TECHNICAL MEMORANDUM

DATE	March 18, 2015	**REFERENCE No.**	1114220046-543-TM-Rev1
TO	Derek Holmes, Regional Manager BC Aggregate Operations BURNCO Rock Products Ltd.		
FROM	Kannappan Thiagarajan, Jerry Vandenberg	**EMAIL**	Kthiagarajan@golder.com, jvandenberg@golder.com

PIT LAKE HYDRODYNAMIC MODELLING FOR BURNCO AGGREGATE PROJECT CLOSURE PLAN

1.0 INTRODUCTION

Golder Associates Ltd. (Golder) was retained by BURNCO Rock Products Ltd. to prepare an Environmental Assessment Certificate Application/Environmental Impact Statement (EAC Application/EIS) for a proposed sand and gravel mine project (“the Project”) within the Lower McNab Valley, approximately 35 km northwest of Vancouver, British Columbia. The Proposed Project is located on a 30 hectare (ha) portion of a 320 ha property that has been owned since 2008 by 0819042 BC Ltd and BURNCO Rock Products Ltd. Aggregate resources will be mined from a clear-cut area of the property, situated approximately 500 meters (m) from the marine foreshore and extending northward approximately 600 m toward the southern banks of McNab Creek (Figure 1). Sand and gravel will be extracted from a pit using an electric powered floating clamshell dredge equipped with a primary crusher linked to a floating conveyor system. This equipment will be initially placed on the western area of the deposit and will dig downward to form a wetted pit (filled with natural groundwater input). The dredge will float on the surface of the pit pond. From this location, the floating clamshell will extract material based on the aggregate deposit and mine plan, and is anticipated to gradually enlarge the pit pond to size of approximately 28 ha over a period of 16 years. The majority of groundwater seepage from the pit lake will enter the foreshore area downgradient (i.e., south) of the pit. The surface overflow from the pit, which is only expected from October to April, will enter the constructed groundwater-fed watercourse (WC 2) through an extension that would be constructed as a part of the Project.

To support the water quality modelling of the pit lake and to evaluate long-term effects of pit lake releases to the downstream receiving environment, thermal and hydrodynamic modelling of the pit lake was performed to obtain the vertical profiles of water temperature and total dissolved concentration (TDS). This technical memorandum summarizes the hydrodynamic modelling approach, input data and results within the pit lake and in outflow water during the post-closure period of the Project.

2.0 MODELLING APPROACH

The laterally-averaged, hydrodynamic and water quality model, CE-QUAL-W2 (W2; Cole and Wells 2013) was used to predict vertical water temperature and TDS profiles within the pit lake as well as in outflow from the pit lake entering the surface water system. This model has been applied in numerous studies worldwide to predict temperature, stratification and other variables in reservoirs, rivers and pit lakes. A 17-year simulation was set up, consistent with the availability of meteorological data, as described in the following section of input data compilation.

2.1 Model Input

The model input data used for the simulations include:

- pit lake bathymetry;
- meteorological data;
- inflow and outflow hydrology;
- inflow temperatures; and
- inflow TDS.

Each of these inputs is described in details in the sections below.

2.1.1 Pit Lake Bathymetry

The model was set up by dividing the pit lake equally into 3 longitudinal segments and 47 vertical layers based on the conceptual profile and water level of the pit lake at closure estimated by water balance analysis. The grid comprises 141 active cells with the cell height of 1 m. The segment orientation was set up based on the flow direction. The characteristics of the BURNCO Pit Lake at closure are summarized in Table 1.

Table 1: Characteristics of the BURNCO Pit Lake at closure

Description	BURNCO Pit Lake
Storage volume at closure (Mm^3)	10.05
Closure water surface elevation (m)	5.17
Surface area (km^2)	0.276
Mean water depth (m)	40.1
Receptors	McNab Creek (MCF-7), downstream groundwater-fed watercourses ((MCF-6 and MCF-12)
Segment orientation	North to south

2.1.2 Meteorological Data

Meteorological inputs are the key parameters driving the surface water temperature and mixing in the pit lake. The data used for the model are:

- air temperature;
- dew point temperature;
- wind direction;
- wind speed; and
- solar radiation or cloud cover.

The wind and temperature data used for the model were Environment Canada hourly climate data from Port Mellon, which is close to the project site. The station height at Port Mellon station is 31.85 m above ground surface. Cloud cover data from Vancouver International Airport and solar radiation data from Vancouver UBC were compiled with the Port Mellon station as these data weren’t available for that station. Time series from Port Mellon were repeated to extend the simulation period to the 17-year record available from Vancouver UBC. Meteorological data sources are summarized in Table 2.

Table 2: Summary of meteorological data sources

Station Name	Data	Time Frame
Port Mellon	Air temperature, dew point temperature, wind direction, wind speed.	2008 – 2012
Vancouver International Airport	Cloud cover	2008 – 2012
Vancouver UBC	Solar radiation	1971 – 1988

2.1.3 Inflow and Outflow Hydrology

The water balance at the end of mining was used as the hydrological input for the model (Golder 2014). Monthly average flow rate files were compiled for the following inflows and outflows (Table 3):

- surface runoff inflows;
- groundwater seepage inflows;
- net precipitation and evaporation; and
- surface and groundwater outflow.

All outflows, including surface overflow from the weir at the pit lake outlet and seepages from the pit to downstream groundwater-fed watercourses and McNab Creek, were combined into a single outflow as they were expected to originate from the same segment and range of layers in the model.

2.1.4 Inflow Temperatures

Precipitation temperature was assumed to be equal to air temperature. Constant groundwater temperature (7.5ºC) was assumed for the ground water entering the pit lake from the west. Water temperatures of other inflows were assumed to be the same as McNab Creek surface water temperature (Table 3).

2.1.5 Inflow Total Dissolved Solids

The concentration inputs to the model were set according to measurements at monitoring stations that were used for input to water quality mass balance model at the end of the operation period (Golder 2014). TDS concentrations were the only chemical input used in the model setup. The median of observed concentrations for each inflow was used and assumed to be constant throughout the simulation period (Table 3).

Table 3: Summary of hydrological, chemical and temperature inputs

Flow (m^3/s)		TDS Concentration (mg/L)		Temperature (° C)	
ID	**Description**	**ID**	**Description**	**ID**	**Description**
Q_Runoff_NP_NF	Runoff from area north of pit (not containing separated fines)	C_Runoff_NP_NF	Baseline water quality at surface water monitoring stations MCF-2 and MCF-3	T_Runoff_NP_NF	McNab Creek surface water temperature
Q_Runoff_NP_F	Runoff from area north of pit (containing separated fines)	C_Runoff_NP_F	Water quality from sequential shake flask extraction tests	T_Runoff_NP_F	McNab Creek surface water temperature
Q_Prec_Evap	Net precipitation and evaporation	C_Prec_Evap	Assumed pure water	T_Prec_Evap	Air temperature
Q_GW_WP_NF	Groundwater from west of pit (not containing separated fines)	C_GW_WP_NF	Baseline water quality at groundwater monitoring stations DH10-07S, DH10-07D, DH10-06S, DH10-06D and MW05-1	T_GW_WP_NF	Constant ground water temperature (7.5°C)
Q_GW_NP_NF	Groundwater from north of pit (not containing separated fines)	C_GW_NP_NF	Baseline water quality at surface water monitoring station MCF-1	T_GW_NP_NF	McNab Creek surface water temperature
Q_GW_NP_F	Groundwater from north of pit (containing separated fines)	C_GW_NP_F	Water quality from sequential shake flask extraction tests	T_GW_NP_F	McNab Creek surface water temperature
Q_WaterBal_NP	Water balance correction withdrawal (with an annual total about 0.012% of annual total inflow)	C_WaterBal_NP	Baseline water quality at surface water monitoring stations MCF-2 and MCF-3	T_WaterBal_NP	McNab Creek surface water temperature
Total_Outflow	Sum of surface and seepage outflows to McNab Creek and downstream groundwater-fed watercourses				

2.2 Model Simulations and Sensitivity Analysis

The temperature and TDS vertical profiles during the post-closure period were simulated in the hydrodynamic model according to the proposed mine plan (Golder 2013). The model was run for a 17-year period, and vertical temperature and concentration profiles were generated for each simulation. The hourly surface water temperature near the weir outflow was predicted at different elevations (top 5 m). The hourly outflow temperature, which is a flow-weighted average of the top 5 m, was also predicted. The top 5-m water parcel at the outflow segment was assumed to be the source of surface overflow and seepages from the pit lake, because the mean lake surface elevation at closure was estimated to be about 5 m above sea level.

A “Base Case” simulation was completed using the inputs described in Section 2.1 and default model coefficients. The pit lake is not constructed yet, so there is no observed temperature and concentration data for calibration and validation to that water body. Because the pit lake model could not be calibrated, a sensitivity analysis was completed by changing hydrodynamic variables that would be likely to affect model predictions. The variables altered for the sensitivity analysis are listed in Table 4.

2.3 Comparison Between Simulated and Observed Surface Water Temperatures

Because the lake has not been constructed, model results could not be compared to existing conditions. Instead, the predicted surface water temperatures were compared with the monitored data of an existing lake with a water surface elevation near mean sea level which is located in a similar climate setting.

Haslam Lake is located in the Town of Powell River, about 100 km northwest of the Project. The lake surface area is 1187 hectares, and the mean depth is 55 m. Recorded temperatures from this lake were used for compared to the pit lake predictions.

Table 4: Summary of sensitivity analysis inputs and results

Run no	Description	Max. Surface Water Temp. in °C at Different Depths (m)					Max. Temp. of Pit Outflow From the Top 5 m °C	%age Difference in Temp. Compared to Base Case at different Depths (m)					% Change of Max. Temp. at Pit Outflow
		5	4	3	2	1		5	4	3	2	1	
1	**Base case**	25.8	25.2	15.8	10.9	9.5	15.5						
	Sensitivity Runs (Base Case with additional changes)												
2	Use computed solar radiation and measured cloud cover instead of measured solar radiation	26.0	25.5	15.0	10.3	9.1	15.0	1.1%	1.0%	-5.2%	-5.0%	-3.3%	-3.3%
3	Fraction of solar radiation at sediment to water (0.5 to 1)	25.8	25.2	15.6	10.7	9.4	15.5	0.1%	0.1%	-1.6%	-1.3%	-0.4%	0.1%
4	Wind sheltering coefficient (0.8 to 1.0)	25.6	25.2	15.9	10.9	9.7	15.7	-0.4%	-0.1%	0.4%	0.2%	2.2%	1.3%
5	Sediment temperature (set to half average air temperature)	25.8	25.2	15.5	10.7	9.3	15.5	0.0%	0.0%	-2.0%	-1.9%	-1.5%	-0.1%
6	Sediment temperature (set to double average air temperature)	25.8	25.2	15.6	10.9	9.6	15.5	0.0%	0.0%	-1.5%	0.3%	1.8%	0.2%
7	Double Wind speed	25.3	24.9	19.5	15.4	12.7	18.3	-1.8%	-1.1%	23.1%	41.6%	34.7%	18.5%
8	Beta extinction coefficient (0.4)	25.6	25.1	16.2	10.9	9.5	15.8	-0.8%	-0.4%	2.3%	0.6%	0.5%	1.9%

Base Case
Station height = 31.85 m
Solar radiation = 20 yrs data
Wind sheltering = 0.8
Sediment Temperature = Air temperature
Beta extinction coefficient (0.45)
Fraction of solar radiation at sediment to water = 0.5
Precipitation temperature = Air temperature (Environment Canada Climate data)

3.0 RESULTS AND DISCUSSIONS

Base case predictions and sensitivity analysis of the future temperature and TDS profiles of the water within the pit lake and water entering the McNab Creek and groundwater-fed watercourses are presented in Section 3.1 and Section 3.2, respectively. A comparison between the simulated results and field measurements in Haslam Lake is described in Section 3.3.

3.1 Base Case

The results for the Base Case simulation are as follows:

- Predicted surface water temperature and outflow temperature increased during the summer months (late July to early August) and gradually decreased by about 5ºC in the winter months (November-March) (Figure 2).
- The maximum predicted temperatures for surface water and outflow water were 25.8ºC and 15.5ºC respectively during early August of the 5th year of simulation (Figure 2). The increase in the temperature was due to the increased solar radiation on that particular week.
- The hourly temperature profile during the year with the maximum predicted temperature is presented in Figure 3, where the temperature increases in the afternoon and decreases during the night. Outflow temperature follows a similar pattern with a small time lag (Figure 4). The difference in the peak temperature between the surface water and the outflow water is because the outflow includes the top 5 m of water.
- The annual thermal stratification cycle follows an inverse stratification in winter and persists until air temperature warms in spring. Surface warming continues until the temperatures are almost isothermal in March. Thereafter, the surface water temperature increases and thermal stratification re-establishes until the pit lake reaches maximum stability in late summer (late July to early August). Then the lake surface cools as the temperature drops in autumn and the cooler water mixes downward. The isothermal conditions lead to fall turnover in the upper layers, and then the cycle repeats annually (Figure 5).
- The model predicted a very slight vertical gradient of TDS concentrations due to the slightly lower TDS concentrations of the inflows compared to lake concentrations (Figure 5). These are not likely to be measureable.
- Monthly average outflow temperature from the pit lake is described in Table 5.

Table 5: Monthly average outflow water temperature (ºC) from the pit lake

Year	January	February	March	April	May	June	July	August	September	October	November	December
1	2.9	2.7	5.3	7.6	11.0	12.1	12.9	13.1	12.1	9.5	7.7	5.9
2	3.7	2.6	3.8	7.3	10.8	11.1	12.5	13.5	12.0	9.1	7.1	5.4
3	4.2	4.5	5.2	8.2	11.1	12.0	13.0	14.1	12.8	11.0	7.6	5.9
4	4.7	4.2	4.6	8.9	11.8	12.0	13.0	13.6	12.9	10.1	7.0	5.5
5	4.6	3.4	4.0	7.4	10.6	12.3	12.8	14.1	13.2	11.1	7.6	6.1
6	4.7	3.3	4.8	8.0	11.0	11.9	13.4	12.9	12.3	9.6	7.5	6.0
7	4.0	2.9	3.6	7.1	10.9	12.0	10.8	10.6	11.9	9.6	7.3	5.6
8	4.4	4.6	5.9	9.5	11.4	12.4	13.1	14.1	12.1	9.7	6.9	5.3
9	4.3	3.6	4.6	7.5	11.5	12.8	13.3	13.1	11.9	10.5	7.3	5.8
10	4.8	3.9	4.6	8.8	11.4	12.4	13.2	13.8	12.4	10.2	7.6	6.2
11	4.7	3.2	4.3	6.3	7.5	11.1	12.6	13.4	12.0	10.1	7.7	6.1
12	4.0	2.8	4.3	7.4	10.1	11.5	12.6	13.8	12.5	9.1	7.2	5.6
13	4.3	4.3	6.1	9.3	11.6	12.8	12.4	12.9	12.1	10.5	7.7	6.0
14	4.8	4.2	4.8	8.6	11.4	11.8	12.2	13.3	11.9	10.6	7.1	5.7
15	4.7	3.7	4.2	8.0	10.8	11.7	12.9	13.5	12.4	10.3	7.6	6.2
16	4.8	3.6	5.4	3.4	8.4	11.6	13.8	13.4	12.0	9.6	7.6	6.3
17	4.2	3.0	3.7	6.2	10.2	12.3	12.1	13.7	12.4	9.5	7.2	5.6
17 year average	4.3	3.6	4.7	7.6	10.7	12.0	12.7	13.4	12.3	10.0	7.4	5.8

3.2 Sensitivity Analysis

The sensitivity analysis yielded the following results:

- Turning off the solar radiation and using simulated solar radiation and measured cloud cover data increased the surface water temperature in the top layer from 25.75ºC to 26.04ºC, but decreased the outflow temperature from 15.46ºC to 14.95ºC with 2.8% change compared to the Base Case.
- Increasing the wind sheltering coefficient has negligible effect on the temperature that decreases the surface water temperature at the top layer, but increased the temperature at the bottom layers and outflow temperature less than 2% due to increased vertical mixing.
- Decreasing the sediment temperature to half the annual average air temperature decreases the surface water temperature and outflow water temperature by less than 1%. Similarly, doubling the sediment temperature increased the surface water temperature by 2% and outflow water temperature by less than 1%.
- Doubling the wind speed decreased the surface water temperature in the top layers by 2%, but increased the temperature in lower layers and outflow temperature by over 25% and 15% respectively.
- Decreasing the beta extinction coefficient by 10% decreased the surface water temperature at the top layer by less than 1%, but increased the temperature at the lower layers by more than 10% and outflow temperature by 2% due to increased light penetration.

In summary, the sensitivity analysis indicates that the results are robust under a variety of different conditions, and that the main input that could alter the predictions would be a major change in wind conditions compared to those measured at Port Mellon.

3.3 Comparison Between Simulated and Observed Surface Water Temperatures

The surface water temperature profiles were compared to Haslam Lake and are shown in Figure 6. Predicted surface water temperatures are superimposed on the observed temperature graph from the Watershed Assessment of Haslam Lake Lang Creek Community Watershed (Carson Land Resources Management Ltd 2003).

- The 5 years (4th year to 8th year) of the simulation period that were compared with the literature data followed the same pattern as observed data, with the peak temperature occurring in early August (greater than 26ºC). Predicted increases, declines and minimum temperatures also matched the observed annual cycles.
- The comparison between the simulated and literature data indicates that the model results are reasonable predictions for the pit lake.

4.0 CLOSURE

We trust that this information is sufficient for your immediate requirements. Please contact the undersigned at 250-881-7372 should you have any questions.

GOLDER ASSOCIATES LTD.

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5.0 REFERENCES

Carson Land Resources Management Ltd. 2003. Watershed Assessment of Haslam Lake Lang Creek Community Watershed, Powell River, B.C. Submitted to Weyerhaeuser Company Ltd and Western Forest Products Co. Ltd. September 2003. pp 47. Robert Creek, BC.

Cole, T. M. and S. A. Wells. 2013. *CE-QUAL-W2: A Two-Dimensional, Laterally Averaged, Hydrodynamic and Water Quality Model*, Version 3.71. Prepared for U.S. Army Corps of Engineers, Washington, DC 20314-1000, 777pp.

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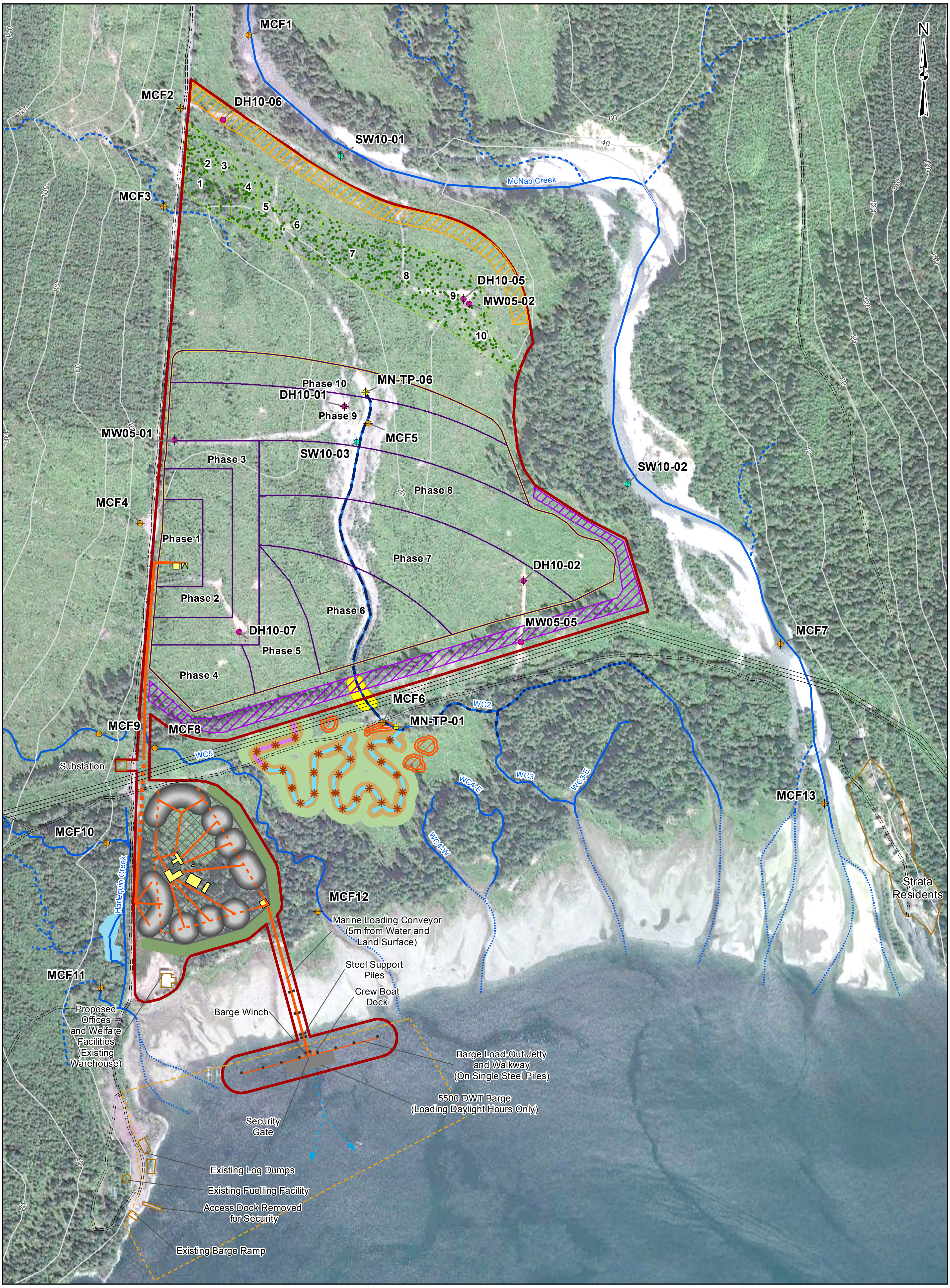


LEGEND

- ✚ Test Pit Location (Golder 2013)
- ✚ Freshwater Quality Sampling Location (Golder 2012)
- ✚ Monitoring Well (Golder 2012)
- ✚ Surface Water Monitoring Station (Golder 2010)
- ▭ Project Area
- ▭ Proposed Aggregate Pit Phase
- ▭ Final Pit Lake Outline
- ▭ Product Stockpile
- ▭ Fines Storage Area
- ▨ Processing Area
- ▭ Existing Feature
- ▭ Existing Log Tenure Area
- ▭ Possible Processing Plant Configuration
- ▨ McNab Creek Flood Protection Dyke
- ▨ Pit Lake Containment Berm
- ■ Processing Area Berm
- — Elevated Conveyor
- ■ ■ ■ Underground Conveyor
- — Barge Load-out
- — Transmission Line
- === Road (Existing)
- — Contour (20m)
- ➤ Barge Route
- ● Pile
- — Permanent / Perennial Watercourse
- - - Intermittent Watercourse
- ······ Intertidal Watercourse

Constructed Watercourse

- Phase 1 (1985)
- Phase 2 (1998)
- Phase 3 (2001 - 2003)

Proposed WC2 Extension (~770 m)

- ■ Proposed Channel Extension: Year 1 Channel Construction
- ■ Proposed Channel Extension: Project Closure Channel Construction
- ■ Top of Bank
- ■ Riparian
- ■ Channel Infill, Riprap and Filter Zone
- ▨ Proposed Amphibian Pond (Combined Area ~1250 m^2)
- — Outlet Structure with Spillway and Low-Level Outlet
- ✱ Wood Debris

REFERENCE

Watercourses from the Province of Britis Columbia and field data. Base data from the Province of British Columbia. Contours from TRIM positional data. Base Imagery from Google Maps 20100807. Projection: UTM Zone 10 Datum: NAD 83

200 0 200

SCALE 1:6,000 METRES

PROJECT

BURNCO ROCK PRODUCTS LTD.
BURNCO AGGREGATE PROJECT, HOWE SOUND, B.C.

TITLE

SITE DEVELOPMENT PLAN

Golder Associates

PROJECT NO. 11-1422-0046			PHASE No.	
DESIGN	PB	27 May. 2014	SCALE AS SHOWN	REV. 1
GIS	DL	10 Mar. 2016	**FIGURE 1**	
CHECK	GW	18 Mar. 2015		
REVIEW	JV	18 Mar. 2015		

Path: X:\Project Data\BC\McNab\Figures\MXD\Surface Water\Appendices\5.5-B\BURNCO_FRESHWATER_Figure_01_Site_Development_Plan.mxd

Figure 2: Simulated water temperature at lake surface and in outflow.

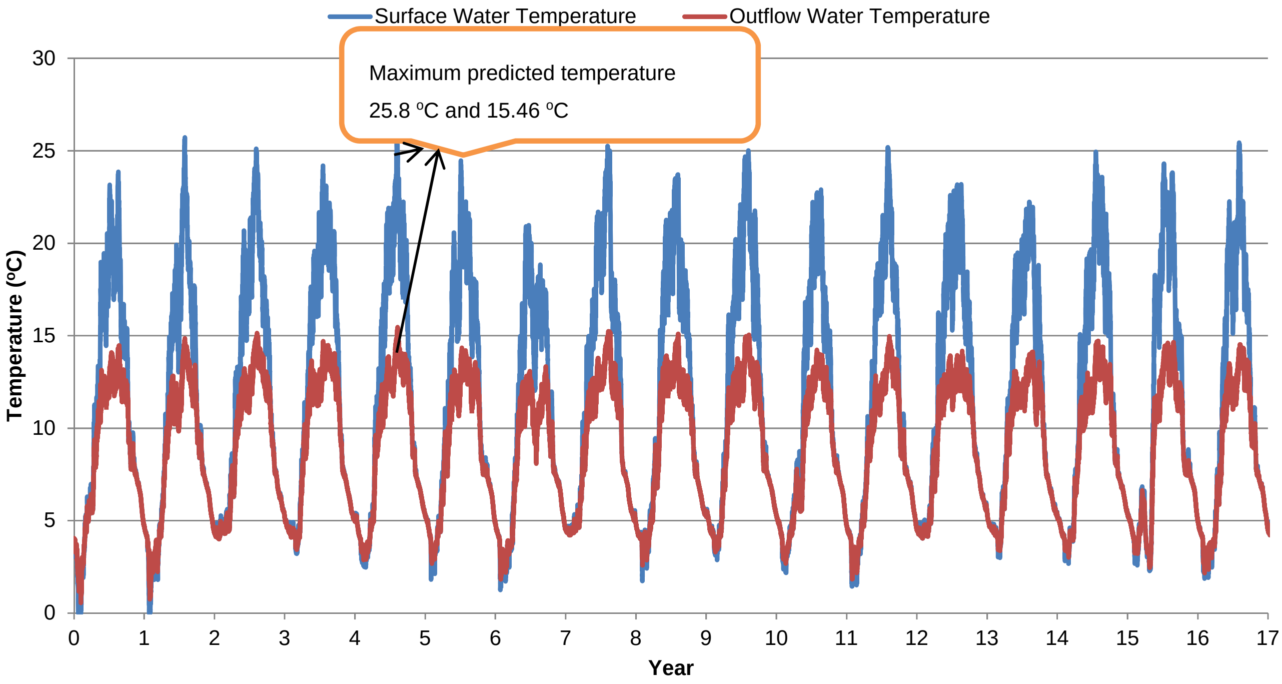
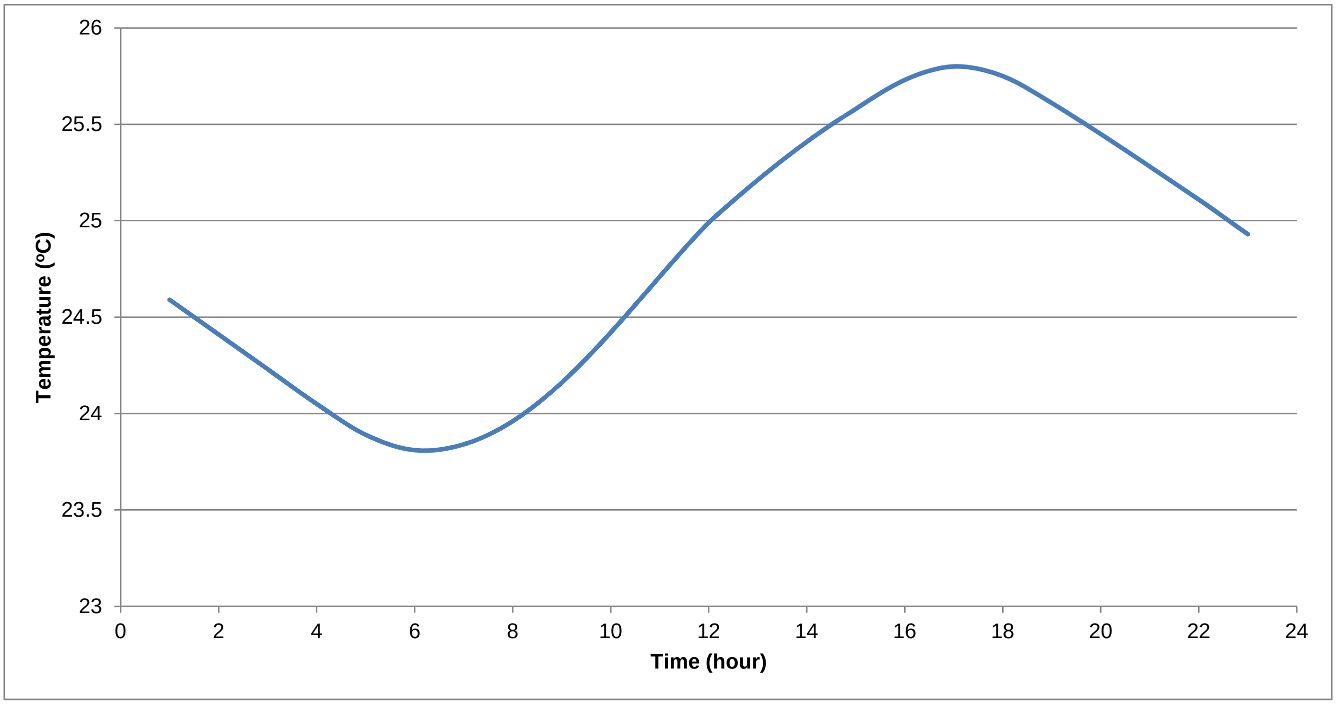
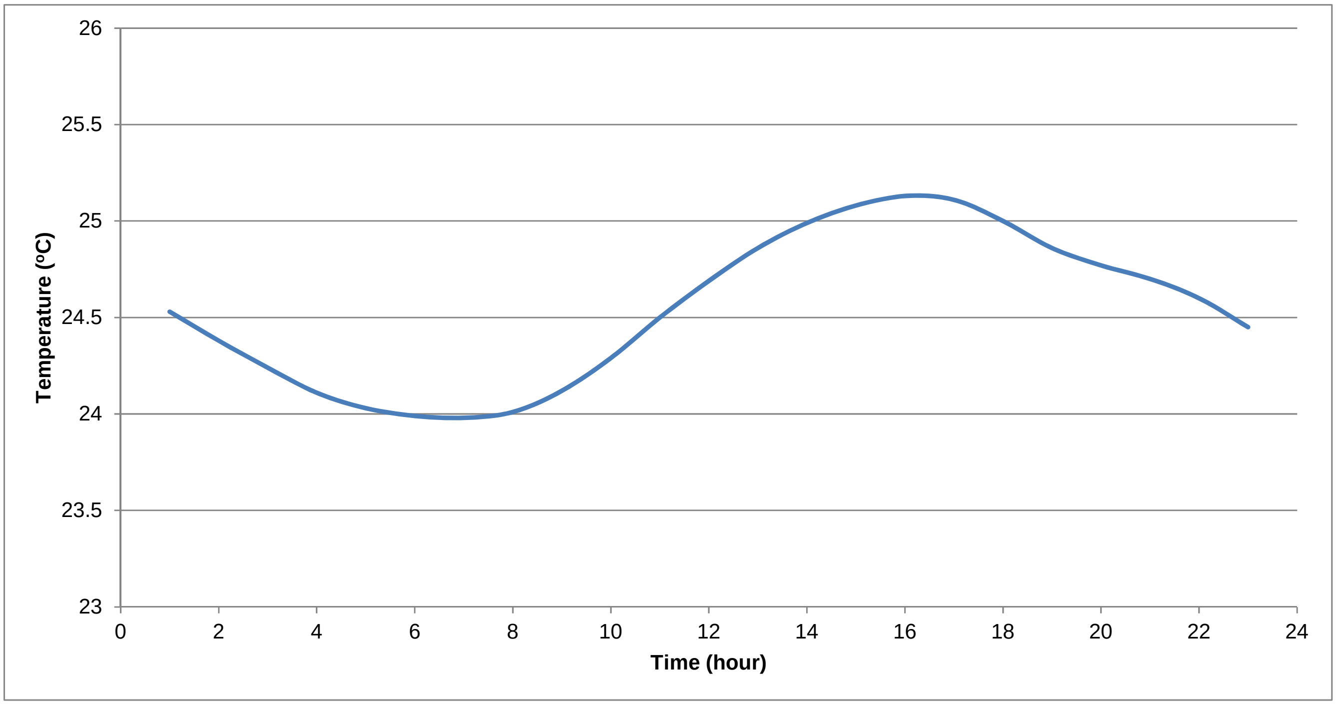


Figure 3: Surface water temperatures during the occurrence of predicted maximum temperature.

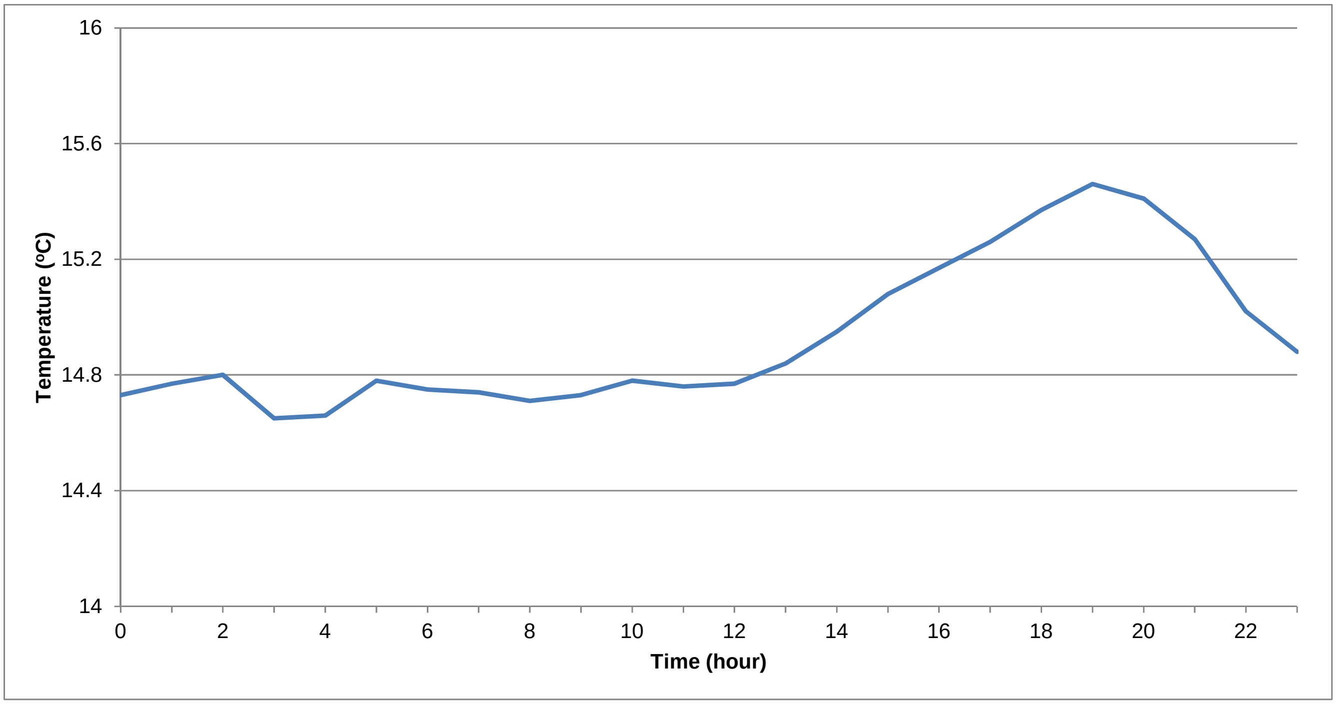


(a) 5th Year

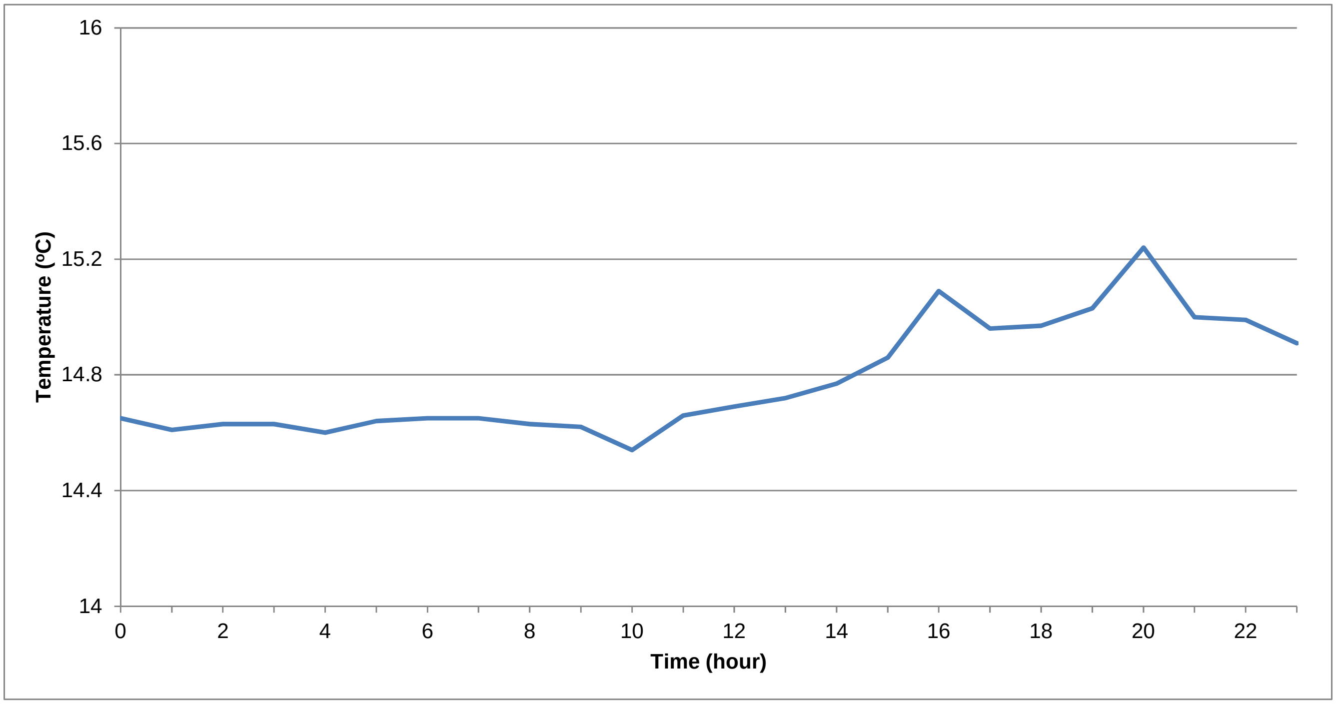


(b) 8th Year

Figure 4: Outflow water temperatures during the occurrence of maximum predicted temperature.

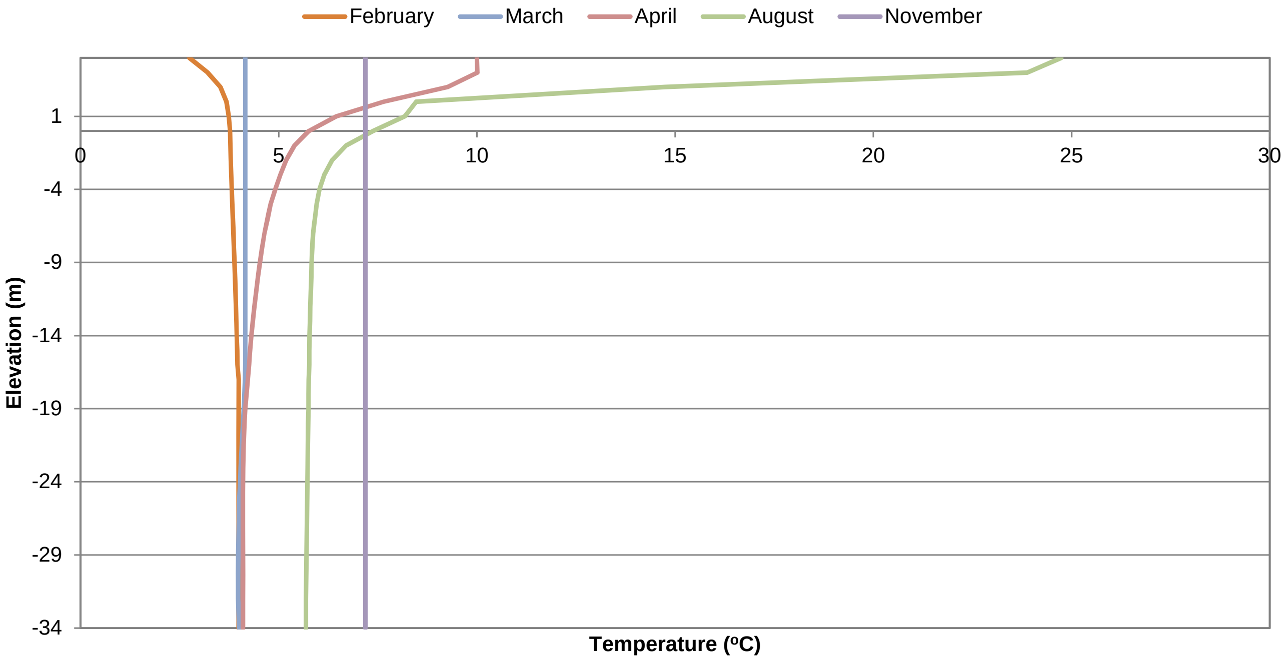


(a) 5th Year

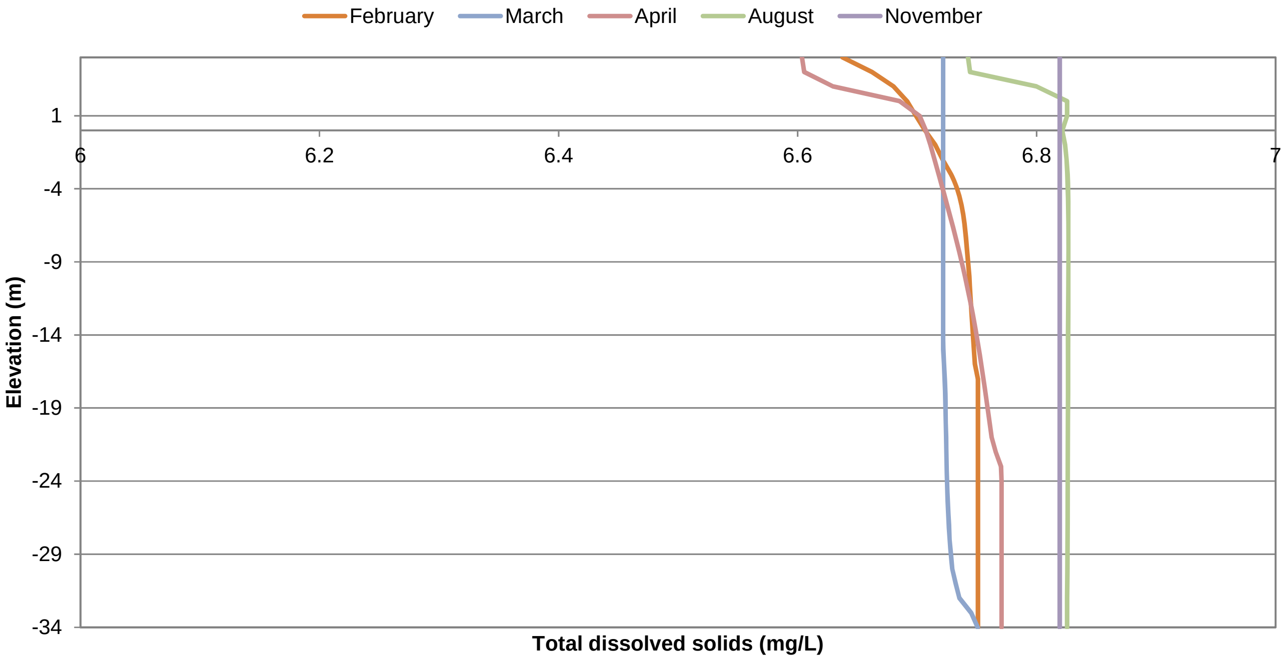


(b) 8th Year

Figure 5: Vertical profiles of simulated surface water temperature and TDS concentrations, typical year.

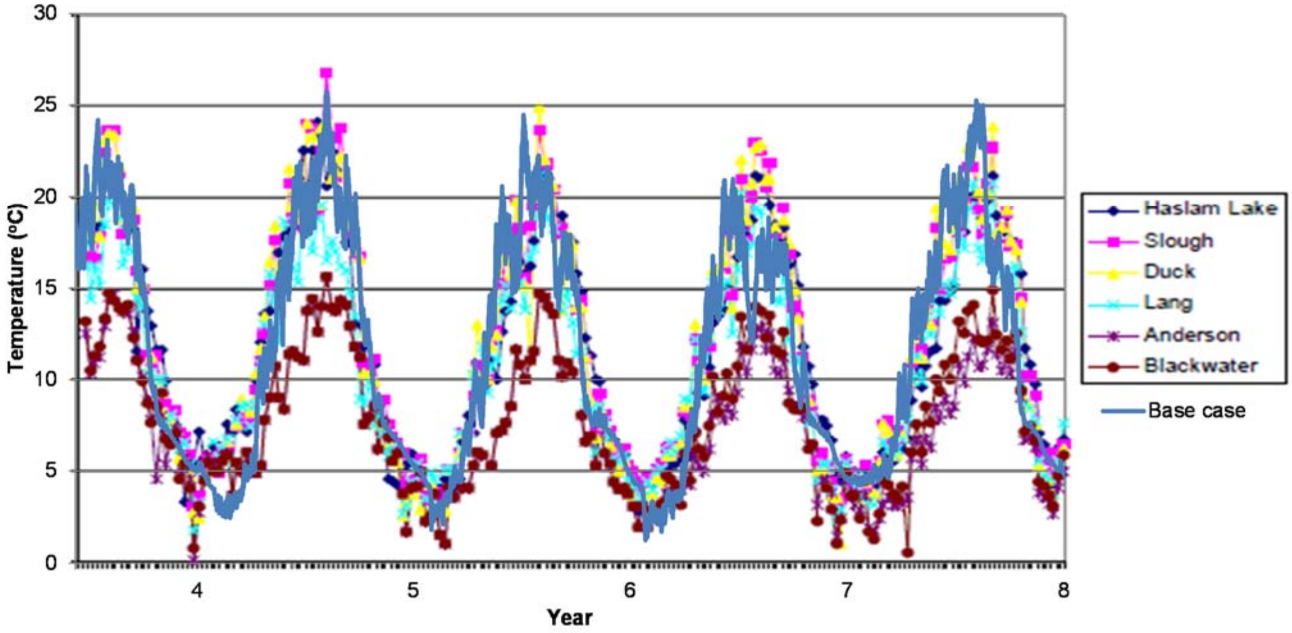


(a) Temperature



(b) Total dissolved solids

Figure 6: Seasonal patterns of monitored and simulated surface water temperature.



Source: Watershed Assessment of Haslam Lake Lang Creek Community Watershed (Carson Land Resources Management Ltd. 2003).