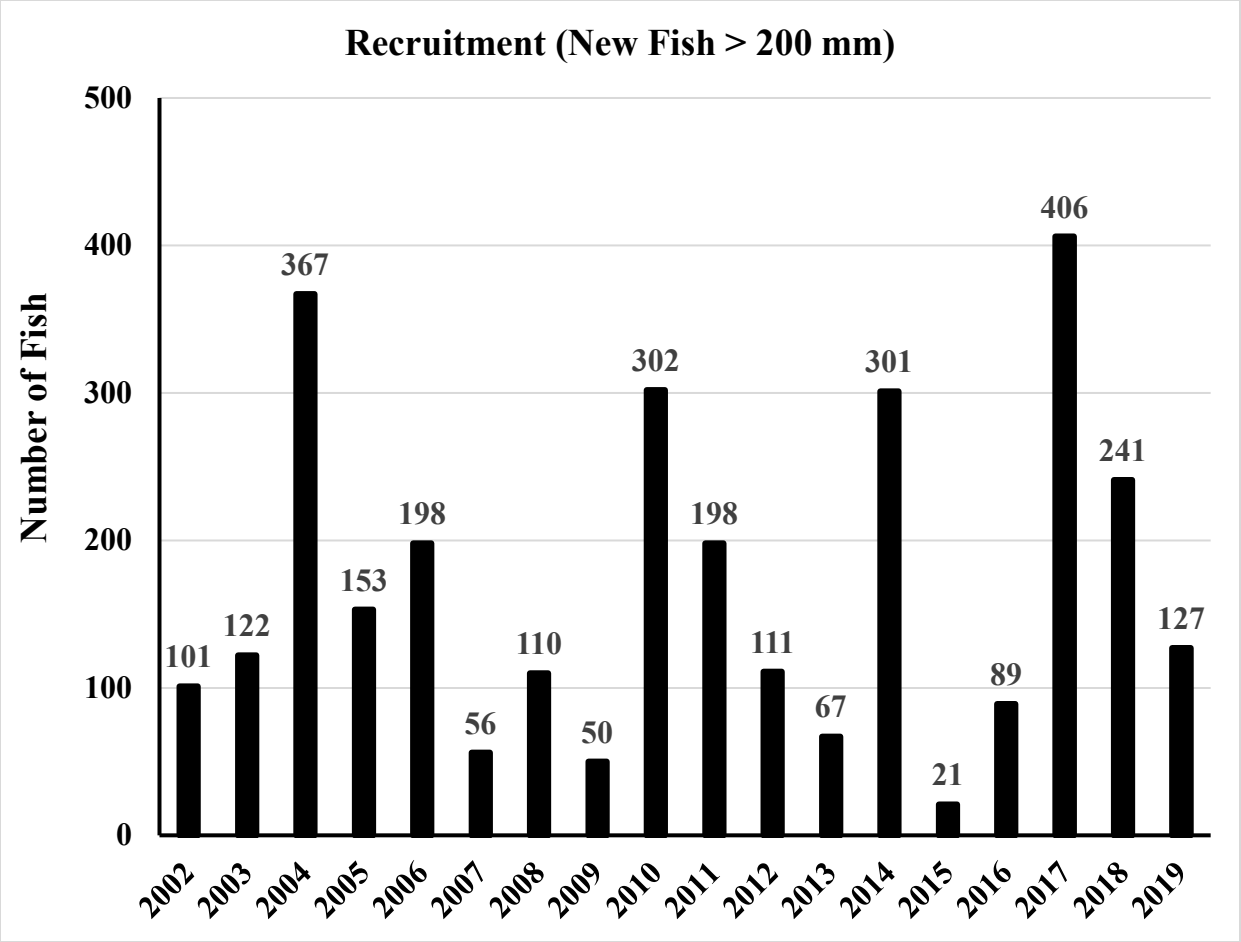

Figure 30. Number of new fish ≥ 200 mm that entered the population but would have been too small to mark in the previous year (based on growth of marked fish), 2002-2019.

Average growth of Arctic grayling prior to the development of the WSR ranged from 3 to 17 mm per year (Figure 31). Average growth substantially increased since the construction of the WSR in 1995. From 2014 to 2018, the highest average annual growth occurred in 2014 and the lowest annual growth occurred in 2015. The 2018 annual average growth rate is slightly less than the peak in 2014. Many factors contribute to the average growth in any given year.

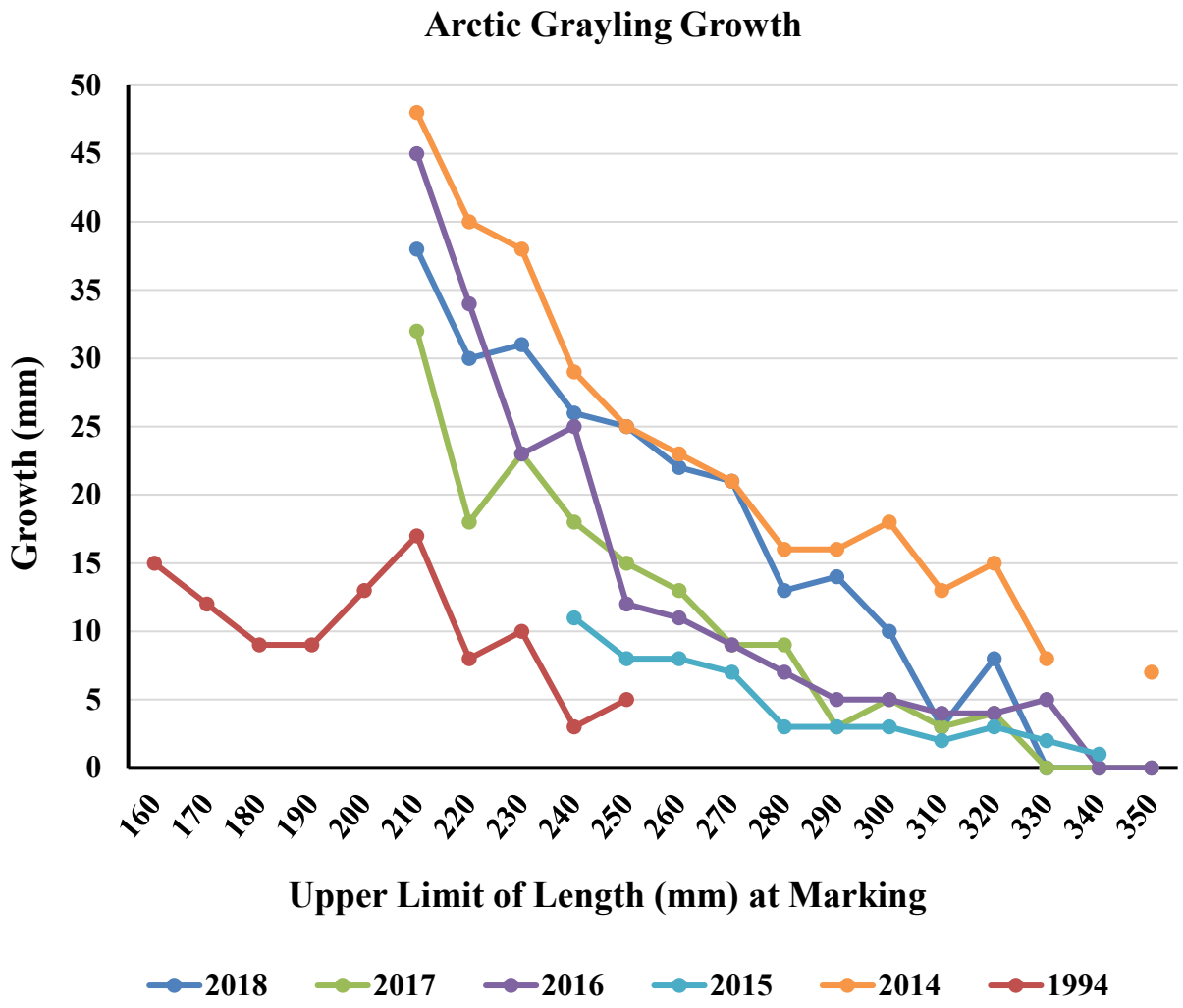

Figure 31. Average annual growth of Arctic grayling by size group in the WSR in selected years including baseline (before WSR) in 1994.

The 2019 length frequency distribution of Arctic grayling caught in the wetlands complex is presented in Figure 32. Data for 1995 is included for comparison. The length distribution frequency has increased since 1995. The 1995 data set was obtained before construction of the freshwater dam and reflects the stunted condition of the population at that time. The entire population length distribution was lower in 2018 than in 2019 resulting from the addition of many new fish, 241 in 2018. In 2019 only 127 Arctic grayling were between 200 mm and 230 mm with mostly larger fish captured.

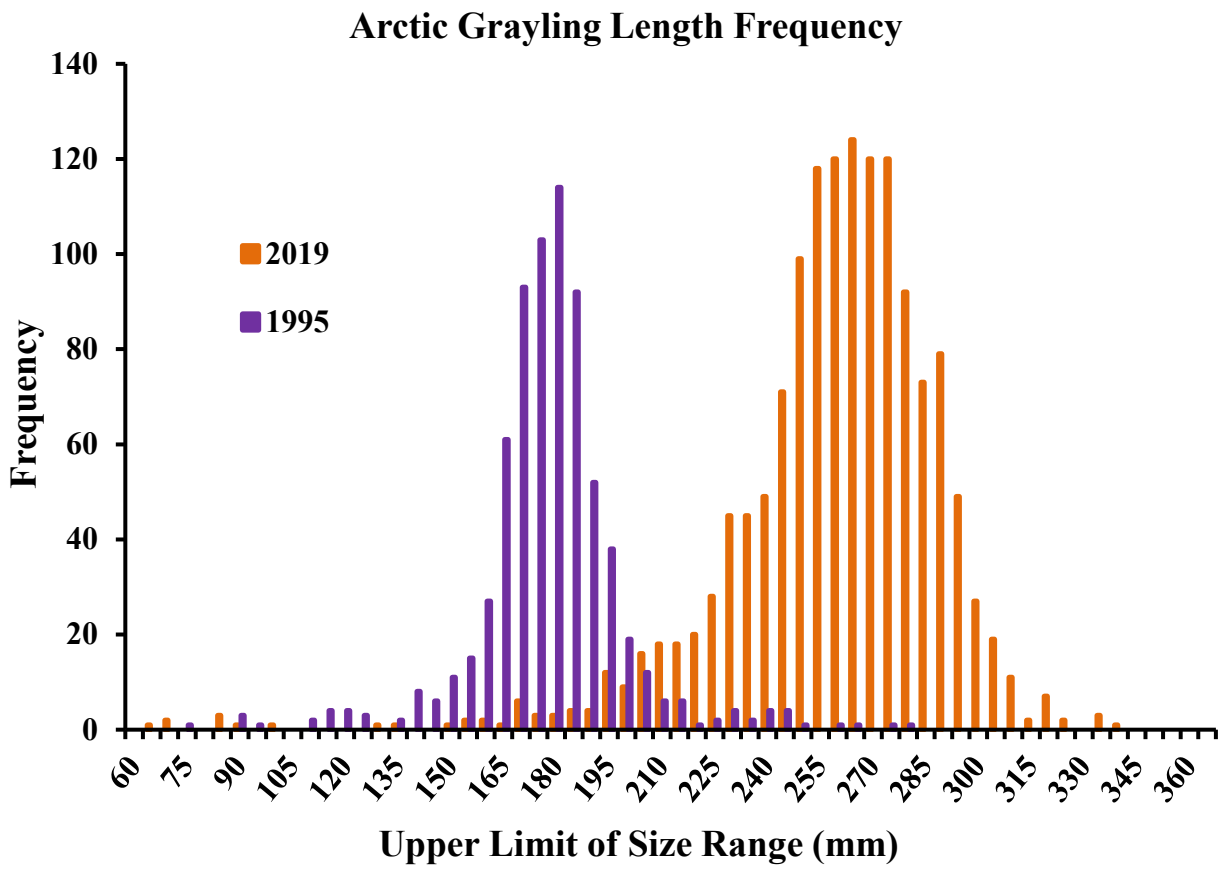

Figure 32. Length frequency distribution of Arctic grayling in spring 1995 and 2019.

Water Supply Reservoir, Burbot

The 2018 burbot population estimate uses the spring of 2018, with both fyke nets and hoop traps, as the marking event and fall 2019, hoop traps only, as the recapture event. Burbot ≥ to 300 mm were tagged with a Floy brand T-Tag near the dorsal fin. During the 2018 marking event, 213 total burbot were captured, 150 were tagged, 72 of which were ≥ 400 mm. During the 2019 recapture event, 124 total burbot were captured, 48 burbot were ≥ 400 mm, and of these, eight fish were recaptures from the 2018 marking event.

The 2018 WSR population estimate of burbot ≥ 400 mm is 402 fish (95% CI: 190 to 613 fish) (Figure 33). This is the highest ≥ 400 mm population estimate made to date. The population of large burbot has been increasing since 2015.

The 2018 WSR population estimate for burbot ≥ 300 mm was not calculated because there were no burbot recaptured in fall 2019 between 300 and 400 mm that had been tagged during the spring 2018 event.

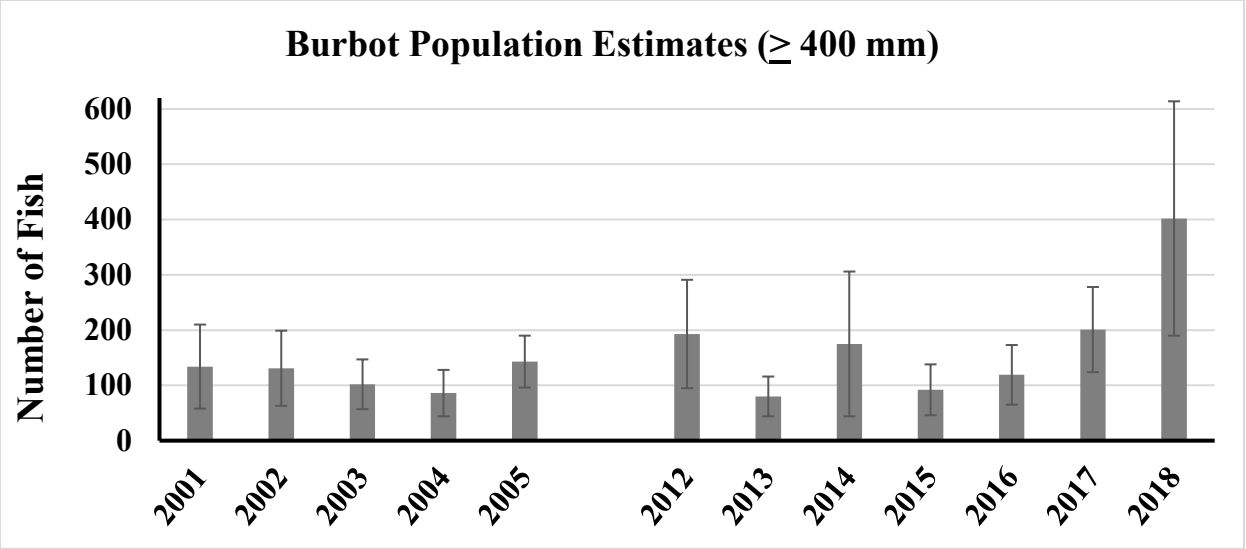

Figure 33. Population estimates of burbot (≥400 mm) in the Fort Knox WSR, 2001 –2018 with 95% confidence intervals shown (no population estimates were produced from 2006-2011).

The 2019 CPUE of all burbot captured was 0.4 fish per day per trap (Figure 34). This is lower than the 2017 and 2018 CPUE estimates of 1.1 fish per trap per day. The 2019 sampling event captured fewer burbot (n = 124) over more days than the 2018 recapture event (n = 213). This is the lowest CPUE since 1996 with the next closest being 0.5 during 2012.

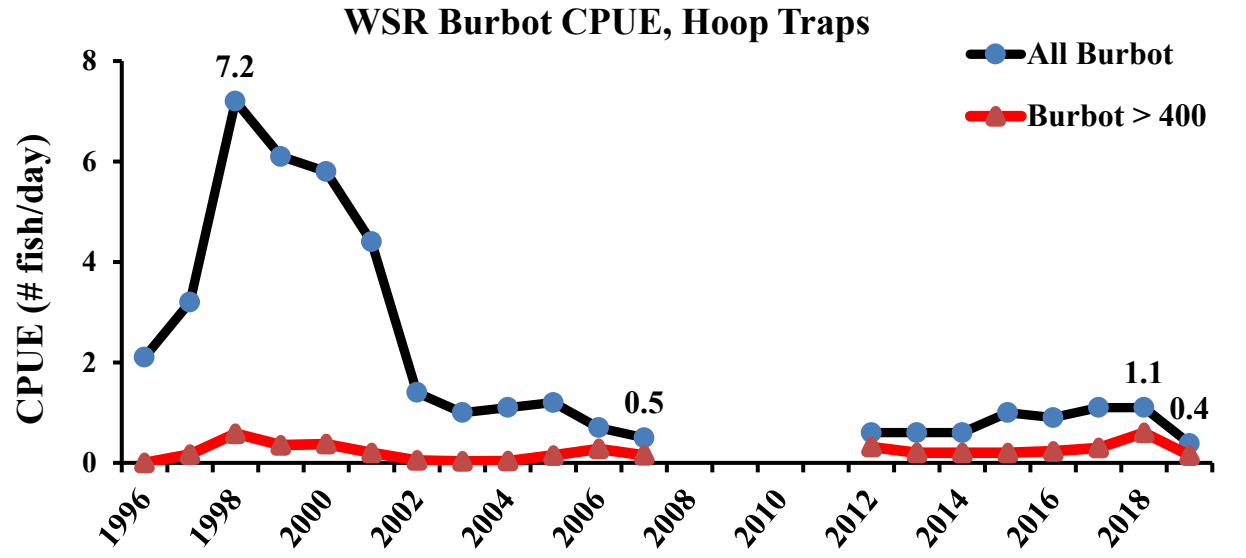

Figure 34. WSR burbot Catch Per Unit Effort (CPUE) in fish per day per trap (#fish/day), 1996-2019.

In fall 2019, 124 burbot were caught in the WSR with hoop traps. Length of burbot ranged from 166 to 735 mm with an average of 391 mm (Figure 35).

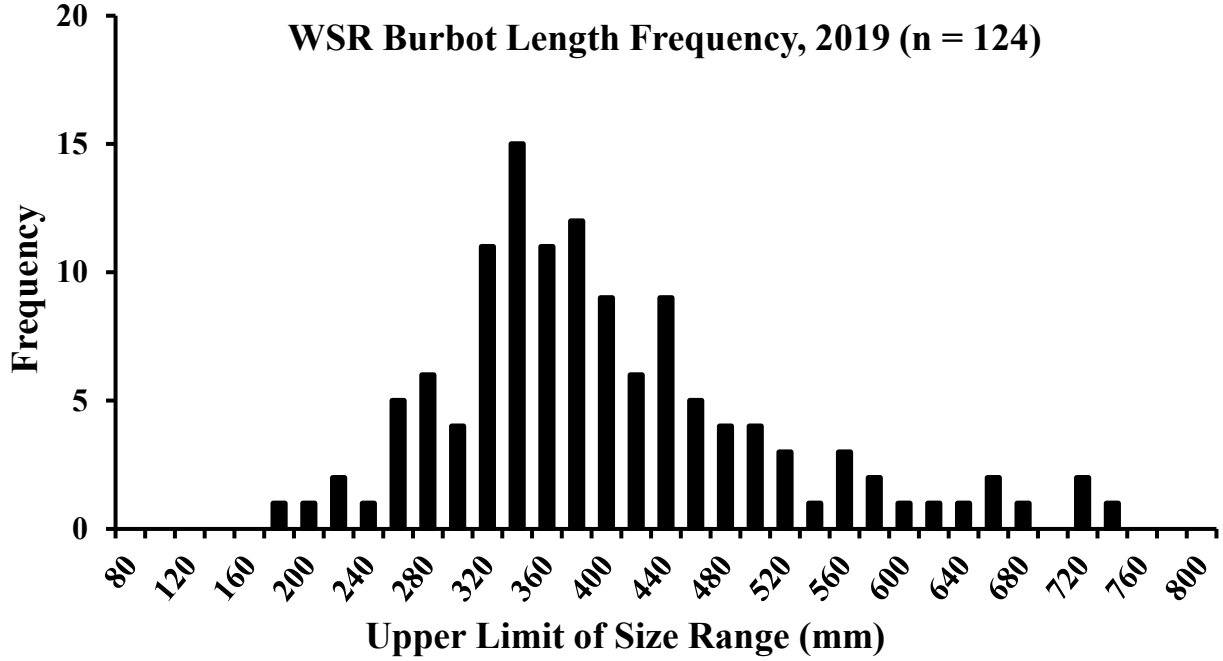

Figure 35. Length frequency of burbot caught in hoop traps in the Fort Knox WSR, 2019.

An annual, 12 month, burbot growth rate in the WSR was not calculated for 2019 due to the 16 months between the May 2018 burbot sampling and October 2019 recapture. Furthermore, only one burbot recapture was obtained in 2016 and 2017 (Figure 36).

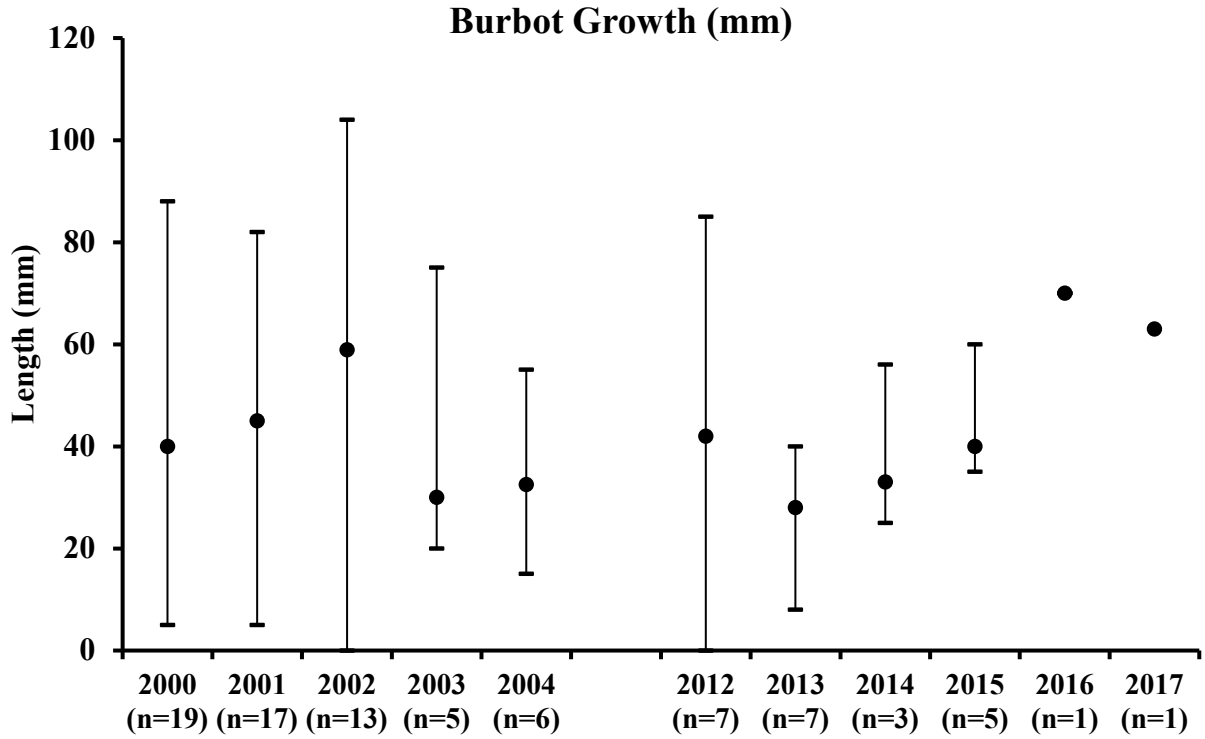

Figure 36. Growth (median, maximum, and minimum) of marked burbot (≥ 400 mm) in the WSR, 2000-2004 and 2012-2017.

One burbot (Tag # 8473) captured in October, was unusually colored, with no light and dark brown mottling (Figures 37 and 38). These unusually colored burbot have been documented during previous years sampling in the WSR, one captured in 2002 and two captured in 2007, and one in 2018.

Figure 37. Burbot with unusual coloration, Fort Knox WSR, October 2019.

Figure 38. Burbot with typical coloration, Fort Knox WSR, October 2019.

Stilling Basin, Arctic Grayling

The stilling basin located immediately downstream of the WSR spillway is fed by groundwater, seepage flow, and surface flow. A narrow notch in the spillway was designed to accommodate surface water discharge from the WSR during winter, without forming aufeis. Aufeis in the spillway has never been observed since it was constructed. In spring 2019, a relatively large volume of water was flowing over the spillway due to the 3000 gpm of RO water being discharged into Fish Creek from Outfall 002.

From June 25 to 27, 2019, the stilling basin was sampled using baited hoop traps for burbot, baited minnow traps for juvenile fish, and angling for Arctic grayling (Figure 40). Minnow traps were fished in the WSR seepage pond southeast of the stilling basin. Population estimates of the stilling basin were last performed in 2007 – 2009 and the estimates ranged from 815 to 1,159 Arctic grayling (Ott and Morris 2009).

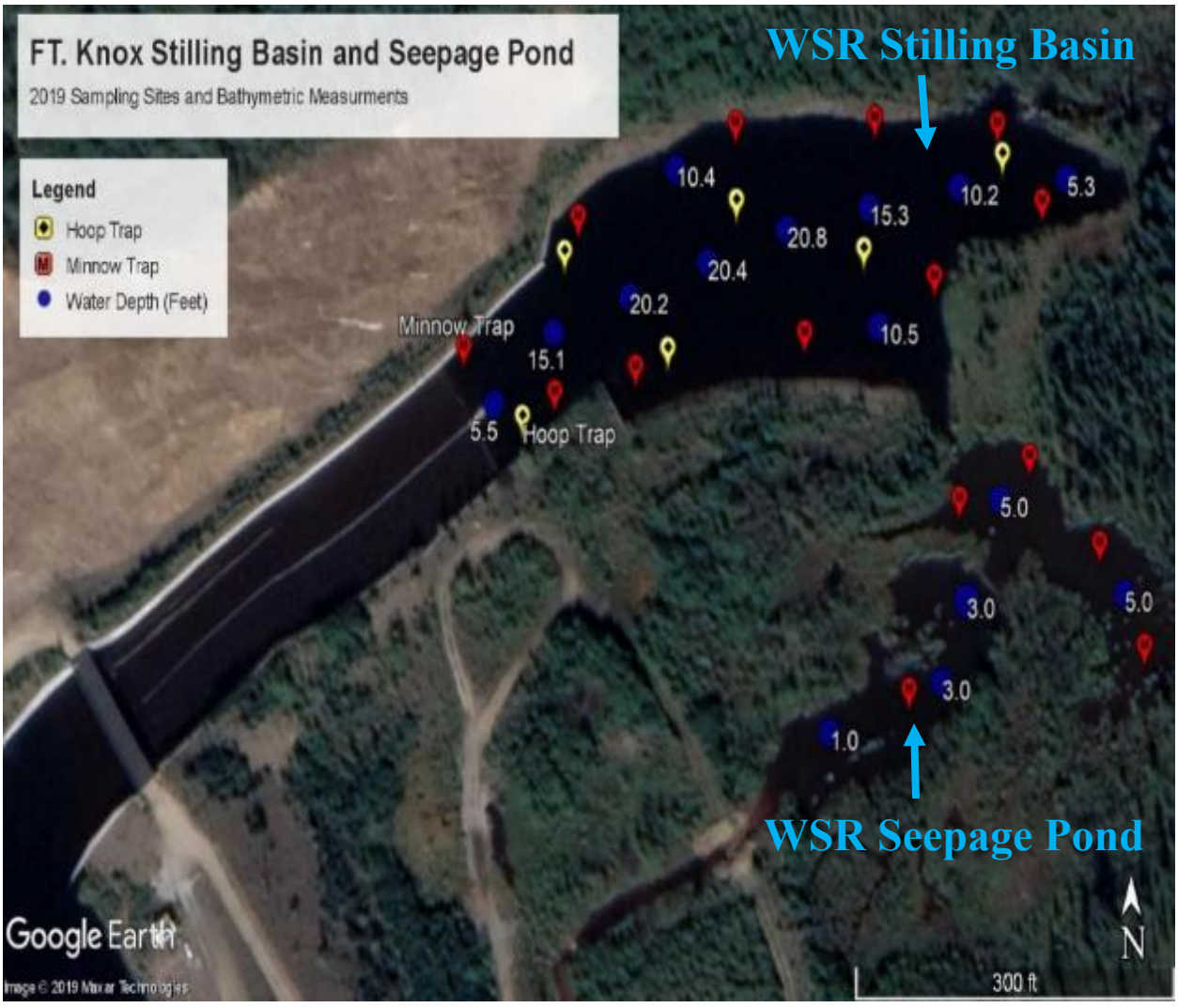

Figure 39. Fort Knox Stilling Basin and WSR Seepage Pond sampling and bathymetries (depth in feet).

Water temperatures in the stilling basin were warm (>20 ºC) in late June and every effort was made to handle and mark fish quickly, minimizing mortality. Seventy-one Arctic grayling from 160-315 mm FL were caught in the stilling basin (Figure 40).

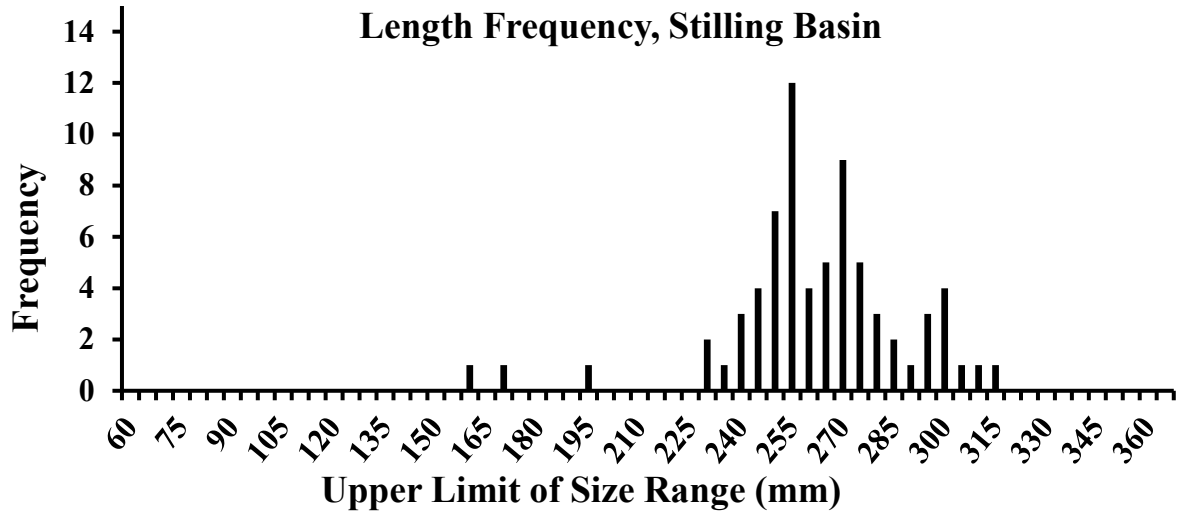

Figure 40. Length frequency distribution of Arctic grayling in the stilling basin, June 2019.

Thirteen of the Arctic grayling were recaptures from fish tagged in the WSR during previous spring sampling events. Five of these fish had been tagged in 2019, seven in 2018, and one in 2017. Length frequency distribution of the fish in the stilling basin was similar to those caught in spring 2019 in the wetlands complex. The Arctic grayling in the stilling basin recruit from the WSR since movement up Fish Creek is unlikely, due to multiple beaver dams.

Ten minnow traps were set in the stilling basin on June 26 and caught three slimy sculpin with 22 hours of effort. Five minnow traps were set in the WSR seepage pond connected to and directly southeast of the stilling basin, no fish were caught in the seepage pond. The seepage pond is fed mainly by waters from the seepage collection system downstream of the freshwater dam. The seepage pond is connected to the stilling basin by a small overflowing creek that is blocked by a large beaver dam. Fish movement between the stilling basin and the seepage pond is unlikely.

From September 25 to October 9, six hours of hook and line angling was performed by ADF&G to capture Arctic grayling in the stilling basin for a population estimate. No Arctic grayling were landed during the sampling effort. The population estimate of Arctic grayling in the stilling basin could not be calculated with zero recaptured fish. Based on the fishing effort and success rate, we presume that the number of Arctic grayling in the stilling basin in September was very low.

Stilling Basin, Burbot

Nine burbot were caught in six baited hoop traps fished in the Stilling Basin for 22 hours on June 27. One small burbot (155 mm TL) and eight larger burbot ranging from 320 to 615 mm TL were

caught. Two of the burbot were recaptures that had been tagged in the WSR in October 2016. This is the first time WSR burbot have been captured in the stilling basin and demonstrates that they also recruit by passage down the spillway, similar to the Arctic grayling. Because low numbers of burbot were captured in June, no additional sampling for burbot was attempted in September.

Stilling Basin Observations, 2019

Stilling Basin Habitat

- Stilling Basin – north and western end shoreline made of large rip rap extending to the bottom in many areas, little to no vegetation growing on rip rap.
- Stilling Basin – eastern half has a muddy and grassy bottom with abundant vegetation on shoreline extending to the bottom.
- No suitable gravel spawning beds were located during visual observations – therefore it is unlikely Arctic grayling successfully spawn in the stilling basin.
- The water level in late September was about two vertical feet lower than observed in late June (Figure 41). This was due to a beaver dam near the outlet of the stilling basin being washed out during a scheduled water release from the WSR for a required spillway inspection (Figure 42). This beaver dam wash out likely led to the dramatic reduction in the numbers of Arctic grayling observed in the stilling basin from June to September as fish were flushed out of the basin and into Fish Creek.

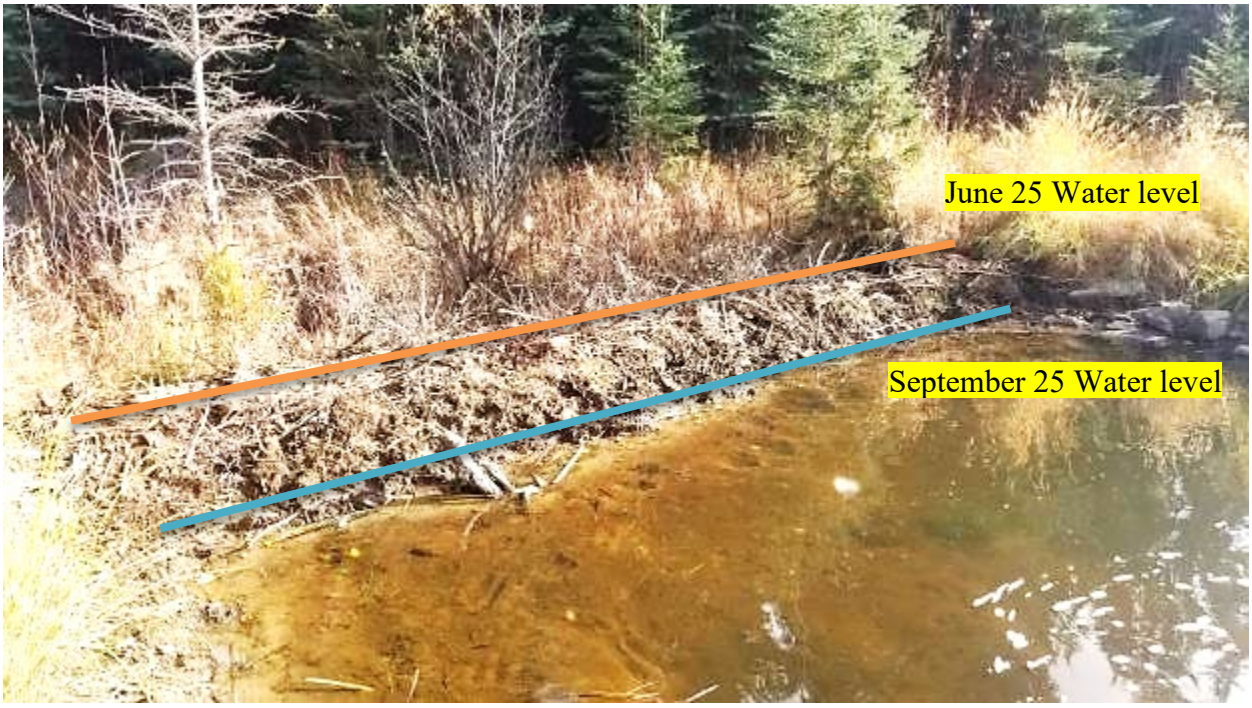

Figure 41. Comparison of Fort Knox Stilling basin water level, June and September 2019.

Figure 42. Fort Knox Stilling Basin outlet after part of the beaver dam was washed out, which lowered the water level by about two vertical feet.

Conclusion

Populations of Arctic grayling and burbot have been established and remain in the Fort Knox WSR. The post-mining population goal for the Arctic grayling in the WSR was set at 800 to 1,600 fish ≥ 200 mm. The spring 2018 population estimate of 6,045 fish ≥200 mm was a decrease from the estimated 2017 population of 7,141 fish but still well above the post-mining population goal. A post-mining population goal was not established for the burbot within the WSR, however a small population of fish larger than 400 mm remains present. In 2018 that population was estimated to be 402 fish.

ADF&G plans to continue to work cooperatively with FGMI to collect data on fish resources and water quality in the WSR and to implement rehabilitation projects designed to increase fish and aquatic habitat values and terrestrial habitats. Active management of beaver populations within the developed wetlands appears to remain a critical component to ensure Arctic grayling have access to spawning areas within the developed wetlands. The WSR appears to remain a critical component to the productive capacity of the wetland complex by providing overwintering and rearing habitat for both Arctic grayling and burbot.

Literature Cited

Chapman, D.G. 1951. Some practices of the hypergeometric distribution with applications to zoological censuses. University of California Publications in Statistics. 1:131-160.

Ott, A.G. and W.A. Morris. 2010. Arctic grayling and burbot studies at the Fort Knox mine, 2010. Alaska Department of Fish and Game Technical Report 10-05. Division of Habitat. Juneau.

Ott, A.G. 2019. Alaska Department of Fish and Game, Habitat Biologist, Personal Communication.

Ott, A.G. and P.T. Bradley. 2017. Fish and water quality monitoring at the Fort Knox Mine, 2017. Alaska Department of Fish and Game Technical Report 17-10. Division of Habitat. Fairbanks.

Ott, A.G., H.L. Scannell, and P.T. Bradley. 2016. Aquatic biomonitoring at Red Dog Mine, 2015. Alaska Pollution Discharge Elimination System Permit No. AK00038652 (Modification #1). Alaska Department of Fish and Game Technical Report 16-01. Division of Habitat. Fairbanks.

Seber, G.A.F. 1982. The estimation of animal abundance. Charles Griffin & Company LTD.

References

Ott, A.G. and P.T. Bradley. 2016. Arctic grayling and burbot studies at the Fort Knox mine, 2016. Alaska Department of Fish and Game Technical Report 16-09. Division of Habitat. Fairbanks.

Ott, A.G., P.T. Bradley, and H.L. Scannell. 2015. Arctic grayling and burbot studies at the Fort Knox mine, 2015. Alaska Department of Fish and Game Technical Report 15-07. Division of Habitat. Juneau.

Ott, A.G., W.A. Morris, H.L. Scannell, and P.T. Bradley. 2014. Arctic grayling and burbot studies at the Fort Knox mine, 2014. Alaska Department of Fish and Game Technical Report 14-08. Division of Habitat. Juneau.

Ott, A.G., W.A. Morris, H.L. Scannell, and P.T. Bradley. 2013. Arctic grayling and burbot studies at the Fort Knox mine, 2013. Alaska Department of Fish and Game Technical Report 13-05. Division of Habitat. Juneau.

Ott, A.G., W.A. Morris, and H.L. Scannell. 2012. Arctic grayling and burbot studies at the Fort Knox mine, 2012. Alaska Department of Fish and Game Technical Report 12-09. Division of Habitat. Juneau.

References (continued)

Ott, A.G. and W.A. Morris. 2011. Arctic grayling and burbot studies at the Fort Knox mine, 2011. Alaska Department of Fish and Game Technical Report 10-06. Division of Habitat. Juneau.

Ott, A.G. and W.A. Morris. 2009a. Arctic grayling and burbot studies at the Fork Knox mine, 2009. Alaska Department of Fish and Game Technical Report 09-05. Division of Habitat. Juneau.

Ott, A.G. and W.A. Morris. 2009b. Arctic grayling and burbot studies at the Fork Knox mine, 2008. Alaska Department of Fish and Game Technical Report 09-01. Division of Habitat. Juneau.

Ott, A.G. and W.A. Morris. 2007. Arctic grayling and burbot studies at the Fork Knox mine, 2007. Alaska Department of Natural Resources Technical Report 07-01. Office of Habitat Management and Permitting. Juneau.

Ott, A.G. and W.A. Morris. 2006. Arctic grayling and burbot studies at the Fork Knox mine, 2006. Alaska Department of Natural Resources Technical Report 06-05. Office of Habitat Management and Permitting. Juneau.

Ott, A.G. and W.A. Morris. 2005b. Arctic grayling and burbot studies at the Fork Knox mine, 2005. Alaska Department of Natural Resources Technical Report 05-06. Office of Habitat Management and Permitting. Juneau.

Ott, A.G. and W.A. Morris. 2005a. Arctic grayling and burbot studies at the Fork Knox mine, 2004. Alaska Department of Natural Resources Technical Report 05-01. Office of Habitat Management and Permitting. Juneau.

Ott, A.G. and W.A. Morris. 2003. Arctic grayling and burbot studies at the Fork Knox mine, 2003. Alaska Department of Natural Resources Technical Report 03-09. Office of Habitat Management and Permitting. Juneau.

Ott, A.G. and W.A. Morris. 2002b. Arctic grayling and burbot studies in the Fork Knox water supply reservoir, stilling basin, and developed wetlands, 2002. Alaska Department of Fish and Game Technical Report 02-06. Habitat and Restoration Division. Juneau.

Ott, A.G. and W.A. Morris. 2002a. Arctic grayling and burbot studies in the Fork Knox water supply reservoir and developed wetlands, 2001. Alaska Department of Fish and Game Technical Report 02-1. Habitat and Restoration Division. Juneau.

Ott, A.G. and W.A. Morris. 2001. Arctic grayling and burbot studies in the Fort Knox water supply reservoir and developed wetlands. Alaska Department of Fish and Game Technical Report 01-2. Habitat and Restoration Division. Juneau.

References (continued)

Ott, A.G. and W.A. Morris. 2000. Fish use of the Fort Knox water supply reservoir and developed wetlands. Alaska Department of Fish and Game Technical Report 00-1. Habitat and Restoration Division. Juneau.

Ott, A.G. and W.A. Morris. 1999. Fish use of the Fort Knox water supply reservoir 1995-1998. Alaska Department of Fish and Game Technical Report 99-2. Habitat and Restoration Division. Juneau.

Ott, A.G. and P. Weber Scannell. 1998. Fisheries use and water quality in the Fort Knox mine water supply reservoir. Alaska Department of Fish and Game Technical Report 98-1. Habitat and Restoration Division. Juneau.

Ott, A.G. and A.H. Townsend. 1997. Fisheries use of the Fort Knox water supply reservoir 1996. Alaska Department of Fish and Game Technical Report 97-2. Habitat and Restoration Division. Juneau.

Ott, A.G. and P. Weber Scannell. 1996. Baseline fish and aquatic habitat data for Fort Knox mine 1992 to 1995. Alaska Department of Fish and Game Technical Report 96-5. Habitat and Restoration Division. Juneau.

Ott, A.G., P. Weber Scannell, and A.H. Townsend. 1995. Aquatic habitat and fisheries studies upper Fish Creek, 1992-1995. Alaska Department of Fish and Game Technical Report 95-4. Habitat and Restoration Division. Juneau.

Weber Scannell, P. and A.G. Ott. 1994. Aquatic habitat of Fish Creek before development of the Fort Knox gold mine 1992-1993. Alaska Department of Fish and Game Technical Report 94-5. Habitat and Restoration Division. Juneau.

Weber Scannell, P. and A.G. Ott. 1993. Aquatic habitat study, upper Fish Creek drainage, with an emphasis on Arctic grayling (*Thymallus arcticus*): baseline studies 1992. Alaska Department of Fish and Game Technical Report 93-4. Habitat and Restoration Division. Juneau.

Technical Reports summarizing field work can be found on the Alaska Department of Fish and Game, Division of Habitat Web Page:

http://www.adfg.alaska.gov/index.cfm?adfg=habitat_publications.main

Appendix 1. A Summary of Mine Development with Emphasis on Biological Factors

2011

- February 9, ADF&G provided input to ADNR on the environmental audit to be conducted in summer 2011. We identified several possible fish and wildlife enhancement projects originally recommended by Buell and Moody (2005).
- March 4, the ACOE issued a permit (POA-1992-574-M19) authorizing construction of the modified dam raise and expansion of the Tailings Storage Facility (TSF).
- April and May, several Plan of Operations amendments were issued by ADNR for work associated with the TSF, waste rock dumps, powerline, topsoil storage, and dewatering.
- May 2, ADF&G provided input to ADNR on the reclamation and closure plan for Fort Knox. Emphasis was on maintaining the existing developed wetland complex downstream of the TSF.
- Our spring sample event for Arctic grayling and burbot ran from May 9 to 24. We caught 1,194 Arctic grayling and 117 burbot in a fyke net set in the WSR.
- The estimated spring 2010 Arctic grayling population was 4,346 fish > 200 mm long and was an increase from the 2009 estimate of 3,223. Recruitment of new fish in spring 2011 was strong with 198 new fish < 230 mm marked.
- Arctic grayling spawned in the wetland complex from Pond D downstream. Beavers had not rebuilt the dams in the wetland complex.
- A constructed osprey nesting platform adjacent to the main pump house in the WSR was occupied in spring – one chick was seen in August. An active raven nest was observed on the rock cut near the freshwater dam.
- Water began flowing over the spillway on May 27, water had not reached the spillway since winter 2009/2010.
- June 2, ADF&G provided written comments on the Fort Knox and True North environmental audit proposals.
- July 19, FGMI pumped about 10,440 gallons of water from the "801 Pond" downstream – environmental staff were notified, and pumping was immediately stopped – water from the "801 Pond" is supposed to be pumped back into sump below the TSF.
- August 4, ADNR informed us of planned changes at Fort Knox including expansion of the heap leach facility from 160 to 300 million tons, the need for a ADEC permit to discharge non-contact water, and the long-term need for a permit and water treatment plant for closure.
- September 13, ADNR approved the drilling of two monitoring wells in the headwaters of Victoria Creek. The purpose of these monitoring wells is to ensure water in Victoria Creek is not impacted by the increased elevation of tailings in the Pearl Creek drainage.

Appendix 1 (continued)

2011

- September 28, we met with FGMI to discuss plans to discharge non-contact water from the Fort Knox pit to the WSR.

2012

- Our spring sample event (Arctic grayling and burbot) began on May 7 and ended on May 30. The estimated spring 2011 Arctic grayling population was 7,378 fish $\geq$ 200 mm long which was an increase of 3,032 from the 2010 estimate. Recruitment of new fish in spring 2012 was strong with 111 new fish < 230 mm marked.
- We caught 140 burbot (175 to 950 mm long) in spring 2012 in hoop traps and fyke nets.
- Arctic grayling spawned throughout the wetland complex, including the upper portion of Channel C, in spring 2012. Beavers had not rebuilt the dams in the wetland complex.
- A constructed osprey nesting platform adjacent to the main pump house in the WSR was occupied in spring 2012.
- Water was flowing over the spillway when we began sampling in the spring of 2012 – water was still overflowing in late October.
- July 13, ADF&G provided input to ADEC on the APDES draft permit for discharge of non-contact water. The discharge point has been changed to the old Fish Creek channel just downstream of Ponds A and B. The ADEC permit was issued on August 15, 2012.
- September 27, ADF&G confirmed that a culvert in the road down the Fish Creek valley had been removed. In our trip report to FGMI, we recommended some additional civil work to ensure that the discharge water stays on the north side of the valley.

2013

- February 20, FGMI received a Notice of Violation from the ACOE for the unauthorized discharge of fill material into 0.28 acres of wetlands.
- March 1, ADF&G informed FGMI that their 2012 Annual Report was extremely well done and FGMI's report was distributed to all habitat offices in the state.
- March 11, the ACOE issued an After-the-Fact authorization covering the 0.28 acres of wetland fill.
- April 25, water quality data (temperature, dissolved oxygen, etc.) were collected in the WSR under ice cover.
- May 4, the ADNR transmitted comments on the December 2012 reclamation and closure plan.

Appendix 1 (continued)

2013

- Our spring sample event (Arctic grayling and burbot) began on May 20 and ended on June 10. The estimated spring 2012 Arctic grayling population was 7,404 fish ≥200
- mm long. Recruitment of new fish in spring 2013 was strong with 114 new fish <230 mm marked.
- We caught 96 burbot (89 to 697 mm long) in spring 2013 in hoop traps and fyke nets.
- Arctic grayling spawned throughout the wetland complex, including the upper portion of Channel C, in spring 2013. Beavers had rebuilt the dams in the wetland complex, but the dams were notched to allow fish passage.
- A constructed osprey nesting platform adjacent to the main pump house in the WSR was occupied in spring 2013.
- Water was not flowing over the spillway when we began sampling, but by May 27 water had begun to flow out of the WSR and over the spillway.
- June 25, we observed Arctic grayling fry (numerous) in the upper portion of Channel C. Very few fry were observed in Pond F and the Pond F outlet.
- October 14, ADF&G submitted comments on the Fort Knox 2013 reclamation plan – eight recommendations were made.
- November 27, ADF&G distributed the Fork Knox technical report for work done in 2013.

2014

- In early April, emails were exchanged to determine when Fish Creek was removed from the list of impaired waterbodies – it was on the 1992 list but was removed from the 1994 list because FGMI had bought out all the existing placer operations and was planning on building the freshwater dam.
- April 2014, the decision was made not to collect winter water quality due to unsafe ice conditions and overflow.
- In spring 2014, we fished a fyke net in the developed wetlands just upstream of the WSR from April 29 until May 9 and then again from May 12 to 15. Arctic grayling spawned throughout the wetland complex in spring 2014. The only beaver dam present was in the upper end of C Channel.
- Our estimated population of Arctic grayling (> 200 mm) for spring 2013 was 6,675 – a slight reduction from the 2011 and 2012 estimates.
- Our estimated population of large burbot (≥ 400 mm) for spring 2013 was 80 – a substantial reduction from the spring 2012 estimate of 193.
- September 29, FGMI notified state agencies that the new Environmental Manager was Bartly Kleven.

Appendix 1 (Continued)

2014

- September 4, we were notified that the road across Solo Creek had failed – FGMI will determine a proper fix – this is the second time the road has failed at the culvert crossing.
- September 26, the developed wetlands and lower Last Chance Creek were inspected. No beaver dams were observed in Ponds D and F and in lower Last Chance Creek (dams had been removed by FGMI during summer).
- October FGMI and ADF&G discussed a draft design for the Solo Creek culvert replacement, conducted a field inspection, and continued discussions to decide what remedial work will be done.
- October 28, ADF&G distributed the Fork Knox technical report for work done in 2014.
- November 12, FGMI submitted a permit application to replace the Solo Creek culvert. ADF&G had several questions regarding the culvert design specifications and FGMI addressed these questions and a permit was issued on November 20, 2014 to install the new 10-foot diameter pipe.

2015

- March 2, we conducted a field visit to observe the discharge point for non-contact mine water to the old Fish Creek channel, which is dry, except for breakup and periods of heavy rain.
- FGMI initiated the discharge of non-contact water (about 250 gallons per minute) in mid-March and the discharge has been continuous except for a few shutdowns. The discharge was authorized by a permit issued by the ADEC.
- April 8 and 9, we collected water quality data in the WSR which was ice covered, high DO concentrations were found in Fish Creek Bay.
- April 17, we collected water quality data in the old Fish Creek channel downstream from where the non-contact mine water was being discharged and found very high DOs in the water – leading us to conclude that the discharge of non-contact mine water resulted in increased DOs in the WSR.
- Early May, we field inspected the culvert replacement in Solo Creek and concluded that it had been installed in accordance with the Fish Habitat Permit.
- Spring 2015, we fished a fyke net in the developed wetlands just upstream of the WSR from May 4 to 8 and then again from May 10 to 13. Arctic grayling spawned throughout the wetland complex in spring 2015.
- Our estimated population of Arctic grayling ($\geq$ 200 mm) for spring 2014 was 5,841 – a slight reduction from the 2011 and 2012 estimates.

Appendix 1 (continued)

2015

- Our estimated population of large burbot (≥ 400 mm) for spring 2014 was 175 – a substantial increase from the spring 2013, but with a large 95% CI.
- June 19 and July 23, we collected Arctic grayling fry in the wetland complex, average size on June 19 was 29.7 mm and on July 23 it was 57.3 mm.
- June 19, we inspected the Last Chance culvert in the Gil Causeway. Material at the east end of the pipe has slumped and the road was blocked with cones and flagging.
- October 28, ADF&G distributed the Fork Knox technical report for work done in 2015.

2016

- March 29 and 31, water quality data were collected at six sites in the WSR, five of which have been sampled nearly annually since 1998. Average winter water column dissolved oxygen at Site 2 (middle of the WSR) was the highest on record and likely the result of the near continuous discharge of non-contact water into the old Fish Creek channel just upstream of the wetland complex.
- In spring 2016, we fished two fyke nets in the developed wetlands just upstream of the WSR and in Pond F from April 25 to May 4. Based on the fyke net catches, most of Arctic grayling spawned in the wetland complex downstream of Pond F.
- Our estimated population of Arctic grayling (≥ 200 mm) for spring 2015 was 5,947 – a slight increase from the 2014 estimate.
- Our estimated population of large burbot (≥ 400 mm) for spring 2015 was 92 - a substantial decrease from spring 2014.
- In early October, hoop traps fished in the WSR captured 26 burbot ranging in size from 200 to 630 mm long.
- October 12, we met with ADEC and FGMI to discuss plans to design and install a new water treatment plant just downstream of the tailings dam with an estimated discharge of 2,000 to 6,000 gallons per minute.
- October 28, we were notified by FGMI that beaver dams at Pond D outlet and downstream of Pond F had been removed.
- December 21, ADF&G sent a summary of our meeting on the new water treatment plant to FGMI.

2017

- April 12 and 19, water quality data were collected at six sites in the WSR, five of which have been sampled nearly annually since 1998. Average winter water column dissolved oxygen at Site 2 (middle of the WSR) was above the 15 year running average and the second highest on record, behind 2016.

Appendix 1 (continued)

2017

- In spring 2017, we fished two fyke nets in the developed wetlands just upstream of the WSR and in Pond F from early May to May 18. Based on the fyke net catches and observations, most Arctic grayling spawned in the wetland complex downstream of Pond F.
- About 100 Arctic grayling adults were moved from the Pond F fyke net and released into Pond D upstream of a barrier. These fish successfully spawned in Pond D as fry were captured on June 29.
- Our estimated population of Arctic grayling (≥ 200 mm) for spring 2016 was 4,396, a decrease of about 1,500 fish from 2015.
- May 26, ADEC issued Waste Management Permit 2014DB002 (Modification #1).
- May 26, ADNR issued a permit amendment for the construction of the Barnes Creek heap leach.
- July 19, ADNR issued a Certificate of Approval to construct a dam for the Barnes Creek heap leach (#AK00315).
- October 12, a site visit was conducted to check on the status of beaver dams in the wetland complex that had been removed recently by FGMI.
- October 24, historic information was provided to FGMI on the status of Fish Creek and why it was taken off the impaired waterbody list in 1994.
- December 12, FGMI, ADF&G, ADNR, and ADEC met to discuss alternatives for tailings disposal, closure configuration for the tailing dam at elevation 1557, and a new water treatment plant.
- December 13, FGMI acquired a new parcel of land that contains an estimated 2.1 million ounces of gold.

2018

- March 14, ADNR approved a POA amendment request to replace the power line trail.
- April 3, 5, and 6, water quality data were collected at six sites in the WSR, five of which have been sampled nearly annually since 1998.
- May 3-May 14, two fyke nets were fished in the developed wetlands just upstream of the WSR and in Pond F.
- Our estimated population of Arctic Grayling (≥ 200mm) for Spring 2017 was 7,141, which is an increase of 2,745 over 2016.
- Our estimated population of large burbot (≥400 mm) was 201 fish, which is an increase of 82 fish over 2016.
- October 9, 2018, the Pond D beaver dam was removed to allow the downstream movement of grayling into the WSR.

Appendix 1 (continued)

2019

- January 15, Fort Knox began the discharge of up to 3000 gpm of Reverse Osmosis (RO) from Outfall 002 into Fish Creek.
- February 20, environmental compliance and management systems audit performed by SRK Consulting found FGMI to be in compliance with all State of Alaska permitting requirements.
- April 3, FGMI requested modification 16 to Plan of Operations (POO) for clearing/grubbing of 15.5 acres of land to stockpile subbase for the Barns Creek Heap Leach facility.
- Between January 15 and April 10, a beaver blocked the Centerline Road culvert between Pond AB and North Creek diverting the 3000 gpm of RO water from Outfall 002 into Fish Creek instead of North Creek.
- April 10, water quality data were collected as six sites in the WSR, and three new sites in Fish Creek. Average dissolved oxygen (DO) at Site 2, (Middle of the WSR) was higher that all previous year's data. Fish Creek sites had higher water temperature (6.0 °C) compared to WSR sites.
- April 12 to May 03, we set one fyke net in Fish Creek near the Pond F outlet to capture Arctic grayling and burbot moving into the developed wetlands.
- Our estimated population of Arctic grayling (≥200 mm) for spring of 2018 was 6,045 fish with a 95% CI of 5,461 to 6,629 fish.
- June 15, FGMI received a Fish Habitat Permit to lower Centerline Road culvert to improve flow of RO water from Pond AB into North Creek.
- June 25 to 27, we captured seventy-one Arctic grayling from 160-315 mm FL and nine burbot from 320 – 615 mm tail length in the stilling basin. Bathymetric measurements were taken in the stilling basin and WSR seepage pond.
- August 27 to 29, WSR water level lowered 1.70 vertical feet for required spillway structural inspection. Water discharged through stilling basin into lower Fish Creek.
- September 25 to October 9, we fished twenty-one hoop traps in the WSR and captured 124 burbot for the 2018 population estimate.
- Our estimated population of large burbot (≥ 400 mm) for spring of 2018 was 402 fish (95% CI: 190 to 613 fish).

Appendix 2. Water Quality Data, from the Fort Knox Water Supply Reservoir (WSR), April 10, 2018.

Site Number (Name)	Date	Depth (m)	Temperature (C)	% Saturation Dissolved Oxygen	Dissolved Oxygen (mg/L)	Conductivity (µ S/cm)	pH	ORP
1 (Middle WSR)	4/10/2019	1	1.60	58.1	7.80	140.6	7.13	463
		2	1.90	55.9	7.46	139.5	7.00	460
		3	1.91	55.6	7.40	139.5	6.99	458
		4	1.90	55.3	7.37	139.3	6.99	457
		5	1.90	55.3	7.36	139.3	7.00	456
		6	1.90	54.7	7.30	135.6	7.00	455
		7	1.99	50.2	6.68	136.7	6.99	457
		8	2.04	42.2	6.38	136.5	6.98	458
		9	2.09	45.6	6.07	136.5	6.98	459
		10	2.11	44.1	5.88	137.3	6.98	459
		11	2.14	42.4	5.62	141.3	6.97	460
		12	2.22	40.0	5.31	141.0	6.96	461
		13	2.28	37.7	5.01	139.8	6.95	462
		14	2.45	33.5	4.41	138.8	6.94	462
		15	2.49	32.3	4.23	140.8	6.93	463
2 (WSR Near Dam)	4/10/2019	1	1.66	57.9	7.73	142.6	7.14	463
		2	1.86	54.7	7.29	139.1	7.08	460
		3	1.92	54.5	7.24	138.4	7.08	459
		4	1.94	54.2	7.21	138.7	7.07	459
		5	1.94	54.0	7.19	138.2	7.07	459
		6	1.93	54.0	7.18	139.0	7.07	458
		7	1.99	52.5	7.06	136.9	7.06	458
		8	2.07	50.2	6.70	135.6	7.06	459
		9	2.16	48.2	6.39	134.3	7.05	459
		10	2.27	46.2	6.14	133.6	7.04	459
		11	2.33	43.7	5.81	132.1	7.03	460
		12	2.34	41.9	5.53	132.5	7.02	461
		13	2.31	40.0	5.28	140.0	7.00	462
		14	2.34	39.5	5.22	141.4	6.99	462
		15	2.38	39.4	5.17	142.0	6.99	463
		16	2.46	39.3	5.15	144.0	6.99	463
		17	2.51	32.0	4.21	144.5	6.95	464
		18	2.65	24.0	3.20	144.3	6.91	465
		19	2.65	14.0	1.88	143.9	6.87	466
		20	2.67	4.1	0.54	152.9	6.87	467

		21	2.78	1.1	0.14	155.4	6.83	466
		22	2.79	0.5	0.06	155.9	6.83	466
		23	2.74	0.3	0.02	164.0	6.83	466
3 (Solo Bay)	4/10/2019	1	1.39	62.2	8.42	140.7	7.12	439
		2	1.79	58.0	7.85	140.9	7.08	439
		3	1.82	55.5	7.41	141.0	7.08	441
		4	1.82	55.0	7.34	141.6	7.08	442
		5	1.84	54.7	7.31	141.2	7.08	443
		6	1.86	53.7	7.17	141.4	7.08	444
		7	1.89	52.0	6.93	141.9	7.07	445
		8	1.98	49.6	6.66	140.8	7.05	446
		9	2.02	47.2	6.30	140.2	7.04	447
7 (Last Chance Bay)	4/10/2019	1	0.99	50.1	6.87	151.6	7.02	439
		2	1.68	46.4	6.27	140.9	7.03	438
		3	1.71	45.3	6.07	141.2	7.02	439
		4	1.75	44.2	5.91	141.0	7.02	440
		5	1.77	43.2	5.79	140.9	7.01	441
		6	1.79	42.0	5.66	139.8	7.01	442
		7	1.87	35.5	4.88	137.9	6.97	443
		8	1.88	16.0	2.21	136.9	6.88	447
11 (Polar Bay)	4/10/2019	1	1.22	47.3	6.45	136.1	7.02	445
		2	1.79	48.4	6.44	138.3	7.02	444
		3	1.85	49.0	6.54	138.8	7.04	443
		4	1.85	49.4	6.58	140.3	7.04	444
		5	1.83	50.2	6.70	140.9	7.05	444
		6	1.86	50.2	6.68	139.8	7.04	446
		7	1.87	46.6	6.22	139.9	6.99	447
		8	1.91	44.9	5.99	139.8	6.97	449
		9	2.02	45.0	5.97	138.9	6.98	449
		10	2.05	45.0	5.90	140.7	6.97	450
		11	2.03	42.5	5.75	143.8	6.94	451
		12	2.09	37.3	5.01	144.9	6.89	453
		13	2.28	30.0	4.02	148.9	6.86	454
12 (Fish Creek Bay)	4/10/2019	1	1.30	57.9	7.83	152.5	7.10	442
		2	1.63	57.5	7.72	150.0	7.10	442
		3	1.69	57.3	7.67	149.7	7.09	443
		4	1.72	57.0	7.64	148.6	7.09	444
		5	1.73	56.9	7.61	149.9	7.09	444
		6	2.10	63.5	8.29	172.9	7.16	442

Appendix 3. Population estimates of Arctic Grayling ≥ 200 mm in the Fort Knox Water Supply Reservoir (WSR), 1995-2018.

Year	[1]	Population Estimate	95% Confidence Interval
1995	[2]	4,358	
1996	[3]	4,748	3,824-5,672
1996	[4]	3.475	2,552-4,398
1998	[5]	5,800	4,705-6,895
1999		4,123	3,698-4,548
2000		5,326	4,400-6,253
2001		5,623	5,030-6,217
2002		6,503	6,001-7,005
2003		6,495	5,760-7,231
2004		6,614	5,808-7,420
2005		7,926	6,759-9,094
2006		5,930	5,382-6,478
2007		4,027	3,620-4,433
2008		3,545	3,191-3,900
2009		3,223	2,896-3,550
2010		4,346	3,870-4,823
2011		7,378	6,616-8,141
2012		7,404	6,775-8,033
2013		6,675	6,217-7,333
2014		5,841	5,235-6,446
2015		5,947	5,111-6,783
2016		4,396	3,913-4,880
2017		7,141	6,176-8,018
2018		6,045	5,461-6,629

[1]Population estimates from 1995-1996 include fish ≥ 150 mm, in all other years fish ≥ 200 mm.

[2]In 1995, we used estimates from the ponds and creeks for the Arctic grayling population; a confidence interval was not applicable to the data set.

[3]The 1996 estimate was made with a capture and recapture event in summer 1996 using fyke nets.

[4]In 1996, Arctic grayling were captured with a boat-mounted electro shocker for both the capture and recapture events in fall 1996 by Sport Fish Division.

[5]Starting in 1998 the population estimates were made using a mark event in the spring of the year of the estimate, and the recapture event in spring of the following year.

Appendix 4. Arctic Grayling Growth in the WSR, 2018-2019.

Upper Limit (mm)	Average (mm)	Maximum (mm)	Minimum (mm)	Sample Size
210	38	61	25	9
220	30	46	6	12
230	31	50	17	20
240	26	42	12	29
250	25	45	5	54
260	22	39	10	46
270	21	40	4	29
280	13	29	0	34
290	14	23	1	6
300	10	16	0	5
310	3	8	0	5
320	8	17	0	6
330	0	0	0	2
340	0	0	0	0
350	0	0	0	0

Appendix 5. Population Estimate of Burbot (≥ 400mm) in the Fort Knox Water Supply Reservoir (WSR), 2001-2018.

Year	Population Estimate	95% Confidence Interval
2001	134	58 – 210
2002	131	63 – 199
2003	102	57 – 147
2004	86	44 – 128
2005	143	96 – 191
2006-2011	No Population Estimates Performed	
2012	193	95 – 290
2013	80	44 – 117
2014	175	44 – 305
2015	92	46 – 138
2016	119	65 – 173
2017	201	124 – 278
2018	402	190 - 613