REVISED
MEMORANDUM

DATE:	July 23, 2020
TO:	Bill McDonough and Chris Prucha, Waste Management (WM)
FROM:	François Richard and Madeleine Corriveau, BluMetric Environmental Inc.
PROJECT NO:	190222-07
SUBJECT:	Expanded Timeframe for Water Balance for the North Lagoon, Waste Management Richmond Landfill, Town of Greater Napanee

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This technical memorandum has been prepared in response to comments from Ministry of the Environment, Conservation and Parks (MECP) regarding the water balance presented in BluMetric (2020)[1]. The time period considered for the initial water balance evaluation was between July 12 and November 20, 2019 (the period for which field measurements of water levels in the lagoon were available). To complement this analysis, MECP requested that the evaluation time frame be expanded to assess the potential influence of seasonal impacts over an extended time period. The expanded timeframe evaluation was provided to MECP in a memorandum issued on May 8, 2020. The present document is an update to the May 8, 2020 document that provides complementary information and addresses comments and questions from the MECP reviewer[2].

Until the end of November 2016, the North Lagoon was not in use and the outlet valve had been left open to prevent accumulation of precipitation. At that time the outlet valve was closed. The period considered in the present evaluation includes the period since December 1, 2016 when it is assumed that the lagoon was empty. The objective of this analysis is to calculate the theoretical cumulative volume in the lagoon since December 1, 2016, and compare the results with recent measurements of existing lagoon liquid volumes.

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[1] North Lagoon Investigation, Waste Management Richmond Landfill Site, March 2020
[2] Emails from Kyle Stephenson dated July 9 and 15, 2020

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METHODOLOGY

Consistent with the approach used in the initial work (BluMetric, 2020), a temporal water balance evaluation was conducted for the North Lagoon using the following simplified equation derived from Davis & Masten (2013):

$$\Delta V\_lagoon = Vprecipitation - Vpe + Vin - Vout$$

Where:
ΔV_lagoon is the volume variation in the North Lagoon;
Vprecipitation is the volume added to the North Lagoon as precipitation;
Vpe is the volume lost to potential evapotranspiration;
Vin is the volume pumped into the North Lagoon; and,
Vout is the volume pumped out of the North Lagoon.

The time period used for the expanded water balance evaluation was December 1, 2016 to May 31, 2020. Each of the input parameters was evaluated on a monthly basis. A summary of input parameters is provided in Table 1 (following text). The simplified equation presented above assumes that the North Lagoon is hydraulically isolated from the nearby hydrographic system and from subsurface flow. These assumptions are considered valid for the North Lagoon as the basin is lined with clay and a geosynthetic liner, and the lagoon is surrounded by a continuous berm.

INPUTS

Vprecipitation

Total precipitation data (including rainfall and snowfall) was obtained from Environment and Climate Change Canada's Belleville weather station (ID 6150689). The Belleville weather station is located approximatively 30 km southwest of the North Lagoon. It should be noted that precipitation can be highly variable over relatively short distances. Relative percent differences as high as 69% have historically been observed between total monthly precipitation recorded by the on-site weather station and the Belleville weather station (e.g., see Chart 1 in Appendix C of BluMetric (March 2020)). However, records from the on-site weather station are incomplete because snowfall is not recorded and the unit was offline during some months over the period considered, thus data from the Belleville station was utilized and provides an adequate estimate of precipitation for this evaluation.

Total monthly precipitation during the period between December 2016 and May 2020 ranged between 23 mm (November 2019) and 202 mm (May 2017).

Vprecipitation was calculated by multiplying monthly precipitation values by the lagoon area estimated from the crest of the surrounding berm (approximately 14,000 m^2)[3], as illustrated on Figure 1. Because the lagoon is enclosed within berms, only the area of the lagoon was considered, with no direct runoff into or out of the lagoon. Monthly precipitation volume estimates are presented in Table 1 (following text), ranging between 316 and 2,824 m^3 during the period considered.

Vin

According to the site records (see WSP, 2020[4] for details), leachate was pumped to the North Lagoon during late winter/early spring 2017, April and November 2018, April and May 2019, and January 2020. Volumes pumped to the lagoon are presented in Table 1 (following text). A total volume of 11,537 m^3 was pumped into the North Lagoon during the period considered in this evaluation.

OUTPUTS

Vpe

The Thornthwaite (1957) equation was used to estimate monthly potential evapotranspiration (PE_m):

$$PE_m = 16\, N_m\, (10\frac{T_m}{I})^a$$

Where:

N_m = a monthly adjustment factor related to hours of daylight;

T_m = the mean monthly temperature in degrees C;

I = the heat index for the year by adding monthly estimates = $\sum i_m = \sum(\frac{T_m}{5})^{1.5}$; and,

$a = 6.7x10^{-7}I^3 - 7.7x10^{-5}I^2 + 1.8x10^{-2}I + 0.49$

[3] BluMetric (2020) and previous versions of the present memo used a lagoon area of 10,100 m^2; this area estimate was refined for this update.

[4] WSP, Richmond Sanitary Landfill Site, Monitoring Report No. 33, March 19, 2020

Vpe was calculated by multiplying PE_m values by the lagoon area. A lagoon area of 12,000 m^2 was used for this calculation. This value is an approximation of the average surface area of liquid available for evaporation within the lagoon over the study period.

As evaporation from open water surfaces depends on many meteorological and environmental variables (such as solar radiation, atmospheric pressure, air and water temperature, air moisture, size and shape of evaporating water body etc.), a simplified equation such as the Thorthwaite equation has some inherent uncertainty; however, the Thorthwaite equation was used for the Moira River Basin study (located approximately 30 km northwest of the site) (Sibul *et al.*,1974[5]) and should provide an adequate estimate for this evaluation. Monthly estimates of potential evapotranspiration are presented in Table 1 (following text), ranging between zero and 1,847 m^3 over the period considered.

Vout

A total of 489 and 298 m^3 of liquid was pumped out of the North Lagoon in August 2019 and May 2020, respectively, and hauled for off-site treatment.

COMPARISON TO SITE DATA

Water level measurements of the North Lagoon were collected between July 2019 and May 2020. Using the data collected during unmanned aerial vehicle (UAV) and bathymetry surveys conducted in November 2019 and processed in the AutoCAD Civil 3D software (see Figure 1), water levels were converted into estimated volumes of water within the lagoon (Table 2). See BluMetric (2020[1]) for details. When more than one water level measurement was collected during a particular month, the measurement taken closest to the end of the month was used for calculation.

[5] Sibul, K, K. Goff and A. V. Choo-Ying, 1974. Water Resources of the Moira River Drainage Basin. Water Resources Report 6. Ministry of the Environment Water Quantity Management Branch https://archive.org/details/waterresourcmoira00sibu/mode/2up

Table 2: North Lagoon Water Levels, Corresponding Elevations and Volume Estimates

Date	Water level from ref point* (m)	Water level elevation (masl)	Volume (m^3)
2019-07-12	1.19	126.16	20073
2019-07-29	1.24	126.11	19442
2019-08-26	1.34	126.01	18258
2019-09-30	1.39	125.96	17627
2019-10-15	1.40	125.95	17548
2019-10-28	1.28	126.07	18969
2019-11-20	1.24	126.11	19442
2019-12-10	1.20	126.15	20000
2020-01-23	1.06	126.30	21801
2020-02-20	1.08	126.27	21491
2020-04-06	0.98	126.37	22733
2020-05-04	0.93	126.42	23354
2020-05-26	0.96	126.39	22981

* Reference elevation at 127.35 masl

RESULTS & CONCLUSIONS

The theoretical volume variation of the North Lagoon estimated using the water balance equation provided above compared to volumes estimated from water levels is provided in Table 1 and shown on Figure 2. Given the probable variation of precipitation recorded in Belleville compared to that experienced at the site, and the inherent uncertainty in estimating potential evapotranspiration, there is generally good agreement between the theoretical and observed volume estimates. In every case, the volumes based on the measured water levels are below those estimated theoretically and the percent (%) difference in volume is relatively consistent (fluctuating within 7.3%).

The comparison between theoretical and measured volume variations in the lagoon was initially presented as Chart 5 in BluMetric (2020) as part of the detailed water balance evaluation conducted using daily data for the period between July 12 and November 20, 2019. Figure 3 presents the updated results using the corrected areas of 14,000 and 12,000 m^2 for precipitation and evapotranspiration, respectively. The results show good agreement between measured and theoretical volumes.

The Thornthwaite equation is considered to be a conservative method of estimating evapotranspiration (i.e. underestimating evapotranspiration), which would result in the actual volumes being less than theoretical volumes. In the Moira River Basin study (Sibul et al., 1974[3]) for example, the Thornthwaite estimate of potential evapotranspiration was about 8% less than the lake-evaporation estimate, similar to other studies cited therein where the Thorntwaite was also found to be low.

While measured water levels are lower than predicted, the difference between theoretical and observed volumes remains relatively constant. If the North Lagoon exhibited significant leakage due to liner integrity issues, the actual measured volume of water in the lagoon would be increasingly lower compared to the theoretical volume computed using the water balance equation. In other words, the difference in the two volumes (illustrated on Figures 2 and 3) would increase over time as the measured volume would decrease due to leakage. This difference has not increased over time, leading to the conclusion that there is no significant leakage from the North Lagoon.

We trust the above is satisfactory. If you have any questions or need further information please do not hesitate to contact the undersigned.

Respectfully submitted,
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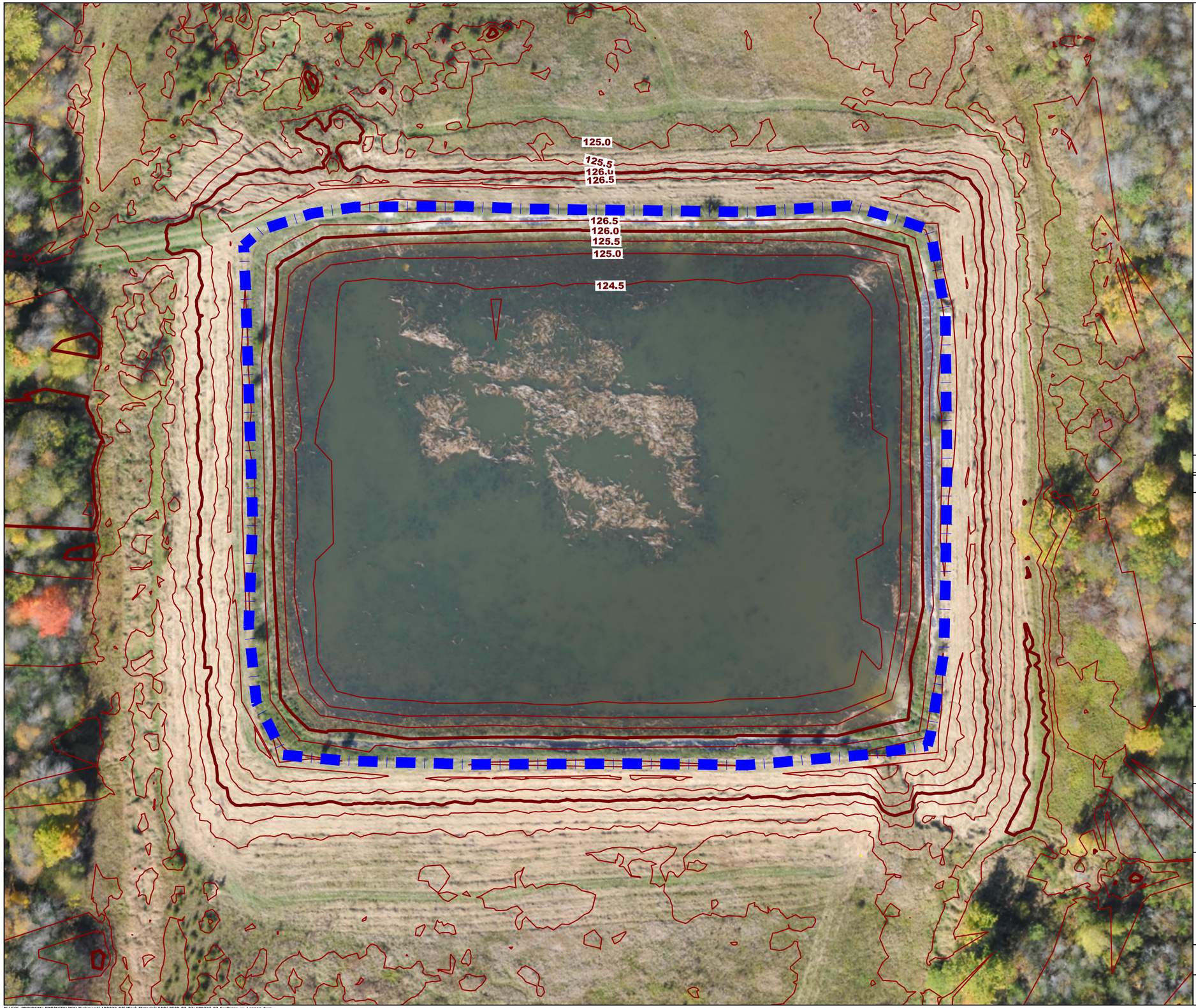
Encl.
Figure 1: North Lagoon Topography and Bathymetry
Figure 2: Results of Simplified Water Balance Compared to Measured Values
Figure 3: Updated Computed vs. Observed Cumulative Volume Variations (July 12 – November 20, 2019)
Table 1: Summary of Input Parameters and Results of Simplified Water Balance

FIGURES



LEGEND

- Elevation Contour (2 m)
- Elevation Contour (0.5 m)
- Crest of Berm

REV.	DESCRIPTION	YY/MM/DD	BY	CHK
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REFERENCES

DO NOT SCALE DRAWING.
THIS DRAWING MAY HAVE BEEN REDUCED. ALL SCALE NOTATIONS INDICATED ARE BASED ON 11"x17" FORMAT DRAWINGS.

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N W E S

CLIENT

WASTE MANAGEMENT

PROJECT

Waste Management Richmond Landfill - North Lagoon Investigation

TITLE

North Lagoon Topograghy and Bathymetry

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PROJECT #	DATE
190222-07	July 22, 2020

DRAWN	CHECKED	DWG NO.	REV
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Figure 2: Results of Simplified Water Balance Compared to Measured Values

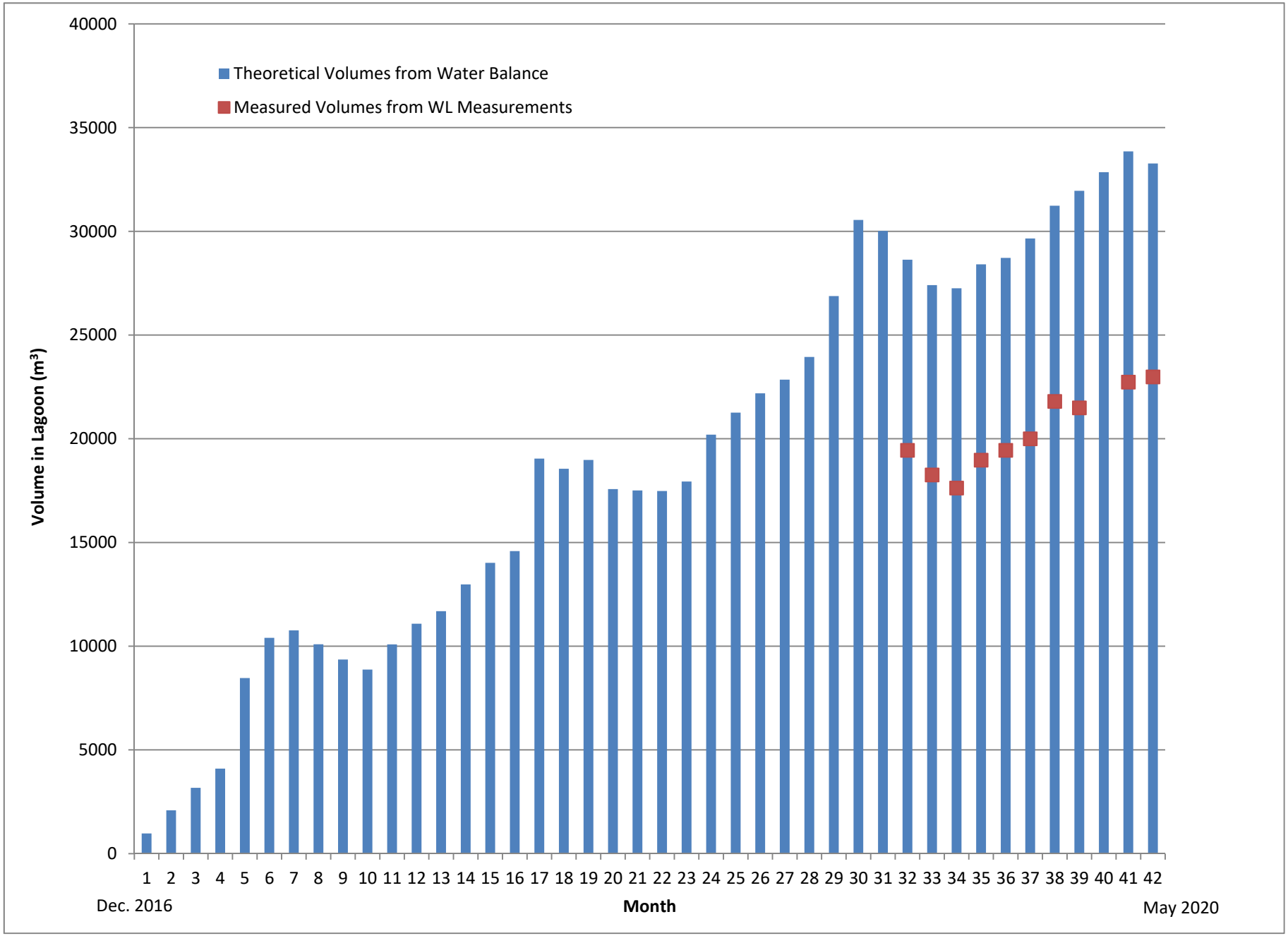
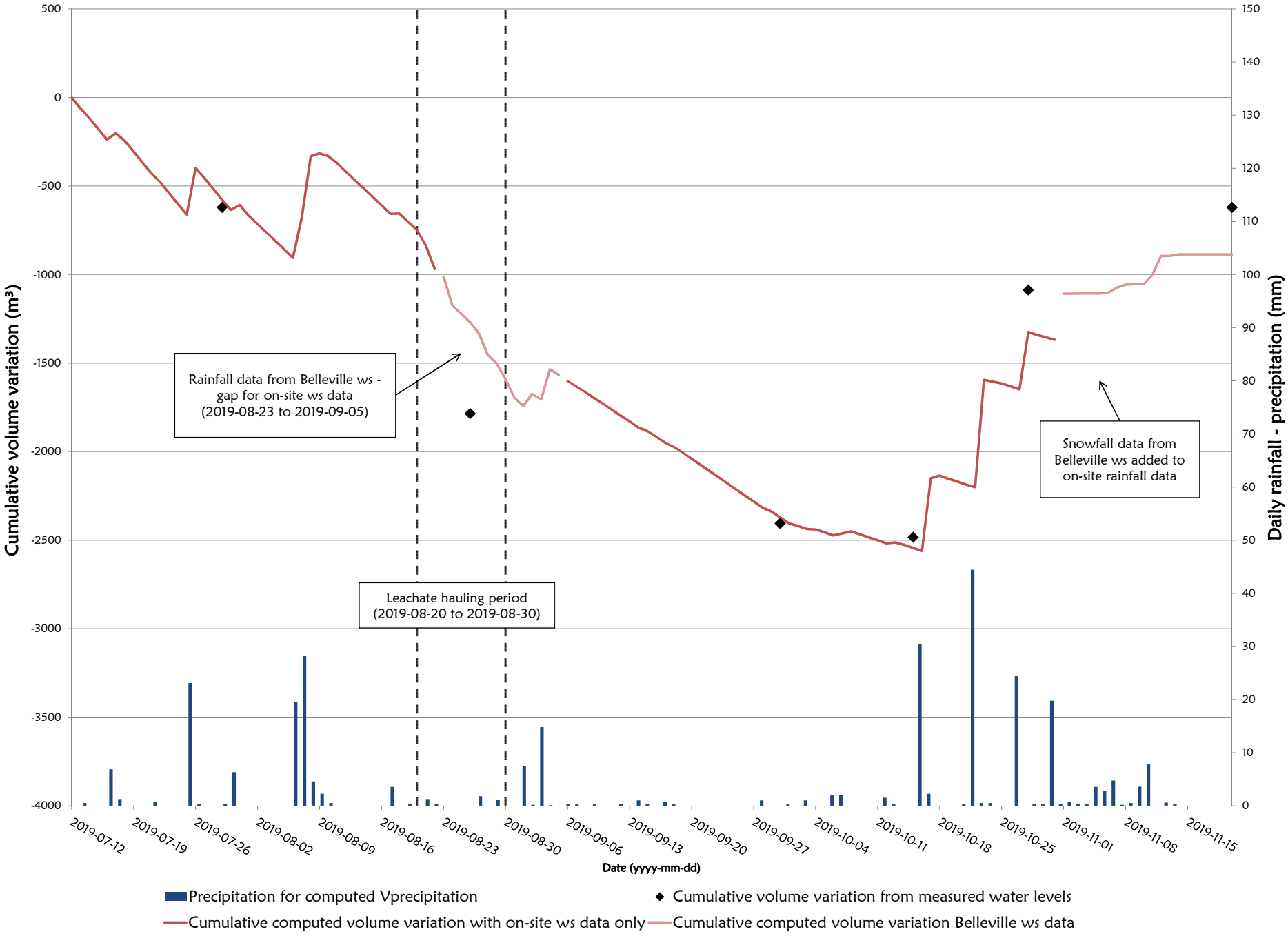


Figure 3: Updated Computed vs. Observed Cumulative Volume Variations (July 12 - November 20, 2019)



TABLES

Table 1: Summary of Input Parameters and Results of Simplified Water Balance

Month	Year	Total Precip (mm)	Vprecip (m^3)	Vpe (m^3)	Vin (m^3)	Vout (m^3)	ΔV (m^3)	Cum Vol. (m^3)	Measured Vol. from WL (m^3)	% difference
December	2016	69.5	973				973	973		
January	2017	79.8	1117				1117	2090		
February	2017	77.5	1085				1085	3175		
March	2017	65.8	921				921	4096		
April	2017	144.4	2022	-517.3	2861		4366	8462		
May	2017	201.7	2824	-880.4			1943	10406		
June	2017	125.9	1763	-1406.0			357	10762		
July	2017	66.1	925	-1593.0			-668	10094		
August	2017	47.3	662	-1399.2			-737	9358		
September	2017	46.6	652	-1137.8			-485	8872		
October	2017	133.7	1872	-654.3			1218	10090		
November	2017	77.8	1089	-96.0			993	11083		
December	2017	43.2	605				605	11688		
January	2018	92.1	1289				1289	12977		
February	2018	74.5	1043				1043	14020		
March	2018	41.8	585	-20.2			565	14585		
April	2018	137.6	1926	-170.3	2702		4459	19044		
May	2018	45.2	633	-1123.9			-491	18553		
June	2018	132.1	1849	-1421.1			428	18981		
July	2018	31.4	440	-1847.0			-1407	17574		
August	2018	111.4	1560	-1622.3			-63	17511		
September	2018	79	1106	-1135.5			-29	17481		
October	2018	62.3	872	-416.2			456	17937		
November	2018	107.7	1508	-41.0	795		2262	20199		
December	2018	75.7	1060				1060	21259		
January	2019	66.6	932				932	22191		
February	2019	47.2	661				661	22852		
March	2019	78.2	1095				1095	23947		
April	2019	98.9	1385	-381.7	1930		2933	26880		
May	2019	112.6	1576	-859.4	2952		3669	30549		
June	2019	62.5	875	-1402.5			-527	30022		
July	2019	29.6	414	-1802.3			-1388	28634	19442	38.2%
August	2019	52.4	734	-1472.9		-489	-1228	27406	18258	40.1%
September	2019	61.5	861	-1010.1			-149	27257	17627	42.9%
October	2019	120	1680	-530.0			1150	28407	18969	39.8%
November	2019	22.6	316	-4.7			312	28718	19442	38.5%
December	2019	67	938				938	29656	20000	38.9%
January	2020	91.7	1284		295		1579	31235	21801	35.6%
February	2020	51.4	720				720	31955	21491	39.2%
March	2020	71.8	1005	-106.5			899	32854		
April	2020	95	1330	-330.5			999	33853	22733	39.3%
May	2020	41.1	575	-859.4		-298	-582	33271	22981	36.6%