Utilization of Hydrodynamic Modeling in Predicting Water Quality and Brook Trout Habitat:

Reclamation of a Mine Impacted Boreal Shield Lake

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by

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Abstract

Mining operations in Ontario are subject to regulatory limits on effluent release into surrounding waterbodies designed to preserve aquatic life. However, said guidelines may not always be enough to prevent damage to the local ecosystem. This study examined Cleaver Lake, Ontario, an 18 m deep shield lake downstream of a copper/zinc mine active from 1987 – 1999. Mine activity resulted in increased levels of chemical constituents that created density induced stratification prohibitive of seasonal lake turnover (meromixis). This condition persisted for more than a decade after closure. Resulting hypoxic conditions of deeper waters caused extirpation of fish such as Brook Trout (*Salvelinus fontinalis*) that require cool water and high dissolved oxygen (DO). The water quality and hydrodynamics of the effluent receiving lake were modeled via CE-QUAL-W2 for the open water season of 2017. The model combined bathymetrical data with inflow, outflow, and meteorological measurements, *in-situ* multiprobe and data logger measurements of water quality characters like DO and temperature, chemical concentrations of potentially problematic metals (zinc = (81 ± 23) µg/L & copper = (3.7 ± 0.63) µg/L) and density altering compounds from samples collected on site to make real-time predictions of Brook Trout habitat. The model has accurately represented the recently observed recovery from a meromictic state. The objectives of this project were to: (1) assess current Brook Trout habitat with CE-QUAL-W2; (2a) predict potential future habitat based on *what-if* scenarios such as a return to elevated levels of chemical effluent received via industry activity and (2b) elevated air temperatures due to climate change. Minimum survivable habitat availability for Brook Trout was shown to be 69.97% in the unmodified model, reduced to 64.47% in the operational industry scenario, and 7.3% in the climate change scenario.

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1.0 Introduction

1.1 Effects of Copper/Zinc Mining on Receiving Water Bodies

Copper naturally occurs largely in the form of copper-sulfide compounds such as chalcocite (Cu_2S) or chalcopyrite ($CuFeS_2$), with a small portion existing as oxidized minerals (Davenport et al., 2002). Zinc most commonly occurs in nature as the sulfide mineral sphalerite (ZnS) and ores are often associated with pyrite (FeS_2) and other trace elements such as cobalt, nickel, arsenic, thallium, selenium and antimony (Sinclair, 2005). Both Cu and Zn are commonly extracted from ore using flocculation/flotation preceding electrowinning methods, though other strategies also exist (Davenport et al., 2002; Sinclair, 2005).

Metal mining produces large quantities of mine waste as by-product of extracted valuable ore. This mine waste (tailings) is often kept in containment pools known as tailings ponds. The tailings contain concentrations of leftover trace metals as well as chemicals used during extraction. These metals and chemicals leach into the water of the tailings pond resulting in effluent that is sometimes released into nearby waterways and can potentially lead to: metal/chemical toxicity to biota (Hale, 1977; Saunders & Sprague, 1967), acidification of water (Akcil & Koldas, 2006; Elberling & Nicholson, 1996), chemical consumption of dissolved oxygen (Elberling & Nicholson, 1996), and meromixis due to density changes (Hutchinson, 1957; Hakala, 2004; Boehrer & Schultze, 2006).

The complications associated with copper zinc mining and its legacy effects with respect to available habitat of Brook Trout (*Salvelinus fontinalis*) in an impacted mine lake will be the major focus here.

1.2 Water Quality Guidelines

The Canadian Council of Ministers of the Environment (CCME) Canadian water quality guidelines (CWQG) for the protection of aquatic life outline generally acceptable concentrations of potential toxicants within waterbodies in Canada. Levels of copper from samples collected at the study site have often exceeded the guideline recommended limit of 2 µg/L which is determined via calculation based on hardness (CCME, 2019).

The CCME does not provide a guideline for zinc concentrations, but the Ontario government does also establish acceptable levels within the Provincial Water Quality Objectives (PWQO) designed for protection of aquatic life. Acceptable zinc levels are established at an interim concentration of 20 µg/L within the PWQO (Government of Ontario, 1998), a value also exceeded by samples from the study site.

Since concentrations of these two metals have been expectedly elevated above governmental guidelines within the study site, values obtained from toxicological studies using the study species of brook trout in relationship to these metals will be focused on in this study and described in section 1.5.

1.3 Water Quality and Hydrodynamics

In addition to potential toxicity caused by release of mining effluent, chemical density gradients may occur in receiving lakes as a result of increased loads of suspended and dissolved solids. Modifications to the density of water may result in changes to the typical hydrodynamics of a water body. A major way this can be expressed is through establishment of a process known as meromixis.

The density of water reaches a maximum near 4°C for pure water, and changes along with both temperature and content of dissolved substances like salt. In Northwestern Ontario lakes which undergo full turnover events (aka holomictic) typically undergo two seasonal turnovers in the spring and fall, driven largely by wind at the water surface when temperatures reach an isothermal point and thus equal density; such lakes are further termed dimictic (Hutchinson & Loffler, 1956; Hakala, 2004). This mixing of the deep and shallow water allows the replenishment of oxygen in deeper regions of a lake where algal/macrophytic production is not a major contributor and is essential for maintaining habitat for many species of fish and benthic invertebrates (Rogora et al., 2018). Stratification happens naturally as a result of temperature differentials that occur seasonally in deep water bodies via development of a thermocline, however, meromixis occurs when a chemically-induced stabilized state exists and holomictic events are prohibited by density gradients within the water column (Hutchinson, 1957; Hutchinson & Loffler, 1956; Hakala, 2004).

When meromixis occurs, the deep-water region which remains stable is termed the monimolimnion and is subject to anoxia and accumulation of chemical constituents. At the top of the water column the mixolimnion exists, which mixes amongst itself and behaves almost as a typical holomictic lake would. In between the mixolimnion and monimolimnion exists the region of rapid change termed the chemocline (Hutchinson, 1957).

Three classifications of meromixis are defined and can be the result of natural lake dynamics or external influences; for example, nutrient enriched lakes may undergo biogenic meromixis as a result of high planktonic activity in the mixolimnion coupled with respiration and decay of organic substances in the monimolimnion that cause density gradients significant enough to prevent full mixing (Boehrer & Schultze, 2006). A second classification of meromixis termed crenogenic meromixis may arise due to an influx of mineralized groundwater entering a freshwater lake at depth and is more common in volcanic lakes (Hakala, 2004; Boehrer & Schultze, 2006). Externally influenced meromixis – or ectogenic meromixis – of lakes occurs when chemical density gradients emerge in the deep region of a water body significant enough to prevent full turnover. This is often due to highly saline water or water with high loads of dissolved solids entering a body of fresh water, or may be caused by an influx of fresh water into a saline water body at the surface – this is also the form of meromixis caused by anthropogenic activity such as mining and runoff of road salt (Hutchinson, 1957; Hakala, 2004; Boehrer & Schultze, 2006).

1.4 Study Site

The site named Cleaver Lake is located approximately 40 km NW of Schreiber, Ontario. Part of the Whitesand River basin emptying into Lake Superior, Cleaver Lake is a Boreal Shield lake with dimensions of 800 m in the N-S direction and 250 m in E-W direction, and depth of 18m at the deepest point. The Whitesand river and lakes along it have historically been home to various salmonid species, notably including the prized sport fish species Brook Trout. Cleaver Lake is situated on the Whitesand River just south of former copper/zinc mining activity. The first mine activity in the area occurred from 1898-1900 at the Zenith sphalerite mine. Next, Zenmac Metals operated a mine site from 1966-1970. The most recent mine activity occurred from 1988-1998 at a third site operated initially by Minnova Inc. and later INMET Mining Inc. All three of the sites discharged mine water into the Whitesand river system just upstream of Cleaver Lake.

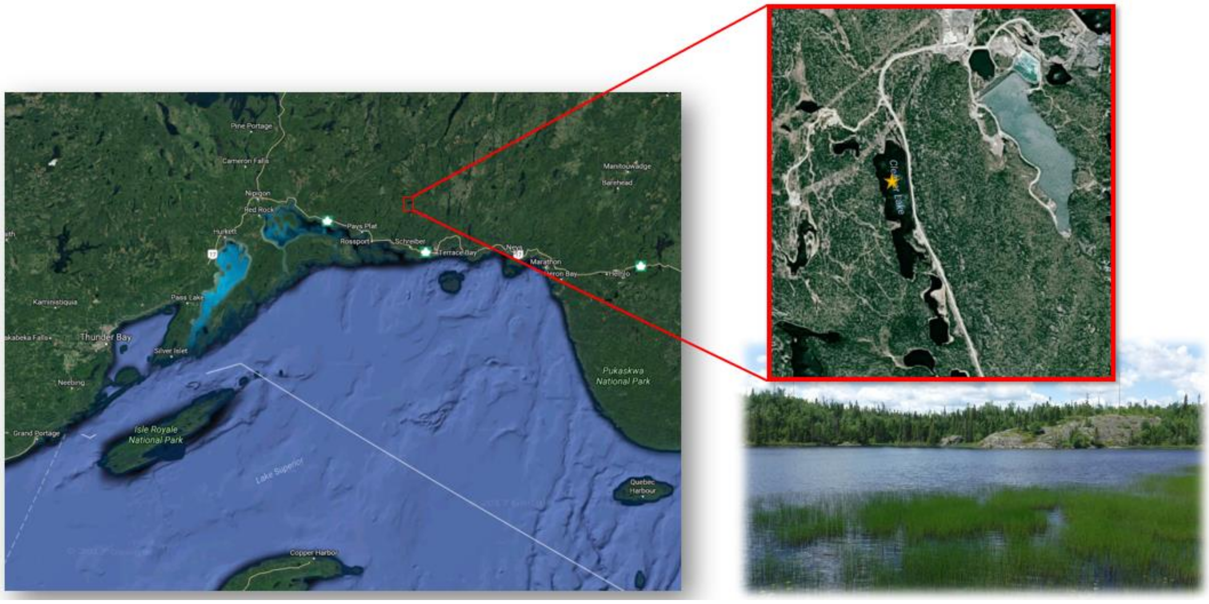

Figure 1.4. Site map of study site in relation to Lake Superior (left), showing position relative to decommissioned mine (top-right), and with a picture taken from the eastern shore adjacent to the northern basin (bottom-right).

Due to the extensive mining history of the area and contamination of the Whitesand river system, good baseline data for Cleaver Lake water quality is unavailable, with the earliest sampling efforts undertaken in 1983 (IEC Beak International, 1984). Legacy impacts from the first two mining operations were already apparent at that time.

Cleanup efforts put in place by INMET Mining Inc., and current property holder First Quantum Minerals LTD. were effective in reducing metal loadings into the system at Cleaver Lake. However, a state of ectogenic meromixis had developed due to elevated loadings of dissolved solids released from the water treatment facilities at the mine site during the 1988-1998 years of operation. This condition had persisted for many years after mine closure and was likely responsible for the extirpation of fish species such as Brook Trout from Cleaver Lake due to depletion of oxygen in the monimolimnion.

1.5 Habitat Requirements and Chemical Tolerance of Brook Trout

Brook Trout are a salmonid species of fish native to North America, and are known to be one of the most adaptable species of the *Salvelinus* genus, inhabiting lakes from small to large, rivers, streams, and even transitioning from fresh to saltwater when living near the coast (Raleigh, 1982). In regards to lacustrine habitat, brook trout prefer cool-water environment and water temperature during the warmest parts of the year appear to be the species' major limitation in habitat selection, with water temperatures above 24°C being generally unsuitable for even short-term residency and temperatures lower than 15.6°C considered optimal (Raleigh, 1982). Brook Trout require high levels of dissolved oxygen (DO) within their habitat to thrive and cannot tolerate concentrations less than 5 mg/L DO, with optimal concentrations of at least 7 mg/L DO in water colder than 15°C and 9 mg/L DO in water above 15°C (Raleigh, 1982).

<u>Zinc</u>

Brook trout have been shown to have higher tolerance to trace metals in their habitat compared to other salmonid species (Nehring & Goettl, 1974; Holcombe & Andrew, 1978). Toxic effects of zinc are affected by other characteristics of the water, most notably: pH, alkalinity and hardness. Increasing pH has been shown to increase toxicity of zinc while increases in alkalinity and hardness reduce the potential for toxicity due to associated shifts in the bioavailability of the metal (Holcombe & Andrew, 1978). Research done by Nehring & Goettl (1974) established a 14-day TL50 concentration of zinc to be 960 µg/L for Brook Trout, compared with 410 µg/L for Rainbow Trout for water with neutral pH. Another study conducted on long term exposure of brook trout to zinc using Lake Superior water (hardness = 45.4 mg/L as CaCO3; pH = 7.0–7.7) showed that levels below 534 µg/L produced no significant effect on the fish, with chronic effects of exposure appearing once levels reach 1360 µg/L (Holcombe et al., 1979). Because of the overlap between results of these past studies, and for the purpose of determining optimal brook trout habitat, the lowest of these values (534 µg/L) was selected for use as a potentially limiting concentration of zinc.

Copper

A study by McKim & Benoit (1971) examined effects of long-term exposure of copper on brook trout at various life stages. When exposing yearling brook trout to copper concentrations of 34 µg/L, survivorship and growth were reduced among the study population, with no significant variation from the control sample at lower tested concentrations (McKim & Benoit, 1971). The tests on juveniles produced results showing that the fish were more susceptible to copper toxicity at early developmental stages - growth was reduced by at least 50% in the populations tested at 17.4 µg/L as well as in a single sample tested at 9.6 µg/L, leading the researchers to establish a maximum acceptable toxicant concentration (MATC) range between the two values of 17.4 and 9.6 µg/L, while a 96-hour acute exposure test carried out during this same study indicated a TL50 value of 100 µg/L of copper (McKim & Benoit, 1971).

Another study into toxic effects of metals on several species of fish also examined copper relationships with brook trout eggs and juveniles, finding no significant effects on survivorship at concentrations below 13 µg/L, though growth was impacted by the end of the 60-day experiment in all concentrations tested above 5 µg/L in soft water (Sauter, 1976). As this study sought to establish a “zero-effect” concentration, 3-5 µg/L was decided upon as the final MATC for Brook Trout herein (Sauter, 1976).

1.6 Climate Change

Global climate change has been anticipated to significantly alter the range of many freshwater fish species, especially those that prefer cold-water environments in temperate regions such as Brook Trout (Meisner, 1990; Comte et al., 2013). Additionally, elevated water temperatures due to climate change pose the potential risk of alteration of physicochemical properties of water bodies, leading to alterations in mixing regimes and extension of the ice-free season at higher latitudes (Keller, 2007; Wegner et al., 2011). This study examined the potential impacts climate change may present for Cleaver Lake by the end of the century according to parameters found in the most recent CCME report (CCME, 2019) via modification of CE-QUAL-W2 model files, and their effects on like dynamics and Brook Trout habitat availability.

1.7 Model Selection

CE-QUAL-W2 (Version 3.72) was chosen for its usefulness in modelling chemical constituents in potentially stratified water bodies and for its ability to be modified for use in predicting the effects of theoretical scenarios. CE-QUAL-W2 is a two-dimensional, laterally averaged water quality and hydrodynamics modelling software available as a free open source download made available by Portland State University. The model was initially developed in 1975 for use in studying water quality in singular reservoirs and was at the time known as LARM (Laterally Averaged Reservoir Model). The model was later expanded to include multiple reservoirs and river segments and was then known as GLVHT (Generalized Longitudinal-Vertical Hydrodynamics and Transport Model). CE-QUAL-W2 Version 1.0 was distinguished through the addition of various water quality algorithms in 1985 and has since been used to represent lakes, rivers, estuaries and any combination thereof that the user may input and is now available as version 4.0 (Cole & Wells, 2017). More detailed descriptions of additions and modifications to the model program since V1.0 can be found within the user manual by Cole & Wells (2017).

The CE-QUAL-W2 model program has been successfully utilized in many lake modelling studies carried out by researchers from varying levels of academia and government, examples include: the USGS recently employed CE-QUAL-W2 modelling in the nearby state of Minnesota when studying the impacts of algal community dynamics and water quality on fish habitat in deep lakes (Smith et al., 2014; Smith & Kiesling, 2019), while researchers in the Albertan tar sands used CE-QUAL-W2 in a study of oil sand pit lakes and were able to develop an add-on sediment diagenesis component to the model that has since been incorporated into the download package (Vandenberg et al., 2015; Prakash et al., 2015).

1.8 Capabilities

Due to the two-dimensional nature of the CE-QUAL-W2 program, it is best suited to applications where the assumption of lateral homogeneity is acceptable, and the major concerns are with longitudinal and/or vertical gradients in water quality. Thus, long and narrow water bodies such as Cleaver Lake are best suited for CE-QUAL-W2 modelling. Water surface elevations, longitudinal and vertical velocities, and temperatures were calculated first in the model before coupling those hydrodynamic computations with water quality information. The model then displayed real-time output data for state based (i.e. organic matter, sediment temperature, dissolved oxygen) and derived variables (i.e. TOC, SOD).

1.9 Limitations

CE-QUAL-W2 assumes the variability in the longitudinal direction of the modelled water body of both hydrodynamics and water quality is negligible, therefore the researcher must be considerate of whether this assumption is fair and if it is important to the study before deciding to undergo the lengthy process of developing a model.

Eddy coefficients were written in the conservative form within CE-QUAL-W2 to calculate turbulence, with several options available for selection. The researcher must decide which vertical transport scheme is the most appropriate in application. Since vertical momentum is not included in the model CE-QUAL-W2 may not be appropriate for use in scenarios where significant vertical acceleration exists within the modelled water body.

As any model is essentially a simplified representation of a complex system, the researcher must always be cautious of the quality of data included, and developers must perpetually seek the newest and best available mathematics to describe interactions within. Computer based modelling requires a significant investment of time, data, and money; thus, the researcher must cautiously decide which factors are most relevant to the questions posed and which are acceptably left out.

2.0 Objectives

The objectives of this study were to (i) construct a functioning CE-QUAL-W2 model of Cleaver Lake using field collected data and updated bathymetric maps that would accurately represent isothermal events and lake turnover, (ii) use the constructed model in determining variations in potential habitat availability for Brook Trout throughout the course of 2017, (iii) develop experimental scenarios to predict the future fish habitat availability in the lake following: (a) reintroduction of mining activity and effluent release from the mine site upstream, and (b) the effects of rising air temperatures due to climate change.

3.0 Hypotheses

It was hypothesized that the CE-QUAL-W2 model would be able to accurately reproduce hydrodynamic phenomena such as lake turnover and that natural recovery from legacy mining impacts was enough to maintain significant brook trout habitat throughout the year in Cleaver Lake, attributable to deep-water refugia in the hot summer months, and reduction of zinc and copper concentrations to within tolerable limits for Brook Trout. It was also hypothesized that the experimental operational mining scenario tested would display altered lake mixing regimes due to chemical density gradients from TDS elevated waters and declines in habitat availability when compared with the unmodified model results for Cleaver Lake. For the climate change experimental scenario, it was hypothesized that thermal stratification would become more pronounced during the ice-free season and the time period between mixing events would be extended, resulting in reduced volumes of survivable and optimal habitat for cold-water species such as Brook Trout.

4.0 Methods

4.1 Water Quality Sampling

Historical water quality data was provided by First Quantum Minerals LTD. in the form of reports by the following consulting firms: IEC Beak Consultants LTD. (1983), B.A.R. Environmental Inc. (1991, 1992), Beak International Inc. (1997, 1998, 1999, 2000), Senes Consulting (2000), Stantec Consulting (2003), and Ecometrix Inc. (2006, 2009, 2012, 2015).

Vertical profiles of the profundal zone of Cleaver Lake were conducted during each trip to the field site using a Hydrolab Datasonde Surveyor 4a for temperature, conductivity, pH, dissolved oxygen, and turbidity. These measurements were recorded in the deepest portion of the lake at 1m intervals. Due to the Hydrolab requiring repairs during the trip in May 2017, data were forwarded from Gerry Landriault of FQML.

Following vertical profile measurements, water samples were collected from the deep area of the lake during each trip to the field site, on dates: March 17, May 11, June 7, July 25, September 7, October 11, and November 13. On each visit, samples were taken in the deep region of the lake near the surface of the lake (0.5 m depth), a deep sample taken from approximately 0.5 m above the substrate, and samples obtained within the middle ranges of the water column where thermal stratification or shifts in conductivity were observed in addition to samples obtained from the inflow to Cleaver and the outflow from it. Additional samples of the inflow and outflow were collected on June 25 and August 3. All samples were gathered using Nalgene sample bottles that were triple rinsed with sample water prior to receiving the sample intended for lab analysis. Samples at depth were gathered using a fourlitre Wildco Kemmerer sampler, with one duplicate sample taken during each trip for QA/QC analysis.

All collected samples were analyzed via at the Lakehead University Environmental Laboratory (LUEL) following ISO/IEC 17025:2005 accredited standard operating procedures. Alkalinity and pH values were determined via titration. Chlorophyll was measured using filtration followed by spectrophotometric analysis. Anions such as nitrate, nitrite, chloride, sulphate, and phosphate were analyzed using ion chromatography (IC). Total dissolved solids (TDS) & total suspended solids (TSS) were analyzed via filtration and gravimetric analysis. Total nitrogen & phosphorus, and dissolved organic carbon were measured using a SKALAR automated chemistry analyzer. Trace metals were analyzed via ICP-AES (most notably copper and zinc). June 7 water samples were also analyzed at LUEL for biological oxygen demand (BOD).

Additional supporting data for model development and calibration was obtained using data logging devices deployed on site. A Davis instruments weather station was deployed on the central peninsula of Cleaver Lake to monitor meteorological variables. Barometric pressure sensing HOBO data loggers were deployed at the inflow and outflow to Cleaver Lake as well as in the lake itself to monitor channel and lake depth. Dissolved oxygen and conductivity monitoring HOBO data loggers were also deployed at 18 m depth in the profundal zone of Cleaver Lake, attached to a string of iButton temperature loggers deployed at every 1m of depth.

4.2 Model Development

Data collection for the initial CE-QUAL-W2 model occurred during the ice-free season of 2017. Inputs required for a working CE-QUAL-W2 model are rather extensive, but can be categorized in to one of six major categories: (1) geometric data, (2) initial conditions, (3) boundary conditions, (4) hydraulic parameters, (5) kinetic parameters, (6) calibration data.

(1) Geometric Data

Geometric data in the form of bathymetric map(s) and volume-area-elevation tables were used to define the shoreline and computational grid of Cleaver Lake. Bathymetric maps were created using GPS tagged data from a Lowrance depth sounder input into the SURFER software suite. Using bathymetry data, segment lengths, widths, depths, and slope were defined. Though longitudinal and vertical spacing may be set at variable distances, incremental variation is crucial to reduce the potential for discretization errors during the model run. Establishment of vertical and longitudinal dimensions began with fine resolution (small cell dimensions) but may be gradually increased to reduce runtimes if excessive. If a shift in results of the model is observed as grid sizes are increased, then the researcher must revert to a smaller grid size to maintain integrity of the model. Results of a properly constructed CE-QUAL model should never be allowed to be affected by the user defined resolution of the computational grid.

The model of Cleaver Lake utilized the initial fine grid sizing of 20 m in the horizontal direction by 1m depth for all grid cells which produced acceptable runtimes precluding the need to increase grid sizing, this resulted in final dimensions of 41 cells laterally by 19 cells in the vertical direction (figure 4.2.1). Cells 1 and 43 are not active within the model, they were simply used to represent the outer boundaries of the lake.

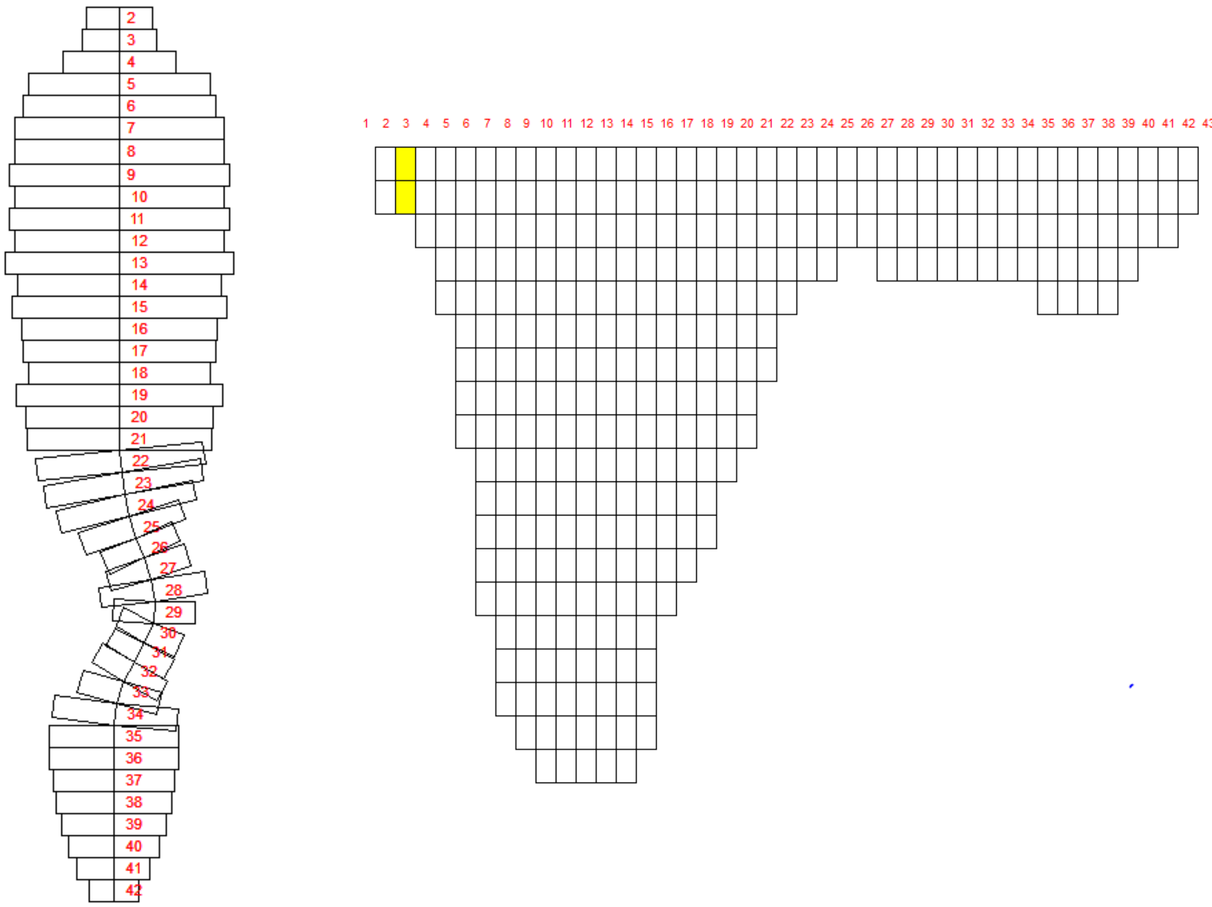

Figure 4.2.1. Top view (left) and side view (right) of the CE-QUAL-W2 computational grid for Cleaver Lake.

Once vertical and horizontal grid sizing were established, the lateral grid dimensions were computed as a function of volume from a calculated volume-area-elevation table iteratively using bathymetric data (figure 4.2.2). The Cleaver Lake bathymetric data for CE-QUAL-W2 input was processed using contour maps generated in SURFER software (figure 4.2.2) to obtain lateral computational grid sizing.

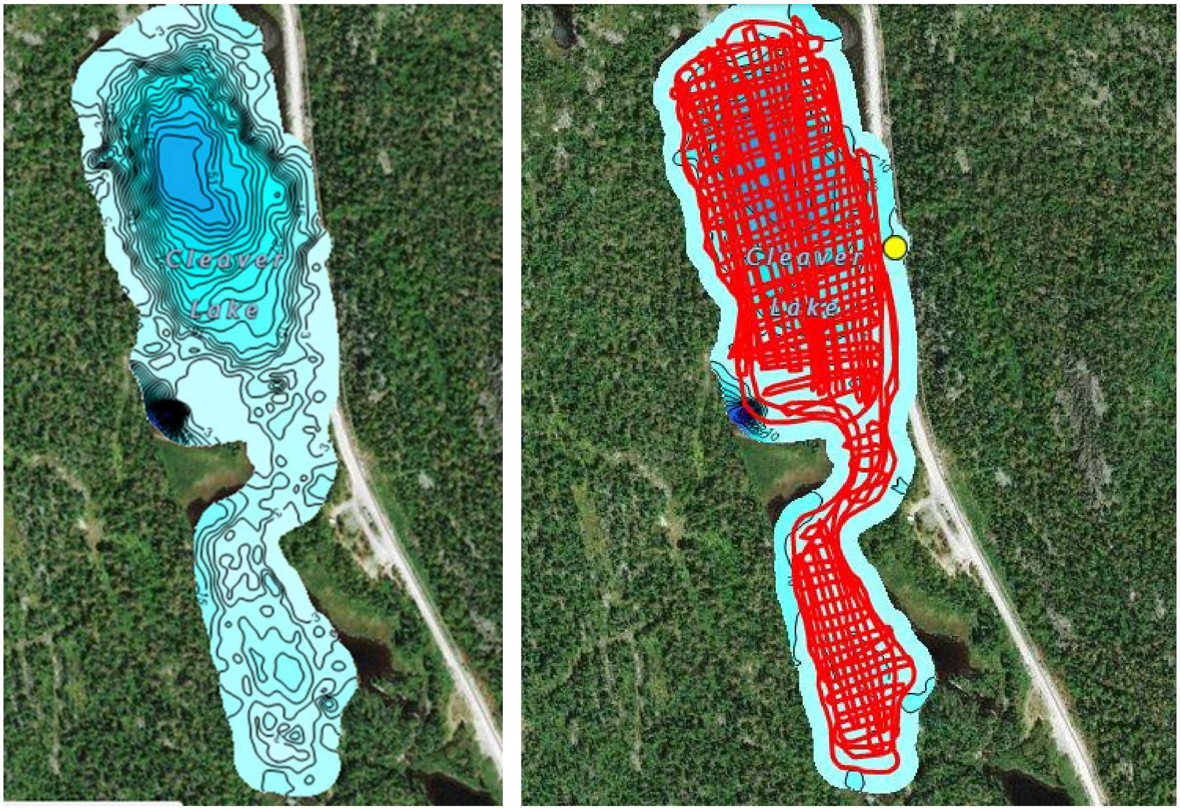

Figure 4.2.2. Bathymetric map (left) and GPS track (right) showing depth sounder collection route for Cleaver Lake.

(2) Initial Conditions

The next step in the CE-QUAL-W2 model construction was setting initial conditions for the required variables: start and end times, temperature, waterbody type – as well as the optional parameters: modelled constituents, inflow and outflow locations, and initial ice thickness. Temperature and constituent values were input as a vertically varying profile. Temperatures and dissolved oxygen were sampled for every 1 m depth using a Hydrolab 4a datasonde during each trip to the site with temperature also recorded every half hour by an array of iButton temperature logging devices set at 1 m intervals in the lake.

The constructed model ran for 185.5 days from May-November 2017 (Julian Day 132-317), with the water body type specified as a lake with a single upstream inflow at the northern end and downstream outflow at the southern. This study used varying vertical profiles for initial conditions of both temperature and constituent concentrations (TDS, NO_3, alkalinity, DO) observed at Cleaver Lake. Since the modelled period began in May after ice-off, ice thickness was not used. All initial condition input data can be found in appendix C.

(3) Boundary Conditions

The first set of boundary conditions for a CE-QUAL-W2 model describes inflow characteristics such as volume, temperature, and constituent concentrations for any specified rivers/tributaries as well as internal flows and precipitation. The Cleaver Lake model specified a segment for the upstream inflow water to enter rather than using the density dependent option, while precipitation was distributed by the model according to surface areas of computational cells. Inflow and outflow volume measurements were taken using a combined approach of stream gaging using a single propeller flow meter during each trip to the site, the data from which was used in a regression analysis to correlate observed flow rates with stream depth determined through the use of a pressure sensing HOBO data logger deployed within 5 m of where manual flow readings were recorded. The regression equations established were:

$$y = Ae^{Bx}$$

Where y = flow rate in m^3/s, x = measured channel depth

Inflow: A = 0.0006 B = 0.0957 R^2 = 0.92

Outflow: A = 0.0523 B = 0.1225 R^2 = 0.9451

Data sheets for all flow/depth readings can be found in appendix B. Additional flows in the form of a distributed tributary (adds water to all surface layers simultaneously) were included to correct the water balance of the Cleaver Lake model via utilization of the included water balance utility to improve model stability. The water balance utility aids in representing non-point sources of water via such channels as runoff/infiltration and snow melt which can be challenging to measure experimentally. Values generated from the water balance utility were included as a distributed tributary inflow, meaning the water was added to all surface cells of the grid simultaneously based on their total surface areas as opposed to entering from a point source. Water quality parameters for the distributed inflow were set to match the characteristics of precipitation used in the model and can be found in appendix C.

Precipitation values were gathered on-site via a Davis instruments weather station set up on the small peninsula near the mid-point of the lake to record data every half hour over the course of the model run for 2017 and are included in the weather station data sheet located in appendix B.

Evaporation is an optional boundary parameter within the model calculated based on air temperature, wind speed and dew point. The Cleaver Lake model had enabled evaporation calculation to ensure an accurate water balance, using data obtained from the Davis weather station (Appendix B).

Surface heat exchange conditions were required by the model and specified in the Cleaver Lake model to operate on a term-by-term basis. The model calculated surface heat exchange using latitude (48.97°N), longitude (-87.30°W), dew point, air temperature, wind speed/direction, and cloud cover. Cloud cover in the model was represented as a scale of 1-10 (a value of 10 representing heavy cloud cover) and was calculated for the site using analysis of data from the on-site weather station (solar radiation) compared with theoretical clear sky radiation obtained using the Bird clear sky model (Bird & Hulstrom, 1981).

Wind stress and gas exchange were computed within the model based on wind speed and direction, as well as a wind sheltering coefficient that may be adjusted by the user. Due to the proximity of the weather monitoring device, it was not expected that significant changes would need to be made to the wind sheltering coefficient, and a value of 0.9 appeared to provide the best results for the Cleaver Lake model (with a value of 1 representing no wind sheltering).

(4) Hydraulic Parameters

Hydraulic parameters in CE-QUAL-W2 describe vertical and horizontal momentum, temperature and constituents in the modelled waterbody, as well as bottom friction and sediment temperature. Model suggested values for vertical and horizontal dispersion/diffusion are suitable for most uses of the model (exceptions are rivers and estuaries where these values need to be increased) and were used for the model of Cleaver Lake. Sediment temperature was adjusted to match the average annual air temperature for the region that the site is located within (3.7°C). Sediment temperature is non-time-variable in the model, but calculates temperature shifts throughout the model run based on the coefficient for heat exchange between sediment and the water column, which was adjusted to 0.99, to allow for accurate temperature predictions in model layers near sediment. The coefficient governing the amount of solar radiation reaching the sediment radiated as heat was increased to 0.9 as this value produced the best model results when calibrating temperature profiles. Solar radiation and other meteorological components of the model such as dew point were obtained from the previously mentioned Davis instruments weather station located on-site.

(5) Kinetic Parameters

CE-QUAL-W2 possesses over 120 different adjustable parameters that dictate how water quality calculations will be treated in the model. These values represent how organic constituents are cycled in the model due to biological processes such as algal extinction, mortality, settling velocity, respiration, decay, etc., as well as non-biological processes like sediment resuspension and particulate settling. Kinetic parameters also describe variables such as sediment oxygen demand (SOD) and reaeration (Cole & Wells 2017).

SOD rates were determined using field sampled sediment cores. Water contained in the samples was carefully decanted out of the container and replaced with oxygenated dDW to disturb the sediment the least amount possible before having an O_2 probe inserted and being placed into a dark chamber at 20°C for 24hr, following procedures outlined by Rong et al. (2016).

As the list of parameters is rather extensive, those used in the Cleaver Lake model have been listed in Appendix C.

(6) Calibration Data

In-pool calibration data for temperature, and water quality constituents were gathered in the field to ensure accurate model performance, as well as to establish initial conditions for the model. This data must be taken with specified time and locational information to be used properly when constructing a model and when checking model accuracy.

Time-variable boundary condition data such as meteorology, inflow and outflow rates/temperatures were also input into the model files during construction. These parameters should be collected as frequently as is feasible to avoid using averaged values (Cole & Wells 2017).

Once finished building the input files for CE-QUAL-W2 and the first simulation was complete, the calibration process began. Observed time-specified calibration data were checked against the model output data the average mean error (AME) between the results was calculated using the following equation:

$$AME = \frac{\Sigma\ (Predicted - Observed)}{Number\ of\ observations}$$

After checking model output values against the observed data, it may be necessary to include new model processes, and adjust various coefficients before attempting another simulation. In the case of Cleaver Lake, the light extinction coefficient was adjusted from the default value for pure water of $0.45m^{-1}$ to $0.595m^{-1}$ following the initial simulation run to match observed data from Secchi disc readings.

4.3 Habitat Availability

CE-QUAL-W2 possesses a fish habitat extension which can be used to output the volume as a value in m^3 and/or as a percentage of the total volume that is suitable to support user specified fish species based on temperature and oxygen requirements. This study was concerned with Brook Trout as a model species, and two sets of parameters were established in the extension to calculate the % volume of Cleaver Lake suitable for (a) survivable and (b) optimal habitat. Parameters for survivable habitat were set to a maximum temperature of 24°C and minimum dissolved oxygen of 5 mg/L DO. Parameters for optimal habitat were set to a maximum temperature of 15.6°C and minimum DO concentration of 7 mg/L.

4.4 Experimental Scenarios

Following successful calibration of the Cleaver Lake CE-QUAL-W2 model, two experimental scenarios were constructed to make predictions about lake turnover and available fish habitat following shifts in influencing factors on lake hydrodynamics.

a. Operational Scenario

The first experimental scenario which was termed the "operational" scenario was modelled using an inflow TDS concentration of 740 mg/L that was recorded during an environmental survey performed by Beak Environmental in October 1997, representing the most recent available data obtained for TDS during the operational years of the Zenmac mine. This scenario was designed to represent the first ice-free period of Cleaver Lake following re-introduction of mining activity and thus effluent release upstream.

b. Climate Change Scenario

The second experimental scenario termed the "climate change" scenario was modelled using modified meteorological parameters set to reflect increasing air temperatures due to climate change. This data set was modified to correspond to a worst case scenario outlined in the 2019 Canadian Changing Climate Report (CCCR) published by the Government of Canada, which predicts a 6.3°C increase in average annual air temperature by the end of the century for Ontario according to a high emission (RCP8.5) scenario in which little to no reduction in global greenhouse gas emissions occurs during the next century (Bush & Lemmen 2019). Meteorological input data and inflow temperatures were adjusted to account for the 6.3°C shift estimated by the CCCR document, sediment temperature was also adjusted from 3.7°C to 10°C to reflect a change in average annual air temperatures. Two versions of this scenario were run, the first simulation did not include oxygen calculations, while the second used the same parameters for oxygen calculation (algae, SOD, BOD, initial conditions) as the original unmodified model scenario. The start times for the modelled periods were adjusted to reflect an earlier ice-off that would be expected in a warmer climate, with flow volumes and temperatures interpolated between the adjusted start date and the beginning of field observed data from 2017.

5.0 Results

5.1 Historical Water Quality

The following chart (figure 5.1.1) was made to depict the development and subsequent dissipation of the chemocline present in the profundal zone of Cleaver Lake from September 1991 to September 2015. At the time of sampling in 2017, no chemocline was present.

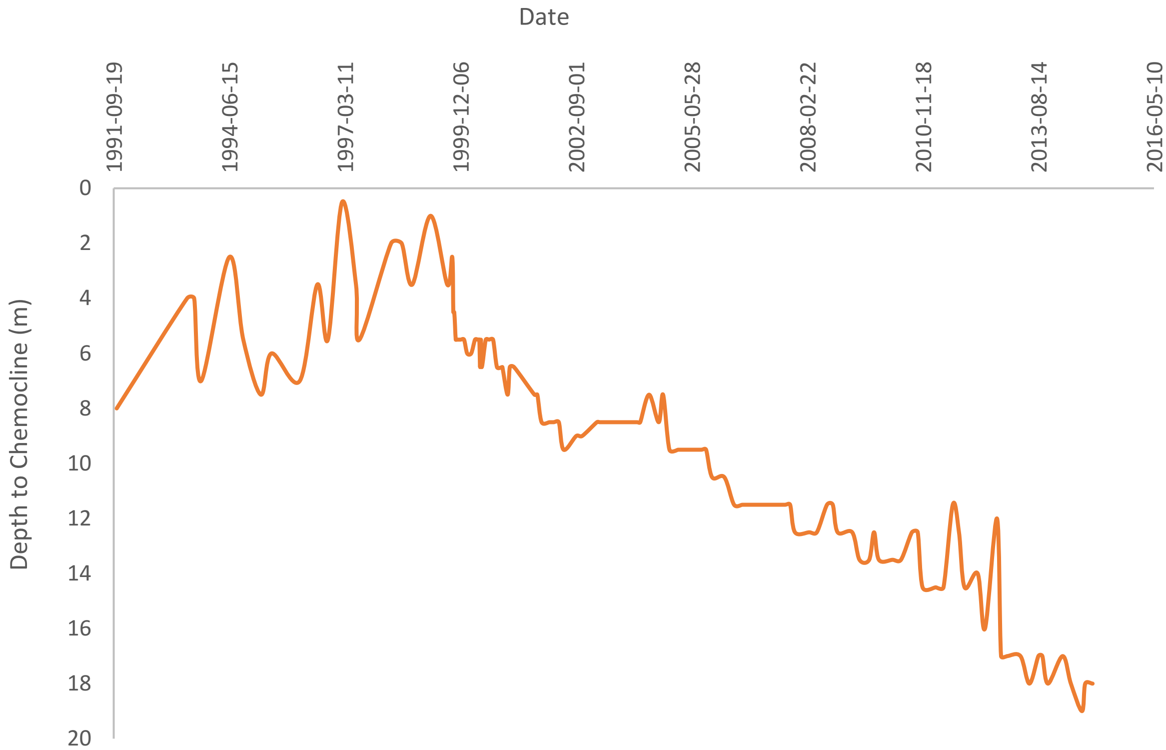

Figure 5.1.1. Depth to the chemocline (m) for Cleaver Lake from September 1991 to September 2015.

The next chart was made to illustrate the changes in concentration of density increasing dissolved solids sampled from the bottom of the profundal zone of Cleaver Lake from October 1997 to October 2017 (figure 5.1.2). The largest shift in concentration of TDS occurred between the 2009 and 2012 sampling efforts by Ecometrix Inc. during which time the associated depth to chemocline was observed to have been increased to 17 m depth from 12.5 m as depicted in figure 5.1.1.

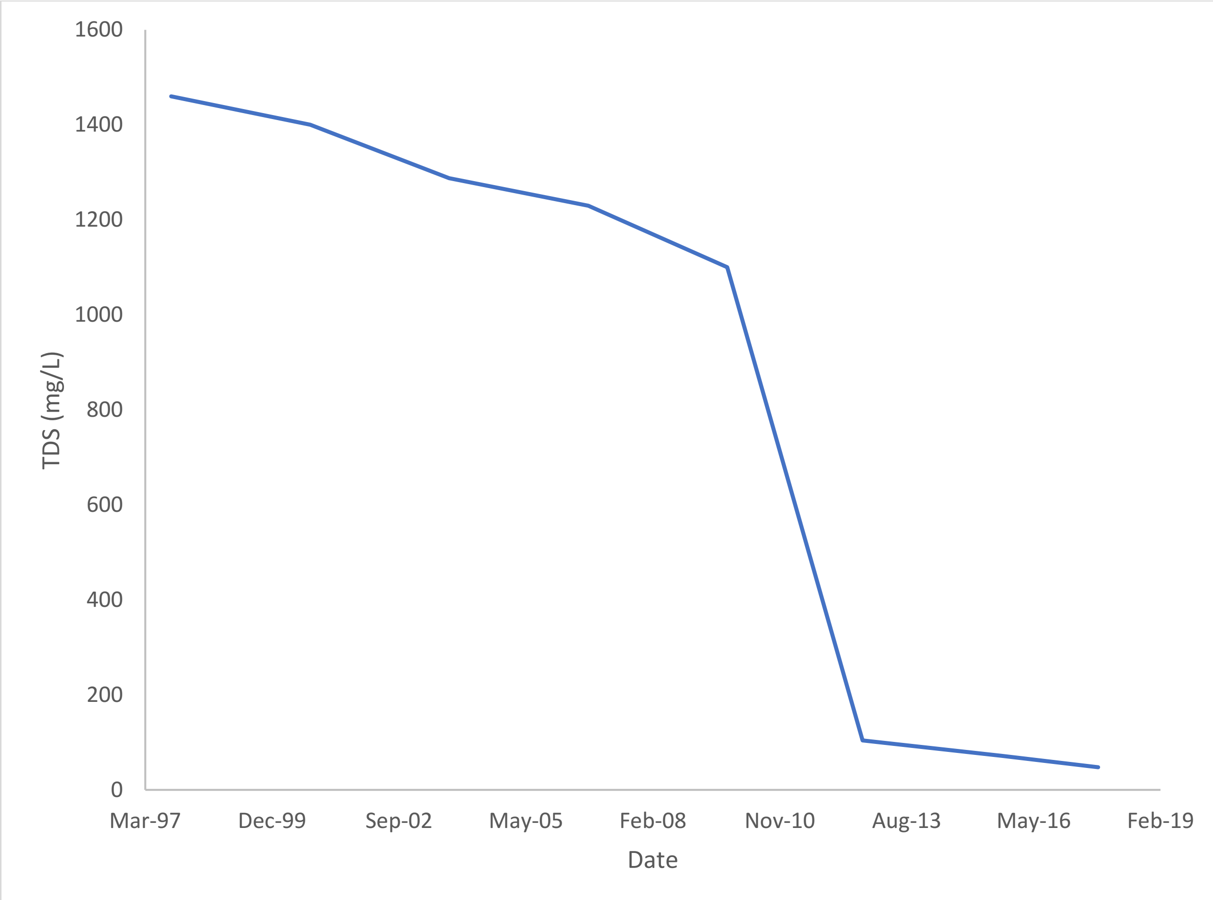

Figure 5.1.2. TDS concentrations in mg/L from samples taken at lake bottom for Cleaver Lake from October 1997 to October 2017.

The next chart was constructed to highlight the concentrations of total copper entering Cleaver Lake from October 1983 to September 2015 (figure 5.1.3). The lowest recorded measurement of 1.4 µg/L was obtained September 2012, with the highest measurement of 20 µg/L recorded on October 1983, prior to most recent mining activity. October samples were selected to reduce seasonal effects, apart from 2012 and 2015 data points which were obtained in September by Ecometrix Inc.

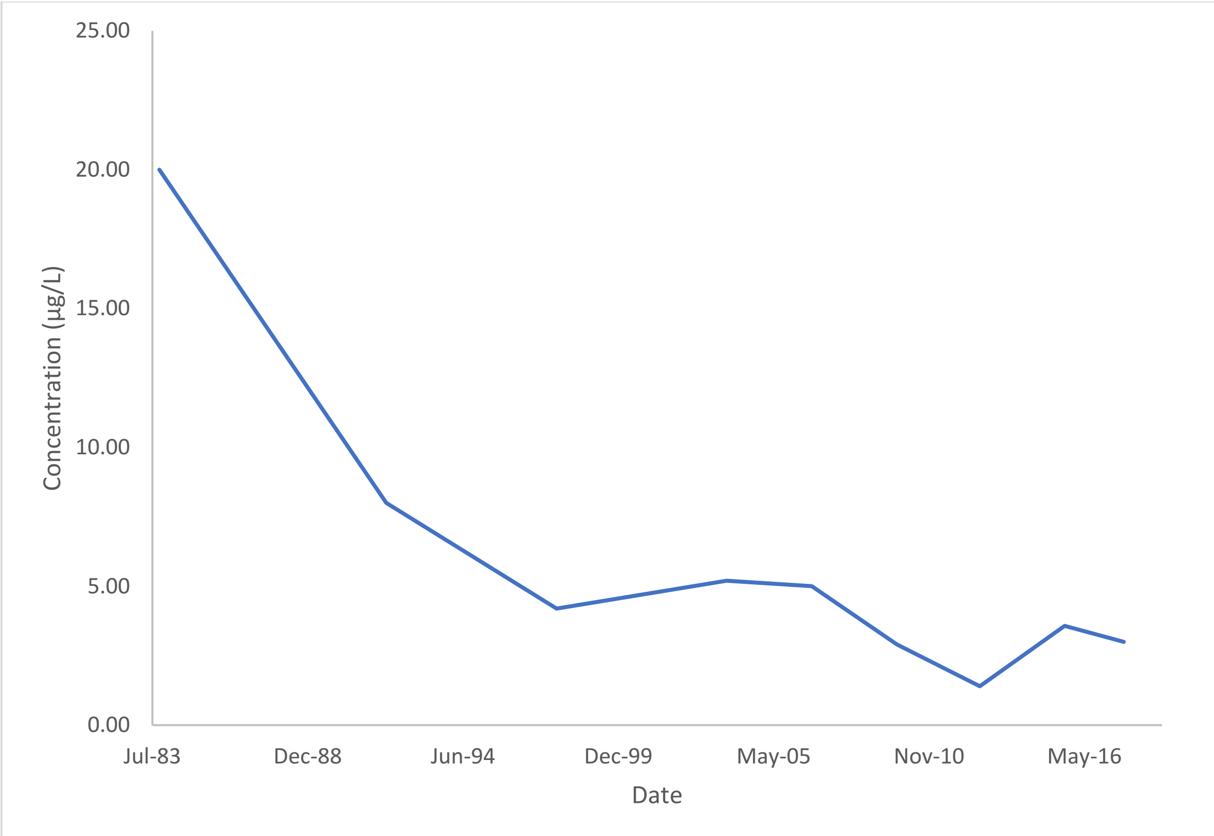

Figure 5.1.3. Total copper concentrations in µg/L for the inflow to Cleaver Lake from October 1983 to September 2015. CWQG limit for total copper = 2 µg/L, zero-effect concentration for Brook Trout = 3-5 µg/L (Sauter, 1976).

Zinc concentrations for the inflow to Cleaver Lake were also plotted from the period of October 1983 to October 2017 in the following chart (figure 5.1.4). All documented measurements have measured above PWQO standards (0.02 mg/L) yet have remained below Brook Trout zero-effect concentration (0.534 mg/L) since October 1999. October samples were selected to reduce seasonal effects except for 2012 and 2015 data points which were measured in September by Ecometrix Inc.

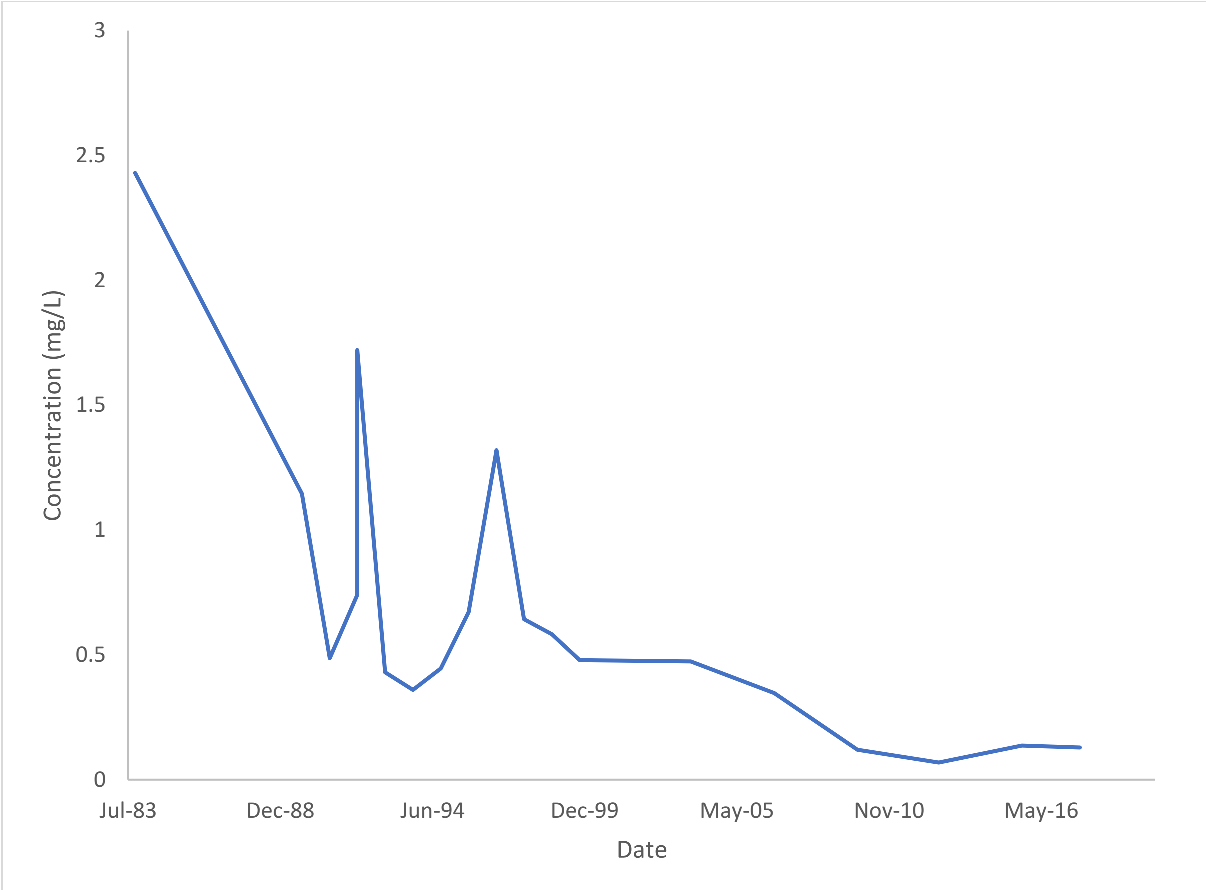

Figure 5.1.4. Total zinc concentrations in mg/L for the inflow to Cleaver Lake from October 1983 to October 2017. PWQO recommended value for zinc = 0.02 mg/L, zero-effect concentration for Brook Trout = 0.534 mg/L (Holcombe et al., 1979).

The following chart depicts the concentrations of zinc measured in mg/L from samples collected in 2017 in the profundal zone of Cleaver Lake (figure 5.1.5). The concentration of zinc in the lake bottom sample taken on June 7 tested below the detectable limit and was thus not included. All other samples tested over the PWQO limit of 0.02 mg/L, yet below the zero-effect limit for Brook Trout of 0.534 mg/L (Holcombe, 1979).

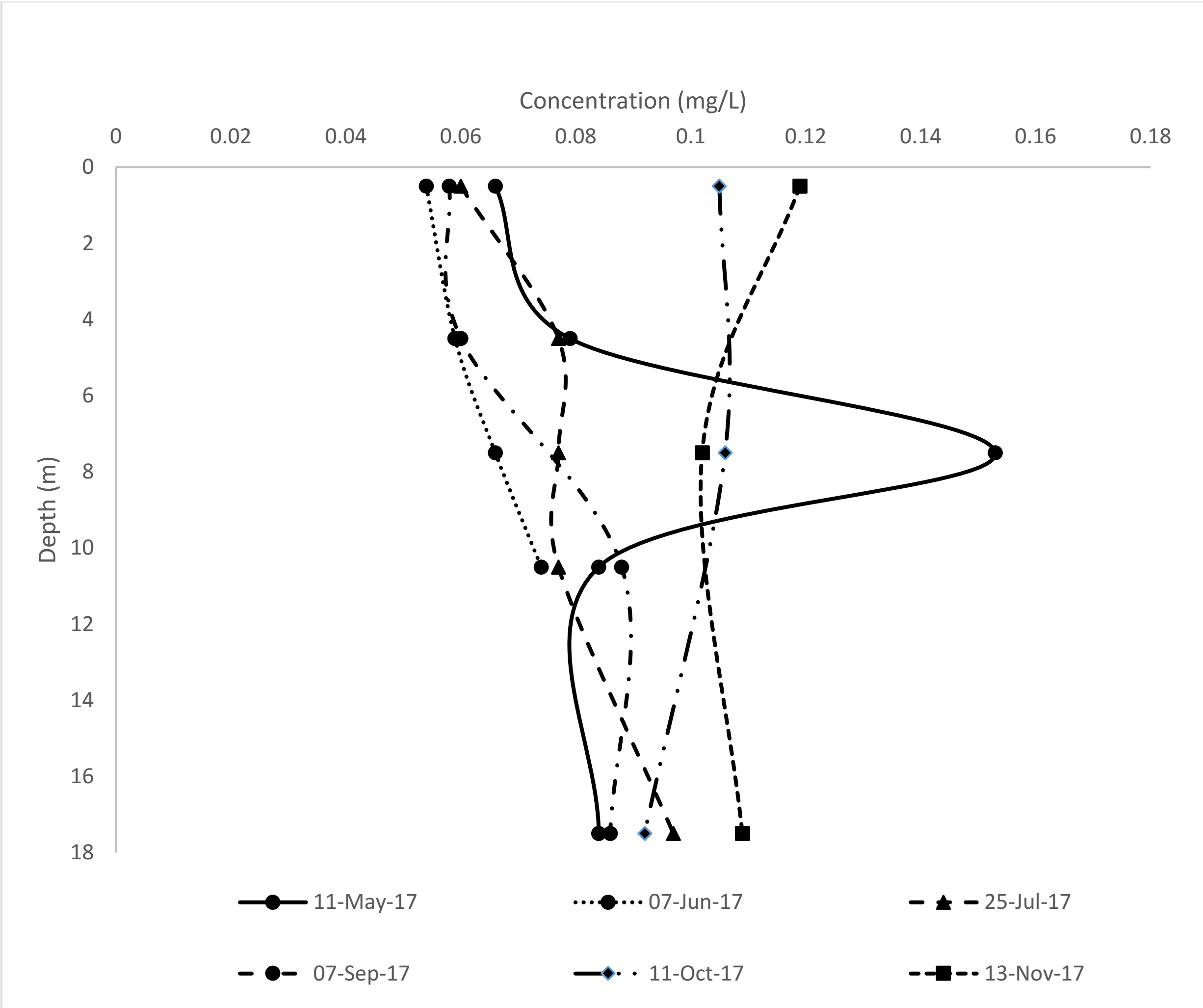

Figure 5.1.5. Total zinc concentrations for 2017 field season in mg/L for Cleaver Lake profundal zone plotted vs. depth in metres. MDL = 0.001 mg/L. Data points included.

The next chart depicts total copper concentrations in µg/L for Cleaver Lake over the 2017 season (figure 5.1.6). All samples tested above the CWQG guideline of 2 µg/L yet remained within the zero-effect limit for Brook Trout of 3-5 µg/L (Sauter, 1976). The lake bottom sample from June 7 tested below detectable limits and was thus omitted.

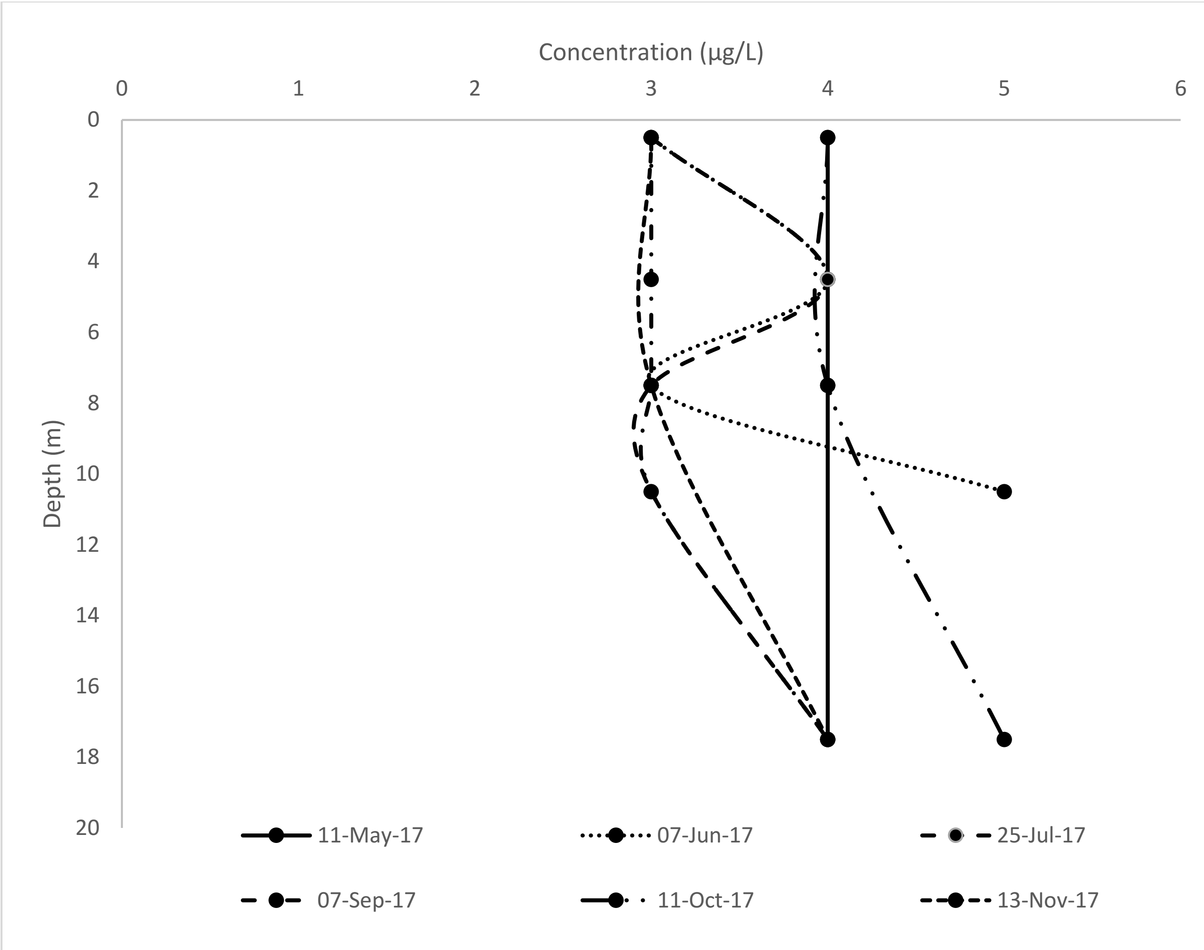

Figure 5.1.6. Total copper concentrations for 2017 field season in μg/L for Cleaver Lake profundal zone plotted vs. depth in metres. MDL = 2 μg/L. Data points included.

5.2 Geometric Data

Volumetric comparison of field collected bathymetrical data with the finalized bathymetry grid utilized in the Cleaver Lake CE-QUAL model showed agreeance between observed values and modelled results, with 98.69% of the total lake volume accounted for within the model, the volume-elevation curve for which follows (figure 5.2.1). The small amount of volume unaccounted for is attributable to the blanking process performed on the original bathymetry grid in order to convert to a CE-QUAL-W2 usable format.

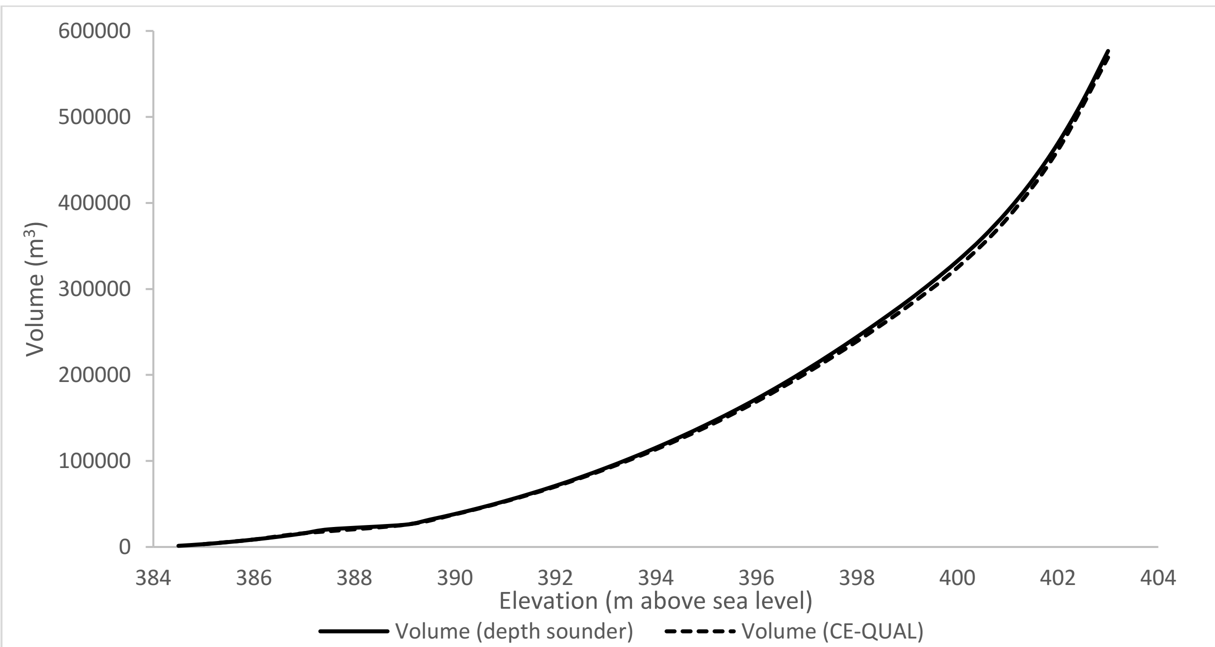

Figure 5.2.1. Volume-elevation graph for Cleaver Lake comparing field data from depth sounder with constructed CE-QUAL-W2 bathymetry grid data.

Water surface elevations were estimated adequately (<2% of total depth variance vs. observed) by the CE-QUAl-W2 model following application of the water balance utility, with minor deviation occurring during late June through September (figure 5.2.2).

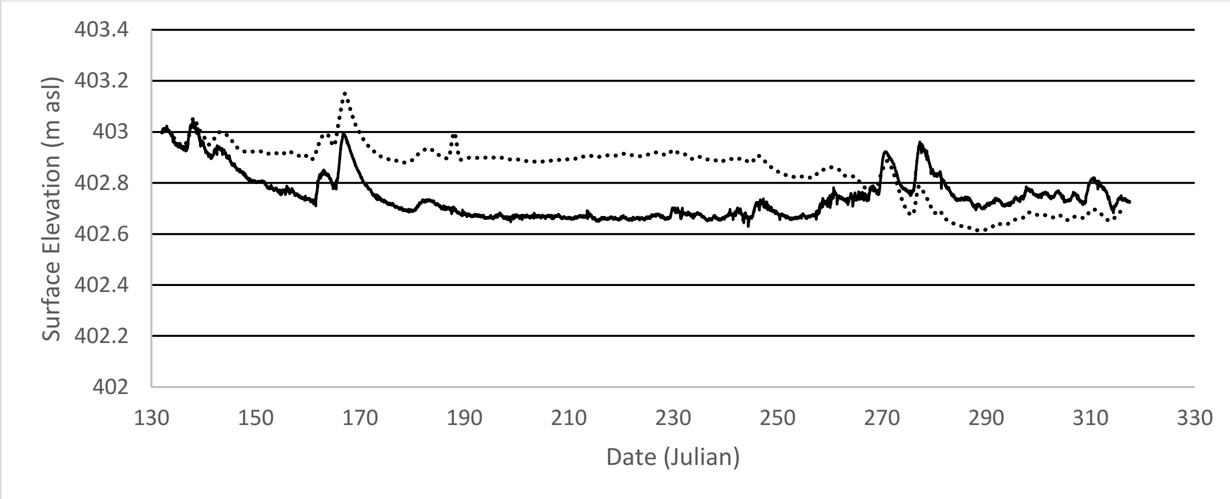

Figure 5.2.2. Water surface elevations for Cleaver Lake in metres above sea level as calculated from field deployed pressure sensor (solid line) and from model output (dotted line).

5.3 Initial Conditions

Initial condition input files for the Cleaver Lake model were constructed using the following field observed vertical profiles for temperature (figure 5.3.1) and dissolved oxygen (figure 5.3.2).

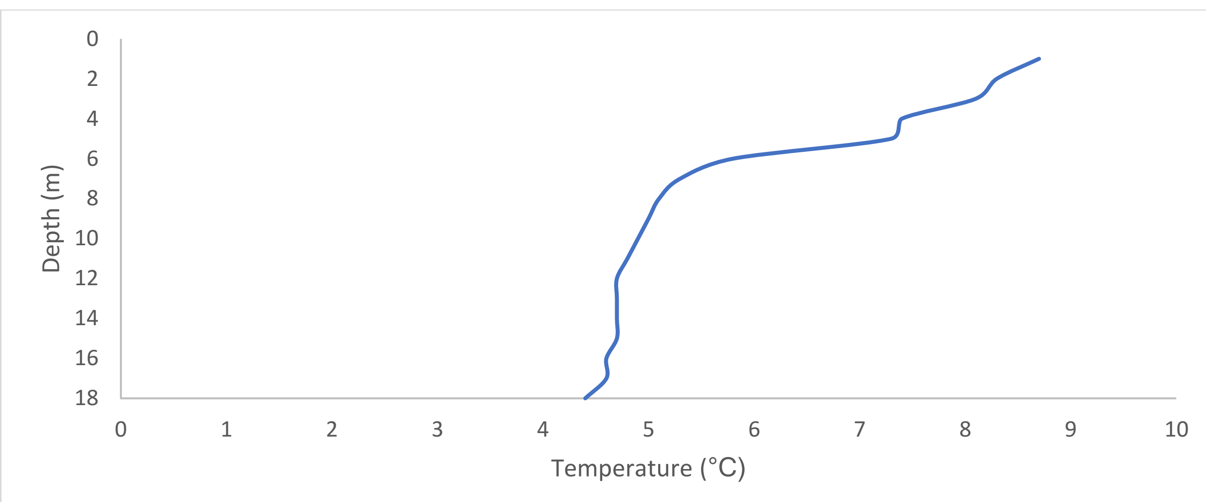

Figure 5.3.1. Temperature profile of Cleaver Lake from May 16, 2017 obtained in the deep profundal zone of the lake.

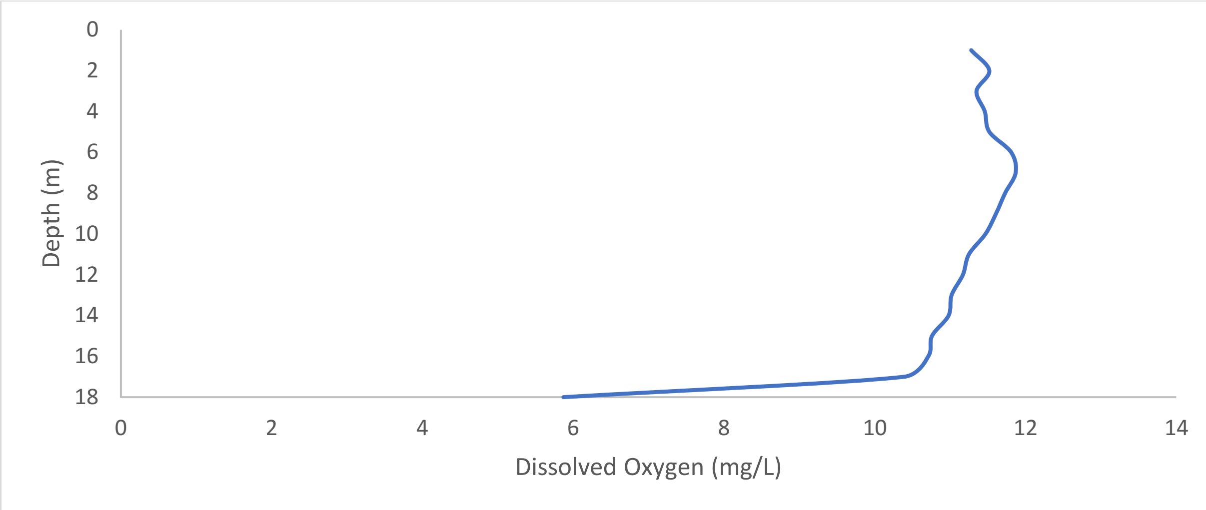

Figure 5.3.2. Dissolved oxygen profile of Cleaver Lake from May 16, 2017 obtained in the deep profundal zone of the lake.

5.4 Boundary Conditions

Barometric pressure readings obtained using the previously mentioned HOBO data loggers were plotted in the following figures (figures 5.4.1 and 5.4.2).

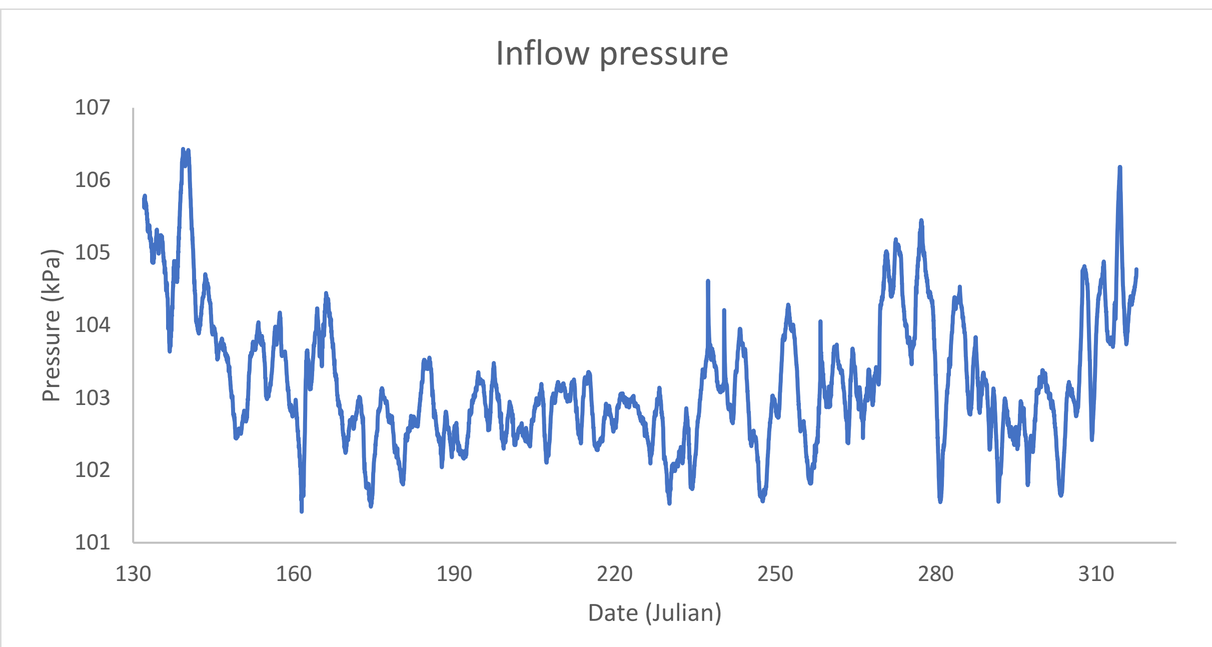

Figure 5.4.1. Barometric pressure sensor readings obtained from the HOBO data logger deployed in the inflow to Cleaver Lake.

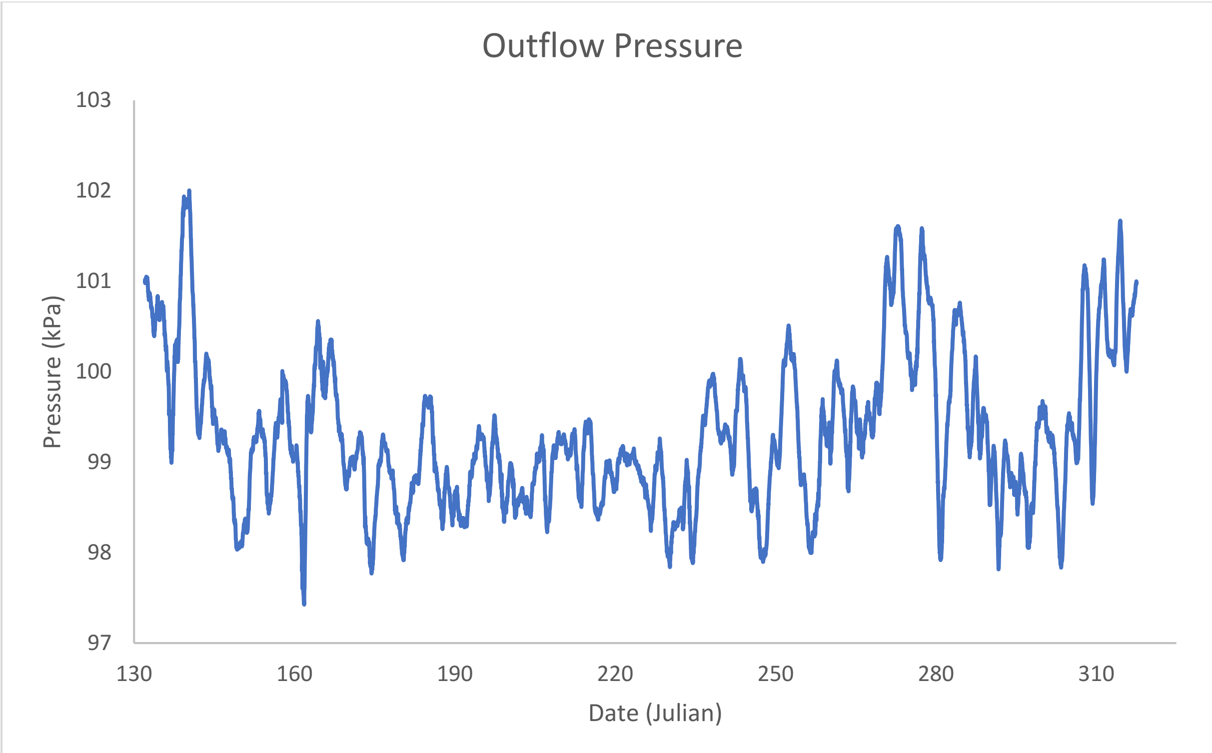

Figure 5.4.2. Barometric pressure sensor readings from the HOBO data logger deployed in the outflow from Cleaver Lake.

In order to calculate the net change in stream depth to estimate flow rates, barometric readings from the HOBO data loggers were compared with barometric readings from the on-site weather station which can be seen in the following figure (figure 5.4.3), with net pressure differentials calculated for correlation using the regression equations mentioned in the methods section. Also included in the figure were the other important boundary condition data required by the CE-QUAL-W2 model: solar radiation, wind speed, and precipitation (figure 5.4.3).

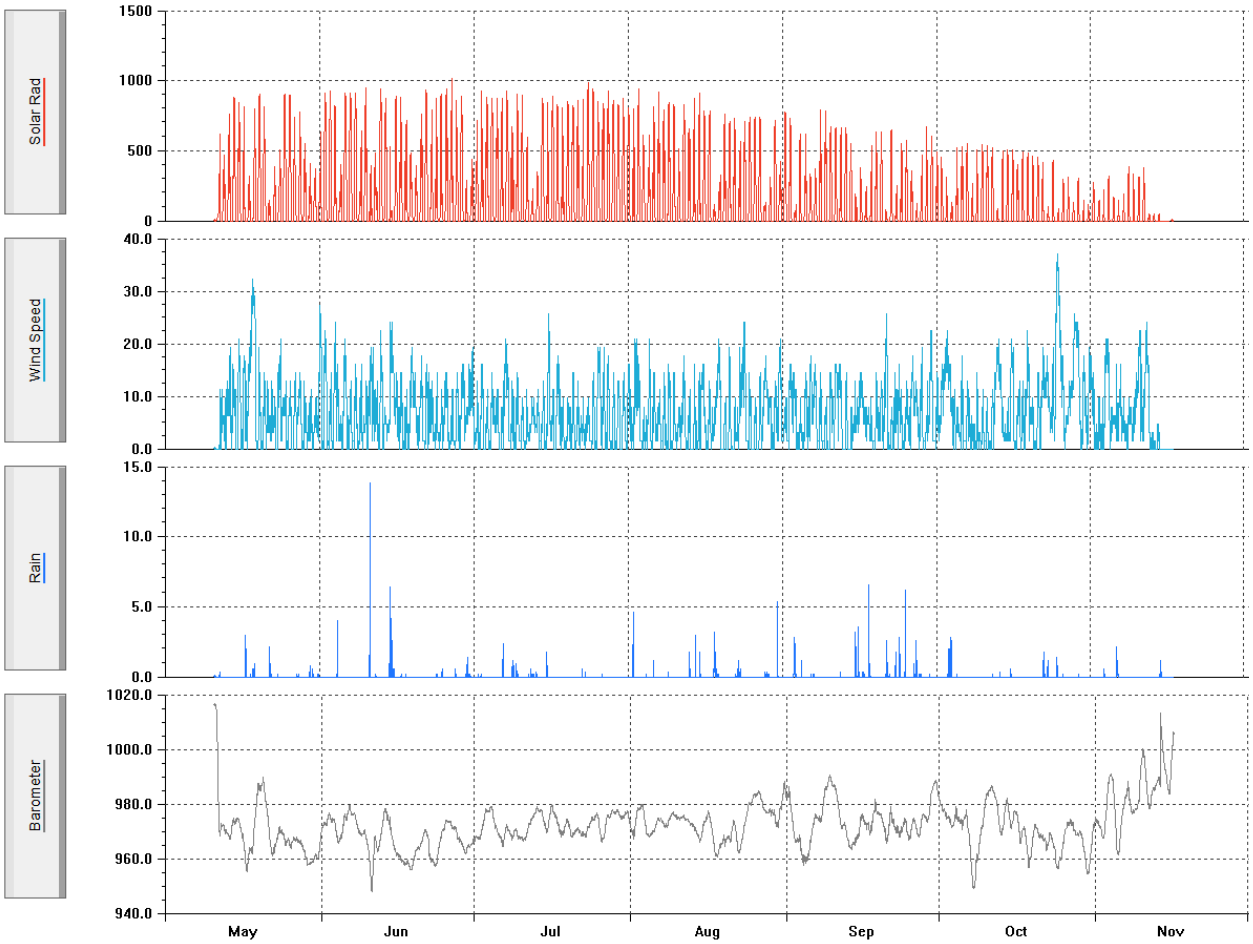

Figure 5.4.3. Boundary condition data obtained from the Davis instruments weather station deployed at Cleaver Lake for the modelled time period. Moving from top to bottom, the uppermost chart depicts solar radiation in W/m^2, the next displays wind speed in km/h, the third shows recorded rainfall in mm, and the bottom chart depicts barometric air pressure in mbar.

The resulting inflow and outflow rates calculated using the established regression equations and net pressure differentials of data loggers deployed in the inflow and outflow locations were plotted in the following figure (figure 5.4.4).

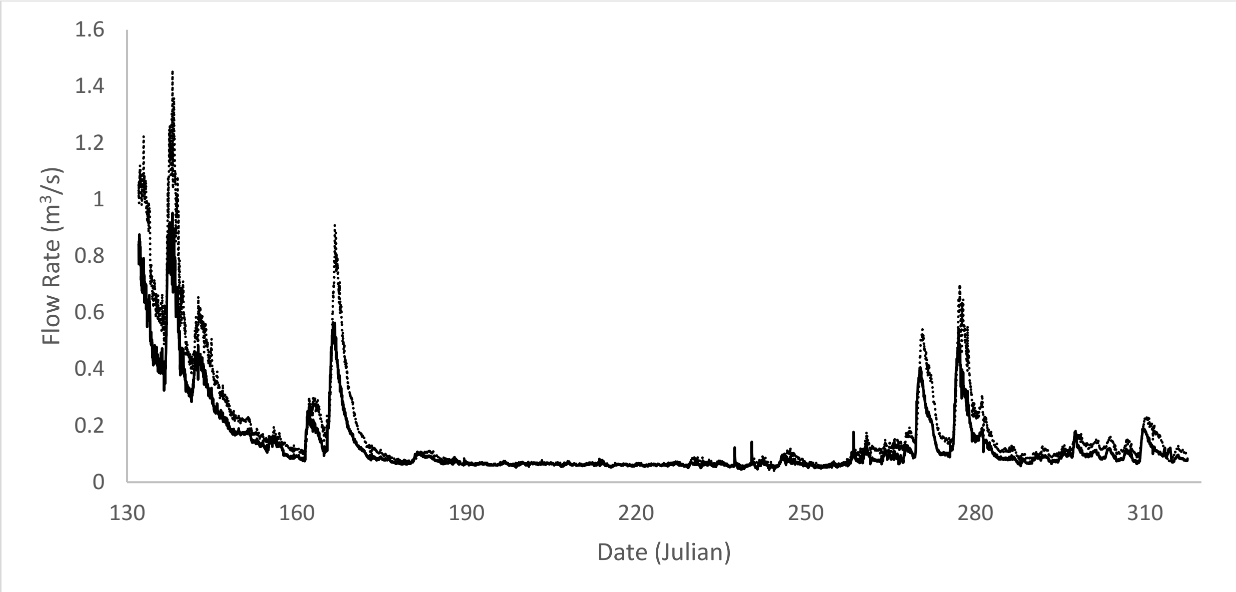

Figure 5.4.4. Calculated flow rates in m^3/s used for CE-QUAL-W2 model input. Inflow rates represented by the solid line; outflow rates represented by the dotted line.

The following graph (figure 5.4.5) depicts the flows added to the model in the form of a distributed tributary as calculated by the water balance utility in the CE-QUAL-W2 program. Necessary additions were most significant during the beginning of the model run (Spring)

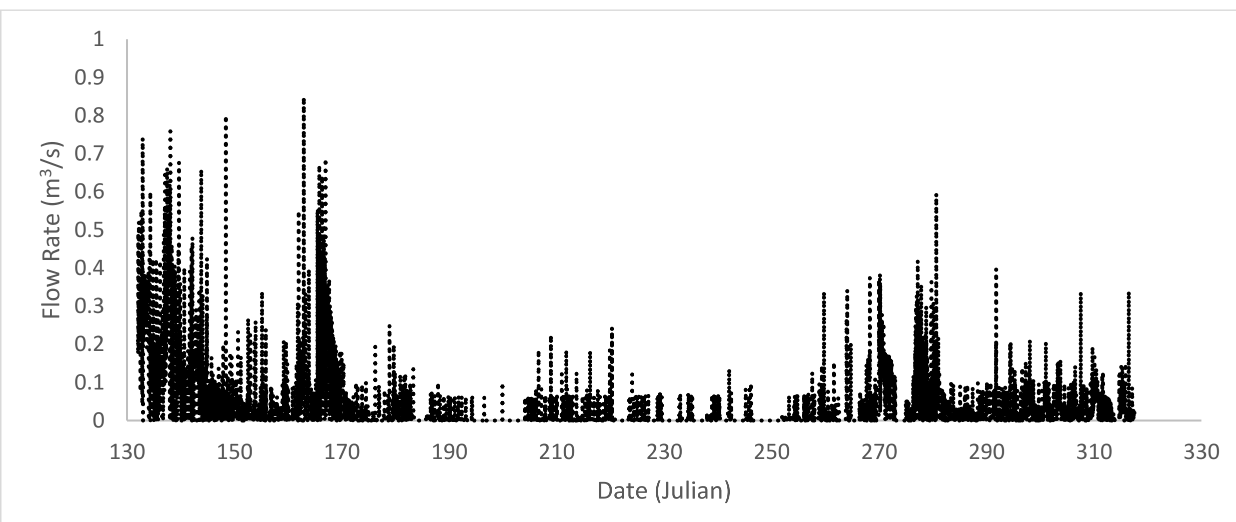

Figure 5.4.5. Additional flow rates to correct water balance within the CE-QUAL-W2 model of Cleaver Lake as calculated by the water balance utility. Rates were measured in m^3/s.

5.5 Kinetic Parameters

Results of the SOD chamber test can be visualized in the following figure (figure 5.5.1). The mean value for SOD calculated via this test was determined to be 1.3404 g/m^2·day with standard deviation of 0.2109. The minimum value in samples tested was 1.0899 g/m^2·day, and the maximum tested was 1.5506 g/m^2·day.

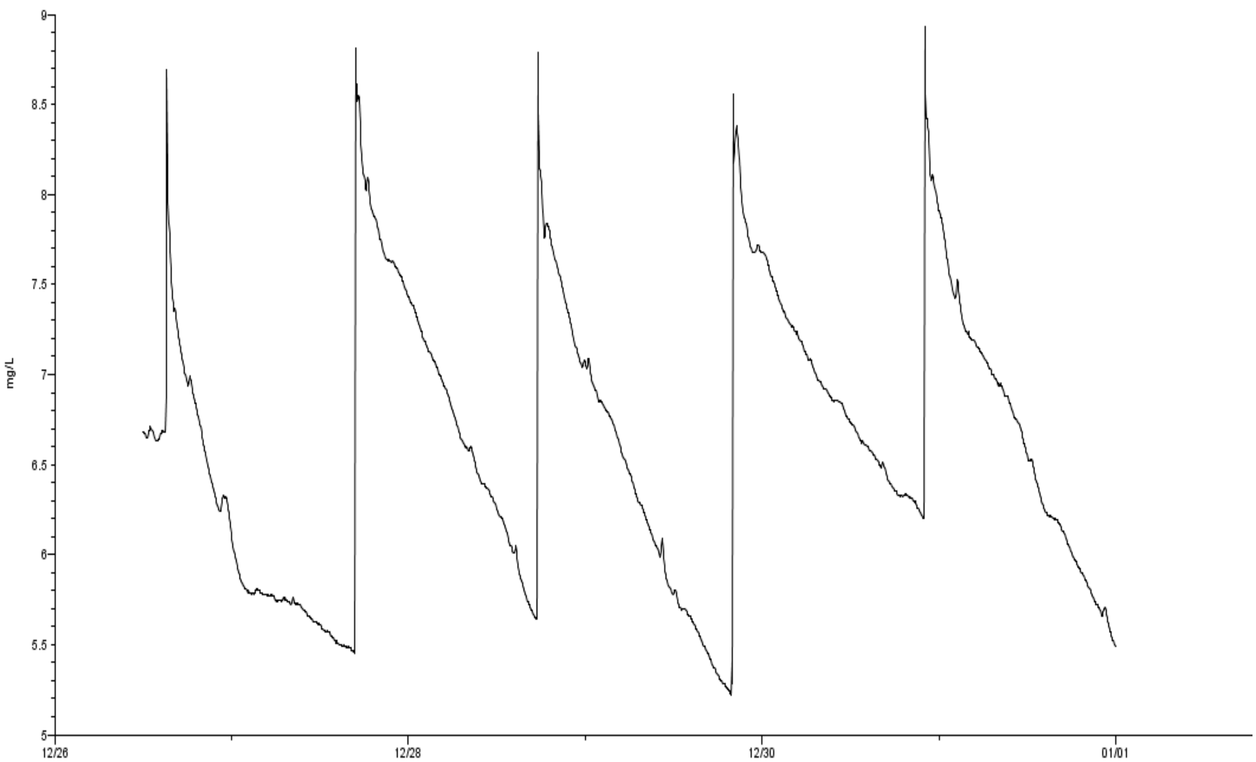

Figure 5.5.1. Dissolved oxygen values from a HOBO data logger used in the SOD chamber test. Five sediment core samples were tested on consecutive days at 20°C in a dark chamber, allowing 24 hours for oxygen consumption in each sample.

5.6 Calibration

Temperature/TDS

The initial run of the model displayed a total AME of 4.31°C during temperature calibration (figure 5.6.1). All calibration points apart from initial conditions and the final date recorded were above 1°C AME, indicating that default model settings were not adequate. At this point, the model was not accurately representing the thermocline of Cleaver Lake and as a result, lake turnover was occurring earlier than recorded by field measurements. This iteration did not yet include cloud cover which plays a significant role in moderating temperature over night, and model coefficients/sediment temperature were not yet adjusted from default settings.

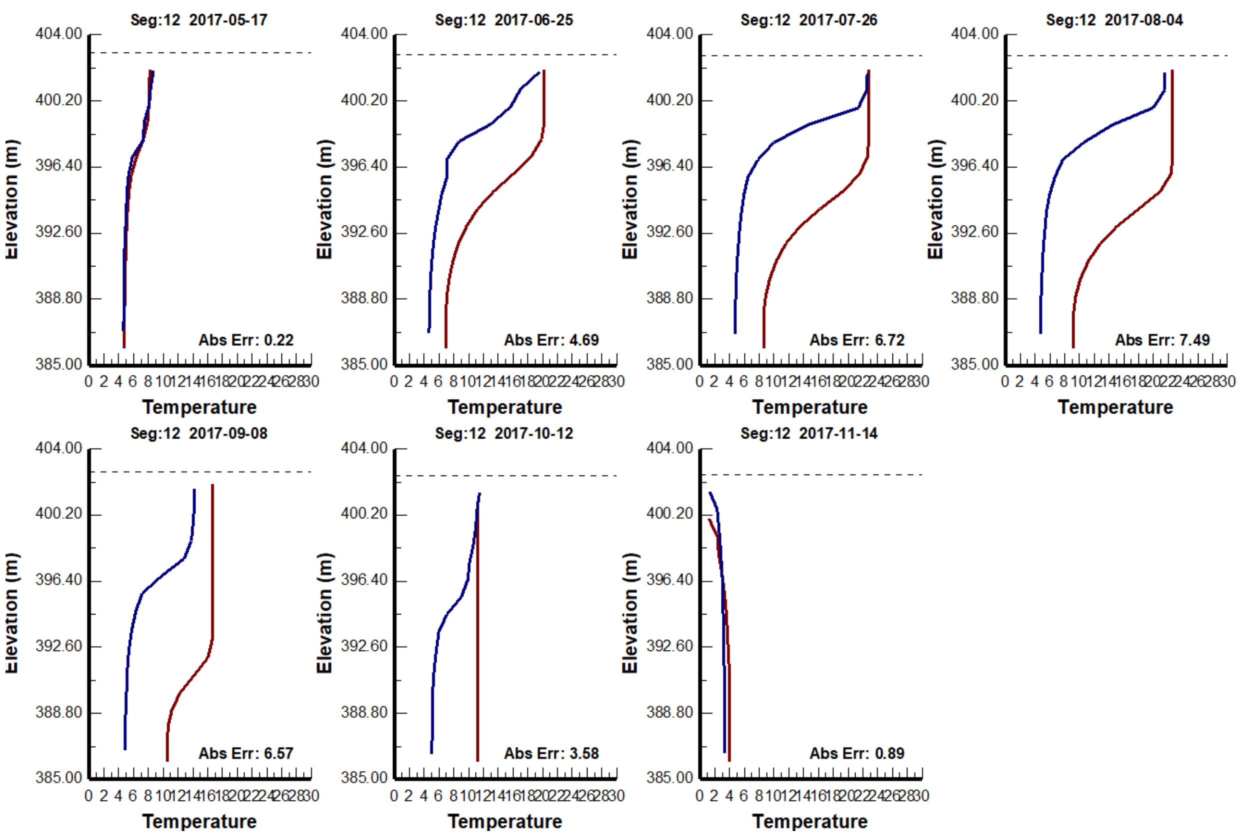

Figure 5.6.1. Temperature calibration profiles with unadjusted model coefficients, prior to cloud cover estimation and sediment temperature adjustment; wind sheltering, and water quality calculations disabled. Field measurements in blue, model output in red. Total AME = 4.31°C.

Following adjustment of sediment temperature, wind sheltering coefficients and inclusion of cloud cover estimation, results were improved to a total AME of 0.657°C (figure

5.6.2). Only the July 26 data point exceeded the desired AME of 1°C, with a value of 1.07°C. The adjustments made resulted in a much more accurate representation of the thermocline in Cleaver Lake.

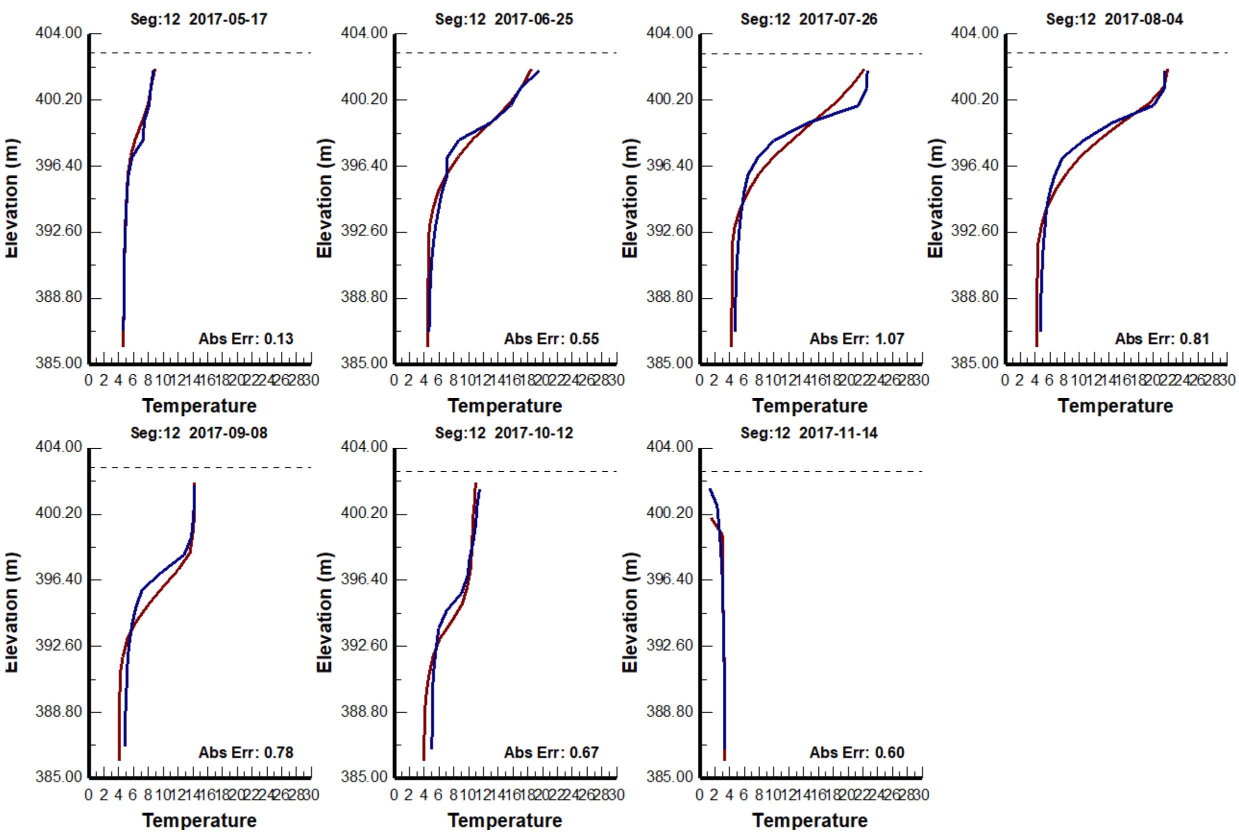

Figure 5.6.2. Temperature calibration profiles following inclusion of cloud cover, wind sheltering coefficients and adjustment of sediment temperature. Field measurements in blue, model output in red. Total AME = 0.657°C.

Following successful temperature calibration, water quality calculations were enabled in the subsequent model runs. Inclusion of water quality calculations did not seem to have any significant impact on temperature calibration. The results follow, displaying a total AME of 0.647°C (figure 5.6.3). The July 26 calibration point once again narrowly exceeded the optimal AME with a value of 1.03°C, this represented a slight improvement over the previous calibration.

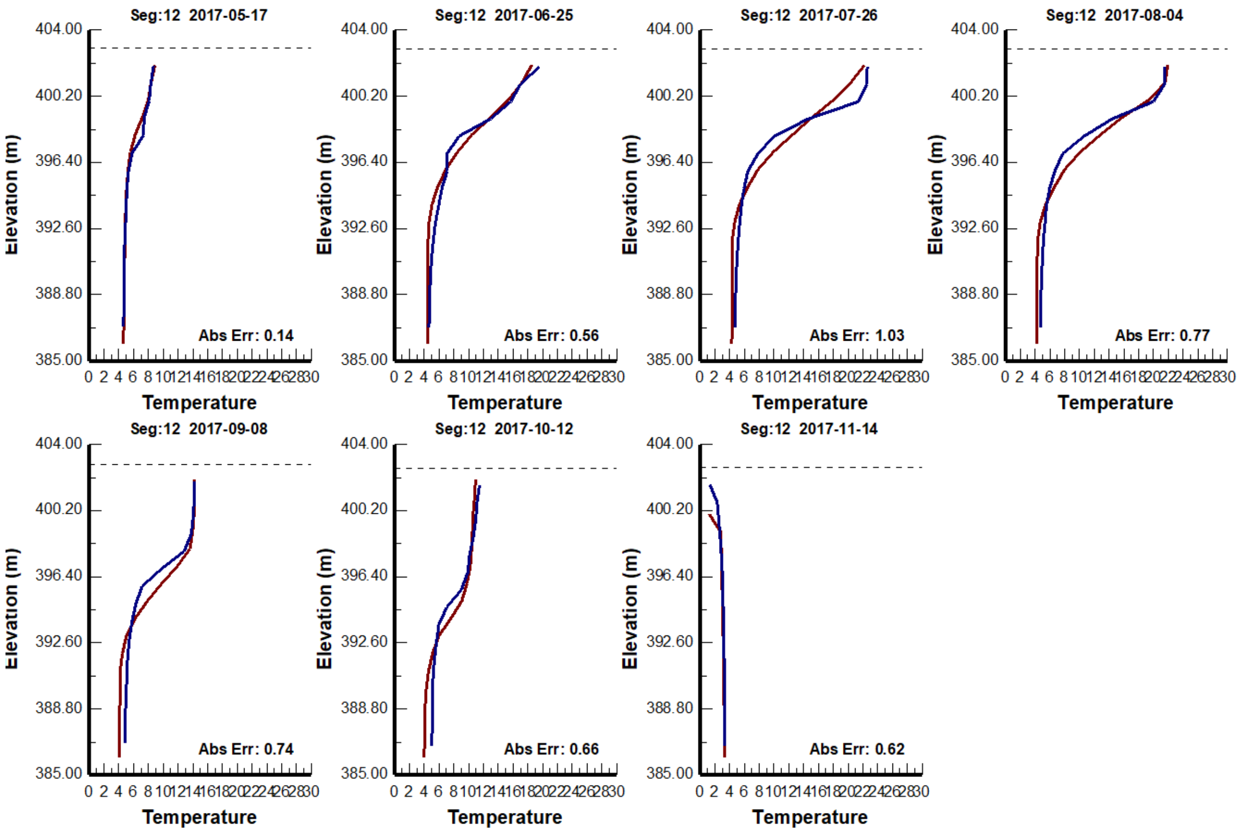

Figure 5.6.3. Temperature profiles for Cleaver Lake after final calibration adjustments with water quality calculations enabled. Field measurements shown in blue, model outputs shown in red. Total AME = 0.647°C.

TDS values within Cleaver Lake were observed to be lower than 100 mg/L in all measured samples. Calibration results returned a total AME of 8.818 mg/L for TDS (figure 5.6.4) which was deemed to be adequate given both the resolution of field measured TDS values and overall low concentrations of TDS.

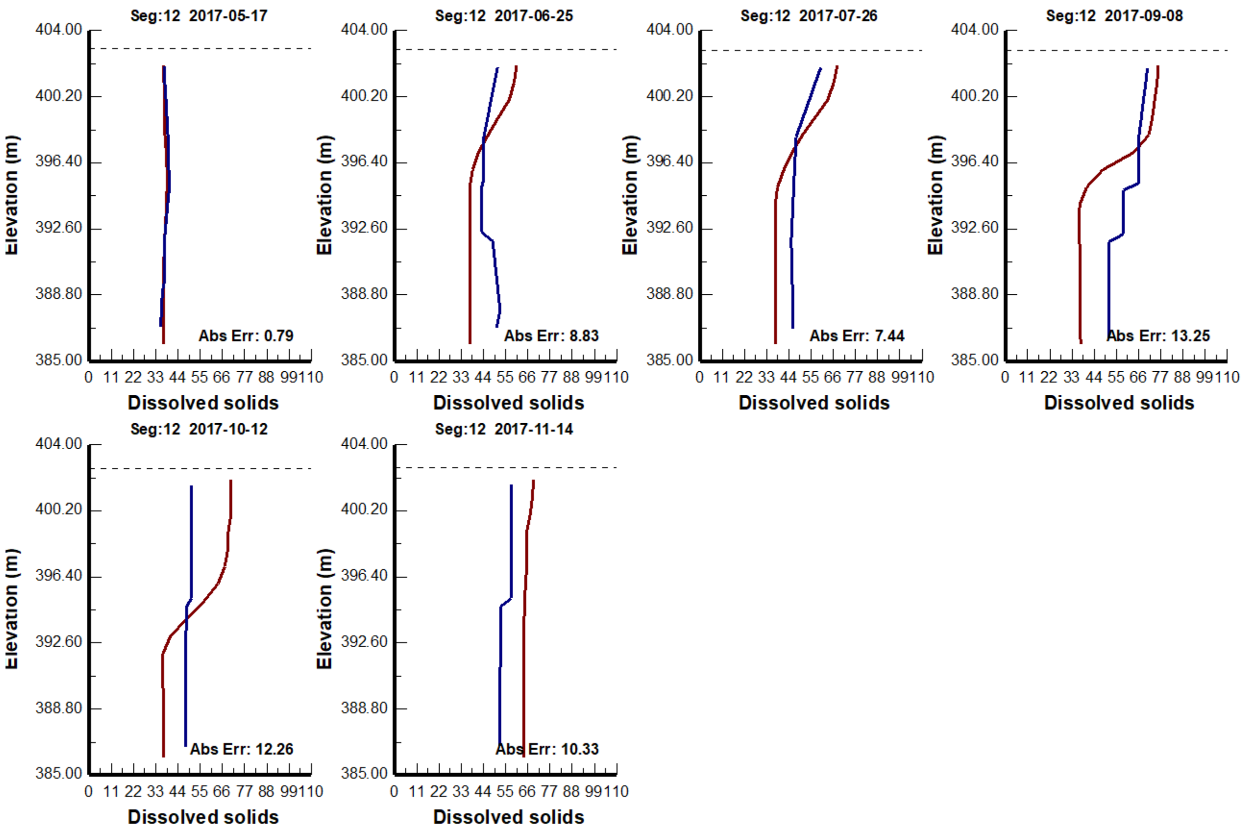

Figure 5.6.4. TDS calibration profiles for Cleaver Lake following temperature calibration and activation of water quality calculations. Total AME = 8.818 mg/L TDS.

Algae/O_2

Following calibration of temperature and TDS, dissolved oxygen and SOD were added to the model for use in determining available fish habitat. This run was expected to display oxygen depletion near the sediment layers in the model due to SOD calculations. Similarly, a lack of algal respiration was expected to result in higher than observed oxygen concentrations near the surface of the water body as oxygen loadings were being calculated from inflows and diffusion from the air at the water surface.

Initial calibration runs of dissolved oxygen yielded a high total AME of 3.572 mg/L, with all data points exceeding AME of 1 mg/L (figure 5.6.5). This indicated improvements to oxygen calculations were required.

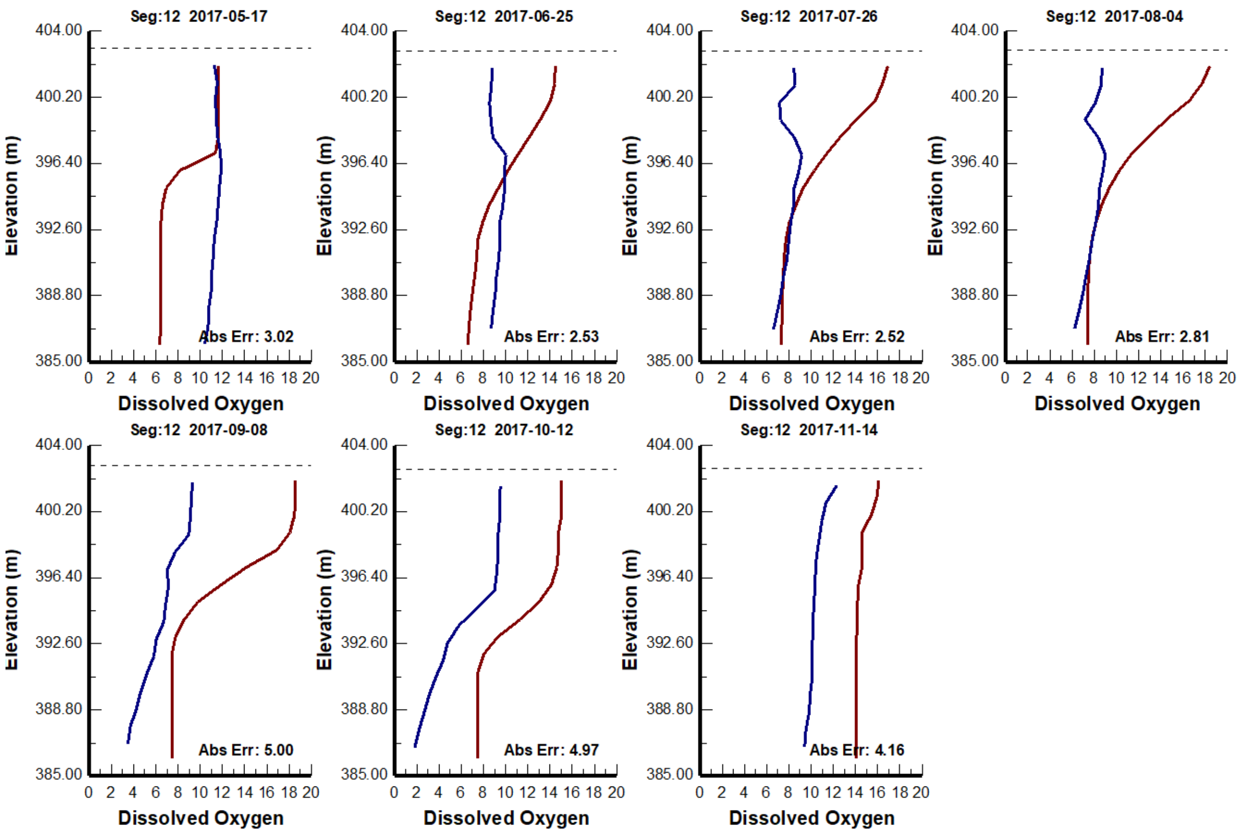

Figure 5.6.5. Dissolved oxygen calibration profiles with O_2 calculations, SOD enabled. Field measurements in blue, model output in red. Total AME = 3.572 mg/L DO.

If extensive algal community information is unavailable as it was in the case of the Cleaver Lake study, a general community assemblage can be represented using the default parameters within the CE-QUAL-W2 model. Following introduction of SOD and O_2 calculations to the model, a representative algal species was added to the model to increase performance, utilizing the CE-QUAL-W2 user manual recommended characteristics (Cole & Wells, 2017). This improved the total AME for dissolved oxygen to a value of 0.570 mg/L, with all individual AME values < 1 mg/L (figure 5.6.6).

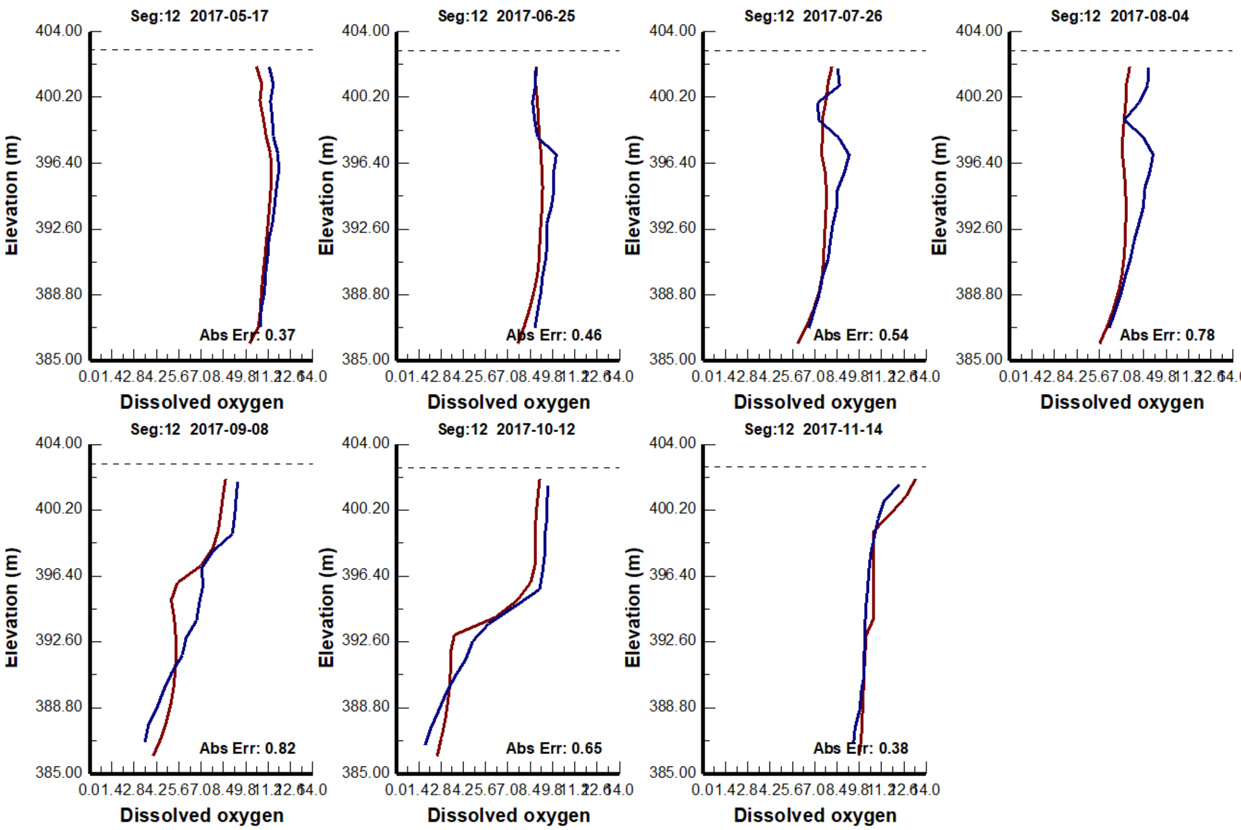

Figure 5.6.6. Dissolved oxygen calibration profiles for Cleaver Lake following addition of representative algal species. Field measurements in blue, model output in red. Total AME = 0.570 mg/L DO.

Brook Trout Habitat

Predicted survivable conditions reached a minimum of 69.97% on July 31 (Julian date 212) amidst several days of high recorded air temperatures (figure 5.6.7), while optimal conditions reached a minimum volume of 0% on August 8 (Julian date 220) and remained at or near 0% for 17 days until August 25 (Julian date 237), as seen in the following graph (figure 5.6.7).

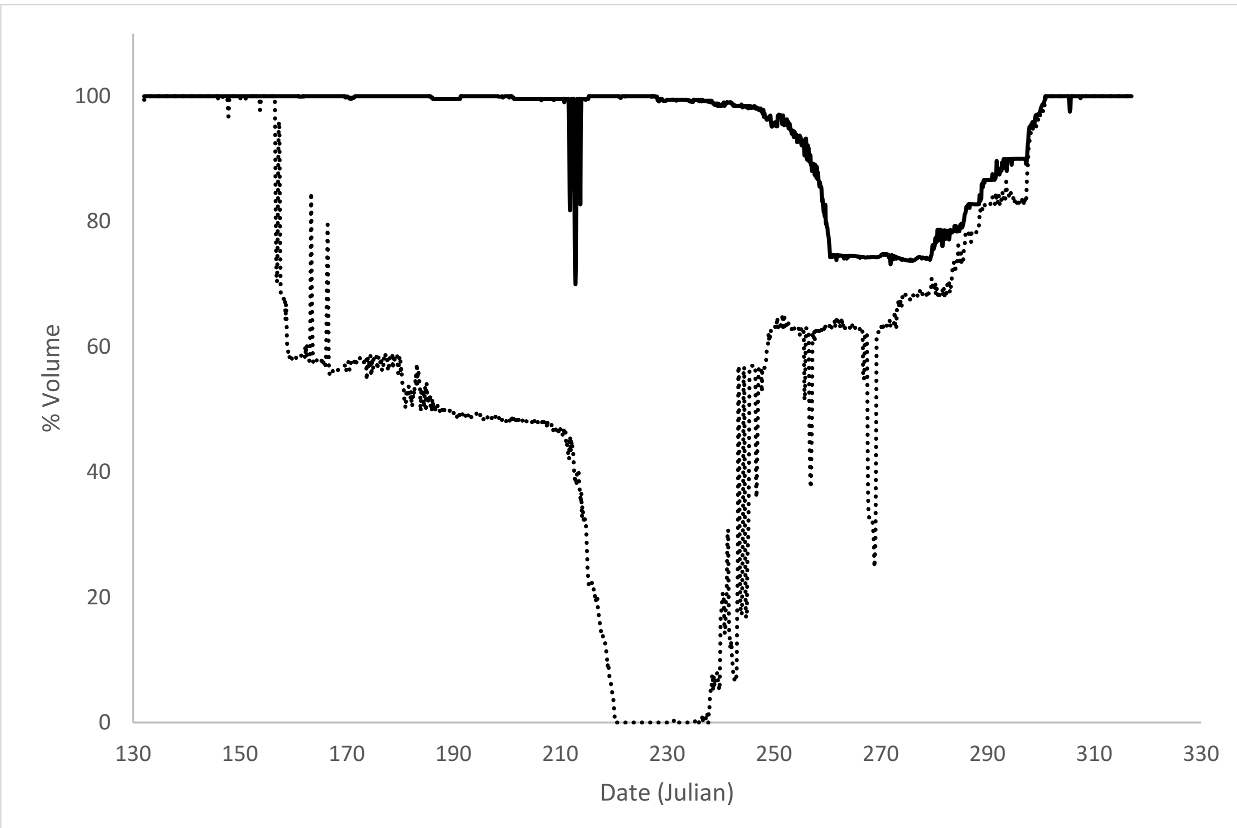

Figure 5.6.7. Graph depicting survivable and optimal habitat for Brook Trout as a percentage of total volume for Cleaver Lake during the modelled time period (May 12 to November 13, 2017). Survivable habitat volume (temperature <24°C, DO >5 mg/L) as solid line, optimal habitat volume (temperature <15.6°C, DO >7 mg/L) as dotted line.

To aid in visualization, the recorded air temperatures were plotted with the date/time of observation in the following figure (figure 5.6.8). The highest air temperature recorded by the on-site weather station was 30.4°C on Julian day 211 (July 30). The lowest recorded temperature of -22.3°C occurred just before midnight of Julian day 313 (November 10).

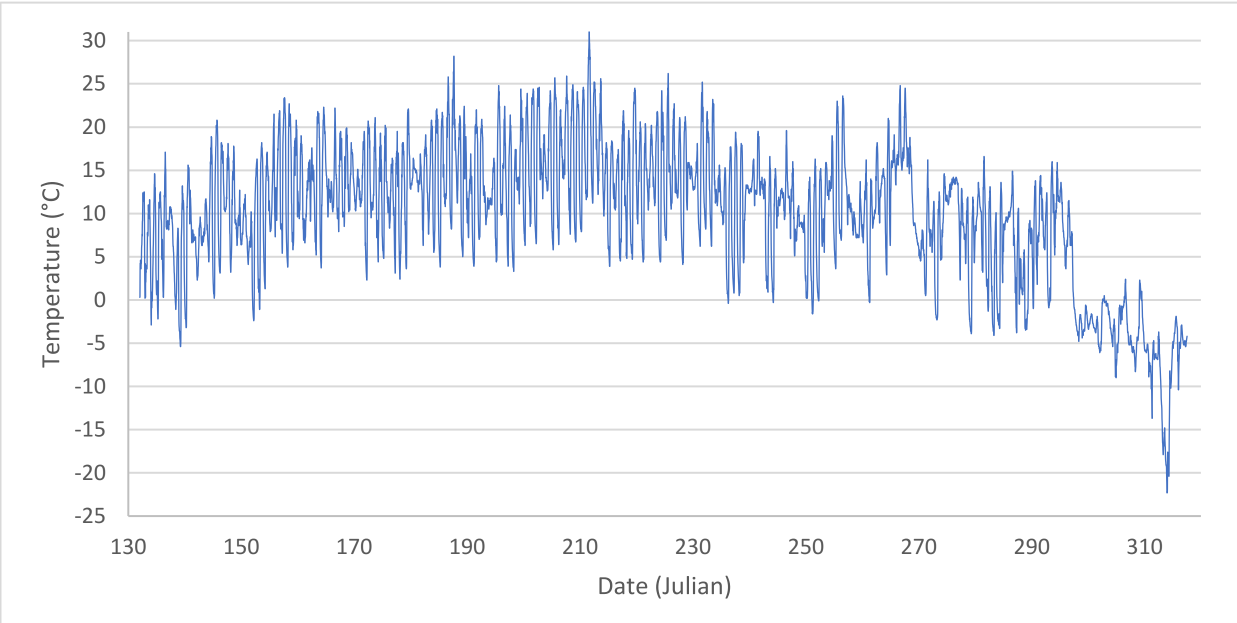

Figure 5.6.8. Recorded air temperatures at Cleaver Lake during the modelled period of May 12 to November 13, 2017.

The following screenshot of the CE-QUAL-W2 animation (figure 5.6.9) was obtained for Julian date 212 to display the modelled conditions of dissolved oxygen and temperature during the predicted period of minimum Brook Trout survivability described in figure 5.6.7. The thermocline of Cleaver Lake (around 8 m depth) was established at this point in the model, with reduction in dissolved oxygen in the shallow end of the lake apparent.

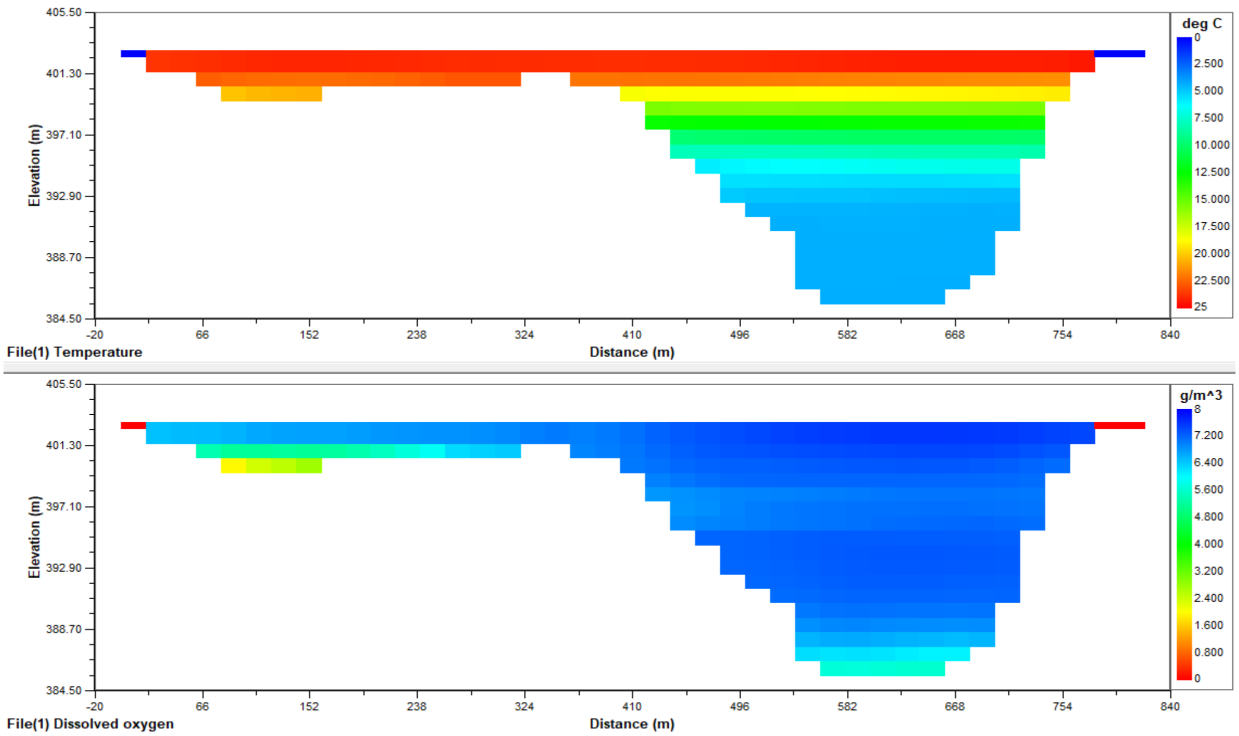

Figure 5.6.9. Screenshot of CE-QUAL-W2 animation for water temperature (top) and dissolved oxygen (bottom) obtained for Julian date 212.9 (July 31).

Supporting calibration data from iButton temperature loggers were included in the following figure and were used to ensure accuracy of the model when predicting the fall isothermal event and depth of the thermocline (figure 5.6.10).

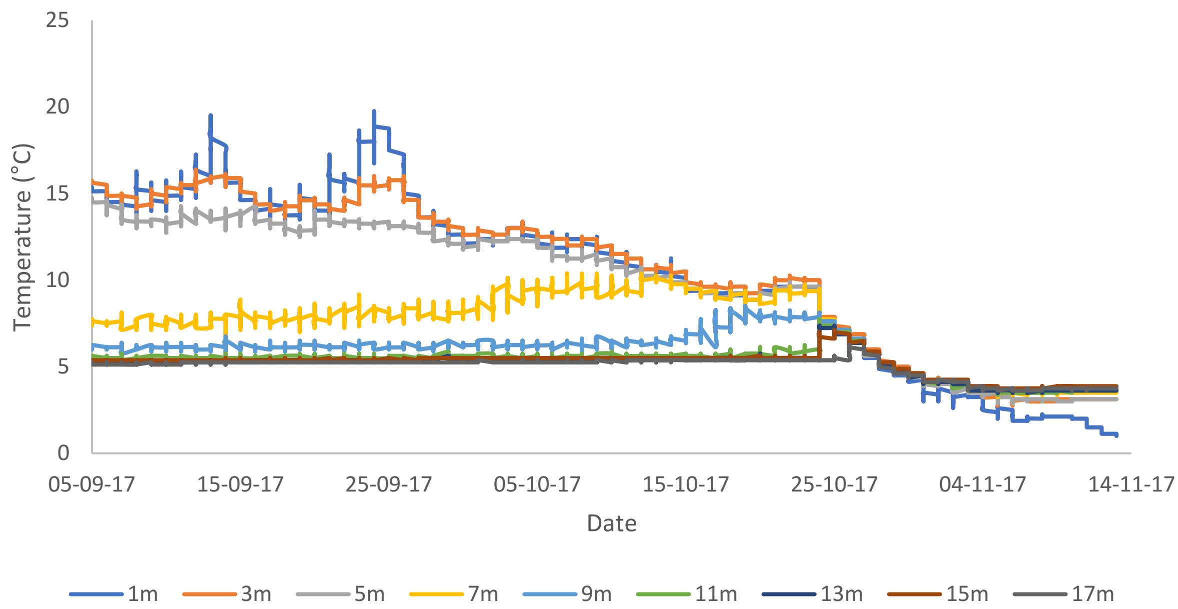

Figure 5.6.10. Water temperature recordings from iButton sensors for every 2m interval for Cleaver Lake.

The following image (figure 5.6.11) was obtained as a contour plot of the CE-QUAL-W2 Cleaver Lake model during establishment of isothermal conditions in the profundal zone as predicted by the model on October 27. This event preceded model predicted turnover.

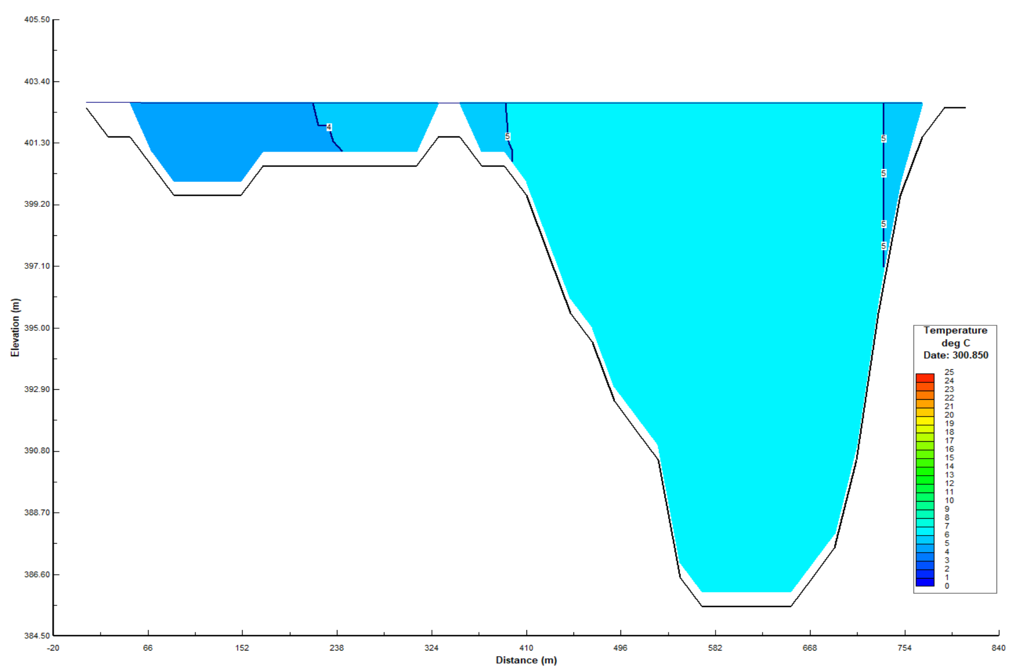

Figure 5.6.11. Contour plot of water temperatures in °C from CE-QUAL-W2 on Julian date 300.85 (October 27).

5.7 Theoretical Simulations

Operational Scenario

The first experimental scenario tested was the operational scenario. Modification of water quality characteristics of the water being received at Cleaver Lake resulted in increased temperatures in the deep profundal zone of the lake, indicated in part by the increased AME values during temperature calibration, which can be visualized in the following figure (figure 5.7.1).

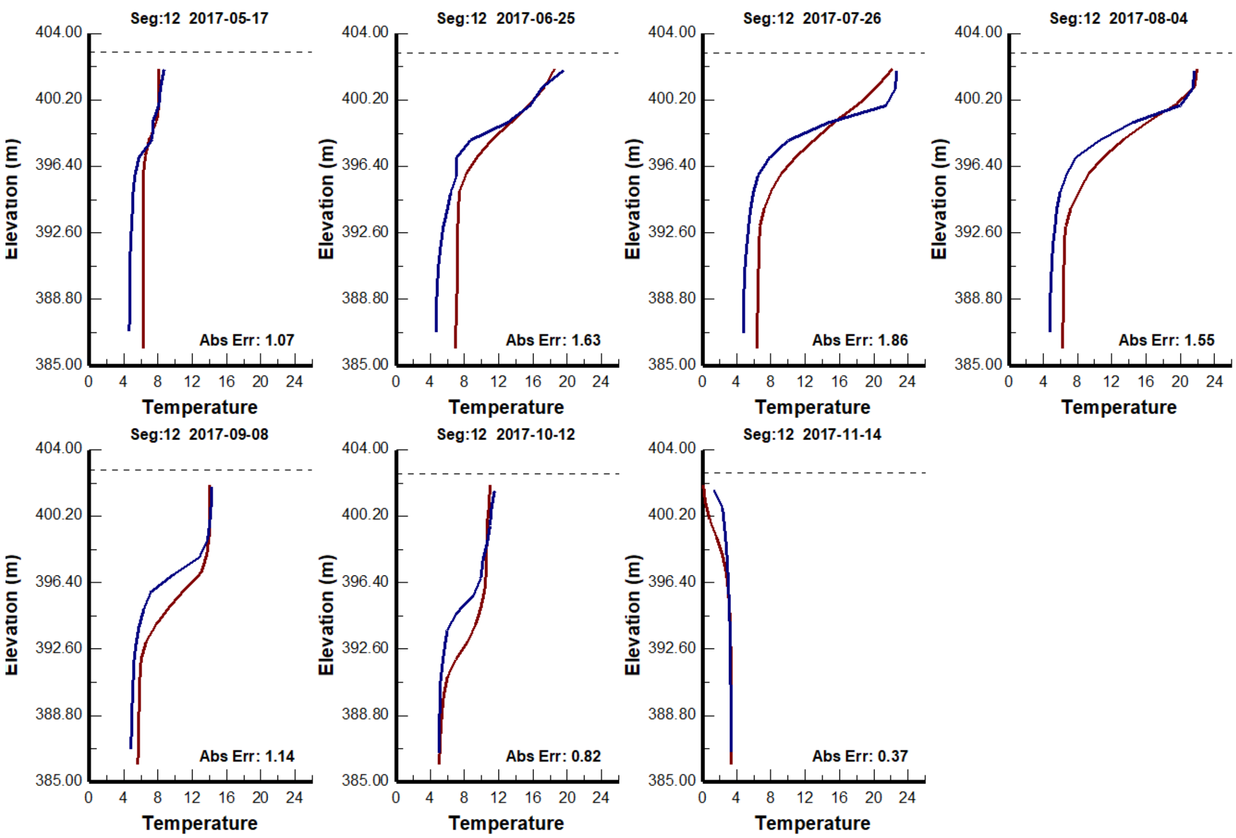

Figure 5.7.1. Temperature calibration profiles for Cleaver Lake in the operational experimental scenario using modified inflow water quality characteristics. Modelled output in red, field observed data in blue.

TDS calibration profiles displayed a significant increase in TDS loadings retained within the waters of Cleaver Lake in the first year following a theoretical return of mining operations upstream. The increases can be visualized in the following figure (figure 5.7.2).

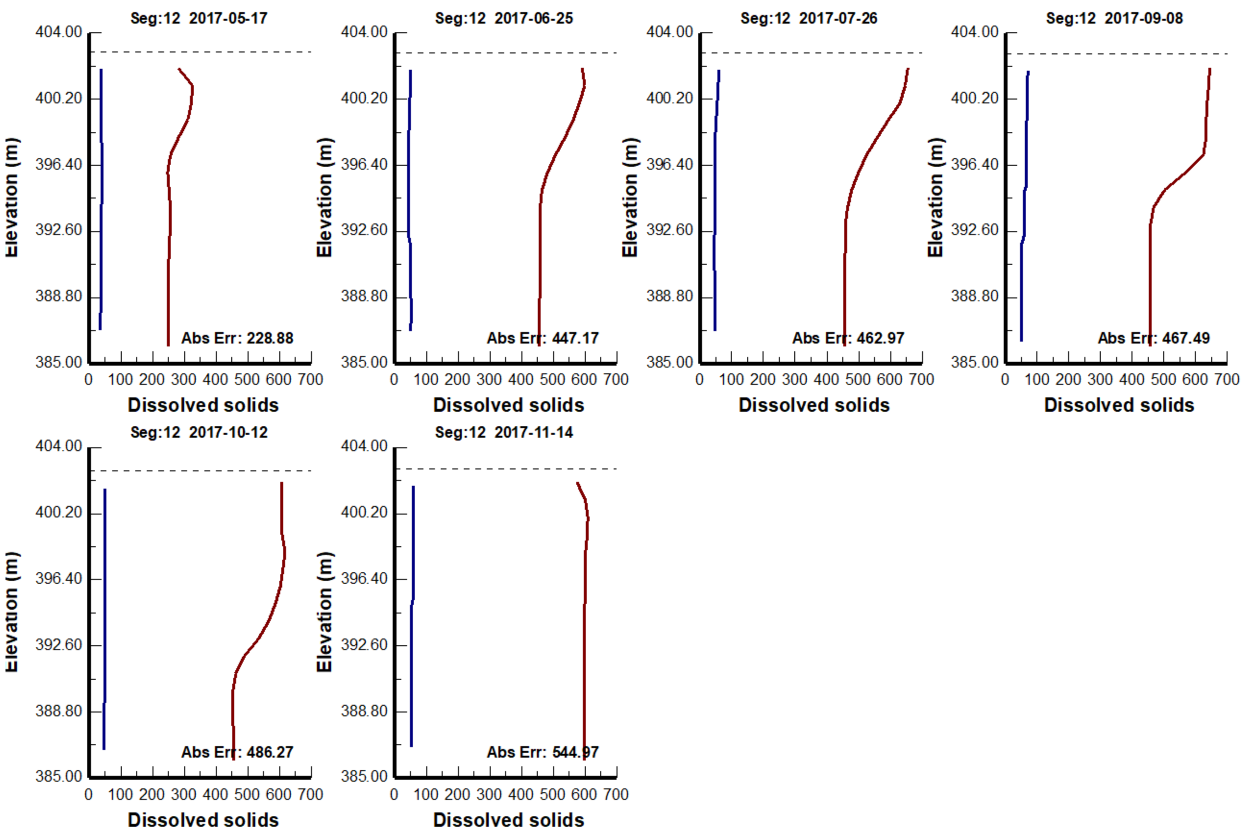

Figure 5.7.2. TDS calibration profiles for Cleaver Lake obtained during the operational experimental scenario utilizing modified inflow water quality characteristics. Modelled output in red, original field data in blue.

Dissolved oxygen profiles were shown to shift in a direction antithetical to suitable Brook Trout habitat in the results of the operational scenario. This can be visualized in the following calibration profiles (figure 5.7.3).

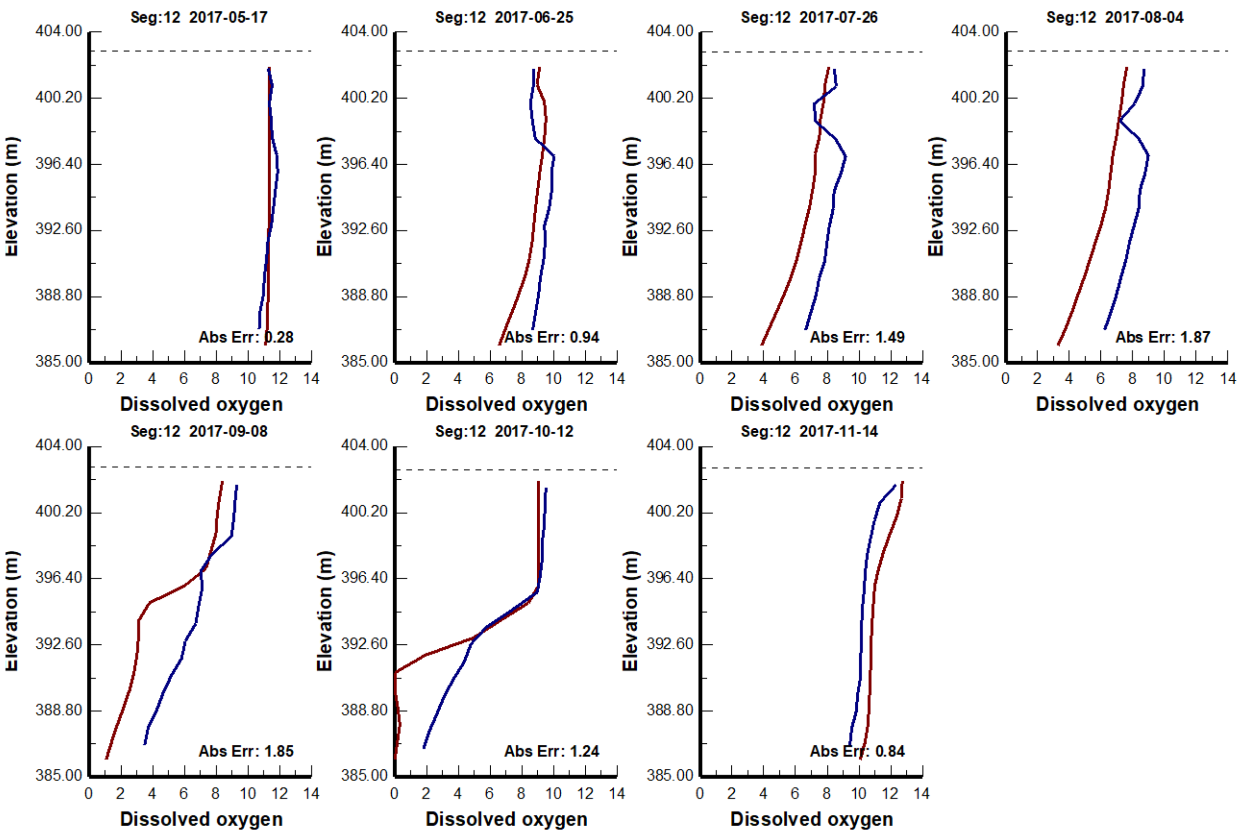

Figure 5.7.3. Dissolved Oxygen calibration profiles for Cleaver Lake in the operational experimental scenario with modified inflow water quality characteristics. Modelled output in red, field observed data in blue.

Total survivable and optimal habitat for Brook Trout were both reduced when compared with the original unmodified model run (figure 5.6.7). Results of the operational scenario habitat availability (figure 5.7.4) are displayed in a graph that follows. The model results reached a minimum of 64.47% for survivable habitat on Julian date 212 (July 31), and displayed an extended period of habitat reduction following. Optimal habitat was similarly impacted, where the 0% volume trend was exhibited for 27 days, from Julian date 213 (August 1) to 240 (August 28), compared with a 17-day trend in the unmodified run.

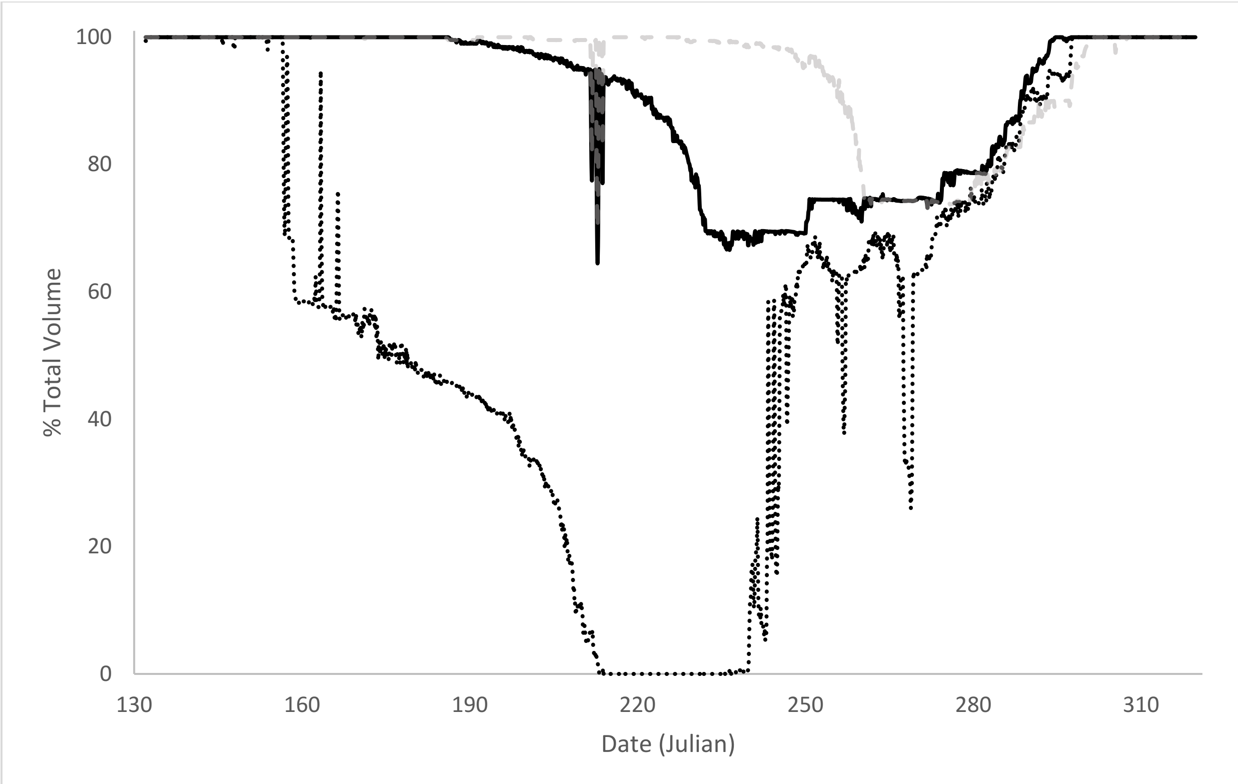

Figure 5.7.4. Graph depicting survivable and optimal habitat for Brook Trout as a percentage of total volume for Cleaver Lake during the modelled time period (May 12 to November 13, 2017) using modified inflow TDS concentration in an operational mining experimental scenario. Survivable habitat volume (temperature <24°C, DO >5 mg/L) as solid line (original model output as grey dashed line), optimal habitat volume (temperature <15.6°C, DO >7 mg/L) as dotted line.

Climate Change Scenario

The climate change experimental scenario was first simplified to include only temperature calculations. Shifts toward higher temperatures compared with field gathered data were observed throughout the water column over the course of the experimental model run and can be visualized in the following graphs (figure 5.7.5).

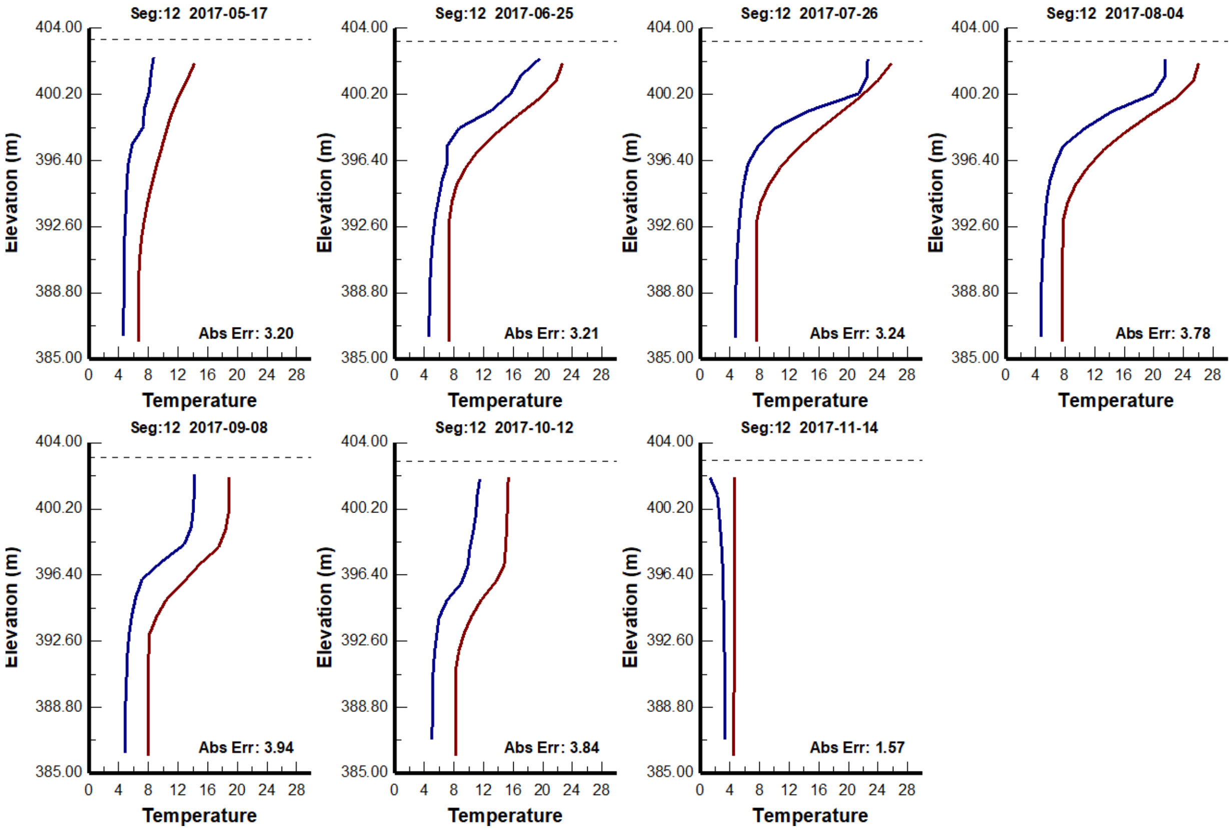

Figure 5.7.5. Temperature calibration profiles for Cleaver Lake in an experimental climate change scenario of +6.3°C annual average air temperature. Modelled output in red, field observed data in blue.

The following contour plot depicts the isothermal event predicted by the CE-QUAL-W2 model in the climate change scenario (figure 5.7.6). The event occurred on Julian date 304 (October 31), with profundal waters becoming isothermal at approximately 8.9°C.

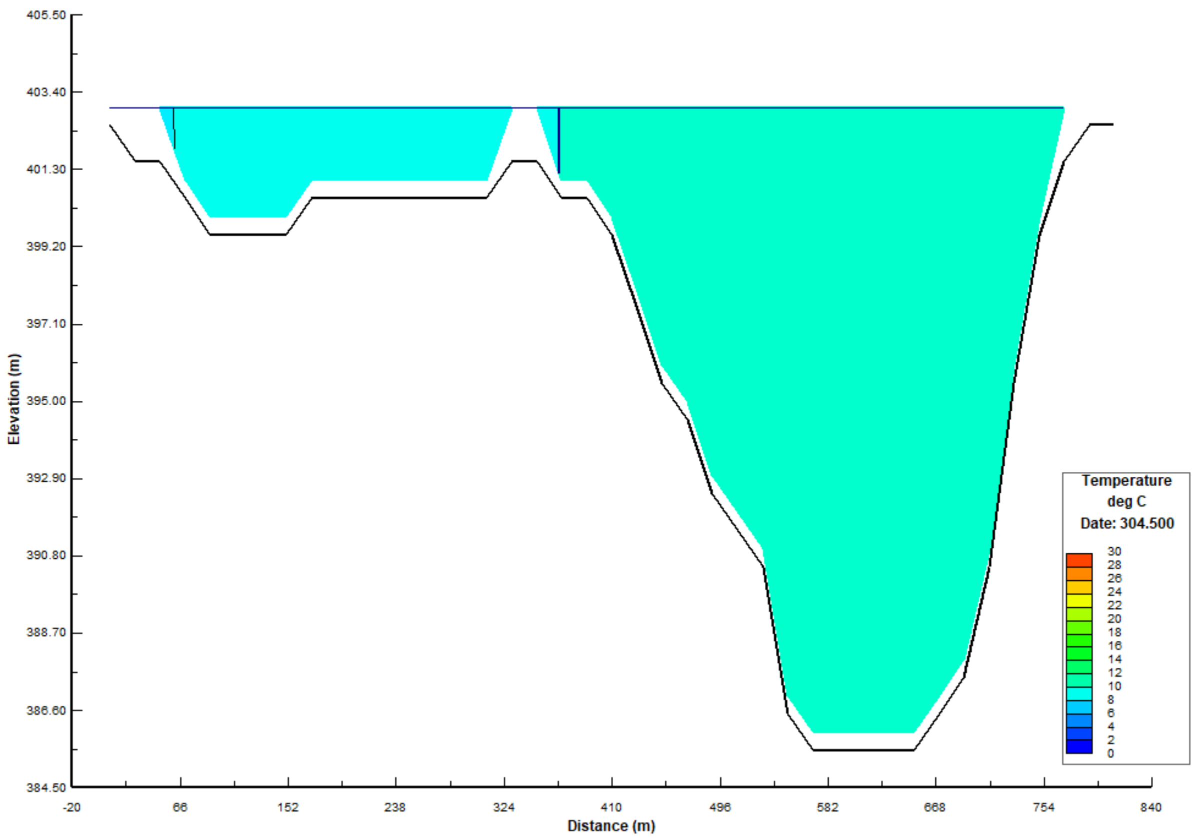

Figure 5.7.6. Contour plot of water temperatures in °C from CE-QUAL-W2 climate change scenario on Julian date 304.5 (October 31).

Habitat availability calculated by the model was based solely on water temperatures for the initial climate change scenario and was graphed in the following figure (figure 5.7.7). Thresholds of 24°C and 15°C were again used as limits for survivable and optimal habitat respectively. Minimum volumes predicted for survivable habitat were approximately 54% from July 26 to August 10 (Julian dates 207 – 222), and approximately 34% optimal habitat availability from July 31 to October 10 (Julian dates 212 – 283).

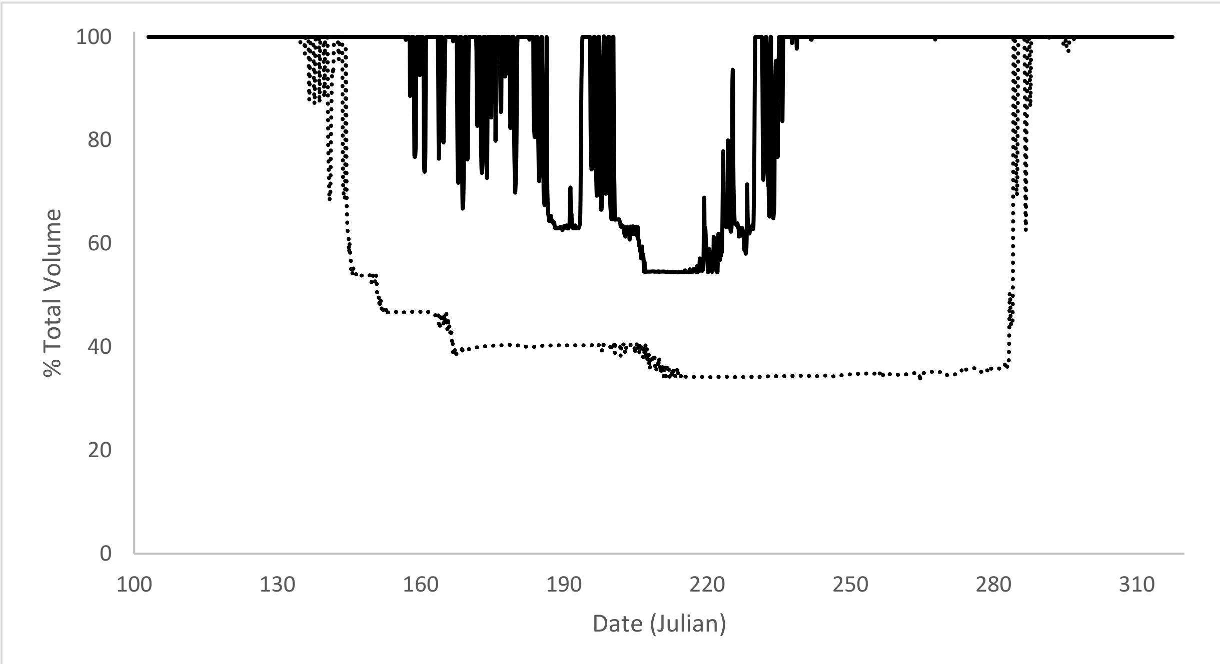

Figure 5.7.7. Graph depicting survivable and optimal habitat based on temperature for Brook Trout as a percentage of total volume for Cleaver Lake using modified meteorological data, inflow temperatures and sediment temperature to represent a theoretical climate change scenario of +6.3°C annual air temperature. Survivable habitat volume (temperature <24°C) as solid line, optimal habitat volume (temperature <15.6°C) as dotted line.

Following the simplified temperature model described, dissolved oxygen calculations were reintroduced into the climate change scenario. The following graphs (figure 5.7.8) depict the dissolved oxygen profiles that were output by the model, compared with the original 2017 field data. Oxygen depletion was more severe when compared with the unmodified results (figure 5.6.6), reaching 0 mg/L below 7 m depth from August through October before fall turnover at the beginning of November when values increased to approx. 10 mg/L throughout the water column (figure 5.7.8).

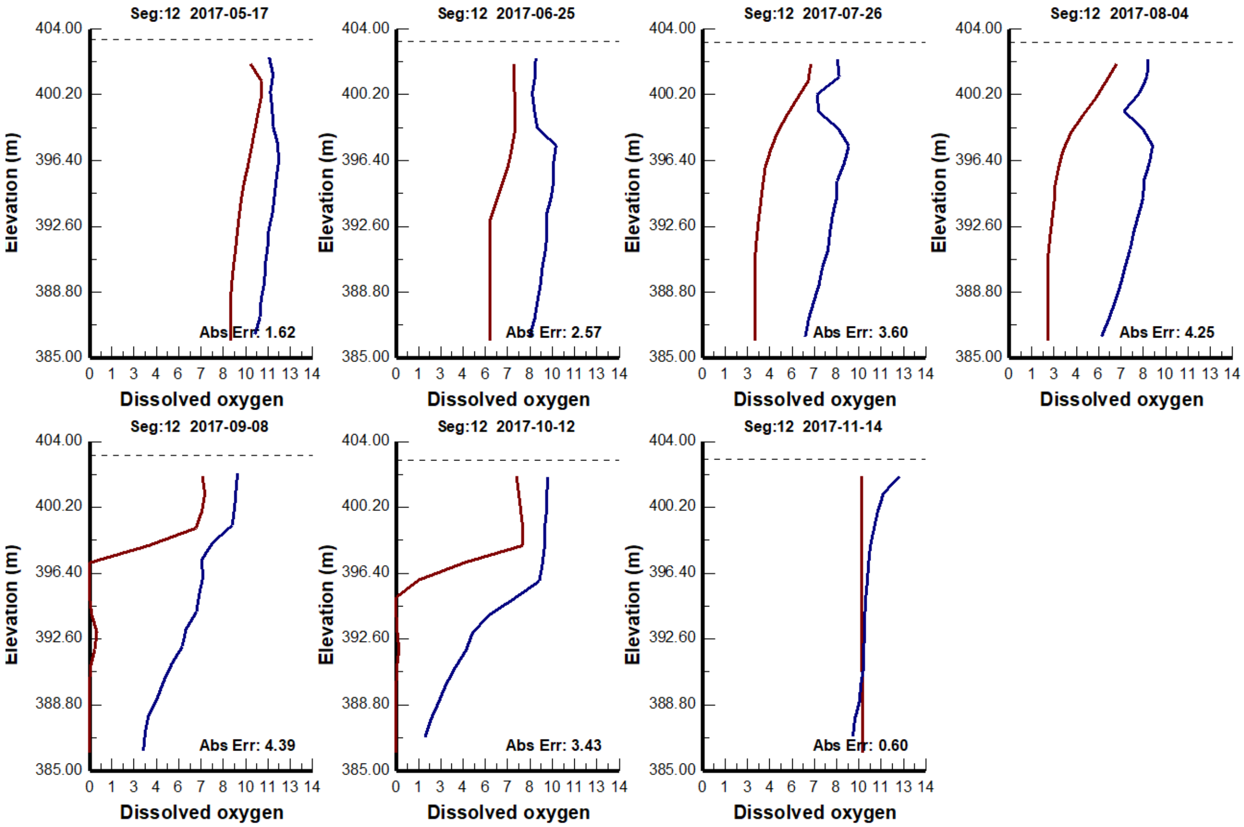

Figure 5.7.8. Dissolved oxygen profiles for Cleaver Lake using modified meteorological data, inflow temperatures and sediment temperature to represent a theoretical climate change scenario of +6.3°C annual air temperature. 2017 field observed values in blue, model outputs in red.

Addition of oxygen calculations altered survivable and optimal habitat conditions for Brook Trout. In contrast to the original model outputs, quantity of optimal habitat was at or near 0% availability for approximately 105 days (Julian date 178 – 283) (figure 5.7.9). Survivable habitat volume also displayed a decrease to a minimum of approximately 7.3% on Julian date 208, remaining near that value for approximately 11 days (figure 5.7.9).

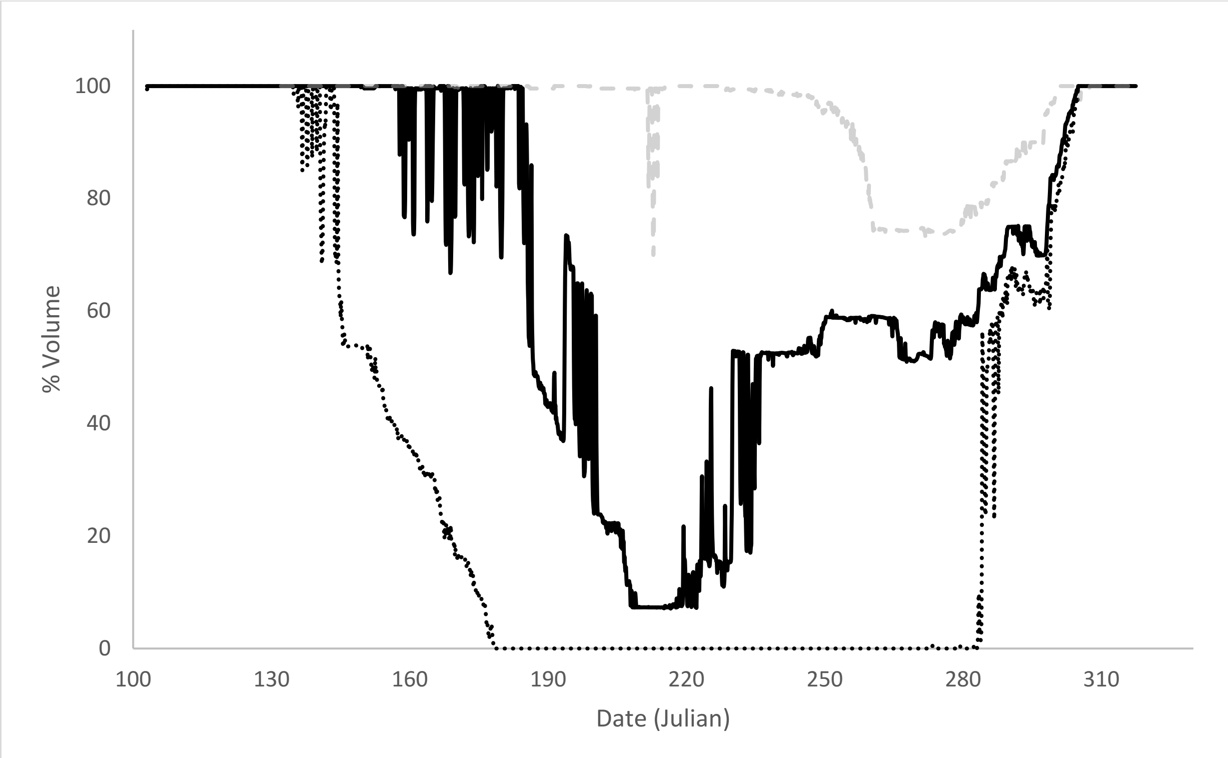

Figure 5.7.9. Graph depicting survivable and optimal habitat based on temperature and dissolved oxygen for Brook Trout as a percentage of total volume for Cleaver Lake using modified meteorological data, inflow temperatures and sediment temperature to represent a theoretical climate change scenario of +6.3˚C annual air temperature. Survivable habitat volume (temperature <24°C, DO >5 mg/L) as solid line (original model output as grey dashed line), optimal habitat volume (temperature <15.6°C, DO >7 mg/L) as dotted line.

6.0 Discussion

6.1 Historical and Present Water Quality

Figure 5.1.3 shows that the mine operated by INMET had a positive influence on reducing the concentrations of copper entering Cleaver Lake as early as 1991, which had been elevated via legacy impacts from the older abandoned mine sites upstream. This reduction has been attributed to development of a freshwater reservoir established farther upstream on the Whitesand River system in the 1990's to collect contaminated runoff from the abandoned Zenmac mine site, in addition to the removal of waste rock and sealing of mine shaft openings (SENES, 2000).

Though cleanup efforts by industry operators were successful in reducing copper loadings into the system at Cleaver Lake, they were not evidently successful in reducing zinc loadings to the same degree which can be seen in figure 5.1.4. This was despite compliance with MOE established discharge limits set out for the mine, suggesting that other unobserved contaminant sources such as runoff from surrounding rock piles may have been responsible for the zinc loadings into Cleaver (SENES, 2000). Since closure of the INMET mine in 1998, levels of zinc loadings have gradually reduced, though remain elevated above PWQO guidelines. However, present concentrations do not likely pose a threat to Brook Trout specifically as the species has a relatively high tolerance to zinc (Nehring & Goettl, 1974).

Treatment of effluent to reduce metal loadings into Cleaver Lake had the effect of increased loadings of density altering dissolved solids. It was the addition of this high-density TDS loaded water entering Cleaver Lake and settling to the bottom (figure 5.1.2) that had caused the meromictic conditions first observed in 1991 (B.A.R. Environmental, 1992) that persisted into the 2010’s as shown in figure 5.1.1.

Gradual reduction in the stability of the chemocline as depicted in figure 5.1.1 has resulted in return to a dimictic state for Cleaver Lake. As of 2012, only slight chemical stratification was still present in the deepest portion of the lake (figure 5.1.2), though stratification was not anticipated to have been strong enough to prohibit fall turnover following the study carried out in October of that year (Ecometrix, 2012), and has not posed an issue in the lake since that time.

6.2 Modelling Current Conditions

The major objectives of this study were to construct and calibrate a CE-QUAL-W2 model of Cleaver Lake, Ontario for 2017 before building modified input files to test hypothetical scenarios experimentally. The bathymetry and orientation of the site made it an ideal candidate for modelling within the two-dimensional CE-QUAL-W2 model.

As mentioned in the methods (section 4.0), utilization of the included water balance utility was required to maintain a stable water surface in the CE-QUAL-W2 model, indicating unobserved ephemeral streams and infiltration of water from the surrounding drainage basin during precipitation events and spring melt may play an important role in moderating the water table height of Cleaver Lake. This is not uncommon when constructing CE-QUAL-W2 models as streamflow gaging is often incomplete and quantifying spring snow melt/runoff from precipitation for the area may prove useful in further studies (Cole & Wells, 2017).

Hydrodynamic properties of the lake were well represented within the model, indicated in part by the fall isothermal event and turnover that followed being accurately represented by the model. Temperature sensors deployed in the deep region of Cleaver Lake observed the isothermal event occurring on October 27, 2017 (figure 5.6.10), which aligns with the model predictions (figure 5.6.11). Temperature calibration results with an AME of 0.647°C (figure 5.6.3) also support the integrity of the model.

The addition of water quality calculations in the model did not significantly affect temperature calibration (figure 5.6.3) and showed that the quantity of TDS and other modelled constituents at the time of sampling were not enough to impact the thermodynamic/hydrodynamic properties of Cleaver Lake.

Dissolved oxygen calibration of the CE-QUAL-W2 model displayed good results, with an AME of 0.570 mg/L (figure 5.6.6) after inclusion of algae and sediment oxygen demand, utilizing the default representative algal community values found in the user manual (Cole & Wells, 2017). Future studies at Cleaver Lake may wish to attempt to identify and characterize the site-specific algal community with greater detail in attempt to further improve results.

6.3 Habitat Availability

Brook Trout are known to seek out and actively defend cold water refugia during hot summer months when water temperatures approach their lethal limits for the species (Biro, 1998), moving to deeper colder water during the day and into the shallows to feed when daily water temperatures decrease (Mucha & Mackereth, 2008; Biro, 1998). Brook Trout also require high dissolved oxygen concentrations in order to survive, generally above 5 mg/L with optimal conditions of >7 mg/L (Raleigh, 1982). Due to the depth of Cleaver Lake, deep profundal waters remain within acceptable temperature limits for Brook Trout throughout the summer (figure

5.6.3), however, oxygen depletion also occurs in these waters around the same time period (figure 5.6.6).

Suitable Brook Trout habitat predictions of the model displayed reduction in % total volume during the summer months as was hypothesized, reaching a minimum value of 69.97% volume (figure 5.6.7). During the summer, habitat classified as survivable was reduced during the hottest days that were recorded (Julian dates 211-213), likely due to a combination of effects. A large portion of Cleaver Lake is less than 5 m deep, and modelled water temperatures near the surface increased beyond the tolerable limits during this time period (figure 3.21). Since sediment oxygen demand and algal growth/respiration are functions of temperature, increased oxygen consumption was also observed in the shallow regions of the lake during this time period when rates of SOD and respiration were highest (figure 3.21). The drop in daily air temperatures observed (figure 5.6.8) directly following the three-day period served to alleviate both the high surface temperatures and the increased rates of oxygen consumption, marking the return to nearly 100% survivable habitat as seen in figure 5.6.7 which was sustained until mid September. The gradual decrease in survivable habitat during September may be attributed to the fact that the thermocline had not yet dissipated at this time of the year, and gradual oxygen depletion had left the hypolimnetic water at less than 5 mg/L DO. Following dissipation of the thermocline during October preceding lake turnover, survivable habitat again increased to 100% as is seen in figure 5.6.7.

The stricter limitations set for optimal Brook Trout habitat (DO > 7 mg/L, temp. < 15.6°C; Raleigh, 1982) resulted in more exaggerated reductions in available lake volume as was anticipated and may be attributed to the same factors as those responsible for reductions in survivable habitat.

The brief increases in optimal habitat predicted by the model on Julian dates 163 and 166 (June 12 and 15) (figure 5.6.7) occurred briefly before sunrise during the part of the year when daily water surface temperatures were near 15°C. Both events were preceded by a 24-hr average temperature <15°C. The 24-hr average temperature preceding the peak on JDAY 163 was 12.1°C, and for JDAY 166 was 12.03°C. Conversely, the sharp declines in optimal habitat shown on JDAY 256 and 268 (September 13 and 25) (figure 5.6.7) followed days of elevated air temperatures, with 24-hr average air temperatures of 14.523°C and 16.208°C respectively.

Following dissipation of the thermocline and the October turnover event, both survivable and optimal Brook Trout habitat returned to 100% total volume when the water column was cold and reoxygenated (figures 5.6.3, 5.6.6 & 5.6.7).

6.4 Experimental Scenarios

Results of the operational scenario (increased TDS inflow concentrations) displayed several interesting phenomena. First the TDS loaded water entering the lake via the inflow appeared to readily sink to the deepest parts of the profundal zone, mixing with the comparatively cold water contained there and presenting elevated temperatures that persisted throughout much of the course of the model run. The temperatures returned to values near those seen in the original unmodified model run following lake turnover in October (figure 5.7.1). The warming of the deep profundal waters resulted in the second noticeable change from original model results, wherein the fall isothermal event that precedes lake turnover occurred several days earlier on October 25 becoming isothermal at a higher temperature of

~6°C. This result also produced turnover in the fall that was extended by several days due to the earlier occurrence of the isothermal event. Dissolved oxygen profiles also displayed a reduction in total DO, especially in the deep regions of Cleaver Lake throughout the year (figure 5.7.3). This may also be a function of the previously mentioned phenomena of the warmer TDS loaded water entering the lake readily sinking to depth at the beginning of the year, as the warmed deep waters observed in this scenario would lead to elevated rates of sediment oxygen demand which are a function of temperature. These events would likely only occur in the first year following introduction of upstream mining activity, as by the end of the model run the concentrations of TDS had formed an isocline at 600 mg/L of TDS (figure 5.7.2), thus increasing the density of the profundal waters and presenting a barrier to a similar trend occurring in following years. As mentioned above, use of the water balance utility was required for model stability, indicating significance of incoming water from the surrounding drainage basin for maintaining the water table of Cleaver Lake. Therefore, in years beyond the first, spring meltwater from the lake surface and surrounding drainage basin may play an important role in the development of a meromictic state for Cleaver Lake following reintroduction of mining activity. Such water would presumably contain much lower quantities of density increasing constituents such as dissolved solids and may serve to in effect cap the lake and encourage stability of a chemocline. Future studies at the site could benefit greatly from further observation of these inputs, as well as extension of the period modelled to include over-winter data and additional seasons to further examine this hypothesis. Survivable Brook Trout habitat availability reached a minimum of 64.47% compared with 69.97% in the original model run on July 31 (Julian date 212).

This study only examined the worst-case scenario (RCP 8.5) for climate change projected by the CCME (2019) annual report. Further research of Cleaver Lake utilizing the CE-QUAL-W2 model grid developed could benefit from inclusion of more moderate climate change scenarios. The initial climate change scenario utilized only temperature calculations within the model to ensure stability after modification of meteorological data inputs and initial conditions. The results showed an expected increase in temperature throughout the water column over the course of the model run (figure 5.7.5), along with a four-day delay of isothermal conditions when compared with the unmodified model run (figures 5.6.11 & 5.7.6). It should be noted that the results of the Brook Trout habitat availability calculations performed in this portion of the study only represent one part of the whole picture. For instance, survivable conditions for Brook Trout reached a minimum value of 54.4% lake volume, with only 34% of lake volume remaining within an optimal temperature range during summer and early fall (figure 5.7.7). During this period, the region of the lake considered survivable by the calculation of the model was the hypolimnetic region of the profundal zone, which was observed both by the original model outputs and field recorded data to have been the same region in time and space where oxygen depletion was approaching maximum effect preceding the fall lake turnover event. Given that knowledge and considering that spring ice melt and thus spring lake turnover and thermal stratification would be expected to occur earlier in the year in a warmer climate, oxygen depletion in the hypolimnetic waters of Cleaver Lake by late July would be expected to be more severe and onset earlier than in the original model. Thus, it could be inferred that the true value of survivable volume for Brook Trout in the lake during mid to late summer would be significantly lower than the predicted 54%.

To attempt to further illuminate the issues faced by Brook Trout at Cleaver Lake in a warmer planet, a secondary climate change scenario in which oxygen calculations were enabled was performed in attempt to further describe shifts in habitat availability. Due to many potential unknowns regarding shifts in algal population structure and dynamics, nutrient concentrations/loadings, altered meteorological phenomena and flow regimes that would be likely to occur by the year 2100, results of the secondary climate change scenario examined should be interpreted cautiously. This version of the model predicted on August 3 (Julian date 215) a minimum of 7.17% of the volume of Cleaver Lake would remain survivable to Brook Trout during the summer (compared with a minimum of 69.97% in the original model run), while optimal habitat was predicted to be entirely unavailable for 105 days, spanning from late June to early October (figure 5.7.9). The predictions of this model scenario (figure 5.7.9) represented a reduction of the minimum survivable habitat available for Brook Trout by 62.8% of the total volume of Cleaver Lake by the year 2100 when compared with the unmodified model run (figure 5.6.7) and extended the duration of unavailable optimal habitat by a factor of 6.15 (17 days in unmodified model vs. 105 days in climate change scenario). Oxygen depletion beyond the survivable limits of Brook Trout was apparent in the results as early as June throughout much of the water column in this scenario (figure 5.7.8).

This interpretation of the model results is in line with conclusions of other studies regarding Brook Trout and other cold-water fish species. Previous studies have predicted that climate change will force cold-water species such as Brook Trout into higher altitudes and latitudes as temperatures rise, while also expanding the range of cool/warm-water competitor species such as Rainbow Trout and Smallmouth Bass (Meisner, 1990; Comte et al., 2013).

Climate change also has the potential to significantly impact other complex biotic interactions in lake ecosystems by altering flow regimes, precipitation, watershed dynamics, increased UV-B radiation and earlier ice-off, which is likely to have profound consequences on many fish species and the other organisms they depend on (Schindler et al., 1996; Keller, 2007, Wegner et al., 2011, Comte et al., 2013).

In a warmer world, fish species in the boreal region would need to adapt to altered schedules of spawning, which are generally in sync with spring ice-melt, as well as changes to the food web since peak algal population dynamics would also likely shift in response to earlier ice-melt (Keller, 2007). Due to combinations of these factors, researchers have estimated the total available range of Brook Trout habitat in the USA may be reduced by as much as 77% by the end of the century (Wenger et al. 2011).

7.0 Conclusions

As was hypothesized, the CE-QUAL-W2 program was able to accurately depict lake conditions and turnover for Cleaver Lake as of 2017. The lake should be able to support a population of Brook Trout throughout the year with respect to temperature and dissolved oxygen requirements. Though optimal habitat was predicted to be extremely limited or unavailable altogether nearing the end of summer, survivable habitat during the same time period should be significant (nearly 70%).

Simulation of increased effluent received via re-introduction of mining activity did not interfere with lake turnover during the modelled period as was hypothesized but did have a slight impact on survivable and optimal habitat for Brook Trout. However, mining activity could be expected to last for a period much longer than the single year modelled. Given the history of the site as outlined in section 5.1 (figure 5.1.1), coupled with the fact that meromixis was not first observed until the third year of most recent mine operation, there is reason to expect that over time meromictic conditions could re-emerge as a result of water with elevated levels of dissolved solids entering Cleaver Lake, posing a potential barrier to longevity of fish populations present at that time.

The simplified temperature model used initially in the climate change scenario allows for some interesting conclusions. Lake turnover did not appear to be interrupted due to warmer air temperatures, but thermal stratification during the ice-free season was predicted by the model to be maintained for a longer period when compared with the unmodified model results as was hypothesized. Even without oxygen calculations and requirements considered, a reduction in survivable habitat in Cleaver Lake for Brook Trout was shown in the results, with the minimum volume of survivable habitat reduced to 54% from approximately 70% in the original model. Incorporation of oxygen calculations to the climate change model enhanced the severity of those predictions, shown by further reduction of the minimum survivable volume to 7%, even without the influence of shifts in other biotic and abiotic dynamics that researchers predict would occur in such a scenario.

Given the results of this experiment and other supporting studies (Meisner, 1990; Schindler et al., 1996; Keller, 2007, Wegner et al., 2011, Comte et al., 2013), it can be predicted that global climate change presents an even greater risk to the permanency of cold-water fish species such as Brook Trout in the Boreal Shield region than mining operations; especially granted that recovery time of the world's atmosphere and biosphere would be measured in centuries or millennia as opposed to decades for recovery from the impacts of mining activity.

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Appendix

Appendix A – Water Chemistry Data Tables

The following tables (A.1, A.2) were used in making figures 5.1.2, 5.1.3, and 5.1.4 using all available historical data compiled from consulting reports provided by FQML (B.A.R. Environmental, 1992, 1992; Beak International Inc., 1998, 1999, 2000, 2000; Ecometrix Inc., 2007, 2010, 2013, 2016; IEC Beak, 1984; SENES Consultants Ltd., 2000; Stantec Consulting Ltd., 2004).

Table A.1. Inflow chemistry data from consulting reports for TDS, copper, and zinc from 1983 to 2015.

Date	TDS (mg/L)	Cu (ug/L)	Zn (mg/L)
Oct-83	54	20.00	2.43
Oct-89			1.145
Oct-90			0.486
Oct-91			0.74
Oct-91		8	1.72
Oct-92			0.43
Oct-93			0.36
Oct-94			0.445
Oct-95			0.671
Oct-96			1.32
Oct-97	740	4.2	0.643
Oct-98			0.582
Oct-99			0.479
Oct-03	58	5.2	0.474
Oct-06	90	5	0.346
Oct-09	76	2.9	0.12
Sep-12	46	1.4	0.0685
Sep-15	70	3.57	0.137

Table A.2. Lake bottom chemistry data from consulting reports for TDS from 1997 to 2015.

Date	TDS (mg/L)
Oct-97	1460
Oct-00	1400
Oct-03	1288
Oct-06	1230
Oct-09	1100
Sep-12	104
Sep-15	72

The tables on the following pages (A.3 - A.10) were results received from LUEL testing conducted on 2017 water samples obtained from Cleaver Lake. Tables A.9 and A.10 contain stream samples only. As copper and zinc concentrations were of the greatest concern to the study, their concentrations have been highlighted for easier identification.

Table A.3. LUEL water chemistry results for May 11, 2017 samples.

LABID:				004	005	006	007	008	009	010	011	012	013	014	015
CUSTID:				CL IN ;	URFACE	4.5m ;	7.5m ;	10.5m ;	13.5m ;	17.5m ;	CL OUT	ULVERT	FB ;	TB ;	Cl In field ;
				05/11/17	05/11/17	05/11/17	05/11/17	05/11/17	05/11/17	05/11/17	05/11/17	05/11/17	05/11/17	05/11/17	dup
Par Code	**Description**	**MDL**	**UNITS**												
WALK	Total Alkalinity as CaCO3	1.0	mg/L	5.90	6.10	6.70	6.40	6.90	6.80	6.90	6.8	1.5	<DL	<DL	6.4
WCHLOA	Chlorophyll "a"	0.2	ug/L	3.3	3.2	3.0	2.9	N	2.8	2.9	2.9	N	N	2.0	1.5
WCOND	Conductivity	0.5	uS/cm	25.1	26.9	28.0	27.8	28.0	29.1	30.5	28.3	13.3	0.7	0.7	25.4
WDOC	Dissolved Organic Carbon	0.5	mg/L	8.0	8.8	8.5	8.8	8.9	9.2	8.9	8.8	11.1	0.9	<DL	8.2
WHARD	Hardness (by calculation)	1.0	mg/L	11.1	11.6	12.2	12.2	12.2	12.2	12.8	12.0	4.7	<DL	<DL	11.1
WICCL	Chloride (IC)	0.05	mg/L	0.18	0.47	0.21	0.33	0.27	0.22	0.44	0.23	0.13	0.07	0.09	0.22
WICNO2	Nitrite NO2-N (IC)	0.009	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICNO3	Nitrate NO3-N [IC]	0.009	mg/L	0.066	0.081	0.206	0.342	0.259	0.130	0.239	0.236	0.017	<DL	<DL	0.146
WICP1AL	Total Aluminum	0.005	mg/L	0.270	0.256	0.274	0.271	0.286	0.275	0.280	0.276	0.496	0.006	0.007	0.263
WICP1AS	Total Arsenic	0.005	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1BA	Total Barium	0.003	mg/L	0.005	0.005	0.005	0.005	0.006	0.006	0.005	0.005	0.005	<DL	<DL	0.005
WICP1BE	Total Beryllium	0.002	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1CA	Total Calcium	0.005	mg/L	3.790	3.774	3.972	3.952	4.094	4.092	4.172	3.988	1.342	<DL	<DL	3.644
WICP1CD	Total Cadmium	0.001	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1CO	Total Cobalt	0.005	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1CR	Total Cromium	0.002	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1CU	Total Copper	0.002	mg/L	0.004	0.004	0.004	0.004	0.01	0.004	0.004	0.005	0.002	<DL	0.004	0.004
WICP1FE	Total Iron	0.002	mg/L	0.407	0.340	0.383	0.380	0.406	0.390	0.476	0.375	0.270	0.007	0.007	0.438
WICP1K	Total Potassium	0.01	mg/L	0.22	0.23	0.25	0.25	0.25	0.26	0.26	0.250	0.080	<DL	<DL	0.210
WICP1MG	Total Magnesium	0.01	mg/L	0.63	0.63	0.69	0.69	0.71	0.71	0.72	0.70	0.43	0.01	0.01	0.61
WICP1MN	Total Manganese	0.0002	mg/L	0.0184	0.0182	0.0229	0.0235	0.0251	0.0252	0.0335	0.0224	0.0108	<DL	<DL	0.0191
WICP1MO	Total Molybdenum	0.010	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1NA	Total Sodium	0.01	mg/L	0.67	0.69	0.74	0.73	0.76	0.76	0.78	0.74	0.47	<DL	<DL	0.64
WICP1NI	Total Nickel	0.002	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1P	Total Phosphorus	0.010	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1PB	Total Lead	0.005	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1S	Total Sulfur	0.05	mg/L	1.44	1.48	1.54	1.52	1.57	1.56	1.58	1.53	0.69	<DL	<DL	1.38
WICP1SB	Total Antimony	0.010	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1SE	Total Selenium	0.010	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1SI	Total Silicon	0.03	mg/L	1.30	1.28	1.42	1.39	1.44	1.44	1.49	1.44	1.59	0.23	0.22	1.29
WICP1SR	Total Strontium	0.005	mg/L	0.008	0.008	0.009	0.009	0.009	0.009	0.009	0.009	<DL	<DL	<DL	0.008
WICP1TI	Total Titanium	0.010	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1TL	Total Thallium	0.010	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1V	Total Vanadium	0.006	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1ZN	Total Zinc	0.001	mg/L	0.057	0.066	0.079	0.153	0.084	0.082	0.084	0.083	0.009	0.002	0.002	0.054
WICP4AL	Dissolved Aluminum	0.030	mg/L	0.210	0.213	0.221	0.223	0.227	0.225	0.224	0.223	0.454	<DL	<DL	0.208
WICP4AS	Dissolved Arsenic	0.030	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4BA	Dissolved Barium	0.050	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4BE	Dissolved Beryllium	0.001	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4CA	Dissolved Calcium	0.01	mg/L	3.47	3.63	3.74	3.76	3.77	3.80	3.95	3.73	1.22	0.02	<DL	3.45
WICP4CD	Dissolved Cadmium	0.002	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4CO	Dissolved Cobalt	0.004	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4CR	Dissolved Chromium	0.002	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4CU	Dissolved Copper	0.004	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	0.007	<DL	<DL	<DL	<DL
WICP4FE	Dissolved Iron	0.025	mg/L	0.210	0.176	0.185	0.190	0.195	0.204	0.231	0.185	0.232	<DL	<DL	0.208
WICP4K	Dissolved Potassium	0.100	mg/L	0.160	0.182	0.184	0.178	0.211	0.207	0.214	0.206	<DL	<DL	<DL	0.176
WICP4MG	Dissolved Magnesium	0.010	mg/L	0.589	0.623	0.669	0.673	0.676	0.683	0.700	0.678	0.398	<DL	<DL	0.587
WICP4MN	Dissolved Manganese	0.005	mg/L	0.016	0.017	0.020	0.020	0.020	0.021	0.023	0.020	0.010	<DL	<DL	0.016
WICP4MO	Dissolved Molybdenum	0.050	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4NA	Dissolved Sodium	0.050	mg/L	0.649	0.706	0.742	0.738	0.740	0.745	0.778	0.749	0.456	<DL	<DL	0.650
WICP4NI	Dissolved Nickel	0.025	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4P	Dissolved Phosphorus	0.050	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4PB	Dissolved Lead	0.025	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4S	Dissolved Sulfur	0.050	mg/L	1.383	1.461	1.511	1.501	1.484	1.488	1.532	1.509	0.669	<DL	<DL	1.386
WICP4SB	Dissolved Antimony	0.0500	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4SE	Dissolved Selenium	0.050	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4SI	Dissolved Silicon	0.050	mg/L	1.785	1.853	2.005	2.026	2.046	2.055	2.083	2.012	2.158	<DL	<DL	1.779
WICP4SR	Dissolved Strontium	0.010	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4TI	Dissolved Titanium	0.010	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4TL	Dissolved Thallium	0.030	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4V	Dissolved Vanadium	0.005	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4ZN	Dissolved Zinc	0.005	mg/L	0.052	0.065	0.077	0.077	0.079	0.080	0.081	0.081	0.007	<DL	<DL	0.052
WICPO4	Phosphate (PO4-P) by IC	0.050	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICSO4	Sulphate (SO4) [IC]	0.03	mg/L	3.88	5.31	4.36	4.55	4.41	4.48	4.63	4.53	2.95	<DL	<DL	4.78
WNH3	Total Ammonia-N	0.100	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WPH	pH	0.000	n/a	6.22	6.21	6.20	6.19	6.21	6.19	6.18	6.24	4.79	4.71	4.73	6.26
WTDS	Total Dissoloved Solids	10.0	mg/L	34.2	37.0	39.0	39.6	37.2	36.2	34.6	35.2	31.4	<DL	<DL	26.4
WTKN	Total K Nitrogen	0.015	mg/L	0.264	0.227	0.122	<DL	0.091	0.227	0.176	0.104	0.238	<DL	<DL	0.219
WTOTN	Total Nitrogen	0.015	mg/L	0.330	0.307	0.327	0.343	0.350	0.356	0.415	0.340	0.255	<DL	<DL	0.365
WTOTP	Total Phosphorous	0.005	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WTSS	Total Suspended Solids	2.0	mg/L	N	<DL	<DL	<DL	<DL	2.0	2.6	<DL	<DL	<DL	<DL	<DL

Table A.4. LUEL water chemistry results for June 7, 2017 samples.

LABID:				004	005	006	007	008	009	010	011	012	013	014	015	016
CUSTID:				CI ;	CD-S ;	CD-10.5 ;	CO ;	CD-17.5 ;	CD-14.5 ;	CD-7.5 ;	CH-S ;	CH-2.5 ;	CD-4.5 ;	CD-S Ldup	LD BLNK	RVL BLNK
				06/07/17	06/07/17	06/07/17	06/07/17	06/07/17	06/07/17	06/07/17	06/07/17	06/07/17	06/07/17	06/07/17	06/07/17	06/07/17
Par Code	**Description**	**MDL**	**UNITS**													
WALK	Total Alkalinity as CaCO3	1.0	mg/L	14.3000	11.1000	7.0000	10.7000	7.7000	10.8000	5.9000	10.9000	10.8000	11.5000	11.2000	<DL	<DL
WBOD	Biochemical Oxygen Demand 5	1.0	mg/L	<DL	<DL	1.1000	1.1000	<DL	<DL	<DL	1.3000	1.0000	1.1000	N	<DL	<DL
WCHLOA	Chlorophyll "a"	0.2	ug/L	N	2.4000	N	N	N	N	N	2.4000	2.9000	N	N	N	1.2000
WCOND	Conductivity	0.5	uS/cm	61.6000	46.9000	29.7000	45.1000	32.5000	46.5000	28.9000	45.0000	45.1000	46.9000	46.7000	0.7000	0.7000
WDOC	Dissolved Organic Carbon	0.5	mg/L	9.0000	9.2000	10.2000	9.0000	10.3000	9.0000	9.9000	9.6000	9.6000	9.1000	8.8000	<DL	<DL
WHARD	Hardness (by calculation)	1.0	mg/L	25.5000	19.9000	12.7000	19.3000	13.8000	19.8000	12.3000	19.5000	19.2000	20.0000	20.0000	<DL	<DL
WICCL	Chloride (IC)	0.05	mg/L	1.0800	0.3300	0.2800	0.6700	0.2700	0.5000	0.5800	0.3200	0.3200	0.3300	0.3400	<DL	<DL
WICNO2	Nitrite NO2-N (IC)	0.009	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICNO3	Nitrate NO3-N [IC]	0.009	mg/L	0.0580	0.0800	0.0750	0.0660	0.0920	0.0540	0.0660	0.0550	0.0490	0.0510	0.0540	<DL	<DL
WICP1AL	Total Aluminum	0.005	mg/L	0.1930	0.1810	0.2650	0.1950	<DL	<DL	0.2570	0.2090	0.1860	0.2070	0.2090	0.0060	0.0060
WICP1AS	Total Arsenic	0.005	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1BA	Total Barium	0.003	mg/L	0.0060	0.0050	0.0060	0.0050	<DL	<DL	0.0050	0.0060	0.0050	0.0060	0.0060	<DL	<DL
WICP1BE	Total Beryllium	0.002	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1CA	Total Calcium	0.005	mg/L	7.2160	6.0820	4.4000	4.2860	<DL	<DL	4.1920	4.5200	4.4080	4.6940	4.6880	0.0090	0.0080
WICP1CD	Total Cadmium	0.001	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1CO	Total Cobalt	0.005	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1CR	Total Cromium	0.002	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1CU	Total Copper	0.002	mg/L	0.0040	0.0030	0.0050	0.0040	<DL	<DL	0.0030	0.0040	0.0030	0.0040	0.0040	<DL	<DL
WICP1FE	Total Iron	0.002	mg/L	0.2810	0.1980	0.3150	0.1910	<DL	<DL	0.2930	0.2150	0.1670	0.2260	0.2280	<DL	0.0040
WICP1K	Total Potassium	0.01	mg/L	0.4300	0.3000	0.2900	0.3300	<DL	<DL	0.2400	0.3300	0.3200	0.3400	0.3400	<DL	<DL
WICP1MG	Total Magnesium	0.01	mg/L	0.8800	0.6800	0.7000	0.7600	<DL	<DL	0.6700	0.7800	0.7700	0.7800	0.7800	0.0100	0.0100
WICP1MN	Total Manganese	0.0002	mg/L	0.0105	0.0128	0.0185	0.0114	<DL	<DL	0.0147	0.0140	0.0112	0.0146	0.0146	<DL	<DL
WICP1MO	Total Molybdenum	0.010	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1NA	Total Sodium	0.01	mg/L	1.9000	1.5400	1.3600	1.5200	<DL	<DL	1.3100	1.5900	1.5500	1.6000	1.6500	0.8000	0.7900
WICP1NI	Total Nickel	0.002	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1P	Total Lead	0.005	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1PB	Total Sulfur	0.05	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1S	Total Antimony	0.010	mg/L	3.6600	2.3300	1.5800	2.5100	<DL	<DL	1.4900	2.5800	2.5600	2.6600	2.6600	<DL	<DL
WICP1SE	Total Selenium	0.010	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1SI	Total Silicon	0.03	mg/L	1.2700	1.2700	1.9100	1.4200	<DL	<DL	1.8000	1.4600	1.4200	1.4300	1.4300	0.3400	0.3400
WICP1SR	Total Strontium	0.005	mg/L	0.0170	0.0110	0.0090	0.0120	<DL	<DL	0.0090	0.0130	0.0130	0.0130	0.0130	<DL	<DL
WICP1TI	Total Titanium	0.010	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1TL	Total Thallium	0.010	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1V	Total Vanadium	0.006	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1ZN	Total Zinc	0.001	mg/L	0.0490	0.0540	0.0740	0.0600	<DL	<DL	0.0660	0.0620	0.0590	0.0590	0.0590	<DL	<DL
WICP4AL	Dissolved Aluminum	0.030	mg/L	0.1580	0.1490	0.1970	0.1370	0.2110	0.1490	0.1990	0.1440	0.1470	0.1480	0.1450	<DL	<DL
WICP4AS	Dissolved Arsenic	0.030	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4BA	Dissolved Barium	0.050	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4BE	Dissolved Beryllium	0.001	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4CA	Dissolved Calcium	0.01	mg/L	8.7500	6.6800	3.9700	6.4300	4.2900	6.6400	3.8800	6.5200	6.4000	6.7100	6.6900	<DL	<DL
WICP4CD	Dissolved Cadmium	0.002	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4CO	Dissolved Cobalt	0.004	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4CR	Dissolved Chromium	0.002	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4CU	Dissolved Copper	0.004	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4FE	Dissolved Iron	0.025	mg/L	0.2120	0.1130	0.1380	0.0730	0.1920	0.1100	0.1270	0.0910	0.0980	0.1120	0.1020	<DL	<DL
WICP4K	Dissolved Potassium	0.100	mg/L	0.4370	0.3370	0.2350	0.3430	0.2710	0.3160	0.2220	0.3160	0.2990	0.3220	0.3220	<DL	<DL
WICP4MG	Dissolved Magnesium	0.010	mg/L	0.8970	0.7890	0.6700	0.7860	0.7370	0.7890	0.6450	0.7830	0.7800	0.7930	0.8010	<DL	<DL
WICP4MN	Dissolved Manganese	0.005	mg/L	0.0060	0.0120	0.0130	0.0080	0.0320	0.0110	0.0100	0.0100	0.0090	0.0120	0.0110	<DL	<DL
WICP4MO	Dissolved Molybdenum	0.050	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4NA	Dissolved Sodium	0.050	mg/L	1.3250	1.0330	0.7110	1.0410	0.8140	1.0190	0.6860	1.0320	0.9850	1.0400	1.0530	<DL	<DL
WICP4NI	Dissolved Nickel	0.025	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4P	Dissolved Lead	0.025	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4PB	Dissolved Sulfur	0.050	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4S	Dissolved Antimony	0.0500	mg/L	3.7340	2.7140	1.5460	2.5970	1.6580	2.6730	1.4760	2.6440	2.5590	2.7250	2.6790	<DL	<DL
WICP4SE	Dissolved Selenium	0.050	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4SI	Dissolved Silicon	0.050	mg/L	1.0820	1.2060	1.6070	1.1900	1.7600	1.2130	1.5640	1.2050	1.1920	1.1990	1.1990	<DL	<DL
WICP4SR	Dissolved Strontium	0.010	mg/L	0.0170	0.0130	<DL	0.0130	<DL	0.0130	<DL	0.0130	0.0130	0.0130	0.0130	<DL	<DL
WICP4TI	Dissolved Titanium	0.010	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4TL	Dissolved Thallium	0.030	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4V	Dissolved Vanadium	0.005	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4ZN	Dissolved Zinc	0.005	mg/L	0.0440	0.0610	0.0700	0.0670	0.0910	0.0640	0.0650	0.0630	0.0660	0.0590	0.0630	<DL	<DL
WICPO4	Phosphate (PO4-P) by IC	0.050	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICSO4	Sulphate (SO4) [IC]	0.03	mg/L	9.4400	7.3800	4.3800	6.5300	4.8300	6.8300	4.0700	6.7700	6.7200	7.0400	7.0200	<DL	<DL
WNH3	Total Ammonia-N	0.100	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WPH	pH	0.000	n/a	6.6520	6.4930	6.2030	6.4640	6.1590	6.4780	6.1070	6.4940	6.4840	6.5100	6.5100	4.6750	4.6800
WTDS	Total Dissoloved Solids	10.0	mg/L	63.4000	56.0000	48.6000	47.8000	46.8000	52.2000	42.8000	45.8000	48.0000	44.2000	51.0000	<DL	<DL
WTKN	Total K Nitrogen	0.015	mg/L	0.2320	0.2280	0.2310	0.2180	0.2450	0.2230	0.1950	0.2080	0.2160	0.2160	0.6690	<DL	<DL
WTOTN	Total Nitrogen	0.050	mg/L	0.2440	0.2330	0.2980	0.2170	0.3280	0.2270	0.2530	0.2050	0.2140	0.2200	0.6750	<DL	<DL
WTOTP	Total Phosphorous	0.005	mg/L	0.0110	0.0110	0.0090	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WTSS	Total Suspended Solids	2.0	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	2.8000	<DL	<DL	<DL	<DL

Table A.5. LUEL water chemistry results for July 25, 2017 samples.

LABID:				004	005	006	007	008	009	010	011	012
CUSTID:				C4.5 ;	CI ;	CO ;	C10.5 ;	C17.5 ;	CSURF	;LDBLNK	RVLBLNK	4.5 labdup
				07/25/17	07/25/17	07/25/17	07/25/17	07/25/17	07/25/17	07/25/17	07/25/17	07/25/1
Par Code	**Description**	**MDL**	**UNITS**									
WALK	Total Alkalinity as CaCO3	1.0	mg/L	10.300	22.800	14.000	9.200	8.900	15.700	<DL	<DL	10.200
WCHLOA	Chlorophyll "a"	0.2	ug/L	1.500	0.400	1.200	N	N	1.100	<DL	N	N
WCOND	Conductivity	0.5	uS/cm	42.600	109.700	61.300	38.600	34.600	67.600	0.800	1.200	41.600
WDOC	Dissolved Organic Carbon	0.5	mg/L	10.000	6.400	8.600	9.300	9.800	8.200	<DL	<DL	9.600
WHARD	Hardness (by calculation)	1.0	mg/L	18.300	44.800	26.100	16.200	14.400	28.900	<DL	<DL	17.800
WICCL	Chloride (IC)	0.05	mg/L	0.460	1.510	0.590	0.420	0.420	0.740	0.090	<DL	0.440
WICNO2	Nitrite NO2-N (IC)	0.009	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICNO3	Nitrate NO3-N [IC]	0.009	mg/L	0.159	0.110	0.107	0.196	0.249	0.070	0.067	<DL	0.178
WICP1AL	Total Aluminum	0.005	mg/L	0.221	0.119	0.137	0.230	0.300	0.137	0.006	0.006	0.221
WICP1AS	Total Arsenic	0.005	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1BA	Total Barium	0.003	mg/L	0.006	0.006	0.007	0.005	0.006	0.007	<DL	<DL	0.006
WICP1BE	Total Beryllium	0.002	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1CA	Total Calcium	0.005	mg/L	4.336	15.300	7.332	5.512	5.056	8.874	0.014	0.016	4.226
WICP1CD	Total Cadmium	0.001	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1CO	Total Cobalt	0.005	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1CR	Total Cromium	0.002	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1CU	Total Copper	0.002	mg/L	0.004	0.003	0.003	0.003	0.004	0.003	<DL	<DL	0.003
WICP1FE	Total Iron	0.002	mg/L	0.220	0.402	0.223	0.282	0.689	0.243	<DL	<DL	0.215
WICP1K	Total Potassium	0.01	mg/L	0.250	0.800	0.390	0.240	0.240	0.450	<DL	<DL	0.250
WICP1MG	Total Magnesium	0.01	mg/L	0.790	1.330	1.030	0.750	0.780	1.100	0.010	0.010	0.780
WICP1MN	Total Manganese	0.0002	mg/L	0.011	0.019	0.014	0.020	0.072	0.010	<DL	<DL	0.011
WICP1MO	Total Molybdenum	0.010	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1NA	Total Sodium	0.01	mg/L	1.050	2.710	1.550	0.970	0.950	1.790	<DL	<DL	1.070
WICP1NI	Total Nickel	0.002	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1P	Total Phosphorus	0.010	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1PB	Total Lead	0.005	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1S	Total Sulfur	0.05	mg/L	2.430	8.050	3.990	2.090	1.710	4.600	<DL	<DL	2.380
WICP1SB	Total Antimony	0.010	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1SE	Total Selenium	0.010	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1SI	Total Silicon	0.03	mg/L	1.530	1.180	1.040	1.720	2.150	1.150	0.370	0.330	1.480
WICP1SR	Total Strontium	0.005	mg/L	0.013	0.032	0.019	0.012	0.011	0.022	<DL	<DL	0.013
WICP1TI	Total Titanium	0.010	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1TL	Total Thallium	0.010	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1V	Total Vanadium	0.006	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1ZN	Total Zinc	0.001	mg/L	0.077	0.050	0.058	0.077	0.097	0.060	<DL	<DL	0.074
WICP4AL	Dissolved Aluminum	0.030	mg/L	0.162	0.088	0.086	0.176	0.219	0.091	<DL	<DL	0.162
WICP4AS	Dissolved Arsenic	0.030	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4BA	Dissolved Barium	0.050	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4BE	Dissolved Beryllium	0.001	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4CA	Dissolved Calcium	0.01	mg/L	5.990	15.430	8.530	5.180	4.460	9.490	<DL	<DL	5.850
WICP4CD	Dissolved Cadmium	0.002	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4CO	Dissolved Cobalt	0.004	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4CR	Dissolved Chromium	0.002	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4CU	Dissolved Copper	0.004	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4FE	Dissolved Iron	0.025	mg/L	0.138	0.295	0.144	0.178	0.385	0.166	<DL	<DL	0.136
WICP4K	Dissolved Potassium	0.100	mg/L	0.234	0.770	0.363	0.230	0.236	0.415	<DL	<DL	0.241
WICP4MG	Dissolved Magnesium	0.010	mg/L	0.791	1.352	1.040	0.759	0.742	1.078	<DL	<DL	0.774
WICP4MN	Dissolved Manganese	0.005	mg/L	<DL	0.012	<DL	0.015	0.059	<DL	<DL	<DL	<DL
WICP4MO	Dissolved Molybdenum	0.050	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4NA	Dissolved Sodium	0.050	mg/L	0.961	2.578	1.434	0.906	0.814	1.576	<DL	<DL	0.952
WICP4NI	Dissolved Nickel	0.025	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4P	Dissolved Phosphorus	0.050	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4PB	Dissolved Lead	0.025	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4S	Dissolved Sulfur	0.050	mg/L	2.330	7.915	3.864	2.112	1.601	4.388	<DL	<DL	2.328
WICP4SE	Dissolved Selenium	0.050	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4SI	Dissolved Silicon	0.050	mg/L	1.313	0.953	0.774	1.616	1.946	0.849	<DL	<DL	1.341
WICP4SR	Dissolved Strontium	0.010	mg/L	0.012	0.029	0.017	0.011	<DL	0.019	<DL	<DL	0.012
WICP4TI	Dissolved Titanium	0.010	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4TL	Dissolved Thallium	0.030	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4V	Dissolved Vanadium	0.005	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4ZN	Dissolved Zinc	0.005	mg/L	0.076	0.041	0.054	0.076	0.090	0.053	<DL	<DL	0.072
WICPO4	Phosphate (PO4-P) by IC	0.050	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICSO4	Sulphate (SO4) [IC]	0.03	mg/L	7.050	23.580	10.900	6.310	4.650	12.450	0.170	<DL	7.380
WNH3	Total Ammonia-N	0.100	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WPH	pH	0.000	n/a	6.393	6.987	6.656	6.295	6.176	6.747	4.809	4.831	6.400
WTDS	Total Dissoloved Solids	10.0	mg/L	47.600	86.000	57.800	45.200	46.600	59.800	<DL	<DL	46.600
WTKN	Total K Nitrogen	0.015	mg/L	0.166	0.177	0.183	0.167	0.175	0.194	<DL	<DL	0.124
WTOTN	Total Nitrogen	0.015	mg/L	0.325	0.287	0.290	0.362	0.424	0.264	0.035	<DL	0.302
WTOTP	Total Phosphorous	0.005	mg/L	<DL	<DL	0.010	<DL	<DL	0.005	<DL	<DL	<DL
WTSS	Total Suspended Solids	2.0	mg/L	<DL	<DL	2.600	<DL	<DL	2.100	<DL	<DL	<DL

Table A.6. LUEL water chemistry results for September 7, 2017 samples.

LABID:				004	005	006	007	008	009	010	011	012
CUSTID:				CS ;	CO ;	CI ;	C4.5 ;	CS ;	C10.5 ;	C17.5 ;	FB ;	TB ;
				09-07-17	09-07-17	09-07-17	09-07-17	09-07-17	09-07-17	09-07-17	09-01-17	09-01-17
Par Code	**Description**	**MDL**	**UNITS**									
WALK	Total Alkalinity as CaCO3	1.0	mg/L	16.8	16.8	20.6	16.5	16.6	8.6	9.9	1.10	1.20
WBOD	Biochemical Oxygen Demand 5day	1.0	mg/L	<DL	<DL	<DL	<DL	N	<DL	1.3	N	N
WCHLOA	Chlorophyll "a"	0.2	ug/L	3.4	2.9	2.1	3.0	N	2.3	2.4	1.2	N
WCOND	Conductivity	0.5	uS/cm	77.3	76.8	106.0	76.7	78.2	33.3	37.4	0.9	0.8
WDOC	Dissolved Organic Carbon	0.5	mg/L	6.9	6.8	6.2	6.6	6.5	8.6	8.8	<DL	<DL
WHARD	Hardness (by calculation)	1.0	mg/L	30.7	31.1	41.3	30.3	31.2	13.8	14.8	<DL	<DL
WICCL	Chloride (IC)	0.05	mg/L	0.82	0.80	1.07	0.80	0.87	0.30	0.38	0.05	<DL
WICNO2	Nitrite NO2-N (IC)	0.009	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICNO3	Nitrate NO3-N [IC]	0.009	mg/L	<DL	<DL	<DL	<DL	<DL	0.305	0.415	<DL	<DL
WICP1AL	Total Aluminum	0.005	mg/L	0.101	0.082	0.094	0.105	0.093	0.243	0.287	<DL	<DL
WICP1AS	Total Arsenic	0.005	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1BA	Total Barium	0.003	mg/L	0.006	0.006	0.006	0.006	0.006	0.005	0.006	<DL	<DL
WICP1BE	Total Beryllium	0.002	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1CA	Total Calcium	0.005	mg/L	10.940	10.526	14.846	10.862	11.078	4.578	4.828	0.011	0.011
WICP1CD	Total Cadmium	0.001	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1CO	Total Cobalt	0.005	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1CR	Total Cromium	0.002	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1CU	Total Copper	0.002	mg/L	0.003	0.002	0.003	0.003	0.003	0.003	0.004	<DL	<DL
WICP1FE	Total Iron	0.002	mg/L	0.210	0.166	0.366	0.215	0.182	0.382	1.204	0.003	0.003
WICP1K	Total Potassium	0.01	mg/L	0.58	0.55	0.82	0.58	0.61	0.28	0.31	<DL	<DL
WICP1MG	Total Magnesium	0.01	mg/L	1.16	1.13	1.56	1.16	1.17	0.72	0.74	0.01	0.01
WICP1MN	Total Manganese	0.0002	mg/L	0.0066	0.0036	0.0102	0.0069	0.0037	0.0342	0.1109	<DL	<DL
WICP1MO	Total Molybdenum	0.010	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1NA	Total Sodium	0.01	mg/L	1.85	1.78	2.63	1.83	1.93	0.81	0.88	<DL	<DL
WICP1NI	Total Nickel	0.002	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1P	Total Phosphorus	0.010	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1PB	Total Lead	0.005	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1S	Total Sulfur	0.05	mg/L	5.16	4.98	7.82	5.08	5.18	1.57	1.47	<DL	<DL
WICP1SE	Total Selenium	0.010	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1SI	Total Silicon	0.03	mg/L	1.27	1.05	1.57	1.30	1.26	2.51	2.51	0.340	0.300
WICP1SR	Total Strontium	0.005	mg/L	0.022	0.021	0.030	0.022	0.022	0.010	0.010	<DL	<DL
WICP1TI	Total Titanium	0.010	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1TL	Total Thallium	0.010	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1V	Total Vanadium	0.006	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1ZN	Total Zinc	0.001	mg/L	0.059	0.045	0.131	0.060	0.058	0.088	0.086	<DL	<DL
WICP4AL	Dissolved Aluminum	0.030	mg/L	0.065	0.057	0.067	0.070	0.064	0.203	0.219	<DL	<DL
WICP4AS	Dissolved Arsenic	0.030	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4B	Dissolved Boron	0.025	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4BA	Dissolved Barium	0.050	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4BE	Dissolved Beryllium	0.001	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4CA	Dissolved Calcium	0.01	mg/L	10.23	10.14	13.73	10.05	10.19	4.21	4.79	0.010	<DL
WICP4CD	Dissolved Cadmium	0.002	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4CO	Dissolved Cobalt	0.004	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4CR	Dissolved Chromium	0.002	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4CU	Dissolved Copper	0.004	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4FE	Dissolved Iron	0.025	mg/L	0.140	0.124	0.282	0.143	0.130	0.281	0.619	<DL	<DL
WICP4K	Dissolved Potassium	0.100	mg/L	0.561	0.542	0.772	0.537	0.563	0.255	0.303	<DL	<DL
WICP4MG	Dissolved Magnesium	0.010	mg/L	1.189	1.188	1.566	1.177	1.191	0.710	0.774	<DL	<DL
WICP4MN	Dissolved Manganese	0.005	mg/L	<DL	<DL	0.008	<DL	<DL	0.029	0.088	<DL	<DL
WICP4MO	Dissolved Molybdenum	0.050	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4NA	Dissolved Sodium	0.050	mg/L	1.813	1.827	2.545	1.789	1.878	0.770	0.889	<DL	<DL
WICP4NI	Dissolved Nickel	0.025	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4PB	Dissolved Lead	0.025	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4S	Dissolved Sulfur	0.050	mg/L	5.467	5.417	8.025	5.288	5.325	1.699	1.652	<DL	<DL
WICP4SE	Dissolved Selenium	0.050	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	0.10	0.12
WICP4SI	Dissolved Silicon	0.050	mg/L	0.937	0.750	1.250	0.957	0.936	2.141	2.275	<DL	<DL
WICP4SR	Dissolved Strontium	0.010	mg/L	0.022	0.022	0.029	0.022	0.022	<DL	0.010	<DL	<DL
WICP4TI	Dissolved Titanium	0.010	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4TL	Dissolved Thallium	0.030	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4V	Dissolved Vanadium	0.005	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4ZN	Dissolved Zinc	0.005	mg/L	0.053	0.040	0.113	0.052	0.052	0.089	0.088	<DL	<DL
WICPO4	Phosphate (PO4-P) by IC	0.050	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICSO4	Sulphate (SO4) [IC]	0.03	mg/L	16.32	16.35	24.85	16.26	16.52	3.48	3.41	<DL	<DL
WNH3	Total Ammonia-N	0.100	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WPH	pH	0.000	n/a	6.66	6.68	6.74	6.65	6.66	6.12	6.13	<DL	<DL
WTDS	Total Dissoloved Solids	10.0	mg/L	73.0	68.6	88.0	66.0	70.4	51.2	55.8	4.84	4.86
WTKN	Total K Nitrogen	0.015	mg/L	0.227	0.169	<DL	<DL	0.437	0.032	<DL	<DL	12.00
WTOTN	Total Nitrogen	0.015	mg/L	0.227	0.169	<DL	<DL	0.437	0.337	0.200	0.15	0.18
WTOTP	Total Phosphorous	0.005	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL	0.15	0.18
WTSS	Total Suspended Solids	2.0	mg/L	<DL	<DL	<DL	<DL	2.4	<DL	2.9	<DL	<DL

Table A.7. LUEL water chemistry results for October 11, 2017 samples.

LABID:				004	005	006	007	008	009	010
CUSTID:				CL 17.5	CL IN	CL SURF	CL OUT	CL 7.5	CL IN REP	LD BLNK
				10/11/17	10/11/17	10/11/17	10/11/17	10/11/17	10/11/17	10/11/17
Par Code	**Description**	**MDL**	**UNITS**							
WALK	Total Alkalinity as CaCO3	1.0	mg/L	5.5	12.3	7.0	6.6	6.3	12.9	<DL
WCHLOA	Chlorophyll "a"	0.2	ug/L	3.2	2.5	2.7	2.9	2.3	2.5	1.4
WCOND	Conductivity	0.5	uS/cm	38.7	81.4	49	45.8	44.9	81.3	0.9
WDOC	Dissolved Organic Carbon	0.5	mg/L	8.2	8.4	10.3	10.3	9.0	8.4	0.6
WHARD	Hardness (by calculation)	1.0	mg/L	16.9	34.5	21.9	20.8	20.0	34.8	<DL
WICCL	Chloride (IC)	0.05	mg/L	0.33	1.20	0.47	0.45	0.39	1.09	<DL
WICNO2	Nitrite NO2-N (IC)	0.009	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICNO3	Nitrate NO3-N [IC]	0.009	mg/L	0.254	<DL	0.020	0.020	0.050	<DL	<DL
WICP1AL	Total Aluminum	0.005	mg/L	0.318	0.186	0.238	0.244	0.252	0.172	<DL
WICP1AS	Total Arsenic	0.005	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1BA	Total Barium	0.003	mg/L	0.006	0.006	0.006	0.006	0.006	0.005	<DL
WICP1BE	Total Beryllium	0.002	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1CA	Total Calcium	0.005	mg/L	5.320	11.642	6.778	6.348	6.440	10.656	<DL
WICP1CD	Total Cadmium	0.001	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1CO	Total Cobalt	0.005	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1CR	Total Cromium	0.002	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1CU	Total Copper	0.002	mg/L	0.005	0.003	0.004	0.004	0.004	0.003	<DL
WICP1FE	Total Iron	0.002	mg/L	1.342	0.407	0.357	0.342	0.408	0.375	<DL
WICP1K	Total Potassium	0.01	mg/L	0.33	0.63	0.38	0.34	0.36	0.57	<DL
WICP1MG	Total Magnesium	0.01	mg/L	0.79	1.44	1.00	0.97	0.95	1.32	0.01
WICP1MN	Total Manganese	0.0002	mg/L	0.1587	0.0153	0.0139	0.0137	0.0281	0.0146	<DL
WICP1MO	Total Molybdenum	0.010	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1NA	Total Sodium	0.01	mg/L	1.21	2.28	1.59	1.38	1.44	2.12	0.63
WICP1NI	Total Nickel	0.002	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1P	Total Phosphorus	0.010	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1PB	Total Lead	0.005	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1S	Total Sulfur	0.05	mg/L	1.57	5.86	2.93	2.64	2.67	5.37	<DL
WICP1SE	Total Selenium	0.010	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1SI	Total Silicon	0.03	mg/L	2.62	1.99	2.05	2.05	2.23	1.79	0.26
WICP1SR	Total Strontium	0.005	mg/L	0.011	0.023	0.014	0.013	0.013	0.021	<DL
WICP1TI	Total Titanium	0.010	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1TL	Total Thallium	0.010	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1V	Total Vanadium	0.006	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1ZN	Total Zinc	0.001	mg/L	0.092	0.129	0.105	0.106	0.106	0.120	<DL
WICP4AL	Dissolved Aluminum	0.030	mg/L	0.231	0.139	0.178	0.182	0.181	0.140	<DL
WICP4AS	Dissolved Arsenic	0.030	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4BA	Dissolved Barium	0.050	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4BE	Dissolved Beryllium	0.001	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4CA	Dissolved Calcium	0.01	mg/L	5.39	11.42	7.0	6.6	6.39	11.51	0.19
WICP4CD	Dissolved Cadmium	0.002	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4CO	Dissolved Cobalt	0.004	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4CR	Dissolved Chromium	0.002	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4CU	Dissolved Copper	0.004	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4FE	Dissolved Iron	0.025	mg/L	0.852	0.32	0.201	0.186	0.238	0.324	<DL
WICP4K	Dissolved Potassium	0.100	mg/L	0.234	0.498	0.310	0.306	0.300	0.533	<DL
WICP4MG	Dissolved Magnesium	0.010	mg/L	0.824	1.465	1.066	1.036	0.971	1.471	0.036
WICP4MN	Dissolved Manganese	0.005	mg/L	0.107	0.009	0.005	<DL	0.009	0.009	<DL
WICP4MO	Dissolved Molybdenum	0.050	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4NA	Dissolved Sodium	0.050	mg/L	8.382	8.300	7.830	6.884	7.241	7.788	5.977
WICP4NI	Dissolved Nickel	0.025	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4PB	Dissolved Lead	0.025	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4S	Dissolved Sulfur	0.050	mg/L	2.040	6.182	3.442	3.010	2.996	6.111	0.354
WICP4SE	Dissolved Selenium	0.050	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4SI	Dissolved Silicon	0.050	mg/L	2.359	1.685	1.865	1.857	1.949	1.693	<DL
WICP4SR	Dissolved Strontium	0.010	mg/L	0.010	0.022	0.014	0.014	0.013	0.023	<DL
WICP4TI	Dissolved Titanium	0.010	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4TL	Dissolved Thallium	0.030	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4V	Dissolved Vanadium	0.005	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4ZN	Dissolved Zinc	0.005	mg/L	0.024	0.033	0.031	0.038	0.020	0.035	<DL
WICPO4	Phosphate (PO4-P) by IC	0.050	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICSO4	Sulphate (SO4) [IC]	0.03	mg/L	4.58	18.94	9.22	8.18	7.94	18.89	<DL
WNH3	Total Ammonia-N	0.100	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WPH	pH	0.000	n/a	5.64	6.37	5.99	5.97	5.85	6.40	4.09
WTDS	Total Dissoloved Solids	10.0	mg/L	47.6	64.4	50.6	50.0	48.0	65.0	<DL
WTKN	Total K Nitrogen	0.015	mg/L	0.269	0.284	0.340	0.325	0.359	0.347	<DL
WTOTN	Total Nitrogen	0.015	mg/L	0.523	0.284	0.360	0.345	0.409	0.347	<DL
WTOTP	Total Phosphorous	0.005	mg/L	0.022	0.022	0.024	0.03	0.022	0.014	<DL
WTSS	Total Suspended Solids	2.0	mg/L	2.8	<DL	<DL	<DL	<DL	<DL	<DL

Table A.8. LUEL water chemistry results for November 13, 2017 samples.

LABID:				004	005	006	007	008	009	010
CUSTID:				CI	CO	CD-S	CD-7.5	CD-17.5	CI Rep.	Field Blank
Par Code	**Description**	**MDL**	**UNITS**							
WALK	Total Alkalinity as CaCO3	1.0	mg/L	21.9	14.0	14.7	12.0	12.3	21.1	<DL
WCHLOA	Chlorophyll "a"	0.2	ug/L	1.7	2.5	1.9	2.0	1.8	1.5	1.0
WCOND	Conductivity	0.5	uS/cm	84.3	54.7	59.0	48.0	48.6	84.0	0.8
WDOC	Dissolved Organic Carbon	0.5	mg/L	8.7	9.6	9.0	9.0	8.6	8.5	<DL
WHARD	Hardness (by calculation)	1.0	mg/L	36.8	23.8	25.7	20.6	20.8	36.6	<DL
WICCL	Chloride (IC)	0.05	mg/L	0.74	0.47	0.53	0.52	0.42	0.75	<DL
WICNO2	Nitrite NO2-N (IC)	0.009	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICNO3	Nitrate NO3-N [IC]	0.009	mg/L	0.064	0.069	0.072	0.076	0.077	0.064	<DL
WICP1AL	Total Aluminum	0.005	mg/L	0.192	0.219	0.209	0.205	0.220	0.193	<DL
WICP1AS	Total Arsenic	0.005	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1BA	Total Barium	0.003	mg/L	0.005	0.005	0.005	0.005	0.005	0.005	<DL
WICP1BE	Total Beryllium	0.002	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1CA	Total Calcium	0.005	mg/L	11.112	5.924	6.766	4.742	4.822	10.530	0.031
WICP1CD	Total Cadmium	0.001	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1CO	Total Cobalt	0.005	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1CR	Total Cromium	0.002	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1CU	Total Copper	0.002	mg/L	0.003	0.003	0.003	0.003	0.004	0.003	<DL
WICP1FE	Total Iron	0.002	mg/L	0.450	0.440	0.444	0.447	0.516	0.452	0.016
WICP1K	Total Potassium	0.01	mg/L	0.53	0.34	0.38	0.32	0.33	0.50	<DL
WICP1MG	Total Magnesium	0.01	mg/L	1.43	1.06	1.11	0.93	0.95	1.38	0.01
WICP1MN	Total Manganese	0.0002	mg/L	0.0174	0.0216	0.0258	0.0322	0.0345	0.0177	0.0002
WICP1MO	Total Molybdenum	0.010	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1NA	Total Sodium	0.01	mg/L	1.84	1.30	1.42	1.22	1.23	1.80	0.38
WICP1NI	Total Nickel	0.002	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1P	Total Phosphorus	0.010	mg/L	<DL	<DL	<DL	<DL	0.14	<DL	<DL
WICP1PB	Total Lead	0.005	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1S	Total Sulfur	0.05	mg/L	5.04	2.94	3.40	2.61	2.60	4.82	<DL
WICP1SE	Total Selenium	0.010	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1SI	Total Silicon	0.03	mg/L	2.27	2.29	2.22	2.05	2.12	2.19	0.24
WICP1SR	Total Strontium	0.005	mg/L	0.021	0.014	0.016	0.013	0.013	0.020	<DL
WICP1TI	Total Titanium	0.010	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1TL	Total Thallium	0.010	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1V	Total Vanadium	0.006	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP1ZN	Total Zinc	0.001	mg/L	0.138	0.119	0.119	0.102	0.109	0.134	<DL
WICP4AL	Dissolved Aluminum	0.030	mg/L	0.175	0.212	0.190	0.187	0.197	0.176	<DL
WICP4AS	Dissolved Arsenic	0.030	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4BA	Dissolved Barium	0.050	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4BE	Dissolved Beryllium	0.001	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4CA	Dissolved Calcium	0.01	mg/L	12.410	7.730	8.410	6.630	6.680	12.470	<DL
WICP4CD	Dissolved Cadmium	0.002	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4CO	Dissolved Cobalt	0.004	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4CR	Dissolved Chromium	0.002	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4CU	Dissolved Copper	0.004	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4FE	Dissolved Iron	0.025	mg/L	0.340	0.326	0.307	0.301	0.344	0.331	<DL
WICP4K	Dissolved Potassium	0.100	mg/L	0.569	0.401	0.417	0.373	0.371	0.580	<DL
WICP4MG	Dissolved Magnesium	0.010	mg/L	1.539	1.165	1.196	1.016	1.028	1.527	<DL
WICP4MN	Dissolved Manganese	0.005	mg/L	0.018	0.022	0.025	0.030	0.032	0.018	<DL
WICP4MO	Dissolved Molybdenum	0.050	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4NA	Dissolved Sodium	0.050	mg/L	1.871	1.279	1.375	1.147	1.158	1.861	<DL
WICP4NI	Dissolved Nickel	0.025	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4PB	Dissolved Lead	0.025	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4S	Dissolved Sulfur	0.050	mg/L	5.178	3.086	3.468	2.782	2.739	5.100	<DL
WICP4SE	Dissolved Selenium	0.050	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4SI	Dissolved Silicon	0.050	mg/L	2.181	2.247	2.126	1.999	2.066	2.193	<DL
WICP4SR	Dissolved Strontium	0.010	mg/L	0.021	0.015	0.017	0.014	0.014	0.021	<DL
WICP4TI	Dissolved Titanium	0.010	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4TL	Dissolved Thallium	0.030	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4V	Dissolved Vanadium	0.005	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICP4ZN	Dissolved Zinc	0.005	mg/L	0.119	0.114	0.112	0.095	0.102	0.115	<DL
WICPO4	Phosphate (PO4-P) by IC	0.050	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WICSO4	Sulphate (SO4) [IC]	0.03	mg/L	17.61	9.93	11.35	10.75	8.71	17.46	<DL
WNH3	Total Ammonia-N	0.100	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WPH	pH	0.000	n/a	6.67	6.43	6.47	6.39	6.32	6.70	5.35
WTDS	Total Dissoloved Solids	10.0	mg/L	79.8	63.4	57.8	52.6	51.8	70.6	<DL
WTKN	Total K Nitrogen	0.015	mg/L	0.185	0.196	0.215	0.220	0.311	0.293	0.095
WTOTN	Total Nitrogen	0.015	mg/L	0.249	0.265	0.287	0.296	0.388	0.357	0.095
WTOTP	Total Phosphorous	0.005	mg/L	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WTSS	Total Suspended Solids	2.0	mg/L	<DL	<DL	<DL	2.0	<DL	<DL	<DL

Table A.9. LUEL water chemistry results for June 25, 2017 stream samples.

LABID:				004	005	006	007	008
CUSTID:				CI ;	CS 0;	CO ;	FB ;	TB ;
				06/25/2017	6/25/2017	06/25/2017	06/25/2017	06/25/2017
Par Code	**Description**	**MDL**	**UNITS**					
WALK	Total Alkalinity as CaCO3	1.0	mg/L	15.00	9.40	9.00	<DL	<DL
WCHLOA	Chlorophyll "a"	0.2	ug/L	2.50	N	2.80	1.50	1.50
WCOND	Conductivity	0.5	uS/cm	68.20	38.50	37.20	0.70	0.60
WDOC	Dissolved Organic Carbon	0.5	mg/L	7.50	9.00	9.50	<DL	<DL
WHARD	Hardness (by calculation)	1.0	mg/L	28.80	16.70	16.00	<DL	<DL
WICCL	Chloride (IC)	0.05	mg/L	0.68	0.33	0.37	<DL	<DL
WICNO2	Nitrite NO2-N (IC)	0.009	mg/L	<DL	<DL	<DL	<DL	<DL
WICNO3	Nitrate NO3-N [IC]	0.009	mg/L	0.04	0.24	0.02	<DL	<DL
WICP1AL	Total Aluminum	0.005	mg/L	0.18	0.24	0.22	<DL	<DL
WICP1AS	Total Arsenic	0.005	mg/L	<DL	<DL	<DL	<DL	<DL
WICP1BA	Total Barium	0.003	mg/L	0.01	0.01	0.01	<DL	<DL
WICP1BE	Total Beryllium	0.002	mg/L	<DL	<DL	<DL	<DL	<DL
WICP1CA	Total Calcium	0.005	mg/L	8.03	5.84	5.23	<DL	<DL
WICP1CD	Total Cadmium	0.001	mg/L	<DL	<DL	<DL	<DL	<DL
WICP1CO	Total Cobalt	0.005	mg/L	<DL	<DL	<DL	<DL	<DL
WICP1CR	Total Cromium	0.002	mg/L	<DL	<DL	<DL	<DL	<DL
WICP1CU	Total Copper	0.002	mg/L	0.00	0.00	0.00	<DL	<DL
WICP1FE	Total Iron	0.002	mg/L	0.39	0.30	0.26	<DL	0.00
WICP1K	Total Potassium	0.01	mg/L	0.46	0.29	0.26	<DL	<DL
WICP1MG	Total Magnesium	0.01	mg/L	1.04	0.81	0.74	0.01	0.01
WICP1MN	Total Manganese	0.0002	mg/L	0.01	0.02	0.02	<DL	<DL
WICP1MO	Total Molybdenum	0.010	mg/L	<DL	<DL	<DL	<DL	<DL
WICP1NA	Total Sodium	0.01	mg/L	2.02	1.37	1.30	0.63	0.70
WICP1NI	Total Nickel	0.002	mg/L	<DL	<DL	<DL	<DL	<DL
WICP1P	Total Phosphorus	0.010	mg/L	<DL	<DL	<DL	<DL	<DL
WICP1PB	Total Lead	0.005	mg/L	<DL	<DL	<DL	<DL	<DL
WICP1S	Total Sulfur	0.05	mg/L	4.18	2.08	1.84	<DL	<DL
WICP1SB	Total Antimony	0.010	mg/L	<DL	<DL	<DL	<DL	<DL
WICP1SE	Total Selenium	0.010	mg/L	<DL	<DL	<DL	<DL	<DL
WICP1SI	Total Silicon	0.03	mg/L	0.92	1.00	0.93	0.18	0.19
WICP1SR	Total Strontium	0.005	mg/L	0.02	0.01	0.01	<DL	<DL
WICP1TI	Total Titanium	0.010	mg/L	<DL	<DL	<DL	<DL	<DL
WICP1TL	Total Thallium	0.010	mg/L	<DL	<DL	<DL	<DL	<DL
WICP1V	Total Vanadium	0.006	mg/L	<DL	<DL	<DL	<DL	<DL
WICP1ZN	Total Zinc	0.001	mg/L	0.06	0.07	0.06	<DL	0.00
WICP4AL	Dissolved Aluminum	0.030	mg/L	0.15	0.16	0.16	<DL	<DL
WICP4AS	Dissolved Arsenic	0.030	mg/L	<DL	<DL	<DL	<DL	<DL
WICP4BA	Dissolved Barium	0.050	mg/L	<DL	<DL	<DL	<DL	<DL
WICP4BE	Dissolved Beryllium	0.001	mg/L	<DL	<DL	<DL	<DL	<DL
WICP4CA	Dissolved Calcium	0.01	mg/L	9.74	5.43	5.18	<DL	0.01
WICP4CD	Dissolved Cadmium	0.002	mg/L	<DL	<DL	<DL	<DL	<DL
WICP4CO	Dissolved Cobalt	0.004	mg/L	<DL	<DL	<DL	<DL	<DL
WICP4CR	Dissolved Chromium	0.002	mg/L	<DL	<DL	<DL	<DL	<DL
WICP4CU	Dissolved Copper	0.004	mg/L	<DL	<DL	<DL	<DL	<DL
WICP4FE	Dissolved Iron	0.025	mg/L	0.29	0.16	0.13	<DL	<DL
WICP4K	Dissolved Potassium	0.100	mg/L	0.48	0.27	0.25	<DL	<DL
WICP4MG	Dissolved Magnesium	0.010	mg/L	1.09	0.77	0.75	<DL	<DL
WICP4MN	Dissolved Manganese	0.005	mg/L	0.01	0.01	0.01	<DL	<DL
WICP4MO	Dissolved Molybdenum	0.050	mg/L	<DL	<DL	<DL	<DL	<DL
WICP4NA	Dissolved Sodium	0.050	mg/L	1.58	0.88	0.84	<DL	<DL
WICP4NI	Dissolved Nickel	0.025	mg/L	<DL	<DL	<DL	<DL	<DL
WICP4P	Dissolved Phosphorus	0.050	mg/L	<DL	<DL	<DL	<DL	<DL
WICP4PB	Dissolved Lead	0.025	mg/L	<DL	<DL	<DL	<DL	<DL
WICP4S	Dissolved Sulfur	0.050	mg/L	4.32	2.09	1.98	<DL	<DL
WICP4SB	Dissolved Antimony	0.0500	mg/L	<DL	<DL	<DL	<DL	<DL
WICP4SE	Dissolved Selenium	0.050	mg/L	<DL	<DL	<DL	<DL	<DL
WICP4SI	Dissolved Silicon	0.050	mg/L	1.23	1.23	1.23	<DL	<DL
WICP4SR	Dissolved Strontium	0.010	mg/L	0.02	0.01	0.01	<DL	<DL
WICP4TI	Dissolved Titanium	0.010	mg/L	<DL	<DL	<DL	<DL	<DL
WICP4TL	Dissolved Thallium	0.030	mg/L	<DL	<DL	<DL	<DL	<DL
WICP4V	Dissolved Vanadium	0.005	mg/L	<DL	<DL	<DL	<DL	<DL
WICP4ZN	Dissolved Zinc	0.005	mg/L	0.07	0.06	0.06	<DL	<DL
WICPO4	Phosphate (PO4-P) by IC	0.050	mg/L	<DL	<DL	<DL	<DL	<DL
WICSO4	Sulphate (SO4) [IC]	0.03	mg/L	10.89	5.05	4.57	<DL	<DL
WNH3	N-NH4+NH3	0.100	mg/L	<DL	<DL	<DL	<DL	<DL
WPH	pH	0.000	n/a	6.70	6.45	6.45	4.58	4.57
WTDS	Total Dissoloved Solids	10.0	mg/L	62.80	48.00	46.20	<DL	<DL
WTKN	Total K Nitrogen	0.015	mg/L	0.22	0.29	0.30	<DL	0.14
WTOTN	Total Nitrogen	0.015	mg/L	0.28	0.32	0.31	<DL	0.16
WTOTP	Total Phosphorous	0.005	mg/L	<DL	<DL	<DL	<DL	<DL
WTSS	Total Suspended Solids	2.0	mg/L	<DL	2.30	<DL	<DL	<DL

Table A.10. LUEL water chemistry results for August 3, 2017 stream samples.

LABID:				004	005	006	007	008
CUSTID:				CI ;	CO ;	I FLD DUP	LD BLNK	RVL BLNK
				08/0317	08/0317	08/03/17	08/03/17	08/03/17
Par Code	**Description**	**MDL**	**UNITS**					
WALK	Total Alkalinity as CaCO3	1.0	mg/L	22.7	15.3	22.8	<DL	<DL
WCHLOA	Chlorophyll "a"	0.2	ug/L	2.6	3.4	2.4	1.8	N
WCOND	Conductivity	0.5	uS/cm	114.1	69.5	114.4	1.2	0.7
WDOC	Dissolved Organic Carbon	0.5	mg/L	6.5	7.9	6.5	<DL	<DL
WHARD	Hardness (by calculation)	1.0	mg/L	45.4	28.0	45.2	<DL	<DL
WICCL	Chloride (IC)	0.05	mg/L	1.56	1.20	1.27	0.11	<DL
WICNO2	Nitrite NO2-N (IC)	0.009	mg/L	<DL	<DL	<DL	<DL	<DL
WICNO3	Nitrate NO3-N [IC]	0.009	mg/L	0.063	<DL	0.024	<DL	<DL
WICP1AL	Total Aluminum	0.005	mg/L	0.107	0.120	0.109	<DL	0.005
WICP1AS	Total Arsenic	0.005	mg/L	<DL	<DL	<DL	<DL	<DL
WICP1BA	Total Barium	0.003	mg/L	0.005	0.007	0.005	<DL	<DL
WICP1BE	Total Beryllium	0.002	mg/L	<DL	<DL	<DL	<DL	<DL
WICP1CA	Total Calcium	0.005	mg/L	15.706	8.292	16.052	<DL	<DL
WICP1CD	Total Cadmium	0.001	mg/L	<DL	<DL	<DL	<DL	<DL
WICP1CO	Total Cobalt	0.005	mg/L	<DL	<DL	<DL	<DL	<DL
WICP1CR	Total Cromium	0.002	mg/L	<DL	<DL	<DL	<DL	<DL
WICP1CU	Total Copper	0.002	mg/L	0.002	0.003	0.002	<DL	<DL
WICP1FE	Total Iron	0.002	mg/L	0.383	0.227	0.384	<DL	<DL
WICP1K	Total Potassium	0.01	mg/L	0.91	0.50	0.92	<DL	<DL
WICP1MG	Total Magnesium	0.01	mg/L	1.42	1.11	1.45	0.01	0.01
WICP1MN	Total Manganese	0.0002	mg/L	0.0191	0.0116	0.0183	<DL	<DL
WICP1MO	Total Molybdenum	0.010	mg/L	<DL	<DL	<DL	<DL	<DL
WICP1NA	Total Sodium	0.01	mg/L	2.58	1.47	2.65	<DL	<DL
WICP1NI	Total Nickel	0.002	mg/L	<DL	<DL	<DL	<DL	<DL
WICP1P	Total Phosphorus	0.010	mg/L	<DL	<DL	<DL	<DL	<DL
WICP1PB	Total Lead	0.005	mg/L	<DL	<DL	<DL	<DL	<DL
WICP1S	Total Sulfur	0.05	mg/L	8.49	4.52	8.71	<DL	<DL
WICP1SE	Total Selenium	0.010	mg/L	<DL	<DL	<DL	<DL	<DL
WICP1SI	Total Silicon	0.03	mg/L	0.94	0.85	1.04	0.25	0.24
WICP1SR	Total Strontium	0.005	mg/L	0.031	0.019	0.032	<DL	<DL
WICP1TI	Total Titanium	0.010	mg/L	<DL	<DL	<DL	<DL	<DL
WICP1TL	Total Thallium	0.010	mg/L	<DL	<DL	<DL	<DL	<DL
WICP1V	Total Vanadium	0.006	mg/L	<DL	<DL	<DL	<DL	<DL
WICP1ZN	Total Zinc	0.001	mg/L	0.043	0.049	0.043	0.028	<DL
WICP4AL	Dissolved Aluminum	0.030	mg/L	0.068	0.078	0.070	<DL	<DL
WICP4AS	Dissolved Arsenic	0.030	mg/L	<DL	<DL	<DL	<DL	<DL
WICP4BA	Dissolved Barium	0.050	mg/L	<DL	<DL	<DL	<DL	<DL
WICP4BE	Dissolved Beryllium	0.001	mg/L	<DL	<DL	<DL	<DL	<DL
WICP4CA	Dissolved Calcium	0.01	mg/L	15.84	9.44	15.84	<DL	<DL
WICP4CD	Dissolved Cadmium	0.002	mg/L	<DL	<DL	<DL	<DL	<DL
WICP4CO	Dissolved Cobalt	0.004	mg/L	<DL	<DL	<DL	<DL	<DL
WICP4CR	Dissolved Chromium	0.002	mg/L	<DL	<DL	<DL	<DL	<DL
WICP4CU	Dissolved Copper	0.004	mg/L	<DL	<DL	<DL	<DL	<DL
WICP4FE	Dissolved Iron	0.025	mg/L	0.279	0.165	0.277	<DL	<DL
WICP4K	Dissolved Potassium	0.100	mg/L	0.839	0.430	0.838	<DL	<DL
WICP4MG	Dissolved Magnesium	0.010	mg/L	1.439	1.129	1.439	<DL	<DL
WICP4MN	Dissolved Manganese	0.005	mg/L	0.012	<DL	0.012	<DL	<DL
WICP4MO	Dissolved Molybdenum	0.050	mg/L	<DL	<DL	<DL	<DL	<DL
WICP4NA	Dissolved Sodium	0.050	mg/L	2.758	1.666	2.756	<DL	<DL
WICP4NI	Dissolved Nickel	0.025	mg/L	<DL	<DL	<DL	<DL	<DL
WICP4P	Dissolved Phosphorus	0.050	mg/L	<DL	<DL	<DL	<DL	<DL
WICP4PB	Dissolved Lead	0.025	mg/L	<DL	<DL	<DL	<DL	<DL
WICP4S	Dissolved Sulfur	0.050	mg/L	8.454	4.526	8.497	<DL	<DL
WICP4SE	Dissolved Selenium	0.050	mg/L	<DL	<DL	<DL	<DL	<DL
WICP4SI	Dissolved Silicon	0.050	mg/L	0.918	0.711	0.917	<DL	<DL
WICP4SR	Dissolved Strontium	0.010	mg/L	0.032	0.019	0.032	<DL	<DL
WICP4TI	Dissolved Titanium	0.010	mg/L	<DL	<DL	<DL	<DL	<DL
WICP4TL	Dissolved Thallium	0.030	mg/L	<DL	<DL	<DL	<DL	<DL
WICP4V	Dissolved Vanadium	0.005	mg/L	<DL	<DL	<DL	<DL	<DL
WICP4ZN	Dissolved Zinc	0.005	mg/L	0.034	0.045	0.035	<DL	<DL
WICSO4	Sulphate (SO4) [IC]	0.03	mg/L	26.83	13.02	25.97	<DL	<DL
WNH3	Total Ammonia-N	0.100	mg/L	<DL	<DL	<DL	<DL	<DL
WPH	pH	0.000	n/a	6.86	6.69	6.86	4.66	4.71
WTDS	Total Dissoloved Solids	10.0	mg/L	90.2	64.6	86.2	<DL	<DL
WTKN	Total K Nitrogen	0.015	mg/L	0.142	0.270	0.188	<DL	<DL
WTOTN	Total Nitrogen	0.015	mg/L	0.205	0.270	0.212	<DL	<DL
WTOTP	Total Phosphorous	0.005	mg/L	<DL	<DL	<DL	<DL	<DL
WTSS	Total Suspended Solids	2.0	mg/L	<DL	<DL	<DL	<DL	<DL

Appendix B – Supporting Field Measurements

Due to the extremely large file sizes of data collected by the logging devices deployed at Cleaver Lake (some upwards of 9000 lines long), the following data sheets have been uploaded to a USB flash drive which is available through the Lakehead University Department of Biology, or delivery can be arranged via email correspondence by contacting akpun@lakeheadu.ca:

1) iButton temperature records for every 1m depth recorded every 30 minutes for the modelled period of May – November 2017
2) Barometric Pressure readings at half hour intervals from HOBO devices deployed: in Cleaver Lake, the inflow to Cleaver, and the outflow from Cleaver
3) Meteorological Data recorded at half hour intervals by the on-site Davis Instruments Weather Station

The following tables were made using data from multiprobe measurements taken in the profundal zone of Cleaver Lake that were used for model calibration. May readings were taken by Gerry Landriault of FQML while awaiting repair of the Hydrolab 4a Datasonde which was used to record all other data points.

Table B.1. Multiprobe vertical profiles for dissolved oxygen for 2017 used in model calibration measured in mg/L. May data provided by Gerry Landriault of FQML while awaiting repair of Hydrolab 4a Datasonde.

DISSOLVED OXYGEN							
Depth	May	June	July	August	Septembe	October	Novembe
0		8.75	8.56	8.62	9.07	9.53	12.91
1	11.28	8.72	8.45	8.71	9.29	9.45	12.32
2	11.52	8.54	8.56	8.63	9.19	9.43	11.33
3	11.35	8.67	7.17	8.12	9.1	9.3	10.98
4	11.46	8.85	7.26	7.17	8.96	9.31	10.75
5	11.52	10.04	8.5	8.35	7.73	9.18	10.51
6	11.81	9.88	9.16	8.99	7.03	8.99	10.4
7	11.87	9.89	8.87	8.78	7.12	7.42	10.33
8	11.73	9.72	8.43	8.45	6.88	5.77	10.23
9	11.61	9.43	8.39	8.38	6.71	4.78	10.17
10	11.47	9.47	8.14	8.1	6.05	4.38	10.13
11	11.25	9.38	7.98	7.79	5.82	3.69	10.1
12	11.17	9.17	7.84	7.57	5.16	3.11	10.1
13	11.02	9.06	7.49	7.25	4.65	2.66	9.91
14	10.98	8.86	7.29	6.97	4.24	2.18	9.83
15	10.76	8.69	6.95	6.62	3.71	1.81	9.54
16	10.71	8.38	6.63	6.22	3.48	1.77	9.42
17	10.39	8.17	6.43	5.78	3.38	1.62	8.93
18	5.87	7.97	6.29	4.79	3.16	1.44	8.08

Table B.2. Multiprobe vertical profiles for specific conductance for 2017 used in model calibration measured in µS/cm^2. May data provided by Gerry Landriault of FQML while awaiting repair of Hydrolab 4a Datasonde.

SP COND							
Depth	May	June	July	August	Septembe	October	Novembe
0		37	69	77	78	47	79
1	32.7	37	69	77	78	47	70
2	32.8	38	69	77	78	47	53
3	32.4	41	67	77	78	47	50
4	32.6	34	43	39	76	46	48
5	32.6	27	29	30	58	47	48
6	32.8	26	27	27	29	48	48
7	33.1	26	28	28	29	41	48
8	33.3	27	29	29	29	35	48
9	33.7	27	29	29	30	32	48
10	33.8	27	30	30	31	33	48
11	34.5	28	30	31	32	34	48
12	34.5	29	31	32	33	35	49
13	34.9	29	31	32	34	35	48
14	35.1	30	32	32	34	36	48
15	35.2	30	32	33	35	36	48
16	35.4	31	33	34	35	37	49
17	36.1	31	33	34	36	37	50
18	36.8	31	33	36	36	37	55

Table B.3. Multiprobe vertical profiles for temperature for 2017 used in model calibration measured in °C. May data provided by Gerry Landriault of FQML while awaiting repair of Hydrolab 4a Datasonde.

TEMP							
Depth	May	June	July	August	Septembe	October	Novembe
0		19.72	22.55	21.54	14.24	11.5	0.48
1	8.7	19.56	22.58	21.57	14.26	11.48	1.31
2	8.3	17.01	22.52	21.5	14.18	11.14	2.32
3	8.1	15.69	21.39	19.99	14.02	10.98	2.54
4	7.4	13.01	14.54	14.42	13.79	10.62	2.73
5	7.3	8.7	9.96	10.62	12.8	10.14	2.87
6	5.8	7.08	7.8	7.76	9.78	9.89	2.99
7	5.3	7.09	6.47	6.69	7.15	9.01	3.05
8	5.1	6.37	5.93	5.97	6.31	7.04	3.14
9	5	5.95	5.58	5.54	5.77	5.96	3.19
10	4.9	5.51	5.35	5.35	5.43	5.67	3.23
11	4.8	5.22	5.17	5.11	5.18	5.38	3.25
12	4.7	4.99	4.99	5.01	5.09	5.18	3.29
13	4.7	4.85	4.88	4.9	5	5.14	3.32
14	4.7	4.75	4.81	4.81	4.92	5.07	3.32
15	4.7	4.68	4.77	4.79	4.88	5.05	3.35
16	4.6	4.65	4.74	4.75	4.86	5.03	3.37
17	4.6	4.62	4.72	4.73	4.84	5.02	3.39
18	4.4	4.58	4.71	4.71	4.83	5.01	3.42

Table B.4. Multiprobe vertical profiles for pH for 2017.

PH						
Depth	June	July	August	Septembe	October	Novembe
0	6.87	7.3	7.44	7.29	6.69	7.37
1	6.87	7.31	7.42	7.29	6.68	7.29
2	6.72	7.29	7.41	7.29	6.65	7.15
3	6.62	6.99	7.19	7.29	6.63	6.98
4	6.44	6.39	6.45	7.21	6.61	6.94
5	6.16	6.1	6.21	6.75	6.59	6.88
6	6.1	6.02	6.08	6.23	6.52	6.85
7	6.09	5.96	6.03	6.12	6.23	6.81
8	6.06	5.9	6	6.08	5.99	6.79
9	6.01	5.9	5.98	6.07	5.87	6.78
10	6	5.89	5.97	6.03	5.84	6.76
11	5.99	5.87	5.97	6.03	5.84	6.75
12	5.99	5.88	5.96	6.01	5.83	6.73
13	5.99	5.87	5.95	6	5.83	6.72
14	5.97	5.87	5.96	5.99	5.82	6.67
15	5.97	5.87	5.97	5.99	5.82	6.64
16	5.97	5.87	5.96	6	5.82	6.6
17	5.97	5.88	5.97	6	5.82	6.54
18	5.97	5.88	5.99	6	5.83	6.47

The following figure depicts dissolved oxygen concentrations from September 16 to November 13, 2017 recorded every half hour and was used to ensure model accuracy when predicting lake turnover.

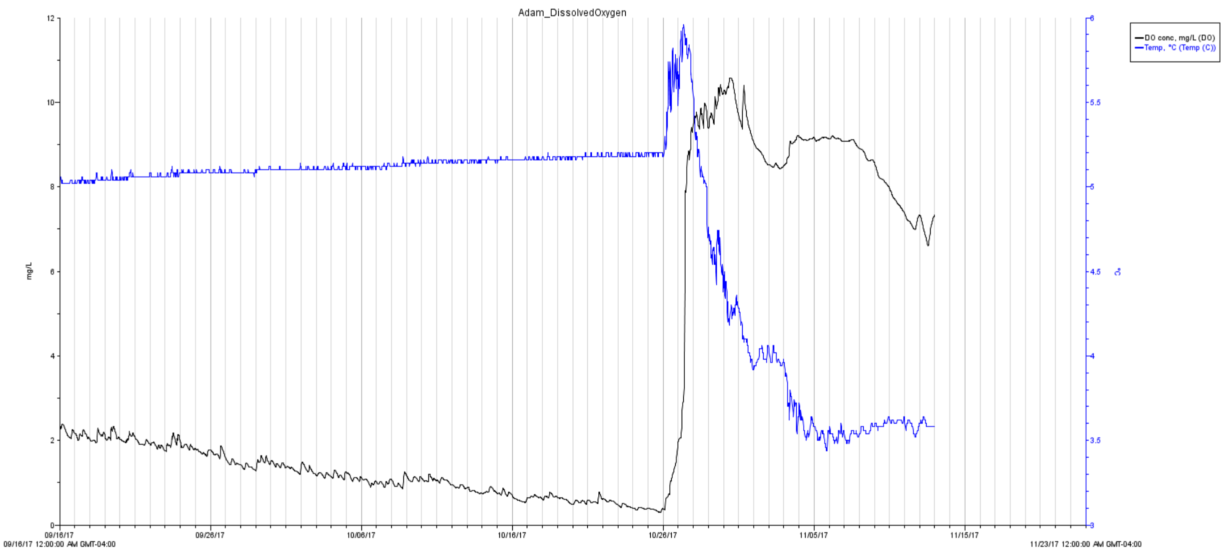

Figure B.1. Dissolved Oxygen and temperature readings from September 16 to November 13, 2017 obtained by HOBO dissolved oxygen probe.

The following figure depicts conductivity recordings from a HOBO conductivity logging device deployed alongside the dissolved oxygen HOBO recording every half hour, used to ensure model accuracy when predicting lake turnover.

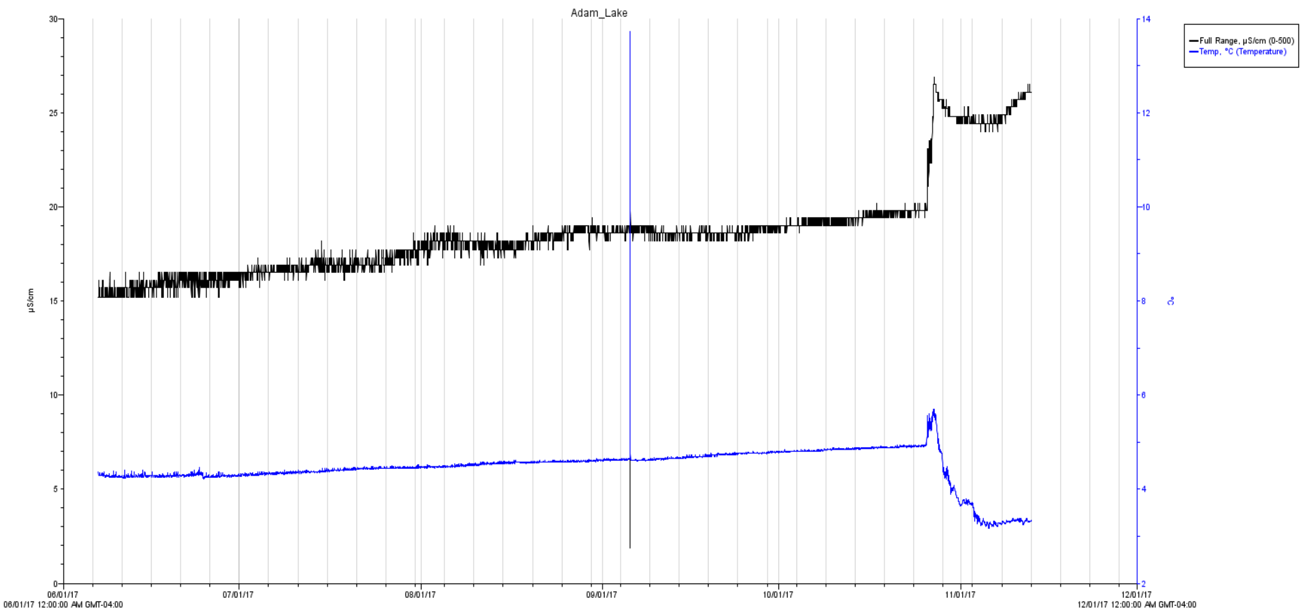

Figure B.2. Conductivity readings in µS/cm² from HOBO device deployed at the bottom of Cleaver Lake from June 7 to November 13, 2017.

The following graphs were made using metered flow measurements recorded in the in and outflows at Cleaver Lake to develop regression equations for use in correlating flow rates via barometric pressure readings from the HOBO data loggers deployed in the streams.

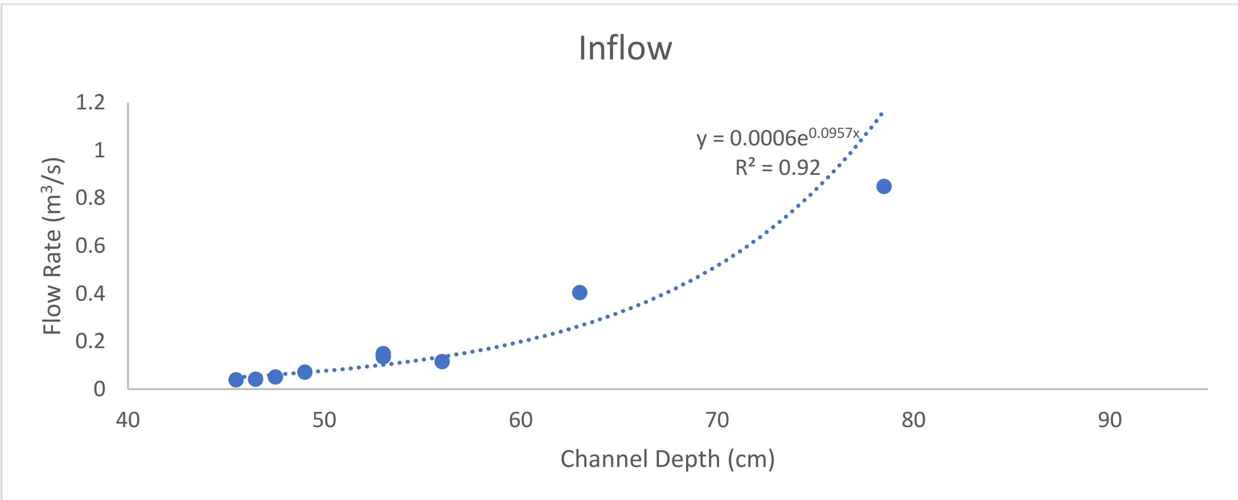

Figure B.3. Measured inflow rates plotted vs. channel depth and established regression equation used in correlating flows from pressure logging HOBO device for Cleaver Lake inflow.

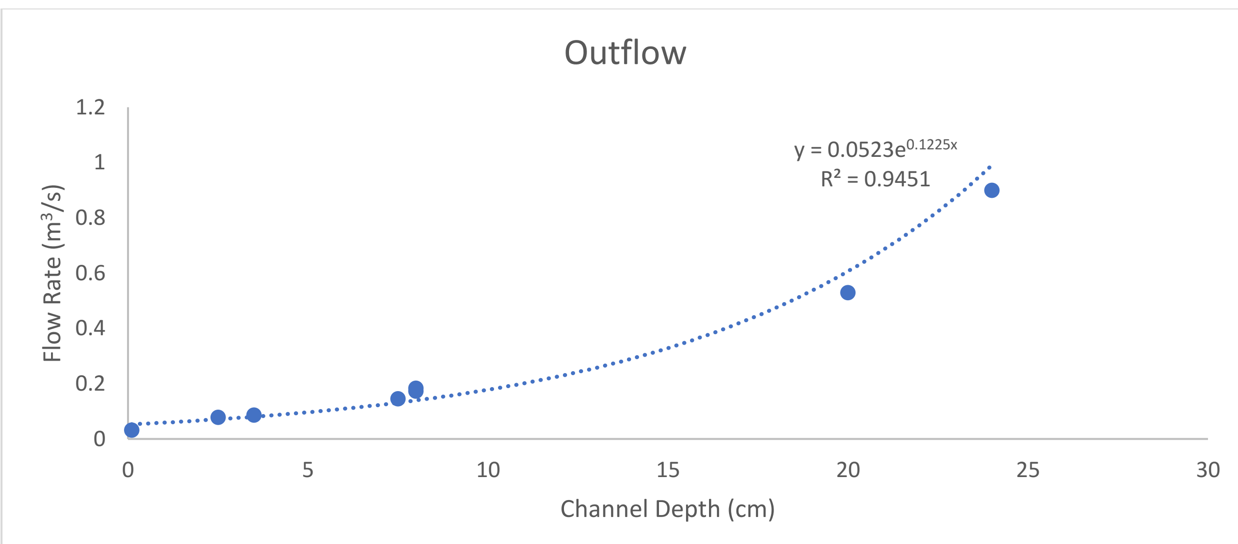

Figure B.4. Measured flow rates plotted vs. channel depth and the established regression equation used in correlating flows from pressure logging HOBO device for Cleaver Lake outflow.

Appendix C – Model Input/Control Files

To conserve space and paper, all CE-QUAL-W2 input files have been uploaded in electronic format to a USB flash drive available through the Lakehead University Department of Biology, or delivery can be arranged via email correspondence by contacting akpun@lakeheadu.ca.