Analysis of the Merritt and Miller (2016) "Nutrient Loadings to Utah Lake" report

I have compared the mass balance values that I obtained analyzing the total phosphorus (TP) loading and hydraulic loading data that LaVere Merritt shared with me to the analogous results provided in the Merritt and Miller (2016) report. In many cases the key details are similar between the two analyses, for example, hydraulic loading to and discharge from Utah Lake, phosphorus output mass flow and phosphorus output concentration from the lake, wastewater treatment plant (WWTP) effluent TP and TN concentrations, and TP retention in the lake. However, in several important ways the results I obtained (Brett 2019) and the results Merritt and Miller (2016) reported differ substantially. I will list these differences below:

1. My analysis of the raw data provided by LaVere Merritt indicated a total TP loading to Utah Lake of 154 tons TP/yr, whereas Merritt and Miller (2016) reported 272 ton/yr.

2. The difference in these two loading estimates is almost entirely due to different WWTP total phosphorus inputs to Utah Lake. I calculated that the Utah Lake TP loading from WWTPs was 92 tons/yr and Merritt and Miller (2016) reported the WWTP loading was 215 tons/yr.

3. The back-calculated WWTP effluent TP and TN concentrations for the two approaches were moderately similar, so the large discrepancy in the WWTP loading estimates is mostly due to Merritt and Miller (2016) using a WWTP hydraulic discharge that was 90% higher than what the data I was provided indicated. I checked the assumed flows for each of the seven WWTP dischargers to Utah Lake. Merritt and Miller (2016) assumed higher flows for all of the WWTPs than the data I was provided indicated.

I discussed this discrepancy with Scott Daly and Mitch Hogsett, and Scott Day offered to supply me with contemporary WWTP discharge flow data for the 2015-2019 time period. The updated WWTP flow data provided by Daly (2019) was quite similar to the flow data used in the Merritt and Miller (2016) analysis. The total flow for the seven largest municipal wastewater treatment facilities (Timpanogos, Provo, Orem, Spanish Fork, Springville, Payson, and Salem) was ≈ 53,000 acre-feet/yr for both the Merritt and Miller (2016) and Daly (2019) datasets, however, the estimated flow from Salem WWTP was five times larger for the Merritt and Miller (2016) dataset.

The updated flow data from the WWTPs that discharge to Utah Lake (Daly 2019) and the original nutrient mass balance data provided to me by Dr. Merritt indicate that WWTPs account for 76% of the phosphorus loading to Utah Lake.

4. Merritt and Miller (2016) reported overall TP and hydraulic loading to Utah Lake was 272 tons/yr and 646,171 acre feet/yr, respectively. Merritt and Miller (2016) also reported the flow weighted TP input concentration to Utah Lake was 634 μg/L. When I calculated the input TP concentration based on the TP and hydraulic loading data reported in Merritt and Miller (2016), i.e., 272 tons/yr and 646,171 acre feet/yr, I obtained an input TP concentration of 341 μg/L. This indicates Merritt and Miller (2016) made a nearly factor two calculation error for this concentration.

5. In several places in their interim loadings report Merritt and Miller (2016) seem to claim that cyanobacteria blooms can only be controlled if the average lake TP concentrations can be reduced down to 30 µg/L (20 and 40 µg/L are also referred to in this context). Merritt and Miller provide no source for this claim. In contrast, Downing et al. (2001) showed the proportion of cyanobacteria in lake phytoplankton communities is a continually increasing non-linear function of TN and TP concentrations. There is nothing special about a TP concentration of 30 µg/L vis-à-vis cyanobacteria dominance except that this concentration is sometimes set as a threshold for eutrophic conditions. [However, 20 µg/L is the most common threshold for eutrophy (Welch and Jacoby 2004.].

8. Merritt and Miller also note that the input TP concentration they incorrectly reported (i.e., 634 µg/L) is 21 times higher than a lake concentration of 30 µg/L. However, this is truly comparing apples to oranges (i.e., the input TP to the lake TP concentrations) and has no bearing on the broader point of cyanobacteria dominance in lakes especially as Merritt and Miller (2016) correctly noted Utah Lake has a high phosphorus retention capacity. The updated phosphorus mass balance data indicate that Utah Lake retains 90% of its phosphorus inputs[1] (assuming for now that the underlying data are correct).

9. As is readily apparent from the basic mass balance equation for any lake, i.e., $TP_{lake} = TP_{input}/(1 + \theta\sigma)$, where θ represents a lake's water residence time and σ represents a first-order rate constant for phosphorus loss to the sediments, the phosphorus concentration in a lake (TP_{lake}) is directly and linearly related to the input TP concentration (TP_{input}) (Brett and Benjamin 2008).[2] What this means in practical terms is that if a lake's TP loading was reduced by a factor of two one should expect that its TP concentration would also decrease by a factor of two (assuming θ and σ stay constant). For example, in the case of Utah Lake according to the original mass balance data provided by LaVere Merritt and the updated WWTP data provided by Scott Daly decreasing the WWTP effluent concentrations from the current average of 2,947 µg/L to an average of 1,000 µg/L would reduce the input TP concentration to Utah Lake from 294 to 146 µg/L. This in turn should reduce the average lake TP concentration from 63.5[3] to 31.5 µg/L.

In summary, the TP and hydraulic loading data reported in Merritt and Miller (2016), i.e., 272 tons/yr and 646,171 acre feet/yr, respectively, indicate an input TP concentration to Utah Lake of 341 µg/L, however, these authors reported this value to be 634 µg/L. My reanalysis of the nutrient budget for Utah Lake based on recently updated data for WWTP discharges provided by Scott Daly indicates phosphorus and hydraulic loading of 254 tons/yr and 699,135 acre feet/yr, respectively. These data indicate an average flow weighted TP input concentration of 294 µg/L. The analysis summarized in this memo is solely based on wet inputs, e.g., WWTP discharges, stream/river runoff, springs/drains, and precipitation onto the surface of Utah Lake. It does not consider dry fallout, which is currently the subject of considerable discussion and debate. All interested parties in the Utah Lake Water Quality Study should work together to create a

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[1] Total Phosphorus retention was calculated as R = (TP loading – TP export)/(TP loading), only counting wet inputs and outputs to Utah Lake.

[2] Because Utah Lake has high evaporative losses, it would be better to envision the simplified mass balance equation in terms of mass flow instead of concentrations, but this change won't affect the general conclusions.

[3] This average Utah Lake TP concentration was obtained from the mass balance data provided by LaVere Merritt. In contrast, the data provided by the Utah Lake data explorer indicates an average TP concentration of 87 µg/L.

“consensus” Utah Lake nutrient mass balance, and this consensus nutrient budget should be published in an archival peer-reviewed limnology journal so that it is widely available to all interested parties. Dr. LaVere Merritt and Scott Daly have already made very important contributions to this consensus document.

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		units	Brett 2019	Merritt & Miller 2016	Daly 2019
1	TP loading	tons TP/yr	152	272	254
2	TN loading	tons TP/yr	2022	2145	2542
3	TN/TP ratio	molar ratio	29.4	17.5	22.2
4	Hydraulic loading	acre feet/yr	674057	646171	699135
5	*Hydraulic loading*	*m3/s*	*26.4*	*25.3*	*27.3*
6	TP input concentration	µg/L	183	341	294
7	TP input conc (Merritt & Miller 2016)	µg/L	-	634	-
8	TN input concentration	µg/L	2432	2691	2947
9	WWTP TP loading	tons/yr	91.8	215	193
10	WWTP TN loading	tons/yr	675	1174	1194
11	% WWTP TP loading	percent	60%	79%	76%
12	WWTP Hydraulic loading	acre feet/yr	27920	53126	52997
13	*WWTP Hydraulic loading*	*m3/s*	*1.1*	*2.1*	*2.1*
14	WWTP TP concentration	µg/L	2666	3281	2956
15	WWTP TN concentration	µg/L	19594	17915	18272
16	TP output mass flow (Jordan R)	tons/yr	23.4	26	24.7
17	Hydraulic export (Jordan R)	acre feet/yr	295286	336045	315666
18	*Hydraulic export (Jordan R)*	*m3/s*	*11.5*	*13.1*	12.3
19	TP output concentration (Jordan R)	µg/L	64.2	62.7	63.5
20	TP retention	unitless	0.85	0.90	0.90

WWTP flows (af/yr)	Brett 2019	Merritt & Miller 2016	Daly (2019)
Orem	4854	8949	9382
Provo	12164	15048	12692
Timpanogos	4446	17169	20238
Springville	2753	4172	3938
Spanish Fork	2381	4884	4683
Salem	467	1200	236
Payson	855	1704	1828