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West Credit River Assimilative Capacity Study

Prepared for: Ainley Group.
Job #: J160005

November 14, 2016

DRAFT FOR COMMENT

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November 14, 2016 HESL Job #: J160005

Mr. Joe Mullan
550 Welham Road
Barrie, ON
L4N 8Z7

Dear Mr. Mullan:

Re: Assimilative Capacity Study for West Credit River – Draft for Comment

We are pleased to submit the draft assimilative capacity study in support of the Class Environmental Assessment (Class EA) for a communal wastewater and collection system for the Village of Erin and Hillsburgh. We have summarized baseline data on water quality and flow and used the 7Q20 flow value derived by CVC to model effluent limits and flows using CORMIX to estimate near field mixing and QUAL2K to estimate far field assimilation processes. The effluent limits recommended will meet all required water quality objectives in the West Credit River and the mixing zone characteristics modelled meet the regulatory requirements of the MOECC. We have also presented several alternative designs for the effluent outfall itself to accommodate efficient mixing in the near field under Phase 1 and Full Build Out effluent flows.

Please provide this draft report to the study team for review. We thank you for the opportunity to work on this project and look forward to receiving any comments and finalizing the study.

If you have any questions please do not hesitate to contact me.

Sincerely,
Per. Hutchinson Environmental Sciences Ltd.

Neil Hutchinson, Ph.D., President
Neil.Hutchinson@environmentalsciences.ca

Signatures

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1. Introduction

The Town of Erin is currently completing a Class Environmental Assessment (Class EA) for a communal wastewater and collection system for the Village of Erin and Hillsburgh. A Servicing and Settlement Master Plan (SSMP), by B.M.Ross in 2014, completed part of Phase 1 and part of Phase 2 of the Class EA process. The SSMP identified a general area (along Wellington County Road 52) for the location of a wastewater treatment plant (WWTP). The Town is now engaged in completing Phase 1 and Phase 2 of the EA and moving on to complete Phase 3 and Phase 4.

A preliminary Assimilative Capacity Study (ACS) was completed by B.M.Ross (2014) as part of the SSMP. The intent of the preliminary ACS was to assess the feasibility of a wastewater treatment plant (WWTP) with surface water discharge to the West Credit River in the reach between 10th Line and Winston Churchill Blvd. The preliminary ACS demonstrated this was feasible but recommended that the next phases of the EA should include a review of dissolved oxygen and temperature impacts, and potential for effluent storage. The Ontario Ministry of the Environment and Climate Change (MOECC) confirmed that the original ACS be updated to include hydrodynamic modelling and additional stream flow information collected since the ACS was completed.

This ACS report provides an update to the preliminary ACS completed as part of the SSMP to include:

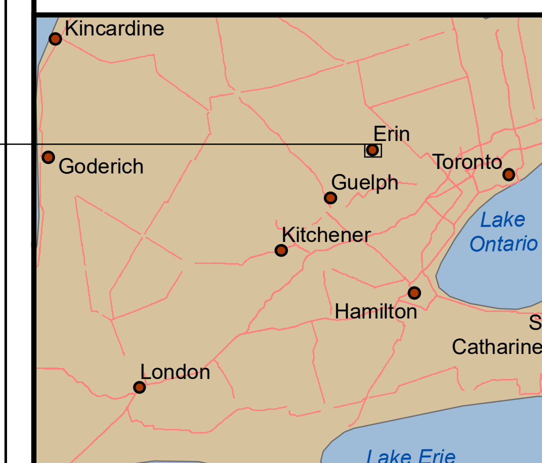
- Recent (2016) water quality data collected for the West Credit River at 10th Line;
- An updated 7Q20 low flow statistic for the West Credit River at 10th Line;
- Mixing zone modelling (using CORMIX) to predict the size and shape of the mixing zone; and
- Hydrodynamic, far-field modelling (using QUAL2K) to predict downstream concentrations of oxygen, temperature, nitrate, and ammonia.

1.1 Study Area

The study area for the ACS is presented on Figure 1. Generally it follows the West Credit River and extends just upstream and downstream of 10th Line and Winston Churchill Blvd., respectively. A large aggregate pit is located to the north-west, and Wellington Road 52 is located to the south-east, along with some residential properties. The study area is located downstream of the Village of Erin.

CVC completed an extensive Existing Conditions Report (CVC 2011) as part of the SSMP, which summarized the hydrogeology, hydrology, geomorphology, aquatic ecology (fish and benthos), water quality, and hydraulics in the study area. Much of the information used for the preliminary ACS was collected from this report, as it provides an excellent baseline of the natural environment in the study area. The West Credit River downstream of 10th Line has been designated as a cold-water aquatic community due to the presence of brook trout. The most productive brook trout spawning reaches and the best brook trout populations in the West Credit River are located downstream of Erin Village (CVC 2011) and the longest contiguous brook trout habitat in the Credit River watershed is the West Credit River between Erin and Belfountain.

Figure 1:
Site Location



- Stream
- Road
- Study Area
- Waterbody

N

0 125 250 500 750 1,000 m

Prepared by: Eric Dilligeard
Data Source: LIO, HESL, Esri Imagery.
Coordinate System: NAD 1983 UTM Zone 17N

Project Lead: Tara Roumeliotis and Deborah Sinclair
Project: Town of Erin Class EA Wastewater Servicing. Assimilative Capacity Study
Project#: 160005

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2. Background

In 2014, B. M. Ross completed an ACS of the West Credit River. The study investigated the impact of three discharge scenarios on the West Credit River: existing population of Erin (3,087 people), existing population of Erin and Hillsburgh (4,481 people), and a future population scenario of 6,000 people. The impact of the WWTP discharge on the West Credit River was estimated using a mass-balance approach with monthly 75th percentile background water quality and monthly 7Q20 flows. Background water quality was based on the long-term Provincial Water Quality Monitoring Network (PWQMN) station located at Winston Churchill Blvd. (station 06007601502). The monthly 7Q20 estimates were calculated by CVC and included a 10% reduction factor for climate change.

B.M.Ross used the effluent objectives and limits outlined in Table 1, and a maximum effluent flow rate of 2,610 m^3/d, and predicted that water quality in the West Credit River met all PWQOs with the exception of total phosphorus in September. Total phosphorus concentrations were predicted at 0.0308 mg/L, just slightly above the PWQO of 0.03 mg/L. The report concluded that a surface water discharge with an average daily discharge rate of 2,610 m^3/d (6,000 people) would not negatively impact the stream. The report recommended that dissolved oxygen modelling, thermal impacts, and effluent storage be investigated as part of future stages of the EA (B.M.Ross 2014).

Table 1 Effluent Quality Criteria Proposed by B.M.Ross (2014)

Parameter	Treatment Objectives	Non-Compliance
pH	<7 and >8.6[a]	<7 and >8.6 [a]
Total Suspended Solids (mg/L)	3.0	10
Total Phosphorus (mg/L)	0.1	0.15
Total Ammonia (mg/L)	0.4	2.0
Total Kjeldahl Nitrogen (mg/L)		3.0
Nitrate Nitrogen (mg/L)	5	6
E. coli (org/100 mL)	100	100
Dissolved Oxygen (mg/L)	5 (min)	4 (min)
BOD5 (mg/L)	3.6	7.5
Temperature	17	<8 and >19 [b]

Note: a – this has been interpreted as pH >7 and <8.6; b – this has been interpreted as temperature >8 and <19.

The Ontario Ministry of the Environment and Climate Change (MOECC) confirmed (letter from Ms. Barbara Slattery dated October 31, 2015 to Ms. Christine Furlong, Triton Engineering) that the original ACS be updated to include:

- Mixing zone analysis to include both the lateral and longitudinal plume dimensions;
- Hydrodynamic modelling to predict dissolved oxygen and temperature;

- Worse-case flow scenario should be September (i.e. month with lowest flow); and
- Update ACS to incorporate additional streamflow data (finalize 7Q20 estimate).

HESL used these comments from the CVC and MOECC to prepare an updated work plan (HESL: memo to B. Slattery et al. May 2 2016) for the ACS for review and final approval by the study team.

2.1 Pre-Consultation Meeting with MOECC and CVC

On May 30, 2016 HESL, the Ainley Group and Triton Engineering attended a pre-consultation meeting with the MOECC and CVC. The purpose of the meeting was to review the updated ACS work plan with MOCC and CVC and discuss any questions or concerns with the proposed approach (modelling, field investigations and analyses). The group approved the ACS work plan with the following modifications:

1. Water quality modelling will be completed for a 10th Line discharge, as the most conservative location. The West Credit River at Winston Churchill Blvd. is characterized by higher flows and higher water quality than 10th Line as a result of groundwater discharge between the two sites.
2. The dye study and water quality modelling would extend downstream of the study area (i.e. Winston Churchill Blvd.) to capture Winston Churchill Blvd. as a potential discharge location.

3. Stream flow would be measured at Winston Churchill Blvd. to compare with measurements collected at 10th Line. .

Minutes from the meeting are presented in Appendix A.

2.2 Policies

Ontario's Ministry of Environment and Climate Change (MOECC) have established policies and guidelines that direct the discharge requirements for waste water treatment plants (WWTPs) in the province. In "*Water Management* Policies*, Guidelines and Provincial Water Quality Objectives of the Ministry of Environment and Energy"* (MOE 1994a) the MOE provides direction on the management of surface water and groundwater quality and quantity for the Province of Ontario. The two policies that relate to the determination of WWTP discharges limits are:

> Policy 1 – In areas which have water quality better than the PWQO, water quality shall be maintained at or above the objectives.
>
> Policy 2 - Water quality which presently does not meet the PWQO shall not be degraded further and all practical measures shall be taken to upgrade the water quality to the objectives.

The PWQO (Provincial Water Quality Objectives) are numerical and narrative criteria that serve as chemical and physical indicators representing a satisfactory level for surface waters (i.e. lakes and rivers) and where it discharges to the surface, the groundwater of the Province of Ontario. The PWQO are set at a level of water quality, which is protective of all forms of aquatic life and all aspects of the aquatic life cycles during indefinite exposure to the water (MOE 1994a).

In Deriving Receiving Water Based, Point-Source Effluent Requirements for Ontario Waters (MOE 1994b), the MOECC provides guidance with regard to the requirements for point-source discharges and the procedures for determining effluent limits. For continuous discharges to streams and rivers, the 7Q20 low-flow statistic is used as a basic design flow to determine the assimilative capacity. The 7Q20 flow represents the minimum 7-day average flow with a recurrence period of 20 years. This value determines the 5% chance of there not being adequate streamflow to properly dilute the point discharge. The 75th percentile concentration is used to determine background water quality when developing receiver-based effluent limits, and is to reflect the existing conditions of the receiver. The 75th percentile background concentrations are also used to determine the Policy status for each of the contaminants expected in the effluent. The following presents MOECC guidance for effluent limits based on receiver Policy Status.

- For Policy 1 receivers, an evaluation is made as to what treatment or other measure is required to maintain water quality at or above the PWQO. Although some lowering of the water quality is permissible, violation of the PWQO is not allowed.
- For Policy 2 receivers no further lowering of water quality is permitted, and all reasonable and practical measures to improve water quality shall be undertaken (MOECC 1994b).

2.3 7Q20 statistic

A Water Survey of Canada (WSC) gauge located in the West Credit River at 8th Line provides a long-term (1983 - present) record of flow. Due to differences in geological conditions between the catchment area of this station and the WWTP study area (i.e., West Credit River between 10th Line and Winston Churchill Blvd.), flows from 8th Line could not be pro-rated for catchment size at 10th Line for the preliminary ACS (B.M.Ross 2014).

A flow gauging station was established at 10th Line in July 2013 by Credit Valley Conservation (CVC). Insufficient data has been collected from this station to determine a reliable 7Q20 low flow statistic; a minimum of 10 years of data are required. Flows measured at this gauge, however, were used by CVC to develop a flow transposition factor between the 8th Line and the 10th Line data. The preliminary ACS used 7Q20 flows for 10th Line as determined by CVC using a transposition factor based on stream flows collected from July to October 2013 at 10th Line. Additional flow data have been collected since the preliminary ACS to refine the transposition factor. In 2016, CVC recalculated the 7Q20 low flow statistic for 10th Line, using data from July 2013 to December 2015 (Appendix B). The new 7Q20 flow statistic for 10th Line of 225 L/s includes a 10% reduction to account for effects on climate change.

3. Approach and Methods

The preliminary ACS (B.M.Ross 2014) used water quality data from the Provincial Water Quality Monitoring Network (PWQMN) station located on the West Credit River at Winston Churchill Blvd. (PWQMN 06007601502) as input to their ACS. This station is located in the study area and has a long-term record of water quality (1975-2015). The updated ACS, however, draws on water quality information collected from the 10th Line upstream of Winston Churchill Blvd. which was contained in the Existing Conditions Report (CVC 2011) and updated with new data collected as part of this study. Groundwater discharge between the 10th Line and Winston Churchill Blvd. results in improved water quality downstream and so provides a more conservative estimate of background water quality.

A CORMIX water quality model was used to determine the size and shape of the effluent plume and water quality in the mixing zone. Oxygen and temperature modelling of the discharge in the River, as requested by the MOECC and CVC and recommended in the preliminary ACS, was completed using the QUAL2K model. The QUAL2K model was also used to predict the influence of assimilation processes beyond the mixing zone on downstream concentrations of ammonia and nitrate. The QUAL2K model requires a large amount of site-specific physical, chemical and biological information to accurately simulate the effect of the effluent on the receiver. The data to complete the modelling was assembled from the background data and updated with data from the current water quality, quantity and detailed field studies conducted in the summer of 2016. The additional field studies were undertaken as inputs into the ACS included:

- Diurnal Oxygen Surveys - used as input into the QUAL2K model and to determine if oxygen is a limiting factor at night when photosynthesis is low and respiration is high
- Physical Attributes Survey – to define and characterize distinct reaches in the West Credit River within the study area for input into the hydrodynamic model
- Dye Tracer Study – to calculate time of travel and longitudinal dispersion of effluent as input to the Qual2K model

The methods used for the field investigations and ACS are outlined in the following sections.

3.1 Confounding Factors

In early July 2016 the CVC became aware of backwater effects at their 10th Line flow gauge caused by a beaver dam located approximately 20 m downstream of 10th Line. The time of construction of the dam is unknown, but CVC believes that water levels (and hence calculated flows) at 10th Line from approximately May 20, 2016 were impacted by downstream beaver dams (Tim Hurts, CVC personal communication). The presence of beaver dams downstream of the water level gauge at 10th Line caused the pooling of water and flooding of banks upstream of 10th Line. As a result, accurate flow measurements could not be calculated from the CVC gauge from ~ May 2016 onwards.

The presence of the beaver dams should not influence the water quality data collected by HESL in 2016. Water samples were collected at 10th Line from May to July 2016. In August and September 2016 the sampling station was moved 75 m downstream of 10th Line, outside of any influence of the beaver activity. In May, June, and July, stream flows were measured just upstream of 10th Line at the CVC flow gauge. Flows measured during this period may include influence (e.g. backwater effects) from beaver dams located downstream. In August and September, stream flows were measured ~ 75m downstream of 10th Line, to avoid interference from the beaver dam.

A dye tracer study was conducted on August 25, 2016 (Section 3.5). The dye was injected approximately 75 m downstream of 10th Line, downstream of the influence of the beaver dam. The presence of the beaver dam at 10th Line did not influence the dye study, as the study was conducted well outside of its influence.

3.2 Water Quality

Monthly water quality samples were collected from the West Credit River at 10th Line (Figure 2) from May to September 2016 on:

- May 27, 2016

- June 29, 2016
- July 27, 2016
- August 25, 2016
- September 28, 2016

Water samples were collected 75 m downstream of 10th Line during August 25 and September 28 sampling events to avoid the influence of the beaver dam.

During each sampling event grab samples were collected from the centre of the watercourse for analysis of:

- 5-day and ultimate carbonaceous biochemical oxygen demand (CBOD5 and CBODu),
- total phosphorus (TP),
- orthophosphate (PO_4),
- total dissolved phosphorus (TDP)
- total Kjeldahl nitrogen (TKN),
- nitrate (NO3) and nitrite (NO2),
- total ammonia nitrogen (TAN),
- total suspended solids (TSS),
- chlorophyll *a*, and
- volatile suspended solids (VSS).

After sample collection, water samples were stored in laboratory-provided coolers containing ice packs and shipped to ALS in Waterloo, Ontario for analysis. Field measurements of pH, dissolved oxygen (DO; mg/L and % saturation), temperature (°C) and specific conductivity (µS/cm) were collected with a water quality multi-parameter meter (YSI 600 QS). Field pH and temperature were used to calculate un-ionized ammonia using the equation from Appendix A of MOE's document "Water Management" (MOE 1994).

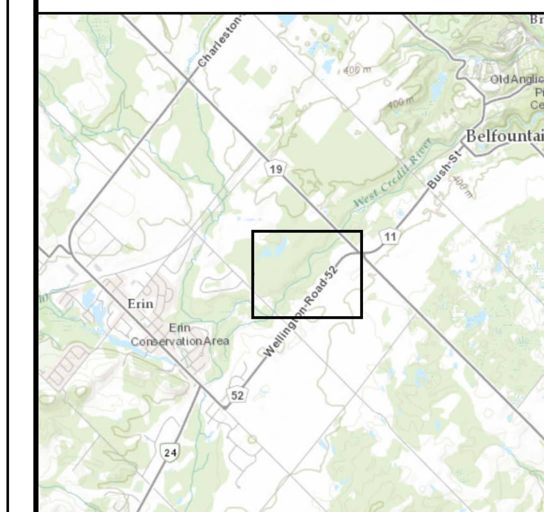
The relationships between these variables are used by the QUAL2K model to predict far-field water quality.

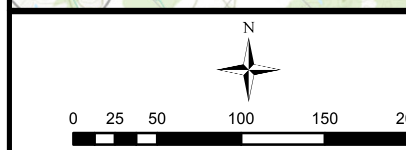
3.2.1 Diurnal DO Surveys

Three dissolved oxygen (DO) loggers (Optical Dissolved Oxygen Loggers, HOBO Model U26-001) were installed in the West Credit River at three locations: 10^{th} Line, Winston Churchill Blvd., and the mid-point between the two stations on June 10, 2016 (Figure 2). The DO loggers were calibrated prior to deployment, and programmed to measure dissolved oxygen (mg/L) and temperature (ºC) every 0.5 hours. The loggers were retrieved on August 25, 2016; the logger between the two stations was likely vandalized and was not retrieved. A DO logger was also installed 75 m downstream of 10^{th} Line from August 25 to September 28, 2016 to assess dissolved oxygen concentrations downstream of 10^{th} Line. The dissolved oxygen measurements were used as input into the QUAL2K model (Section 3.7), and to assess aquatic habitat conditions in the West Credit River.

Figure 2:
Monitoring Locations in
West Credit River Study Area

- ● Monitoring Site
- PWQMN Station 06007601502
- CVC Flow Station
- HESL DO Logger
- HESL Flow Station
- HESL Water Quality
- Stream
- Road





Prepared by: Eric Dilligeard
Data Source: LIO, HESL, Esri Imagery.
Coordinate System: NAD 1983 UTM Zone 17N

Project Lead: Tara Roumeliotis and Deborah Sinclair
Project: Town of Erin Class EA Wastewater Servicing. Assimilative Capacity Study
Project#: 160005

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3.3 Stream flow

Stream flow was measured at 10th Line and Winston Churchill Blvd. (Figure 2) during each sampling event[1] using an OTT MF Pro brand flow meter. From May to July stream flows were measured just upstream of 10th Line at the CVC flow gauge. Flows measured during this period may include influence (e.g. backwater effects) from the beaver dams located downstream. The August and September flows were measured ~ 75 m downstream of 10th Line to avoid interference from the beaver dam.

Stream velocity was measured at a minimum of 10 points across the stream cross-section. At points where the water depth was less than 0.5 m, the water velocity was measured at 0.6 of the water depth. Where water depths were greater the 0.5 m the velocity was measured at 0.2 and 0.8 of the depth and the mean of these values computed. The area-velocity method was used to calculate stream discharge. Manual streamflow measurements are generally accurate to within 6-19% (Harmel et al. 2006) of the actual flow in the watercourse, with lower flows being less accurate.

3.4 Stream Characterization

On June 10, 2016 a detailed field reconnaissance of the West Credit River between 10th Line and Winston Churchill Blvd. was carried out by HESL scientists. The purpose of the reconnaissance was to develop a better understanding of the proposed receiving environment, identify potential influences on water quality and the assimilation process, and to define and characterize distinct sections (also known as reaches) of the river for the purpose of informing the 1-dimensional river model, QUAL2K.

The QUAL2K model requires spatial segmentation of the river into a series of reaches, which are sections of similar hydrogeometric characteristics, (i.e., depth, cross sectional area, bank slopes, channel slopes, average velocity and average flow), channel pattern, bed materials, bank composition, and influence of riparian and in-stream vegetation on flow. HESL scientists surveyed the longitudinal slope of the river and the left and right bank slopes at eight locations within the study area. In addition, the field reconnaissance made note of any of the following items:

- human contact points
- upstream inputs or modifiers that may affect assimilation such as tile drains or impoundments
- inputs or structures downstream of the discharge such as tributaries, tile drains or impoundments
- Substrate type
- In-stream vegetation (macrophyte growth)
- Large woody debris
- Riparian vegetation
- Tree canopy and percent of shading

HESL field notes from the reconnaissance are attached in Appendix C.

In addition to the reconnaissance conducted by HESL, fluvial geomorphologists from Palmer Environmental Consulting Group (PECG) carried out a comprehensive stream assessment of the West Credit River study

[1] *Stream flow was not measured at Winston Churchill Blvd.during the May27, 2016 event.*

area between 10th Line and 80 m downstream of Winston Churchill Blvd. on June 29, 2016. Although the focus of PECG's assessment was evaluating potential outfall locations, (to be reported in Phase 3 and 4 of the EA), their study observations on channel morphology, bed and bank materials, and existing erosion sites were incorporated into the physical attributes survey results of HESL.

3.5 Dye Tracer Study

Tracer testing was conducted on August 25, 2016 under a low flow of 0.37 m^3/s, as measured by HESL staff on the day of the tracer test at a location approximately 75 m downstream of 10th Line and outside of the influence of the beaver dam. Data gathered during the tracer tests were used to calculate time of travel, velocity, and longitudinal dispersion for use in the far-field 1-dimensional river model (QUAL2K) of the West Credit River and to provide a one-time calibration of the model using the flow and velocity conditions on that date.

Rhodamine WT dye, a fluorescent xanthene dye that is pink in colour, was used as the tracer for the study. Rhodamine WT dye was chosen because it is a stable, non-toxic, and chemically non-reactive dye that is easily measured in the field. The substance is non-carcinogenic, and is safe if it comes into contact with skin. Rhodamine WT dye tracers are also very robust over a variety of different flow regimes.

A slug injection tracer test was carried out whereby a known amount of tracer was added to West Credit River approximately 75 m downstream of 10th Line (Figure 3). This injection location was selected because it was downstream of the zone of influence from the beaver dam near 10th Line.

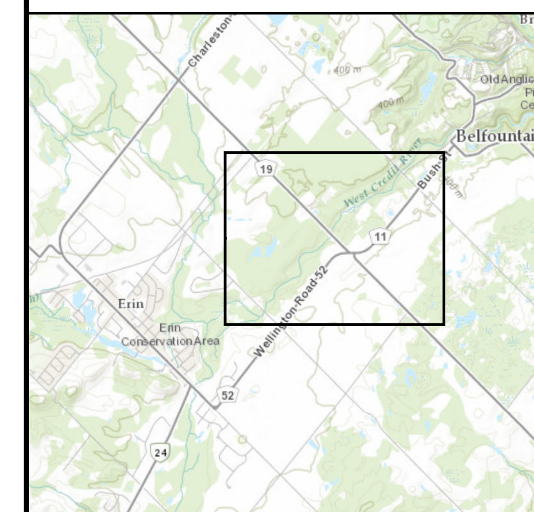
Fluorometers (YSI 600 OMS instruments equipped with Rhodamine WT optical sensors) were placed in the West Credit River at five locations downstream of the tracer injection site, as follows:

- Fluorometer 1 at 105 m downstream of the injection point;
- Fluorometer 2 at 486 m downstream of the injection point;
- Fluorometer 3 at 1,373 m downstream of the injection point;
- Fluorometer 4 at 1,687 m downstream of the injection point; and
- Fluorometer 5 at 2,827 m downstream of the injection point (Figure 3);

The fluorometers were equipped with an optical sensor to determine the concentration of Rhodamine WT in the water, in units of µg/L (ppb), and were set up to collect one measurement every 10 seconds for the duration of the test. The fluorometers were capable of measuring concentrations of Rhodamine WT with a resolution of 0.1 ppb. The Rhodamine WT optical sensors were calibrated in the field on a 2-point scale that included 0 ppb and 100 ppb Rhodamine WT. The 100 ppb solution was mixed in the field from a 20% Rhodamine WT dye solution, which was obtained from a national supplier.

Figure 3:
Dye Tracer Study,
Fluorometer Locations

- Fluorometer Station
- Injection Point
- Stream
- Road



N

0 50 100 200 300 400 m

Prepared by: Eric Dilligeard
Data Source: LIO, HESL, Esri Imagery.
Coordinate System: NAD 1983 UTM Zone 17N

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To begin the slug injection tracer test, a certain volume of Rhodamine WT 20% dye solution was mixed into a bucket containing 10 L of water collected from the West Credit River. The volume of tracer required was estimated by applying the following empirical equation by Kilpatrick (1989):

$$V_s = 3.79 \times 10^{-5} \frac{QL}{v} C_p \qquad \text{Equation (1)}$$

where Vs is the volume of Rhodamine WT 20% dye, in mL;

Q is the flow rate of the West Credit River, in ft^3/s;

L is the length of the measurement reach, in ft;

v is the mean-stream velocity, in ft/s; and

Cp is the peak concentration at the sampling site, in µg/L.

Equation 1 was used to determine the amount of Rhodamine WT 20% dye needed, such that the peak tracer concentration detected at the furthest fluorometer (about 2.8 km downstream) would be detectable by the fluorometer. The 10L bucket containing the Rhodamine WT 20% mixture was then quickly emptied across the width of the river to simulate an instantaneous injection. The time of the injection was recorded. Photograph 1 shows this instantaneous injection, Photograph 2 shows the West Credit River looking downstream of the injection point approximately 10 seconds after the instantaneous injection, and Photograph 3 shows the West Credit River approximately 1 minute after the instantaneous injection. The "parabolic-shaped" velocity profile which is the result of stream velocities that are higher through the centre of the river, and slower along the banks is clearly shown in Photograph 3.

Photograph 1. Rhodamine WT slug test dye injection on the West Credit River (Photo credit: Christine Furlong, Triton Engineering Services Limited)

Photograph 2. Rhodamine WT Dye Plume Approximately 10 seconds after Slug (Instantaneous) Injection

Photograph 3. Rhodamine WT Dye Plume Approximately 1 minute after Slug (Instantaneous) Injection.

The measured Rhodamine WT concentrations versus time were graphed for each of the fluorometer stations, with the time axis, (the x-axis), beginning at the recorded time of the slug injection, as illustrated in the following theoretical example (Figure 4).

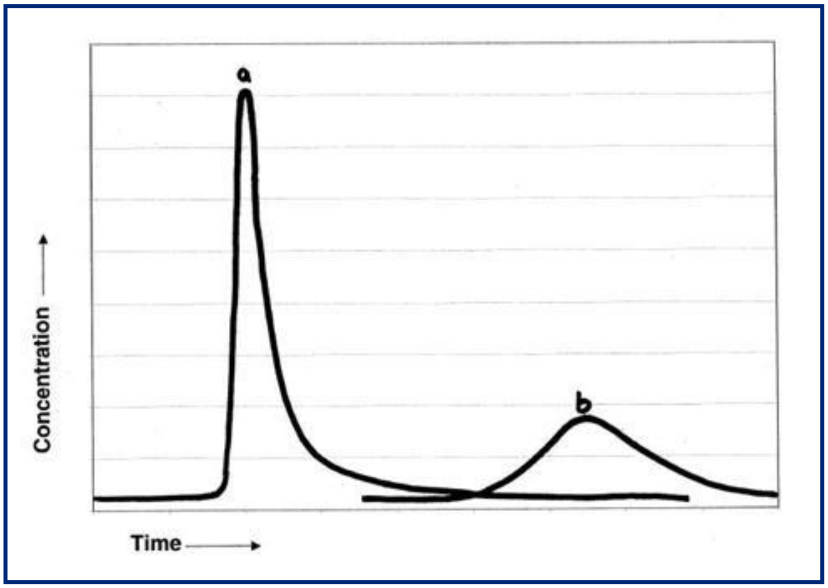


Figure 4. Example Graph of Rhodamine WT Concentration Versus Time for a Slug Injection Test

Figure 4 shows that the fluorometer closest to the injection point (i.e., line a in the figure) would exhibit a tracer peak that was higher and seen sooner than the peak at the other fluorometer station located further downstream (i.e., line b in the figure). The time of travel and longitudinal dispersion were computed by comparing the peak Rhodamine WT concentrations and the time between the slug injection and the peak.

The travel time ($\bar{t}$) between the dye injection point and a given fluorometer station was calculated by the following equation:

$$\bar{t} = \frac{\sum_{i=0}^{n-1}(c_i t_i + c_{i+1} t_{i+1})(t_{i+1} - t_i)}{\sum_{i=0}^{n-1}(c_i + c_{i+1})(t_{i+1} - t_i)} \qquad \text{Equation (2)}$$

where ci is the Rhodamine WT concentration at a given time, in µg/L;

ti is the corresponding time, in minutes elapsed since the time of injection; and

n is the number of data points collected by the fluorometer.

The temporal variance (s_t^2) was calculated from the data collected at each fluorometer by the following equation:

$$s_t^2 = \frac{\sum_{i=0}^{n-1}(c_i t_i^2 + c_{i+1}t_{i+1}^2)(t_{i+1} - t_i)}{\sum_{i=0}^{n-1}(c_i + c_{i+1})(t_{i+1} - t_i)}$$ Equation (3)

The mean velocity (U) between two fluorometer stations was calculated by the following equation:

$$U = \frac{x_2 - x_1}{\overline{t_2} - \overline{t_1}}$$ Equation (4)

where x is the distance between the dye injection point and the fluorometer, in m.

The longitudinal dispersion coefficient (E) between two stations was calculated by:

$$E = \frac{U^2(s_{t2}^2 - s_{t1}^2)}{2(\overline{t_2} - \overline{t_1})}$$ Equation (5)

The calculated times of travel, mean velocities, and dispersion coefficient values between each of the five fluorometer locations were input into the QUAL2K model for the West Credit River.

3.6 Mass Balance Modelling

The potential volume of treated effluent flows from the proposed Erin WWTP are limited by total phosphorus concentrations with respect to both treatment technology limits for TP removal in wastewater and fully mixed TP concentrations in the West Credit River. A mass balance model was used to back-calculate allowable maximum effluent flows based on a range of potential effluent TP concentrations and fully mixed TP concentrations in the river, assuming homogenous concentrations across the river cross-section.

Although there are several processes leading to loss of phosphorus from the water column of a river over the course of a year, these are balanced out by resuspension such that on average, phosphorus is not retained in a river system. The West Credit River was therefore assumed to not act as a net sink for TP and TP was assumed to behave as a conservative parameter. Modelling these processes is difficult using an un-calibrated water quality model and lacking an existing discharge where assimilation processes could be observed in the field. A mass balance model of phosphorus loadings to the West Credit River was therefore used as a conservative estimate of the likely total phosphorus concentrations under a variety of effluent limits.

Determination of the water quality in the West Credit River, at the point of complete and homogenous mixing between the WWTP effluent and the river, was achieved by solving the following mass-balance equation for $C_{d/s}$:

$$Q_{u/s}C_{u/s} + Q_{WWTP}C_{WWTP} = (Q_{u/s} + Q_{WWTP})C_{d/s}$$ (Equation 6)

Where:

$Q_{u/s}$ is the upstream flow in the West Credit River, prior to the proposed WWTP discharge;

$C_{u/s}$ is the upstream West Credit River concentration for the parameter of interest;

Q_{WWTP} is the Erin WWTP effluent flow;

C_{WWTP} is the Erin WWTP effluent concentration for the parameter of interest; and

$C_{d/s}$ is the fully mixed downstream concentration in the West Credit River for the parameter of interest.

The mass balance model does not assume any mixing zone – it is based on the fully mixed river concentrations and treats phosphorus as a conservative parameter – one which does not undergo any assimilation reactions after discharge.

Equation 6 was re-arranged to solve for Q_{WWTP} in order to determine the maximum possible effluent flows under a variety of TP effluent concentrations (Table 2), while maintaining TP concentration in the West Credit River at the site-specific objective of 0.024 mg/L (Appendix D).

$$Q_{WWTP} = \frac{Q_{u/s}(C_{d/s} - C_{u/s})}{C_{WWTP} - C_{d/s}} \quad \text{(Equation 7)}$$

HESL was directed by Ainley Group to carry forward a Phase 1 WWTP effluent flow of 3,380 m^3/s and a Full Build Out flow of 7,172 m^3/s for the complete assimilation modelling exercise based on the results of the TP mass balance modelling. These model results are detailed in Section 4.5.

Table 2. Mass Balance Modelling Inputs – Total Phosphorus

Parameter	Value	Rationale
Upstream West Credit River flow ($Q_{u/s}$)	0.225 m^3/s	The 7Q20 value, as calculated by Credit Valley Conservation (*Update of Low Flow Assessment (7Q20) for the West Credit River Assimilative Capacity Study (Erin SSMP),* CVC, June 2016).
Upstream West Credit River TP concentration ($C_{u/s}$)	0.016 mg/L	75th percentile concentrations of HESL (2016) and CVC (2007 & 2008) water quality data collected at 10th Line (15 data points)
WWTP effluent TP concentration (C_{WWTP})	0.15 to 0.04 mg/L	Effluent TP concentrations were varied from 0.15 mg/L (the effluent limit concentration proposed in the B.M. Ross, 2014, *West Credit River Assimilative Capacity Study*) to 0.04 mg/L (approaching the current limit of treatment technology)
Downstream West Credit River TP concentration ($C_{d/s}$)	0.024 mg/L	Recommended downstream maximum TP concentration based on Environment Canada and CCME guidance. (See Appendix D for additional details).

Mass balance modelling of total ammonia nitrogen (TAN) and nitrate were also completed as a “starting point” in determining effluent limits for these parameters (Equation 6) using the Phase 1 and Full Build Out effluent flows which were derived from the TP mass balance modelling (Equation 7) (Table 3). Since nitrification of TAN (and the generation of nitrate) in the West Credit River would be expected given that the river is well oxygenated (Section 3.1.3), these parameters were further modelled using the far-field longitudinal river model QUAL2K, which accounts for nitrification as well as denitrification. The QUAL2K modelling is discussed in Section 2.5. For the mass balance modelling of TAN, a mass balance to determine downstream temperature and pH was also carried out, and these downstream values then used to calculate fully mixed un-ionized ammonia concentrations.

Table 3. Mass Balance Modelling Inputs – Total Ammonia Nitrogen and Nitrate

Parameter	Value	Rationale
Upstream West Credit River flow ($Q_{u/s}$)	0.225 m^3/s	The 7Q20 value, as calculated by Credit Valley Conservation (*Update of Low Flow Assessment (7Q20) for the West Credit River Assimilative Capacity Study (Erin SSMP),* CVC, June 2016).
Upstream West Credit River concentration for parameter of interest ($C_{u/s}$)	• TAN – 0.055 mg/L • (Temperature – 21.18°C; pH – 8.21)* • Nitrate – 1.9 mg/L	• TAN and nitrate - 75th percentile concentrations of HESL (2016) and CVC (2007 & 2008) water quality data collected at 10th Line (15 data points). • Temperature – 75th percentile of August 2016 HESL temperature logger measurements at 10th Line • pH - 75th percentile of CVC hydrolab data (June and Aug 2008)
WWTP effluent concentration for parameter of interest (C_{WWTP})	• TAN – 0.7 to 1.3 mg/L • Nitrate – 5 to 6 mg/L • (Temperature 19°C; pH – 8.6)*	• Effluent TAN concentrations were varied from 1.3 mg/L (from email correspondence dated October 3, 2016 from the MOECC providing guidance on effluent limits [Appendix E]) to 0.07 mg/L (the Full Build Out TAN concentration required to meet the PWQO of 0.02 mg/L for un-ionized ammonia at fully mixed downstream). • Temperature – as proposed in the B.M. Ross, 2014, *West Credit River Assimilative Capacity Study*. • pH – as proposed in the B.M. Ross, 2014, *West Credit River Assimilative Capacity Study*. • Effluent nitrate concentrations were varied from 5 to 6 mg/L, the effluent objective and limit concentrations proposed in the B.M. Ross, 2014, *West Credit River Assimilative Capacity Study*.
WWTP effluent flow (Q_{WWTP})	Phase 1 – 0.039 m^3/s Full Build Out – 0.083 m^3/s	From results of the TP mass balance modelling, HESL was directed by Ainley Group to carry forward a Phase 1 WWTP effluent flow of 3,380 m^3/d (0.039 m^3/s) and a Full Build Out flow of 7,172 m^3/d (0.083 m^3/s).

3.7 Far-Field Water Quality Modelling (QUAL2K)

QUAL2K is a one-dimensional (1-D) river and stream water quality model, supported by the United States Environmental Protection Agency (US EPA), which is typically used to assess the environmental impact of pollution discharges along rivers. A wide range of water quality parameters and chemical and biological pollutants within the river can be modelled, including temperature, pH, dissolved oxygen (DO), carbonaceous biochemical oxygen demand (CBOD), nitrogen species, phosphorus species, and suspended solids.

Since QUAL2K is a 1-D model, the model assumes that all point source inputs (such as the outfall from the WWTF) are instantaneously mixed laterally and vertically at each particular point in the river. Variation in each water quality parameter modeled occurs only longitudinally (in the x-direction along the length of the river), and is computed as water is transported out of each reach and into the next. The QUAL2K model is known as a far-field model since its water quality predictions apply beyond the point in which the effluent is fully mixed with the river, also known as the far-field. Near-field modelling to the point of complete mixing was carried out using the CORMIX mixing zone model, Section 2.6; however, it is important to note that the QUAL2K model takes into account a larger variety of water quality and physical parameters and processes and thus is both more complex and more precise regarding the fate of pollutants in the river than the mixing zone model, CORMIX.

The outfall for the WWTP is proposed between 10th Line and Winston Churchill Blvd. Thus the West Credit River was modeled using QUAL2K from a point approximately 100 m upstream of the 10th Line to a point approximately 40 m downstream of Winston Churchill Blvd., for a total river model length of about 1.7 km. This 1.7 km stretch was sub-divided into smaller sections called "reaches", which are sections of the river with similar geomorphologic characteristics (Section 3.4) based on our physical attributes survey, to create an accurate simulation of the river for the model. A total of 6 reaches were identified for the model, denoted as Reach 0 through Reach 5, where Reach 0 is located upstream of 10th Line (Section 4.3, Figure 9).

3.7.1 Model Input

The main input parameters for the QUAL2K model are summarized in Table 4.

The far-field modelling was limited to the summer scenario since it is the most critical season due to increased water temperatures which result in increased speciation of ammonia to its un-ionized form. As such, summer temperatures are reflected in the model inputs.

Table 4. Model Input Parameters for QUAL2K Far-field Assimilation Modelling

Parameter	Value	Rationale
Receiving Water Characteristics (West Credit River at 10th Line)		
pH	8.21	• The 75th percentile of CVC hydrolab data (June and Aug 2008) • Note that 75th percentile of HESL 2016 and CVC (2007-2008) point measurements was 8.11
Water temperature	21.18 °C	• The 75th percentile of August 2016 HESL temperature logger measurements at 10th Line

Parameter	Value	Rationale
		• Note that the 75th percentile summer temperature (June through August 2016) from the HESL temperature logger was 20.66ºC
Dissolved oxygen	7.72 mg/L	• 25th percentile August 2016 HESL DO logger at 10th Line • 7.93 mg/L – 25% June to August 2016 HESL DO logger
Conductivity	613 µS/cm	• 75th percentile from CVC hydrolab data (June and Aug 2008) • Note that 75th percentile of HESL 2016 and CVC (2007-2008) point measurements was 600 µS/cm
Nutrients	TAN: 0.055 mg/L Nirate-N: 1.90 mg/L TKN: 0.590 mg/L TP: 0.016 mg/L Inorganic P: 0.0081 mg/L Organic P = TP-InorgP Organic N = TKN-TAN	• 75 percentile of HESL (2016) and CVC (2007 & 2008) data collected at 10th Line (15 data points) • Organic phosphorus and Inorganic phosphorus – based on 75th percentile of HESL (2016) data collected at 10th Line (5 data points)
Inorganic Solids (ISS)	ISS= TSS-VSS TSS: 3.2 mg/L VSS: <3 mg/L	• 75th percentile of HESL 2016 data collected at 10th Line (5 data points). Did not use CVC data because TSS had high detection limit of 10 mg/L and no VSS data.
$cBOD_{fast}$	2.70 mg/L	• 75th percentile of HESL 2016 cBODu collected at 10th Line (5 data points)
Chlorophyll a	2.72 µg/L	• 75th percentile of HESL 2016 data collected at 10th Line (5 data points)
Alkalinity	281 mg/L	• From May 2011 report by CVC, Aquafor Beech Inc, and Blackport Hydrogeology Inc.: *Erin Servicing and Settlement Master Plan, Phase 1 – Environmental Component – Existing Conditions Report.*
E. coli	160 cfu/100 mL	• CVC 2007-2008 (10 points)
Flow	0.225 m^3/s	• 7Q20 flow at 10th Line, from CVC 2016 report: *Update of Low Flow Assessment (7Q20) for the West Credit River Assimilative Capacity Study (Erin SSMP)* • Accounts for climate change (subtracted 10% from 7Q20 flow)
Manning's n	0.035 – 0.045	• Initially based on June 10, 2016 field reconnaissance, refined through calibration with river velocities computed from dye tracer study
Bottom Algae coverage	15% to 40%	• Based on the June 10, 2016 field reconnaissance
Channel slope	0.0008 to 0.003	• From June 10, 2016 survey, averaged within each reach, refined through calibration with river velocities computed from dye tracer study
Bank slope	0.17 to 0.66	• From June 10, 2016 survey

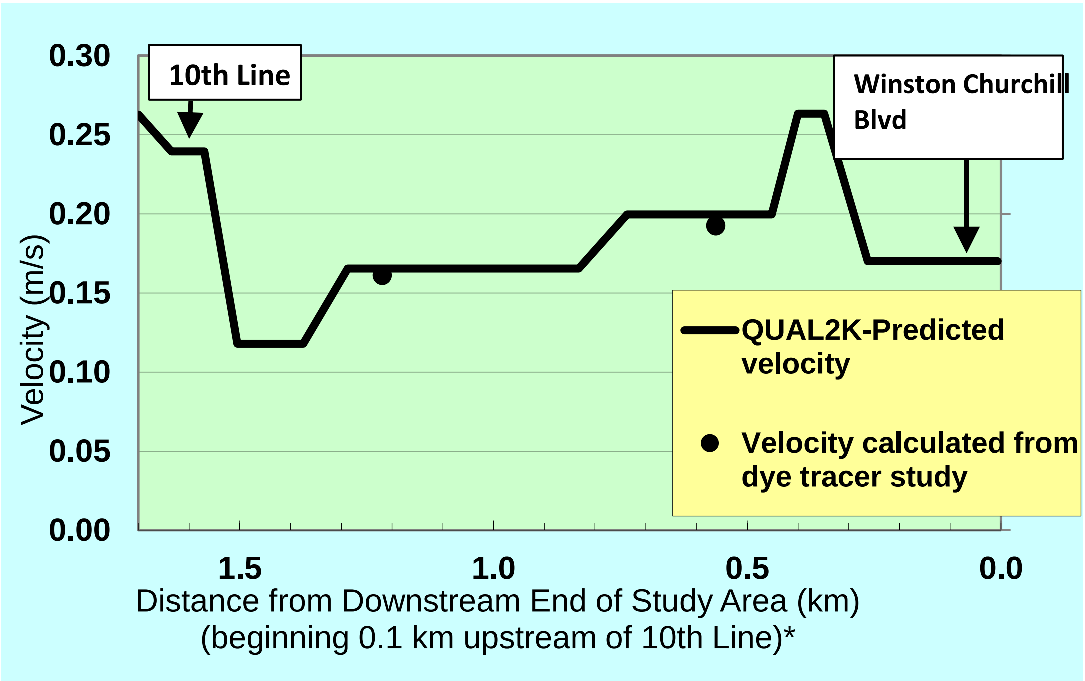
Parameter	Value	Rationale
Air Temperature	21.9°C to 29.7°C	• From Environment Canada's Historic Climate Data records for August 25, 2016 for Georgetown WWTP
Dew Point Temperature	17.7°C to 22.2°C	• From Environment Canada's Historic Climate Data records for August 25, 2016 for Georgetown WWTP
Wind speed	2 m/s	• Recommended for conservative design conditions
Shade	20% to 53%	• From June 10, 2016 survey, averaged within each reach
Effluent Characteristics (Proposed Erin WWTP)		
Flow rate	Phase 1 – 0.039 m^3/s Full Build Out – 0.083 m^3/s	• From results of the TP mass balance modelling, HESL was directed by Ainley Group to carry forward a Phase 1 WWTP effluent flow of 3,380 m^3/d (0.039 m^3/s) and a Full Build Out flow of 7,172 m^3/d (0.083 m^3/s).
TAN	Phase 1 – 1.3 mg/L (summer); 2 mg/L (winter) Full Build Out – 0.7 mg/L (summer); 2 mg/L (winter)	• Phase 1 - From email correspondence dated October 3, 2016 from the MOECC providing guidance on effluent limits (Appendix E), confirmed through mass balance modelling. • Full Build Out - From mass balance modelling: TAN concentration required to meet the PWQO of 0.02 mg/L for un-ionized ammonia at fully mixed downstream.
Temperature	19°C	• Maximum value, as proposed in the B.M. Ross, 2014, *West Credit River Assimilative Capacity Study*.
pH	8.6	• Maximum value, as proposed in the B.M. Ross, 2014, *West Credit River Assimilative Capacity Study*.
Nitrate-N	5 mg/L	• As proposed in the B.M. Ross, 2014, *West Credit River Assimilative Capacity Study*, confirmed value through mass balance modelling.
TP	Phase 1 – 0.07 mg/L Full Build Out – 0.045 mg/L	• From mass balance modelling, TP effluent concentrations relating to desired effluent flows.
cBOD	5 mg/L	• From email correspondence dated October 3, 2016 from the MOECC providing guidance on effluent limits (Appendix E).
Dissolved oxygen	4 mg/L	• From email correspondence dated October 3, 2016 from the MOECC providing guidance on effluent limits (Appendix E), and as proposed in the B.M. Ross, 2014, *West Credit River Assimilative Capacity Study*.

Parameter	Value	Rationale
Conductivity	1,000 µS/cm	• Based on measured effluent conductivity from existing WWTPs in southern Ontario (Simcoe WPCP, Delhi WPCP).
TSS	5 mg/L	• From email correspondence dated October 3, 2016 from the MOECC providing guidance on effluent limits (Appendix E).
E.coli	100 CFU/100 mL	• From email correspondence dated October 3, 2016 from the MOECC providing guidance on effluent limits (Appendix E), and as proposed in the B.M. Ross, 2014, *West Credit River Assimilative Capacity Study*.
Model Parameters		
CBOD oxidation rate	2 /d	Set near mid-point of range (0 to 5/d). The West Credit River does not have a high background CBOD concentration; however, oxidation of CBOD requires DO, and therefore to be conservative in our estimates of DO sag concentration in the study area, we set the CBOD oxidation rate at the mid-point of the range instead of at the low end.
Organic nitrogen - hydrolysis	0.1 /d	Conservative estimate. Set at low end of range (0 to 5/d).
Organic nitrogen – settling velocity	0.1 /d	Conservative estimate. Set at low end of range (0 to 2/d).
Nitrification rate	5/d	Set near mid-point of range (0 to 10/d). Literature review of similar streams indicates range of 0.2 to 9/d (EPA 1985). Note that nitrification is at its maximum at pH=8.5 and temperatures between 25 and 35 deg C and is high in shallow streams, thus medium to high rates would be expected for West Credit River. Further downstream TAN concentrations derived by mass balance (Section 4.5) conservatively assume zero nitrification, so the QUAL2K model nitrification rate provides a more realistic scenario.
Denitrification	0.1 /d	Set at low end of range (0 to 2/d). High rates of denitrification would not be expected in the West Credit River study area since it is well oxygenated with low CBOD.
Organic P - hydrolysis Rate	0.1 /d	Conservative estimate. Set at low end of range (0 to 15/d).
Reaeration Model	Tsivoglou-Neal	Default model selection in QUAL2K.

Although no point source currently exists within the West Credit River study area with which to calibrate and validate the water quality predictions of the QUAL2K model, the hydraulic component of the model was calibrated using the river velocities calculated from the dye tracer study conducted on August 25, 2016

(Section 3.3) and the river flow measured on that same day at a location approximately 75 m downstream of 10th Line (and outside the influence of the beaver dam). Manning's n values and channel slopes were varied in order to calibrate the hydraulic model results to those computed from the dye tracer study.

The precision of the hydraulic predictions from the QUAL2K model calibration are presented graphically in Figure 5, where the dye tracer study (i.e., field-calculated) velocities are plotted against the model-predicted velocities. Note that the river velocities computed from the dye tracer study are plotted at the mid-point location between fluorometer stations. The average velocity in the study area, computed through the dye tracer study results, was 0.17 m/s. The QUAL2K average velocity in the study area was 0.177 m/s. Thus the hydraulic results from the QUAL2K model calibrated well to the field results and the model was deemed to be acceptable for use in predicting far-field water quality.



*QUAL2K model calculates using a descending distance from the upstream-most point in the study area. In this case, the model begins at 1.7 km (which corresponds to 100 m upstream of 10th Line) and ends at 0 km (which corresponds to 40 m downstream of Winston Churchill Blvd.).

Figure 5. QUAL2K Velocity Calibration Results

3.8 Mixing Zone Modelling (CORMIX)

The receiver (i.e., West Credit River) water quality must be maintained within PWQO except for the volume of water within the mixing zone. From *Deriving Receiving Water Based, Point-Source Effluent Requirements for Ontario Waters* (MOE, 1994b), the mixing zone is defined two ways:

- The volume of water contiguous to the discharge in which the effluent undergoes physical mixing with the receiver such that dilution by mixing is the dominant process reducing effluent concentrations in the water; or
- The volume of water contiguous to the discharge in which concentrations of effluent parameters exceed their respective PWQOs.

The mixing zone model provided information on effluent plume behaviour and pollutant concentrations in the near-field mixing zone. The mixing zone model focused on the physical component of modelling, where assimilation processes were dominated by mixing and dilution of the effluent with the receiving waters. (Note that in order to model assimilation of pollutants by the complex physical, chemical and biological processes in a river system beyond the point of complete mixing, the far-field water quality model QUAL2K was applied, as detailed in Section 3.7).

The mixing zone modelling focussed on ammonia as the potentially toxic component of the effluent that is assimilated by a) dilution in the near field area through initial mixing with the river and b) nitrification, the biological conversion of ammonia to nitrate. There were two aspects to the assessment of ammonia:

- The requirement that undiluted effluent be non-acutely lethal at the point of discharge. This was calculated without the need for an assimilation model and is based solely on the toxicity of ammonia in the effluent; and
- The determination of the size and characteristics of the mixing zone for ammonia in the West Credit River since this is the volume of water in which concentrations will exceed the PWQO of 0.02 mg/L of un-ionized ammonia (MOE, 1994). The mixing zone is allowed under MOECC surface water quality Policy 5 (MOE, 1994). The size of the mixing zone is determined by modelling the physical mixing of effluent with the river and then setting an ammonia limit for the effluent which will maintain the un-ionized ammonia concentration below the PWQO outside of the mixing zone. For a smaller receiver such as West Credit River, this limit will be lower than that required to maintain non-lethal effluent.

The near-field mixing of the proposed Erin WWTP discharge with the West Credit River was hydrodynamically modeled using CORMIX Version 10.0. CORMIX is a software system developed by Cornell University for the analysis, prediction, and design of aqueous toxic or conventional pollutant discharges into diverse water bodies. The model classifies the discharge configuration into generic flow classifications and then assembles and executes a sequence of sub-models to simulate the hydrodynamic behaviour of the discharge, calculating the plume trajectory, dilution and maximum centerline concentration. CORMIX was used to predict water quality up to and including the point of complete mixing between the effluent and the West Credit River. Downstream of the point of complete mixing, the QUAL2K model was used to predict water quality in the West Credit River, as discussed in Section 3.7.

The basis of the CORMIX model is a flow classification system. The model classifies the discharge configuration into generic flow classifications based on dimensionless length scales (Gomm, 1999). Once the flow has been classified, the model assembles and executes a sequence of sub-models to simulate the hydrodynamic behaviour of the discharge, and calculates the plume trajectory, dilution and maximum centerline concentration. CORMIX uses these different sub-models to predict mixing in both the near-field region and far-field region from the discharge point. The terminology "near-field" and "far-field" in the internal CORMIX usage have no relation to the point of complete mixing – the near-field region refers to the region where the initial jet characteristics, including momentum flux and buoyancy flux, and outfall geometry govern the plume mixing. The "far-field" region is representative of where conditions existing in the ambient environment (such as density current buoyant spreading and passive diffusion within the West Credit River) govern the trajectory and dilution of the plume. The distance to the boundary between the near-field to far-field regions depends on the model input parameters as determined by river characteristics and the scenario modelled (i.e. effluent flow, discharge configuration).

The CORMIX model output displays the predicted centerline concentration moving downstream from the outfall location. The centreline concentration is the maximum concentration and the corresponding x, y and z co-ordinates are returned in the model output (x – longitudinal distance downstream; y – across river width; z – river depth). To compute concentrations laterally outward from the centerline concentration at any given longitudinal point (i.e., x is constant, varying y), the following formula was used:

$$C(n) = C_c e^{-\left(\frac{n}{b}\right)^2} \qquad \text{(Equation 8)}$$

Where:

C(n) is the lateral concentration;

C_c is the centreline concentration;

n is the y co-ordinate position measured transversely away from the centreline concentration position y-coordinate; and

b is the plume half-width and the longitudinal position of interest.

Note that this formula can only be applied to the "far-field" predictions of the CORMIX model, which were those areas of the mixing zone governed by buoyant spreading and passive diffusion.

The Erin WWTP discharge to the West Credit River for Phase 1 flows was modeled using CORMIX3, a subsystem which is used for buoyant surface discharges, and schematized as a round pipe located at the water surface level. The Phase 1 flows were also modelled using the CORMIX2 subsystem for multi-port discharges, schematized as a buried 5 m long multi-port diffuser running parallel to the south bank of the West Credit River, with vertical ports located along the river bed. The Full Build Out flows were modelled using the same CORMIX2 system for multi-port discharges.

3.8.1 Model Inputs

Table 5 presents the CORMIX model inputs. Note that the CORMIX model could not be calibrated or validated because no point source currently exists. The rationales for each of the inputs are provided immediately following the table.

Table 5. CORMIX Model Inputs – Total Ammonia Nitrogen

Input Parameter	Effluent Flows		
	Phase 1 – single pipe	Phase 1 – multi-port diffuser	Full Build Out - multi-port diffuser
Effluent Worksheet:			
Conservative/non-conservative pollutant	Non-conservative		
Decay rate (1/d) if non-conservative	5	5	
Discharge Concentration (mg/L)	1.3	0.7	
Discharge excess concentration (mg/L)	1.245	0.645	
Effluent flow rate (m^3/s)	0.039	0.083	
Effluent temperature (°C)	19.0		
Ambient Worksheet:			
Average channel depth (m)	0.4		
Depth at discharge (m)	0.3	0.4	
Wind speed 2 m above water surface (m/s)	2		
Ambient West Credit River flow rate (m^3/s)	0.225		
Ambient Concentration (mg/L)	0.055		
Bounded width (m)	11		
Bounded appearance	Highly irregular		
Manning's n	0.035		
Ambient temperature (°C)	21.18		
Ambient pH	8.21		
Discharge Worksheet (CORMIX3):			
Discharge bank (looking downstream)	Right	n/a	n/a
Discharge configuration	Flush with bank	n/a	n/a
Horizontal angle (degrees)	90 (pipe enters perpendicular to bank)	n/a	n/a
Discharge pipe diameter (m)	0.2	n/a	n/a
Bottom depth invert (m)	0.2	n/a	n/a
Discharge Worksheet (CORMIX2):			
Discharge bank (looking downstream)	n/a	Right	
Diffuser length (m)	n/a	5	
Distance from bank (m)	n/a	0.5	
Port height above river bottom (m)	n/a	0	
Port diameter (m)	n/a	0.05	
Contraction ratio	n/a	1	
Total # of ports	n/a	10	15
Alignment angle (degrees)	n/a	0 (diffuser is parallel to current)	

Input Parameter	Effluent Flows		
	Phase 1 – single pipe	Phase 1 – multi-port diffuser	Full Build Out - multi-port diffuser
Vertical angle of port discharge (degrees)	n/a	90 (vertical, pointing upward)	
Mixing Zone Worksheet:			
PWQO (in mg/L)	0.02[A]		
Excess concentration for the WQS (mg/L)	0.220		0.205

Notes: A – PWQO for un-ionized ammonia; n/a – not applicable

Effluent Worksheet

Parameters may be modeled as either conservative (concentrations are reduced by physical mixing and dilution only) or non-conservative (concentrations are reduced by biological assimilation processes). TAN was modeled as a non-conservative parameter with a rate of decay of 5/d. This is the same nitrification rate used in the QUAL2K model. A literature review of similar streams indicated a range of 0.2 to 9/d (EPA 1985). Note that nitrification is at its maximum at pH=8.5 and temperatures between 25 and 35 deg C and is high in shallow streams, thus medium to high rates would be expected for the West Credit River. TAN concentrations derived for further downstream by mass balance (Section 3.6) conservatively assume zero nitrification, so the nitrification rate of 5/d provides a more realistic scenario.

The discharge excess concentration refers to the excess concentration of the effluent above background (i.e., West Credit River at 10th Line) concentrations. The 75th percentile background TAN concentration was 0.055 mg/L (calculated from HESL 2016 and CVC 2007 and 2008 data). For Phase 1 effluent flows, the summer TAN effluent limit is proposed at 1.3 mg/L and for Full Build Out, the TAN summer effluent limit is 0.7 mg/L. Therefore, the discharge excess concentration for Phase 1 was 1.245 mg/L (i.e., 1.3 mg/L – 0.055 mg/L) and for Full Build Out was 0.645 mg/L (i.e., 0.7 mg/L – 0.055 mg/L).

The discharge flows were from results of the TP mass balance modelling: HESL was directed by Ainley Group to carry forward a Phase 1 WWTP effluent flow of 3,380 m^3/d (0.039 m^3/s) and a Full Build Out flow of 7,172 m^3/d (0.083 m^3/s).

The effluent temperature was the maximum summer value, as proposed in the B.M. Ross 2014 report, *West Credit River Assimilative Capacity Study*.

Ambient Worksheet

The West Credit River flow was assigned the 7Q20 value of 0.225 m^3/s, calculated by CVC (Appendix B). This 7Q20 value includes a 10% reduction as an estimate of future climate change on low flow.

Inputs for the bounded width, and the depth at discharge in the West Credit River near 10th Line were based on measurements collected during the 2016 field events. For the river geometry, CORMIX requires that the cross-section of the river be "schematized" as a rectangular channel. The average depth dimension was calculated based on the depth measurements made 75 m downstream of 10th Line (and outside of the influence of the beaver dam). The depth at discharge was set at 0.3 m for the pipe discharge (Phase 1) since the pipe would be originating from the bank and therefore be a smaller depth than the average depth in the river. For the multi-port diffuser discharge, the depth was set to the full average depth of 0.4 m since the diffuser was modelled as resting on the river bottom.

A wind speed of 2 m/s was used for all scenarios. In the absence of field data, this is the velocity recommended by CORMIX for conservative design conditions.

Manning's n (describing channel roughness and friction) was set at 0.035 based on hydraulic model calibration completed for the QUAL2K model (Section 3.7). The bounded appearance of "highly irregular" was set based on field observations of the local sinuosity of the river.

The ambient temperature of 21.18°C was the 75th percentile of August 2016 HESL temperature logger measurements at 10th Line.

Discharge Worksheet

Under the "discharge" worksheet, the discharge bank location is the location of the nearest bank to the outfall when facing downstream[2] in the direction of the river flow. For the Erin WWTP outfall, this would be the right bank (i.e., south bank).

For the Phase 1 single pipe discharge scenario:

- The discharge was modelled as being flush with the bank, rather than protruding or co-flowing.
- The horizontal angle was the angle of the discharge channel centreline with respect to the direction of river flow. Since the channel enters perpendicular to the bank, the angle was set to 90°.
- The pipe diameter of 0.2 m and bottom depth invert of pipe of 0.2 m were set based on model runs to minimize the size of the mixing zone.

For the Phase 1 and Full Build Out multi-port diffuser scenarios:

- The diffuser length were set to 5 m, oriented parallel to the bank and river current (i.e., an alignment angle of 0°), at a distance of 0.5 m from the bank. This configuration was set based on model runs to minimize the size of the mixing zone, while allowing for fish passage along the bank opposite to the diffuser.
- The diffuser ports were located along the river bed, oriented vertically upward (i.e., a vertical angle of 90°), with port diameters of 0.05 m. We have proposed 10 ports for the Phase 1 discharge and 15 ports for the Full Build Out discharge. (Therefore five ports would be "closed off" for Phase 1 flows and "opened up" for Full Build Out flows). Recommended pipe discharge velocities are within the range of 3 m/s to 8 m/s (Doneker, 2007). The number of ports and their diameter were based on velocity calculations, and while the resulting velocities at Phase 1 and Full Build Out were on the low end of this range, these smaller velocities prevent the plume from quickly spreading across the width of the river,

[2] *Note that, conventionally-speaking, bank direction is typically assigned as standing facing upstream. CORMIX assumes facing a downstream direction when assigning bank direction.*

thereby allowing for fish passage. Detailed modeling of discharge port configuration will be carried out in subsequent project stages.

- The contraction ratio represents the “roundedness” of the discharge port. A ratio of 1 was used to represent a well-rounded port.

Mixing Zone Worksheet

Mixing zone modelling requires calculation of the “excess concentration” for the water quality standard over the upstream (background) concentration, or the amount of additional concentration that could be added to the background concentration to maintain the total concentration below the PWQO.

There is no PWQO for TAN but the PWQO for un-ionized ammonia is 0.02 mg/L. As such, the maximum excess concentration for TAN in order to remain below the PWQO for un-ionized ammonia was determined by back-calculating TAN from an un-ionized ammonia concentration of 0.02 mg/L using downstream, fully mixed pH and temperature values that were derived by mass balance for Phase 1 and Full Build Out flows, and subtracting the upstream TAN concentration of 0.055 mg/L from this concentration (Table 6).

Table 6. Calculated Downstream River pH and Temperature and Maximum Excess Concentration of Total Ammonia Nitrogen in the Effluent, for CORMIX Input

Parameter	Phase 1 (0.039 m^3/s)	Full Build Out (0.083 m^3/s)	Rationale
Upstream West Credit River pH and Temperature	pH – 8.21 Temperature – 21.18°C		• The 75th percentile of CVC hydrolab data (June and Aug 2008) • The 75th percentile of August 2016 HESL temperature logger measurements at 10th Line
WWTP pH and Temperature	pH – 8.6 Temperature – 19°C		• Maximum values, as proposed in the B.M. Ross, 2014, *West Credit River Assimilative Capacity Study*.
Resulting Downstream pH and Temperature	pH – 8.27 Temperature – 20.86°C	pH – 8.32 Temperature – 20.59°C	• By mass balance
Maximum TAN allowable to meet PWQO for un-ionized ammonia at downstream pH and temperature	0.275 mg/L	0.260 mg/L	• Calculated using equation given in *Water Management* (MOE 1994)
Excess TAN concentration over background	0.220 mg/L	0.205 mg/L	• Subtraction of maximum effluent TAN concentration (row above) from 0.055 mg/L (upstream river TAN concentration)

4. Results

4.1 Water Quality

Water quality results are presented in Table 7. Water quality measurements collected at 10th Line confirmed our understanding of baseline conditions for the West Credit River. In 2016 water quality at 10^{th} Line was very good with low concentrations of suspended sediment (TSS), and nutrients (e.g. nitrate, TKN, TP, and ammonia). Total phosphorus (TP), and un-ionized ammonia (UI-TAN) concentrations were well below their PWQO values of 0.03 and 0.02 mg/L respectively; indicating Policy 1 status for these parameters. Dissolved oxygen concentrations were above the PWQO (temperature dependant), indicting a well oxygenated system.

Water samples were also collected at 10^{th} Line in 2007 and 2008 (CVC 2011). This water quality data was used to characterize background water quality to inform the ACS. Water quality from 2016 was similar to water quality data measured in 2007 and 2008 (CVC 2011; Table 3), which the exception of TSS. The detection limit for TSS in 2007 and 2008 (<10 mg/L) was higher than the detection limit (<2 mg/L) and TSS concentrations in 2016, therefore comparisons between these results cannot be made. The 2007, 2008, and 2016 data were used to compute the 75^{th} percentile concentrations for the ACS modelling (as per MOECC guidance, Section 1.4). Due to the differences in TSS detection limits between sampling years, only the 2016 TSS data was used to ensure that background concentrations were not overestimated.

Water quality data collected from the West Credit River at Winston Churchill Blvd. (PWQMN station 06007601502) from 2000-2014 was compared to data collected at 10^{th} Line for 2007, 2008, and 2016. The 75^{th} percentile concentrations computed for Winston Churchill Blvd., are for the most part, similar or lower than the 75^{th} percentile concentrations calculated for 10^{th} Line. The lower concentrations of nutrients at Winston Churchill Blvd. has been attributed (CVC 2011) to the input of groundwater between these two stations. The 10^{th} Line statistics (e.g. 75^{th} percentile, median and average values) are based on 5-15 sampling points collected over 3 years (2007, 2008, and 2016), while the Winston Churchill Blvd. statistics are based on 144-164 sampling points over 14 years (2000-2014). Although the statistics calculated for 10^{th} Line are based on a reduced dataset as compared to Winston Churchill Blvd., the 75^{th} percentile concentrations are more conservative (higher predicted background) than those calculated for Winston Churchill Blvd., and therefore were used as inputs into the water quality models (as recommended by CVC and MOECC).

Table 7 Water Quality of West Credit River

Location	Date	Source	VSS	TSS	TAN	UI-TAN	NO_3-N	NO_2- N	TKN	PO_4	TDP	TP	cBOD	cBODu	Chl a (µg/L)
	PWQO/CWQG					0.02	3	0.06				0.030			
	27-May-16	HESL	<3	4.8	<0.020	0.0006	1.50	<0.01	0.72	<0.003	0.0059	0.0136	<2	3	3.91
	29-Jun-16	HESL	<3	2.4	<0.020	0.0002	1.42	<0.01	0.58	<0.003	0.0062	0.0155	<2	<2	1.97
	27-Jul-16	HESL	<3	3.2	0.027	0.0006	1.27	<0.01	0.53	<0.003	0.0113	0.0162	<2	2.7	2.63
	25-Aug-16*	HESL	<3	2.0	0.023	0.0016	1.27	<0.01	0.35	<0.003	0.0081	0.0103	<2	<2	2.72
	28-Sep-16*	HESL	<3	2.0	<0.020	0.0009	1.58	<0.01	0.39	0.0035	0.0060	0.0088	<2	<2	0.598
	31-Oct-07	CVC		<10	0.030	0.001	2.4		0.5			0.007	<2		
	26-Sep-07	CVC		<10	0.150	0.011	0.8		0.6			0.030	<2		
	26-Nov-07	CVC		<10	0.090	0.000	2.3		0.4			0.009	<2		
10th Line	31-Jan-08	CVC		<10	0.070	0.001	2.3		0.6			0.003	<2		
	26-Mar-08	CVC		<10	0.050	0.000	2.0		0.5			0.014	<2		
	29-Apr-08	CVC		<10	0.060	0.002	1.5		0.5			0.007	<2		
	25-Jun-08	CVC		<10	0.010	0.001	1.3		0.5			0.011	<2		
	27-Aug-08	CVC		<10	0.010	0.000	1.8		0.6			0.015	<2		
	30-Sep-08	CVC		<10	0.030	0.001	1.7		0.5			0.02	<2		
	05-Nov-08	CVC		<10	0.030	0.001	1.8		0.4			0.02	<2		
	75%		3	3.2	0.055	0.0010	1.9	0.010	0.59	0.003	0.008	0.016	2	2.7	2.72
	median		3	2.4	0.030	0.001	1.58	0.010	0.50	0.003	0.006	0.014	2	2	2.63
	n		5	5	15	15	15	5	15	5	5	15	15	5	5
Winston Churchill Blvd. (2000-2014)	75%			4.0	0.019	0.0003	2.11	0.009	0.43	0.0025		0.015	1.0		
	median			2.3	0.011	0.0002	1.72	0.007	0.36	0.0011		0.011	0.6		
	n			158	164	144	163	164	164	164		164	156		

*Notes: all values in mg/L unless noted, *water samples collected 75 m downstream of 10th Line.*

4.1.1 Dissolved Oxygen and Temperature

Diurnal DO and temperature records (June 10 to August 25, 2016) for the West Credit River at 10th Line and Winston Churchill Blvd. are presented on Figures 6 and 7. Dissolved oxygen conditions in the West Credit River were excellent during this period. Concentrations ranged from 6.71 to 12.98 mg/L at 10th Line, and 7.44 to 12.44 mg/L at Winston Churchill Blvd., well above the PWQO of 6 mg/L for water temperatures of 10 ºC or more (Figures 6 and 7). Nighttime maxima for dissolved oxygen indicated supersaturated conditions. Minimum dissolved oxygen concentrations were slightly higher, and maximum concentrations were slightly lower at Winston Churchill Blvd. (Table 8) than 10th Line, indicating lower diurnal fluctuations in dissolved oxygen. Groundwater discharge in this reach reduced the temperature (Table 8) which would increase dissolved oxygen minima.

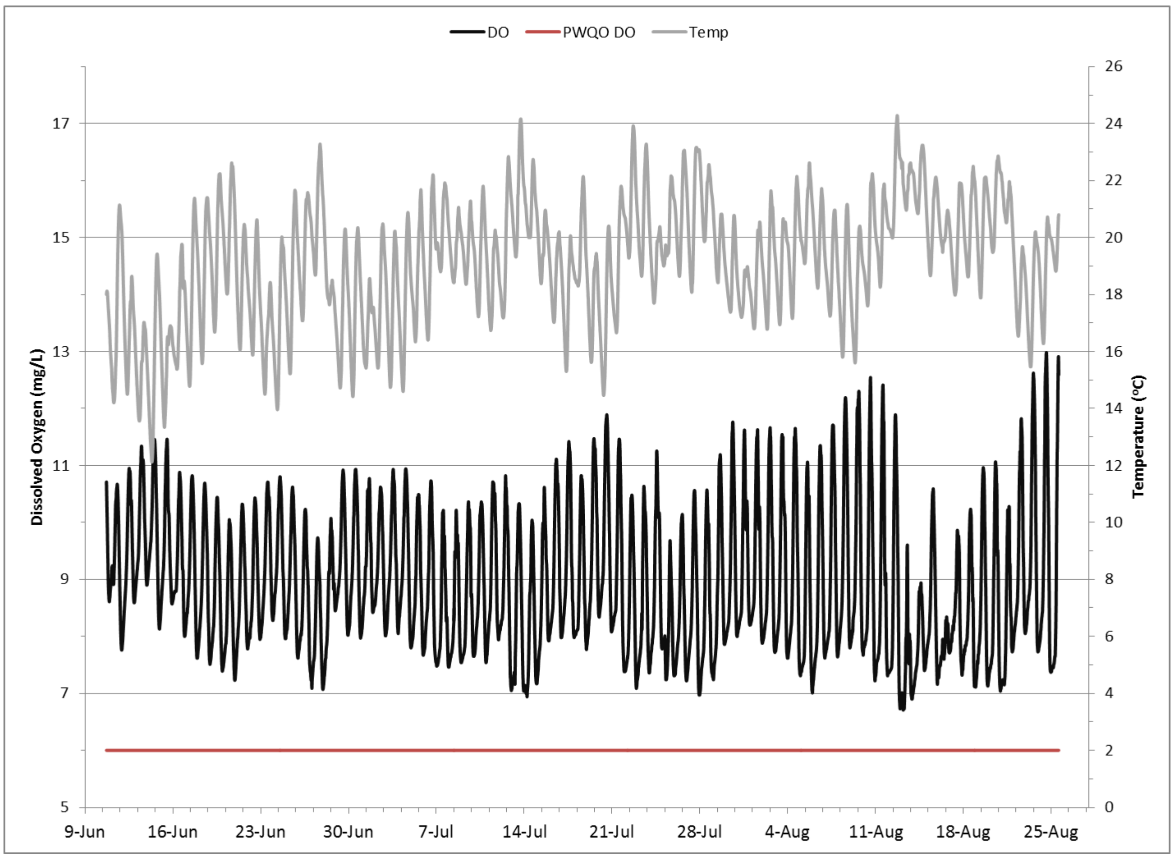


Figure 6 Continuous Dissolved Oxygen and Temperature measurements in the West Credit River at 10th Line (June 10 to August 25 2016)

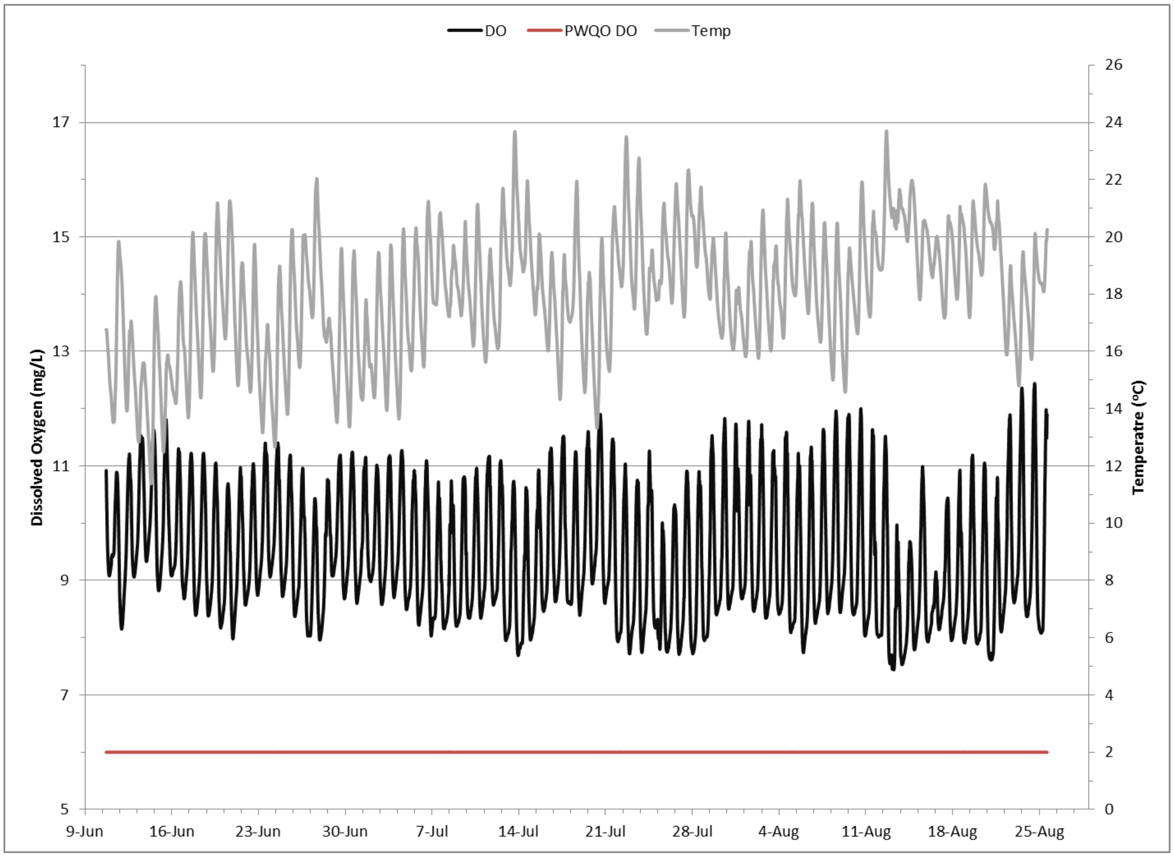


Figure 7 Continuous Dissolved Oxygen and Temperature measurements in the West Credit River at Winston Churchill Blvd. (June 10 to August 25 2016)

Twenty fifth (25th) percentile dissolved oxygen concentrations were calculated (Table 8) for each location as input into the QUAL2K model. Twenty fifth percentile concentrations calculated for 10th Line were lower than those calculated for Winston Churchill Blvd., were and thus a conservative estimate of upstream dissolved oxygen conditions for the ACS.

Table 8 Minima, Maxima, and 25th Percentile Dissolved Oxygen Concentrations (mg/L)

	10th Line			Winston Churchill Blvd.		
	Min	Max	25%	Min	Max	25%
June	7.07	11.46	8.28	7.96	11.81	8.89
Jul	6.94	11.89	7.96	7.69	11.90	8.48
Aug	6.71	12.98	7.72	7.44	12.44	8.29
All Data	6.71	12.98	7.93	7.44	12.44	8.5

Water temperatures ranged from 12.12 to 24.28ºC at 10th Line, and 11.38 to 23.70ºC at Winston Churchill Blvd. The maximum water temperatures were below 26 ºC; below CVC's absolute maximum threshold for coldwater habitat. Minimum and maximum water temperatures were slightly lower at Winston Churchill Blvd. than 10th Line (Table 9). The lower water temperatures at Winston Churchill Blvd are likely from groundwater input cooling the water between the two stations. Seventy-fifth (75th) percentile water temperatures were calculated (Table 3) as input into the QUAL2K model. Seventy-fifth (75th) percentile water temperatures calculated for 10th Line were higher than those calculated for Winston Churchill Blvd., and thus are a conservative estimate of upstream water temperatures for the ACS.

Table 9 Minima, Maxima, and 75th Percentile Water Temperatures (ºC)

	10th Line			Winston Churchill Blvd.		
	Min	Max	75%	Min	Max	75%
June	12.12	23.28	19.66	11.38	22.04	18.18
Jul	14.46	24.16	20.66	13.32	23.68	19.53
Aug	15.46	24.28	21.18	14.58	23.70	20.26
All Data	12.12	24.28	20.66	11.38	23.70	19.58

Dissolved oxygen conditions downstream of 10th Line were monitored in September 2016 (Table 10 and Figure 8). Concentrations were well above the PWQO of 6 mg/L for a water temperature of 10 ºC with a minimum concentration of 7.57 mg/L and maximum concentration of 13.27 mg/L. The diurnal fluctuations in dissolved oxygen decreased around September 7, 2016. At the same time, water temperatures in the river began to show an overall cooling. Minimum and minimum temperatures during this period were 10.08 and 22.36 ºC respectively (Table 10).

Table 10 Summary of Dissolved Oxygen and Water Temperatures 75 m downstream of 10th Line

	DO			POWQO	Temp		
	Min	Max	25%		Min	Max	75%
September	7.57	13.27	8.77	6	10.08	22.36	18.6

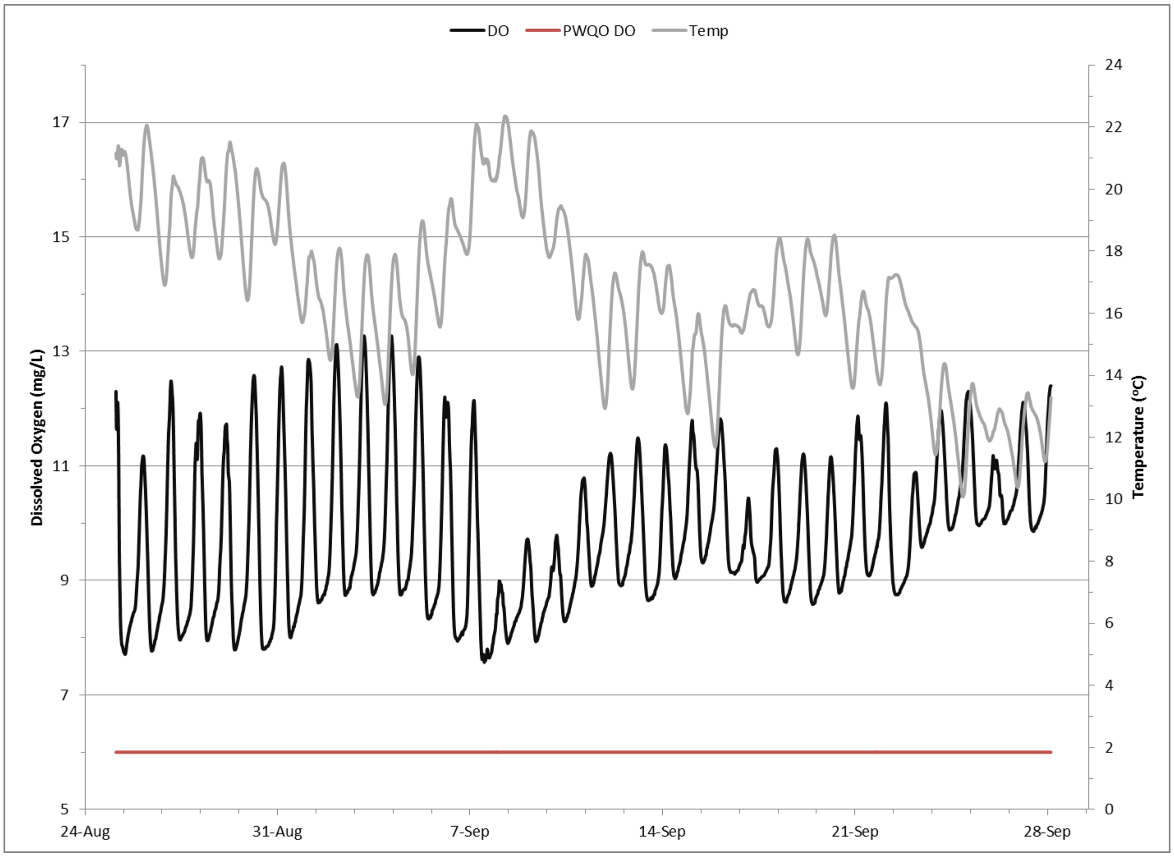


Figure 8 Continuous Dissolved Oxygen and Temperature measured in the West Credit River ~75 m 10th Line (August 25 to September 28, 2016)

4.2 Stream flow

Stream flow was highest in May and decreased throughout the summer months. Flows measured in May, June and July may have been influenced by backwater effects from downstream beaver dam (Table 11). 10th Line flows were greater than the calculated 7Q20 of 225 L/s during each sampling event. The lowest flow of 305 L/s was measured during the August sampling event (downstream of the beaver dam) and was 80 L/s greater than the calculated 7Q20 flow. An increase in flows of 9 to 32% was observed between 10th Line and Winston Churchill Blvd. likely as a result of groundwater inputs.

Table 11 Measured Stream Flows (L/s) in West Credit River

Station	27-May-16	29-Jun-16	27-Jul-16	25-Aug-16	28-Sep-16
10th Line	830 [a]	437 [a]	381 [a]	370 [b]	305 [b]
Winston	N/M	475	502	450	369
% increase	-	9%	32%	22%	21%

Notes: a - downstream beaver dams potentially influencing flow conditions; b – flow measured 75 m downstream of 10th Line; N/M – not measured.

4.3 Stream Characterization

On June 10, 2016 a detailed reconnaissance of the West Credit River study area was undertaken, from 10th Line to Winston Churchill Blvd. A detailed figure showing the river characteristics, distinguishing features such as woody debris, tributary inputs, man-made dams, and the locations of reach breaks (for QUAL2K modelling) was created (Figure 9).

The study area of the West Credit River exhibits an irregular meander pattern. The West Credit River has a relatively moderate trapezoidal cross-section with gentle to steep banks and a bankfull width between approximately 8 m and 12 m within the study area. On the date of the reconnaissance and at all HESL field events (monthly between June and September 2016), the river was easily wadeable.

The water clarity was good, with the river bottom visible. The substrate of the West Credit River in the study area was characterized by fine sediment with some cobbles and rocks. The ratio of fines to rocks/cobbles changed back and forth moving downstream from 10th Line toward Winston Churchill Blvd., but the same combination of substrate was always present (Photograph 4 and 5). A riffle section was noted about 300 m upstream of Winston Churchill Blvd., which was denoted as Reach 5 (Figure 9 and Photograph 6).

The banks were lined with vegetation including tall grasses, shrubs and coniferous trees. Emergent macrophytes were noted along some banks. Bank erosion (under-cutting) was also visible along some bank sections. Beyond the bank vegetation, forest consisting of both coniferous and deciduous trees, lined the north and south banks of river, with the exception of a couple of manicured lawns (residential properties) that were visible on the south river bank.

Fallen woody debris altered the river flow in several sections of the West Credit River study area, as identified on Figure 9 (Photograph 7). In some cases, especially in Reach 3 and Reach 4, the woody debris was thick enough that the river could not be walked. While the woody debris was generally naturally occurring as the result of fallen trees in a dynamic system, beaver dams utilizing the fallen woody debris were noted upstream of 10th Line and about 40 m downstream of 10th Line (Photograph 8). (The beaver dam is discussed in Section 3.1).

Occasional growths of submerged aquatic macrophytes were observed in the West Credit River; however, they were not observed in abundance throughout the study area. Attached algae (periphyton) was noted on some cobbles and rocks (Photograph 5).

Man-made dams created out of cobbles were noted at three locations in the study area (Figure 9, Photograph 9). In some cases the dams had been breached in the centre and in all cases the river water level was near the top or above the man-made dam and was not notably altering flows.