LAKE WATER AND NUTRIENT BUDGETS REPORT

Buffalo River Watershed

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1.0 Introduction

This report addresses the water and total phosphorus (TP) budgets created for lakes in the Buffalo River Watershed (BRW) as described in Task 10 of the Minnesota Pollution Control Agency (MPCA) contract #B55092: Buffalo River Watershed Approach Plan Phase 2. Results of these budgets will be used to inform modeling to be completed during the next steps of the BRW Approach project. Budgets were created for the five lakes in the Sand-Axberg Chain of Lakes in the north-central portion of the BRW. In addition, water and TP budgets were created for each of the five "example" lakes developed under Task 9 of this project (HEI 2011a). Herein, we describe the data and methods used to compute water and TP budgets for the five specific and five "example" lakes during the years 1997-2010.

2.0 Defining Lakes and Watersheds

2.1 Sand-Axberg Chain

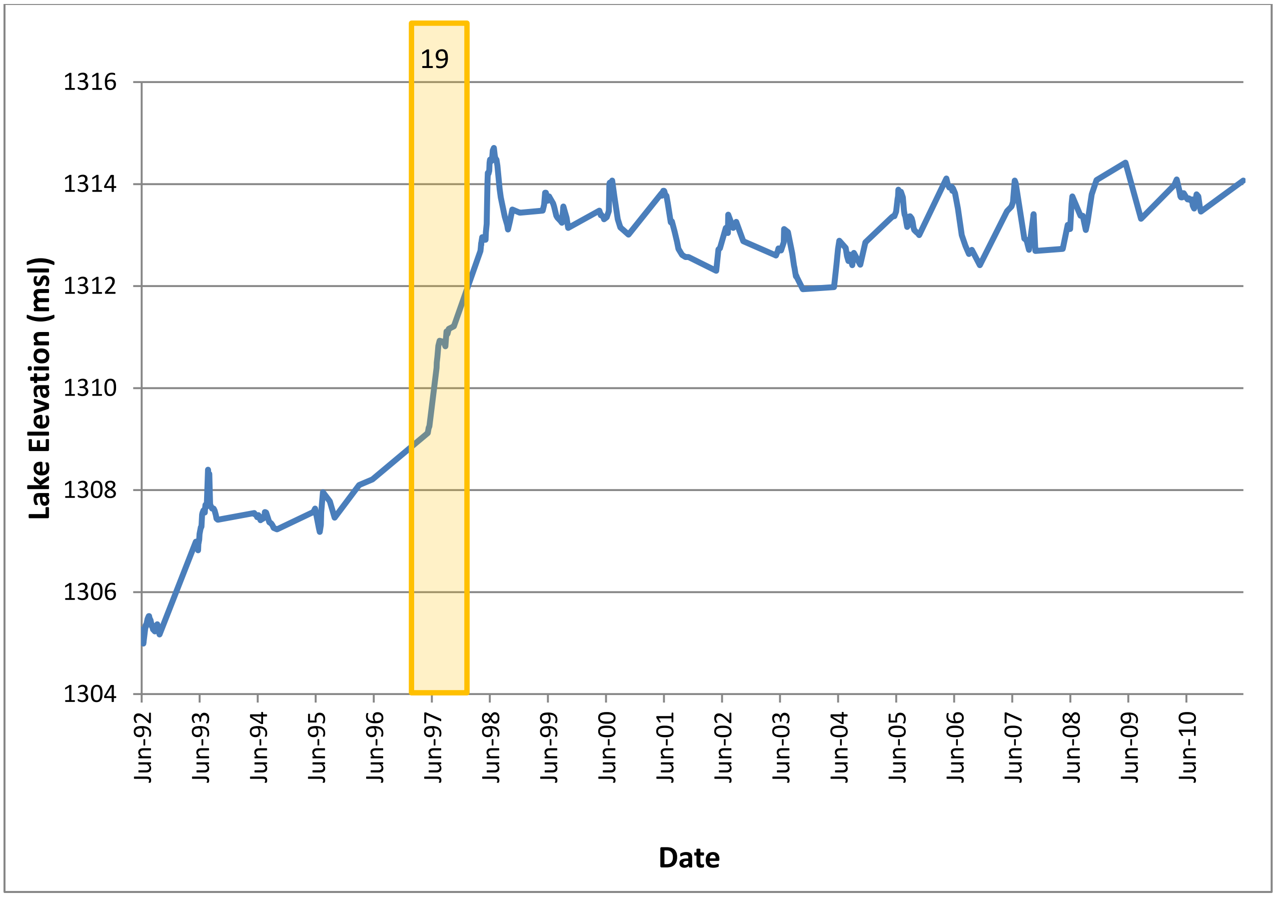
2.1.1 Background

The Sand-Axberg Chain of lakes has been a topic of concern by local citizens and the MPCA for a number of years and is a primary focus of the lakes portion of the Buffalo River Watershed-Wide Total Maximum Daily Load (TMDL) study. The Chain has a long history of anthropogenic impacts, including a basin created in the northwest section of Axberg Lake for use in storing poultry manure and the eventual re-routing of flow from and around this waterbody.

In 1997, the hydrology of the Sand-Axberg Chain was changed significantly as large amounts of precipitation caused extensive flooding that connected closed basins (Paakh, 2011). Prior to 1997, water from Axberg Lake flowed through wetlands into Sand Lake, and from Sorenson Lake to Talac Lake to Sand Lake. In 1997, Erickson Lake (previously a closed basin) flowed into an unnamed lake into the contaminated west basin of Axberg Lake, to Sand (Stump) Lake, to Talac Lake. Sorenson Lake also discharged into Talac Lake. Talac Lake discharged into Yort Lake (previously closed basin). Water discharges from Yort Lake through two outlets and eventually makes its way into Lime Lake. Also in 1997, a secondary outlet was constructed in the main (eastern) section of Axberg Lake, allowing water to exit directly from this area and bypass the (western) constructed basin. A culvert between the main lake basin and the constructed basin was plugged. In 2009, the small unnamed lake to the west of Axberg Lake was also rerouted around the constructed basin to reduce the amount of water entering (and contaminated water leaving) that portion of Axberg Lake.

It appears the changes in the hydrology of the Sand-Axberg chain, which occurred in 1997, continue to this day (Paakh 2011). Water level measurements from Talac Lake (**Figure 1**) show some evidence of this, as water levels since 1997 are four to six feet higher than they were before the change. Given this significant change in the hydrology of the lakes, the water and TP budgets created for this work are concentrated only on the time period since 1997. **Figure 2** displays the flow of water after the hydrology was altered in 1997. **Table 1** displays the morphometric characteristics of the lakes of concern within the Sand-Axberg chain.

Figure 1. Talac Lake water elevation from 1992-2011 noting the altered hydrology in 1997.



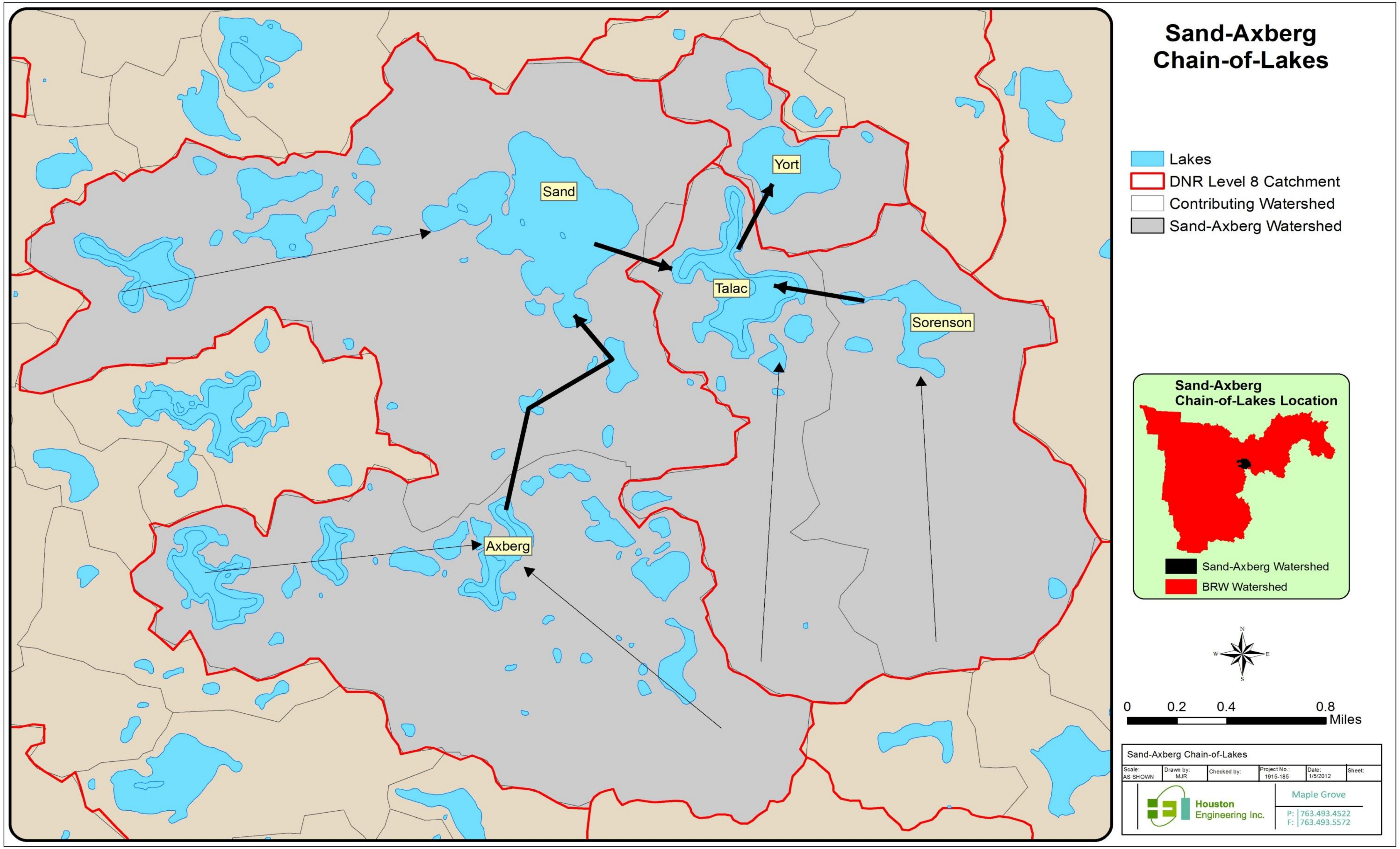


Figure 2. Sand-Axberg chain-of-lakes watershed. Bold arrows indicate direction of flow between lakes. Non-bolded arrows indicate overland flow direction within a lake's watershed.

Table 1. Physical characteristics of lakes within the Sand-Axberg chain-of-lakes.

Lake Name	DNR Lake ID #	Surface Area (acres)[1]	Mean Depth (ft.)	Maximum Depth (ft.)	Lake Volume (ac-ft.)	Contributing Local Watershed Area (acres)	Average Residence Time (months)[2]
Axberg	03066000	33	9	13	294	1,559	6
Sand	03065900	199	15	28	2,982	1,863	32
Sorenson	03062500	78	4.5*	8	351	930	14
Talac	03061900	137	11	13	1,503	602	14
Yort	03061800	58	5*	9	292	231	3

* Regression analysis used to calculate mean depth (HEI 2011a).
[1] Surface area as defined by the MN DNR lakes 24 k data layer.
[2] Average (computed) residence time between 1997-2010.

2.1.2 Contributing Watershed Characteristics

Contributing watersheds for each of the lakes within the Sand-Axberg chain were defined through use of the Minnesota Department of Natural Resources (MN DNR) level 8 autocatchments Geographic Information Systems (GIS) layer. This layer breaks down the MN DNR level 8 catchments into smaller subcatchments to provide finer delineations of contributing areas to lakes across the state. Within the Sand-Axberg chain, subcatchments ranged from three to 1,059 acres. Subcatchments within the area of the Sand-Axberg chain were merged, as shown in **Figure 2**, to define the contributing watershed for each of the five lakes.

An important consideration in the amount of water and TP entering a lake is the characteristics of its contributing watershed. The 2006 National Land Cover Dataset (NLCD) was used to define the Land Use / Land Cover (LULC) component of this analysis. ArcGIS zonal statistics were used to compute the number of raster cells for each NLCD LULC category within each contributing watershed. The percentage of the watershed within each LULC was then calculated. The NLCD layer identifies fifteen LULC categories. These categories were condensed into five general use categories, (forest, water/wetland, cultivated, pasture/open, urban), using methods consistent with those of the MPCA for use in assessment purposes (Anderson 2011). **Table 2** shows how the NLCD LULC categories were condensed. **Table 3** displays the area and percent LULC of the contributing watersheds to the lakes within the Sand-Axberg chain.

Table 2. 2006 NLCD and associated general LULC categories.

NLCD Categories	MPCA Categories
Deciduous Forest Evergreen Forest Mixed Forest Shrub/scrub	Forest
Open Water Woody Wetlands Emergent Herbaceous Wetlands	Water/Wetland
Cultivated Crops	Cultivated
Grassland/herbaceous Pasture/hay Barren	Pasture and Open
Developed Open Space Developed Low Intensity Developed Medium Intensity Developed High Intensity	Urban

Table 3. Area and percent land use / land cover for the contributing watersheds of the Sand-Axberg chain.

Lake Name	Contributing Watershed Area (acres)	Percent Land Use / Land Cover				
		% Water / Wetland	% Urban	% Forest	% Pasture & Open	% Cultivated
Axberg	1,559	18	4	39	9	31
Sand	1,863	21	5	14	8	52
Sorenson	930	10	4	15	16	55
Talac	602	24	2	25	13	37
Yort	231	33	2	9	13	43

2.2 "Example" Lakes

2.2.1 Background

"Example" lakes were developed during Task 9 of this project (HEI 2011a) to describe the general morphometric, water quality, and LULC characteristics that can be expected within an 'average' lake within each ecoregion and relative depth of the BRW. Lakes were divided by ecoregion and relative depths because the Minnesota eutrophication water quality standards for lakes were developed based on these considerations (i.e., the Level III ecoregion and if the lake is "deep" or "shallow" i.e., greater or less than 15 feet maximum depth). During Task 9, the representative values for mean depth, surface area, summertime water quality, and catchment LULC were computed for each "example" lake **Table 4** displays the morphometric characteristics for the "example" lakes.

Table 4. Morphometric characteristics of "example" lakes.

"Example" Lake Group*	Surface Area (acres)	Mean Depth (ft.)	Lake Volume (ac-ft.)	Contributing Watershed Area (acres)	Average Residence Time (months)
LA - Deep	154	14.5	2,233	665	248
LA - Shallow	189	4.9	924	1027	47
NCHF - Deep	182	15.6	2,842	949	164
NCHF - Shallow	220	6.0	1,321	949	102
NLF - Shallow	841	7.4	6,208	1349	3
* LA = Lake Agassiz Plain Ecoregion, NCHF = North Central Hardwood Forest Ecoregion, NLF = Northern Lakes and Forest Ecoregion					

2.2.2 Contributing Watershed Characteristics

Similar to the methods used in the Sand-Axberg chain, contributing watersheds of the "example" lakes were defined through use of the MN DNR level 8 autocatchments. Each lake's contributing watershed was defined as the lake's direct contributing subcatchment and all adjacent contributing subcatchments. All forty-eight lakes that have water quality data available (HEI 2011a) had a contributing watershed calculated in GIS. The mean contributing watershed area was then computed for each ecoregion and relative depth.

The "example" lake's LULC were calculated during Task 9 of this project (HEI 2011a) using an approach similar to that described in **Section 2.1.2**. Those numbers were considered valid for use in this analysis. **Table 5** displays the area and percent LULC in the contributing watersheds of the "example" lakes.

Table 5. Contributing watershed area and percent land use / land cover for "example" lakes.

"Example" Lake Group*	Mean Contributing Watershed Area (acres)	Mean Percent Land Use / Land Cover				
		% Water/ Wetland	% Urban	% Forest	% Pasture & Open	% Cultivated
LA - Deep	665	31	13	14	8	34
LA - Shallow	1,027	25	7	5	4	59
NCHF - Deep	949	25	3	43	14	15
NCHF - Shallow	949	23	4	29	14	31
NLF - Shallow	1,349	56	2	39	3	0
*LA = Lake Agassiz Plain Ecoregion, NCHF = North Central Hardwood Forest Ecoregion, NLF = Northern Lakes and Forest Ecoregion						

3.0 Water and TP Budgets

3.1 Water Budget

A water budget is an accounting for the amount of water entering and leaving a lake over a given time period. In this case, the budgets assume steady state and address the annual condition. Final results are presented as a mean annual water budget. The amount of water moving in and out of a system varies from year-to-year depending primarily on the amount of rainfall occurring in the area. The water budget is important to quantify since different sources of water can contain different quantities of pollutants (in this case, TP). The water budget is also important for use in the calibration and validation of hydrologic and water quality models.

A water budget accounts for "gains" in water to the lake (i.e., precipitation, runoff/inflows, and groundwater inflow) as well as "losses" (i.e., evaporation, surface outflow, and groundwater outflow). The basic water budget equation is shown below. Each of the terms in the equation affects the volume of water in the waterbody (storage).

Basic Water Budget Equation:

Change in storage = surface runoff from contributing watershed + tributary inflow + precipitation – evaporation – surface outflow +/- groundwater +/- error

As discussed in the following sections, very little empirical data was available for developing the water budgets for the BRW lakes. The basic water budget equation was re-arranged to solve for the outflow from each lake, based on locally observed precipitation, computed evaporation, and computed surface water inflows (tributary and runoff). Since no information was available on the annual groundwater flow into and/or out of these lakes, the outflow term that was solved for included both surface water outflow and net groundwater outflow. Error was also explicitly acknowledged. The water budget equation used for modeling the lakes in the BRW is as follows:

Surface outflow +/- groundwater +/- error = surface runoff from contributing watershed + tributary inflow + precipitation – evaporation – change in storage

3.1.1 Surface Water Runoff and Tributary Inflow

Observed surface water runoff data was not available for the area surrounding the Sand-Axberg chain. Some event-based measurements were available from the MPCA in the tributaries connecting the lakes, but no long-term data was collected. The event-based data provided by MPCA covered the time frame from 2000-2010 and contained the following number of tributary inflow measurements for each lake: Axberg (0), Sand (11), Sorenson (12), Talac (6), and Yort (0).

Since little to no data were available to accurately compute surface runoff into each lake, unit runoff values were created for the area, using continuous streamflow data collected at the United States Geological Survey's (USGS) gauging station on the Buffalo River at Hawley, MN (Station number: USGS 05061000). Mean daily flows at the Hawley station are available from 1946-2011. Daily unit runoff values were computed from the USGS data for the time period from 1997 through 2010. These values were then combined with the contributing watershed areas to estimate the annual surface water runoff volume entering each lake in the Sand-Axberg chain . The mean daily unit runoff value computed the 1997-2010 data from the USGS station was 0.014 inches per day.

The surface runoff for the "example" lakes was calculated using the same approach as that for the Sand-Axberg chain. Since the USGS gauging station in Hawley is the closest continuous flow monitoring station with a long period of record to the lakes within the BRW, the unit runoff values from that analysis were deemed appropriate for use. The other flow monitoring stations within the BRW (Buffalo River at Sabin and near Dilworth) lie far to the west of the BRW lakes.

Tributary inflow values for the Sand-Axberg chain water budgets were simulated as equal to the outflow from the next upstream lake. As discussed, due to the nature of data available for this work, the surface water outflow, groundwater, and error terms in the water budget equation were combined in our analysis. The assumption was then made that the groundwater and error components of that term were negligible and that the term could be simplified to reflect only surface water outflow from the lake, which in term became the tributary inflow to any downstream lakes. These assumptions were deemed appropriate due the lack of data available for the work and the anticipated magnitude of the groundwater and error terms compared to that of the surface water outflow.

The “example” lakes were assumed to represent waterbodies without an upstream tributary. As such, the ‘tributary inflow’ term in the “example” lake water budgets was set equal to zero.

3.1.2 Precipitation

Long-term precipitation records (1896-2010) were downloaded from the Minnesota Climatology Working Group Detroit Lakes 1NNE monitoring station (Station number 212142) and were combined with each lake’s surface area to estimate the volume of water entering each lake during the years of study (1997-2010). Mean annual precipitation was estimated at 30.21 inches per year. Lakes within the Sand-Axberg Chain and the “example” lakes used the same precipitation data to estimate contributing volumes.

A large gap existed in the spring 1997 observed precipitation record that was downloaded from the MN Climatology Working Group. To provide a more accurate estimate of precipitation during this time, data from the Better Assessment Science Integrating point & Non-point Sources (BASINS) system was used for the 1997 data. Precipitation data available through the BASINS system has had missing records filled using an approach that relies upon data from nearby national weather stations. Relying on the BASINS data for the year 1997 provided a more accurate accounting of the water that entered the system during this time.

3.1.3 Lake Evaporation

Since evaporation accounts for an important component of the overall water budget for a lake, making an estimate of this process is essential. A method derived from both physical and empirical relationships, accounting for many of the influencing meteorological parameters, was used for this study. The method is well accepted for the estimation of open water evaporation and is known specifically as the combined aerodynamic and energy balance method for lake evaporation. Three methods were analyzed that include the Lake Hefner #1, Lake Hefner #2, and the Meyer Method. The average value among these three methods was used to estimate yearly evaporation from the lakes.

Each evaporation calculation method requires the following data: 1) wind speed; 2) water vapor pressures (expressed as dew point); and 3) air temperature. Data measured by a first-order weather monitoring station at Detroit Lakes (National Climatic Data Center station number 727457) provided the data necessary to compute evaporation for all BRW lakes from 1997-2010. Evaporation values computed from the data at the Detroit Lakes weather station were considered representative of the entire BRW (i.e., applied to both the Sand-Axberg chain, as well as the “example” lakes), given the central location of the station in the watershed and the fact that the only other weather station with sufficient data to compute evaporation (using this approach) is in Fargo, ND, which lies far to the west of the BRW lakes. Evaporation was computed on a daily time-step and summarized annually. The yearly evaporation was combined with each lake’s surface area to estimate the volume of water leaving each lake during the period of study (1997-2010). Mean annual evaporation was estimated at 47.4 inches per year. This value is consistent with data available through the BASINS system.

3.1.4 Change in Storage

The change in lake volume (i.e., storage) over a year was calculated as the difference between the final and initial volumes observed, computed as a function of the lake's water level and surface area. Lake stage data were obtained from the Minnesota DNR lakefinder website (www.dnr.state.mn.us/lakefind/index.html, Accessed November 15, 2011); lake surface areas were computed with a GIS (based on the MN DNR 24K lakes layer). Of the lakes within the Sand-Axberg chain, only Talac Lake had lake stage data available through lakefinder. However, since all the lakes in the chain are interconnected and controlled by the outlets on Yort Lake (Paakh 2011), the stage data from Talac Lake was assumed representative of the relative hydraulics of all lakes within the Sand-Axberg chain during the study period. In other words, if the data in Talac Lake showed an increase of 1.2 feet in a given year, it was assumed that all lakes in the Sand-Axberg chain rose that same level during that year. For calculation purposes, water levels for each day of the study period (January 1, 1997 – December 31, 2010) were estimated by interpolating between actual observations. The change in lake volume for each lake was then computed by multiplying the difference in lake level from January 1 to December 31 of each year by the surface area of the lake.

Given the nature of the "example" lake concept and the lack of widespread water level data across all lakes in the BRW, the 'change in storage' term in the "example" lakes was assumed to be zero. Results of the calculations on the Sand-Axberg chain showed this to be a reasonable assumption, as the mean annual 'change in storage' term in the water budgets of that system are less than 5% of the inflow/outflow terms; a small consideration in the overall water budget.

3.1.5 Groundwater / Surface Outflow / Error

Data on annual groundwater interactions with the lakes of the BRW was not available for this work. Anecdotal information from MPCA staff (Paakh 2011) indicates that prior to 1997 Sand Lake provided groundwater recharge, as the lake had no natural outlet. Sand Lake water levels were observed to decrease at a much faster rate than the other lakes within the Sand-Axberg chain (Paakh 2011). Given the qualitative nature of this information and the lack of more detailed data on groundwater interactions with the Sand-Axberg chain, however, it was not directly useful in developing the water budgets. As such, the groundwater term in each of the water budgets was combined with the surface water outflow and error terms and computed by estimating the remaining terms in the budget equation.

Surface outflow data for BRW lakes was also limited. Some event-based data is available for areal lakes (e.g., Yort Lake had six data points observed between 2000 and 2005), but the data was not sufficient to characterize the annual 'surface outflow' term in the water budget. As such, the 'surface outflow' term was (combined with error and groundwater terms) computed from the remaining input and output data in the water budget. As mentioned, the estimated 'surface outflow' was used as the tributary inflow volume for applicable downstream lakes (by assuming that the groundwater and error terms were negligible or equal to zero).

Error was explicitly accounted for in the water budgets, since each term in the equation has significant amounts of uncertainty associated with it. That uncertainty comes from a number of areas, including errors in the empirical data used to compute the values and uncertainty in the methods of value estimation. Actually quantifying the amount of error associated with these calculations was not possible in this analysis; acknowledging that it exists, however, is a vital component of the work.

3.1.6 Estimated Water Budgets

Using the results from **Sections 3.1.1 through 3.1.5**, the annual water budget from 1997-2010 for all lakes in the Sand-Axberg Chain and "example" lakes were estimated and are shown in **Figures 3-7** and **8-12**, respectively. The year water budget results are shown in **Appendix A**.

Figure 3. Axberg Lake average annual water budget (1997-2010).

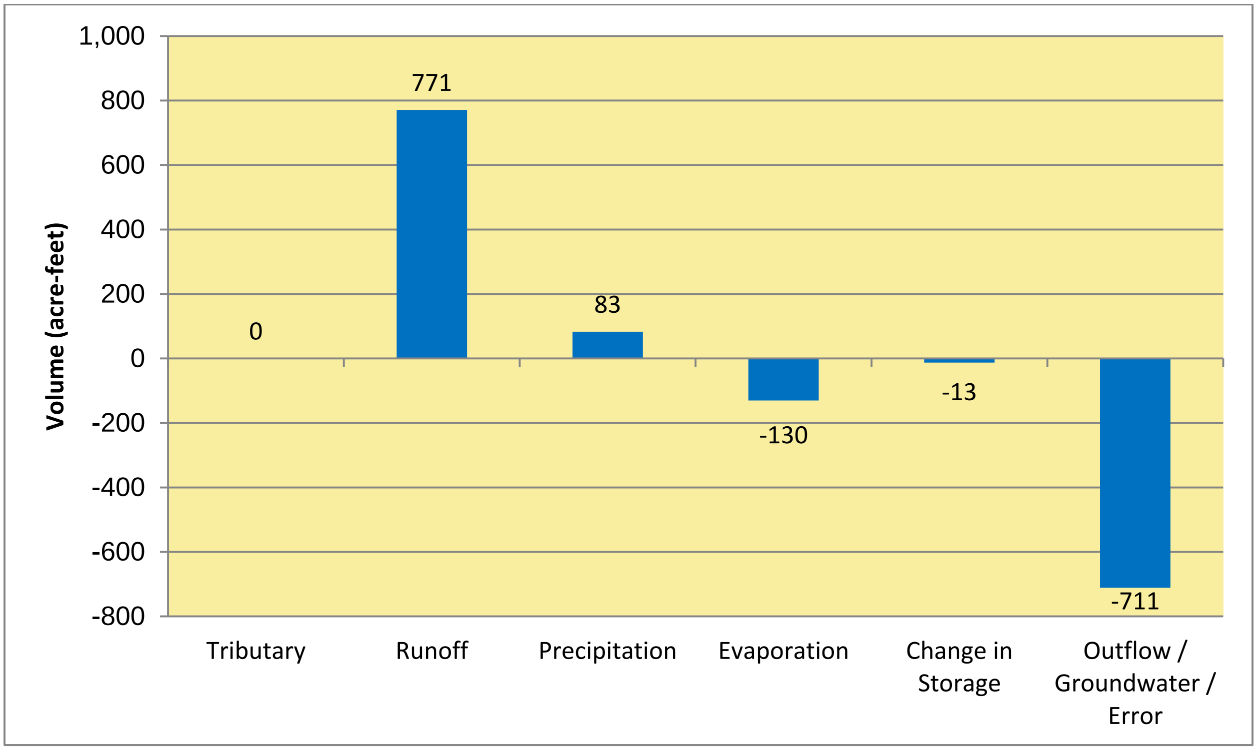


Figure 4. Sand Lake average annual water budget (1997-2010).

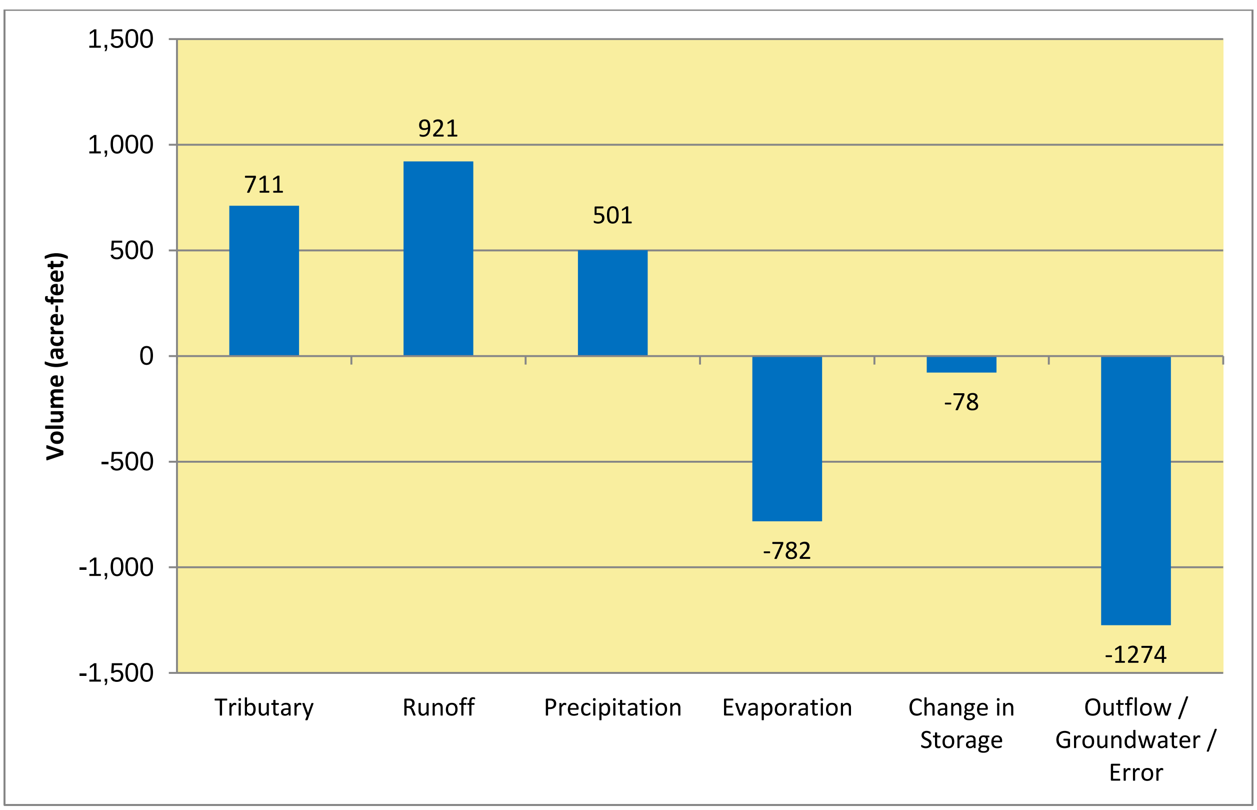


Figure 5. Sorenson Lake average annual water budget (1997-2010).

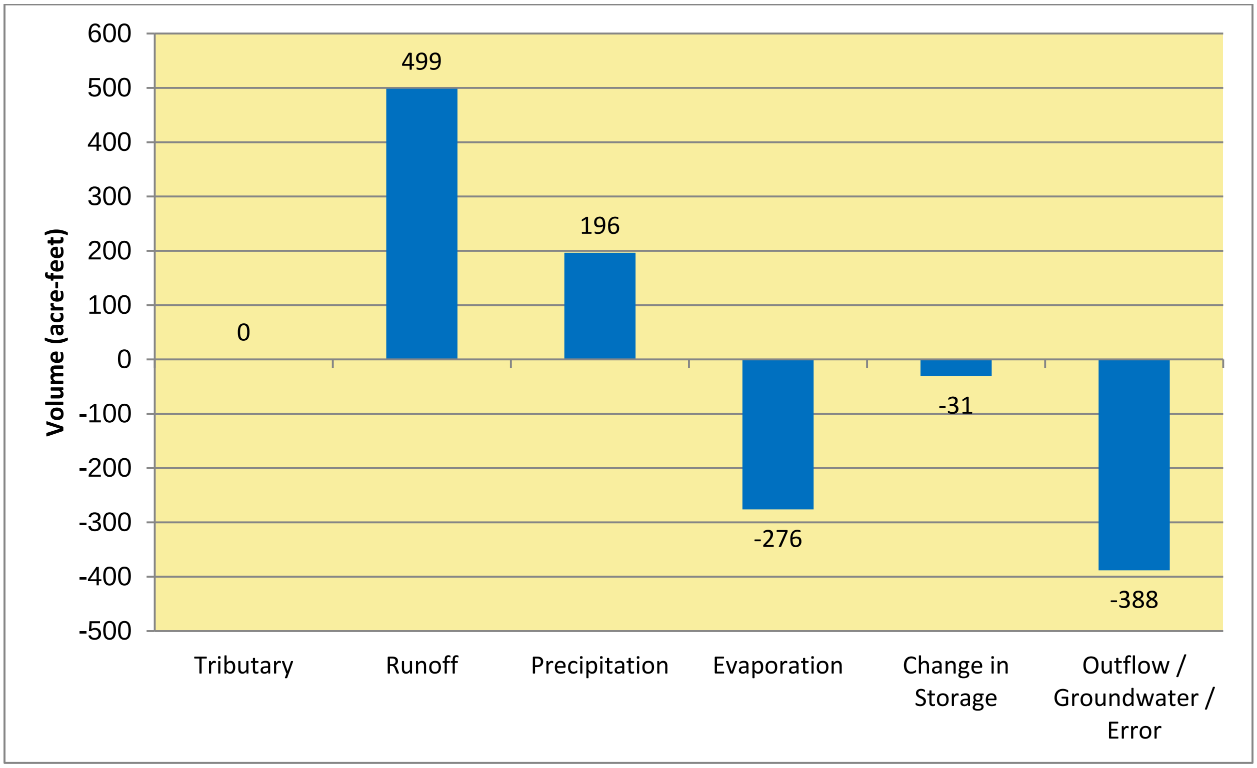


Figure 6. Talac Lake average annual water budget (1997-2010).

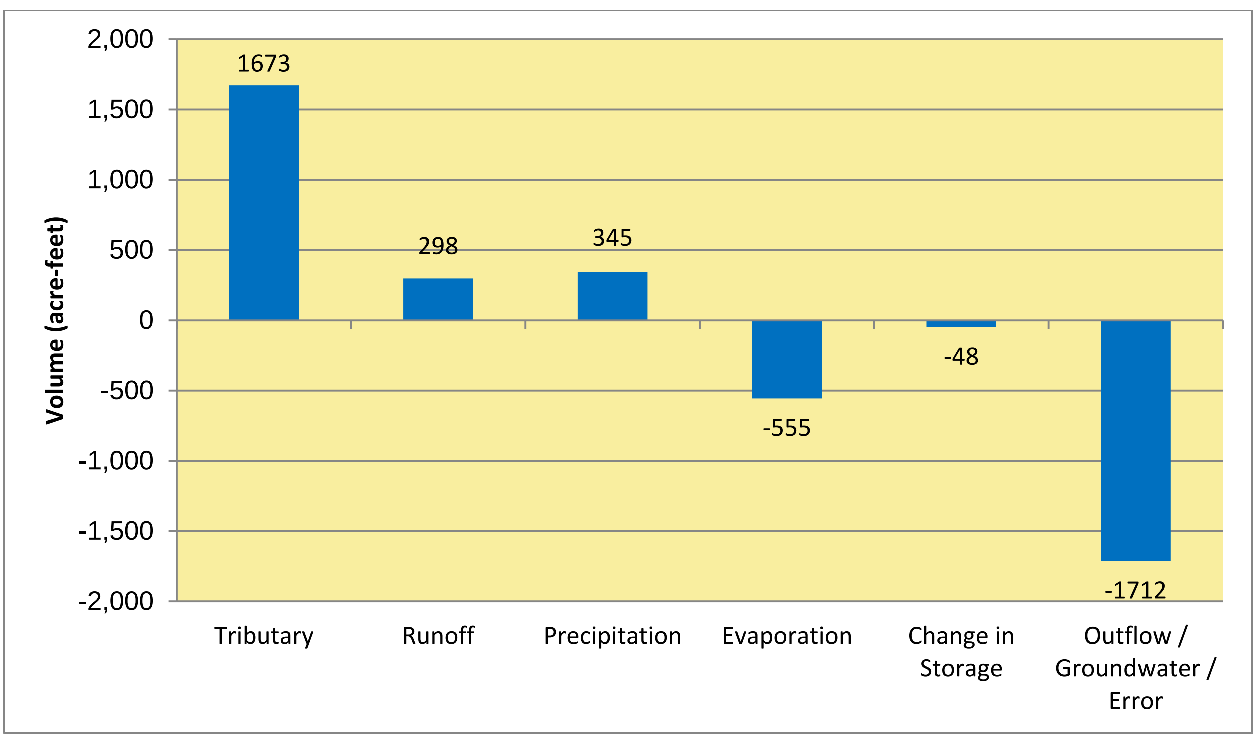


Figure 7. Yort Lake average annual water budget (1997-2010).

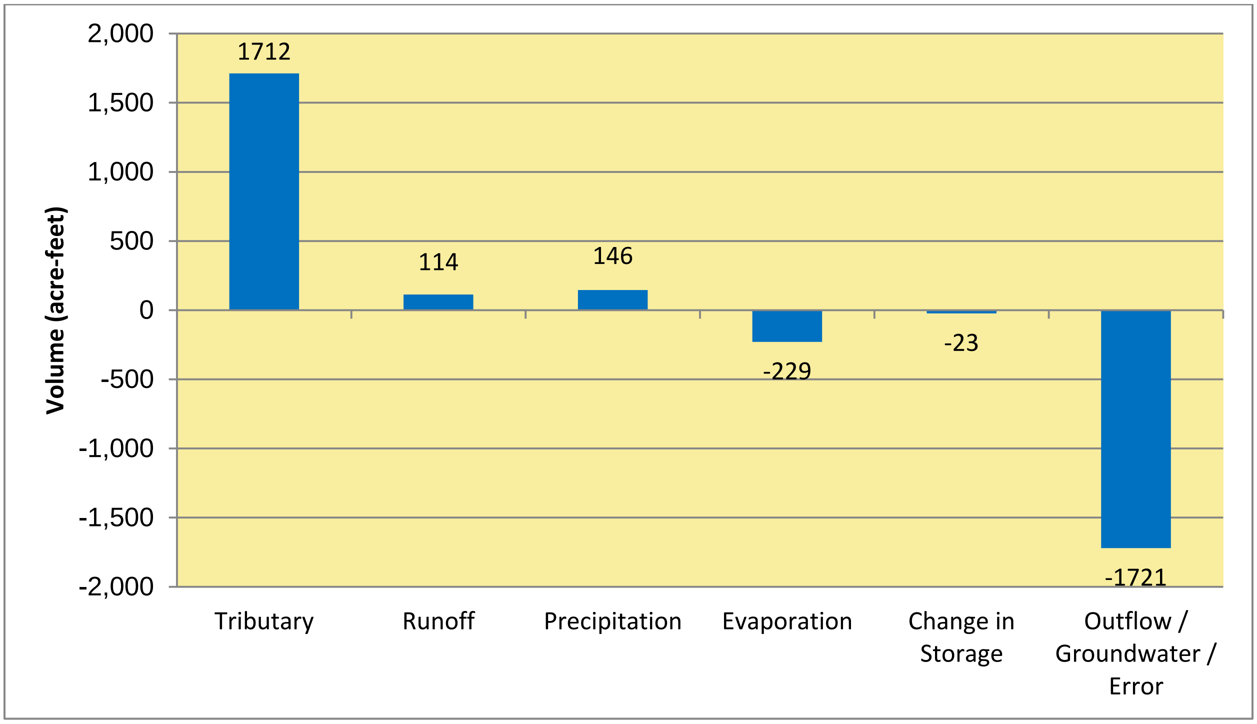


Figure 8. LA Ecoregion – Deep Lakes estimated average annual water budget(1997-2010).

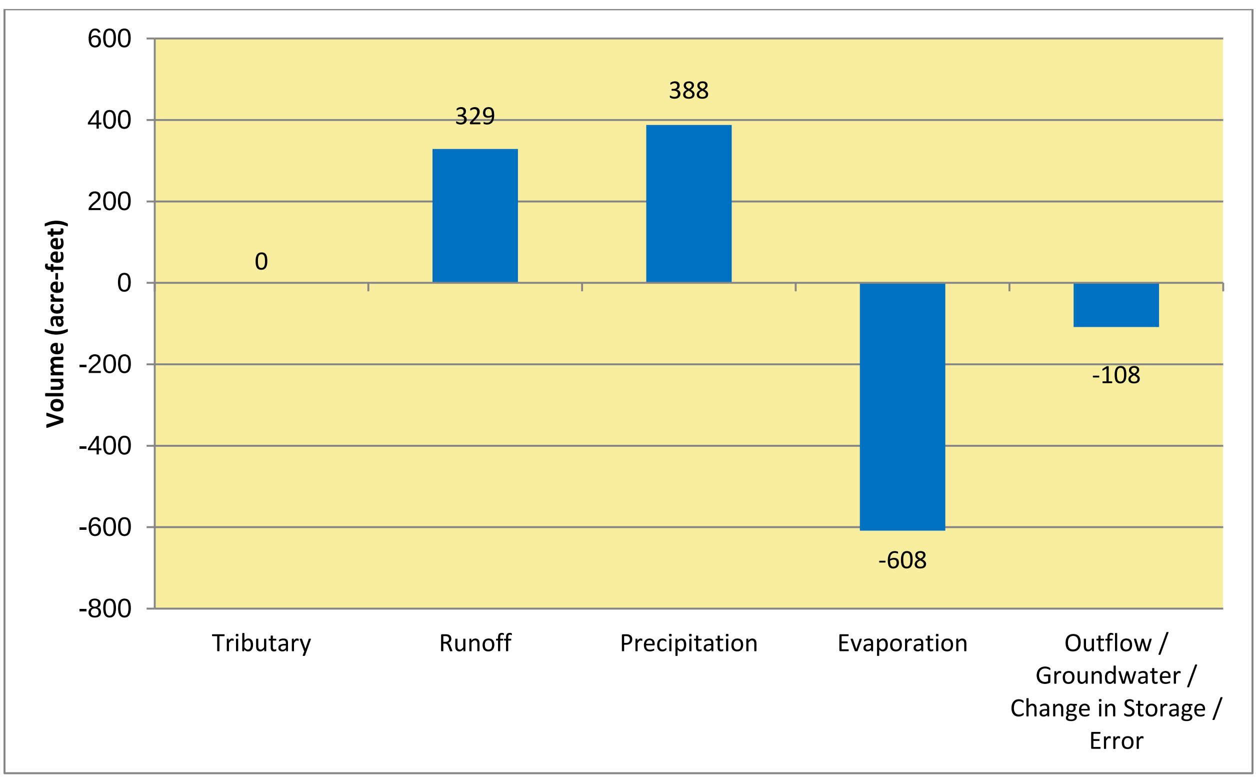


Figure 9. LA Ecoregion – Shallow Lakes estimated average annual water budget (1997-2010).

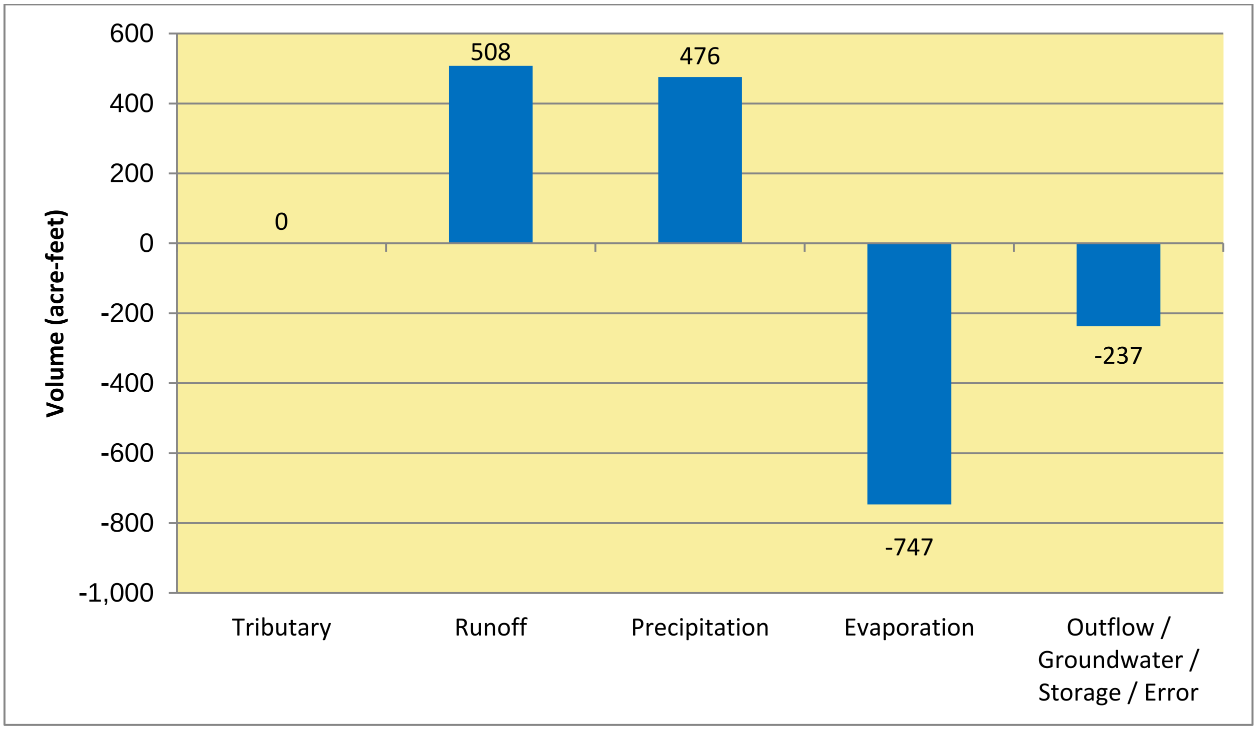


Figure 10. NCHF Ecoregion – Deep Lakes estimated average annual water budget (1997-2010).

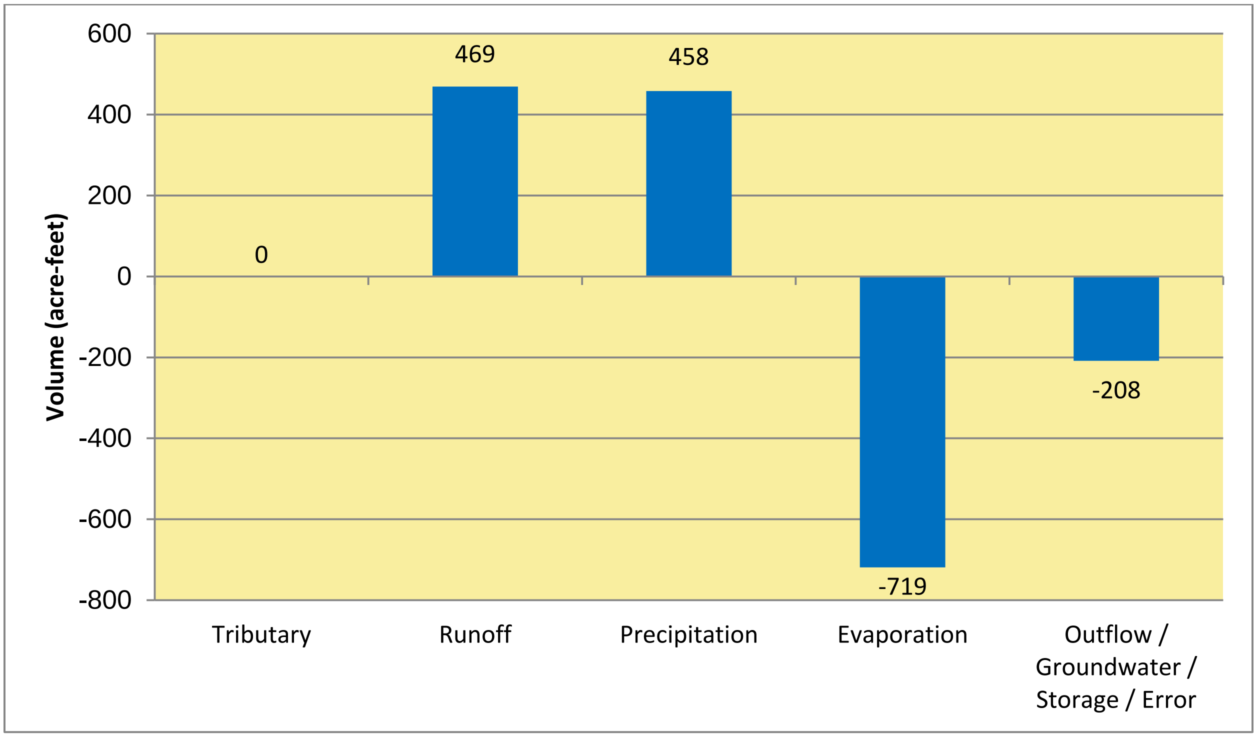


Figure 11. NCHF Ecoregion – Shallow Lakes estimated average annual water budget (1997-2010).

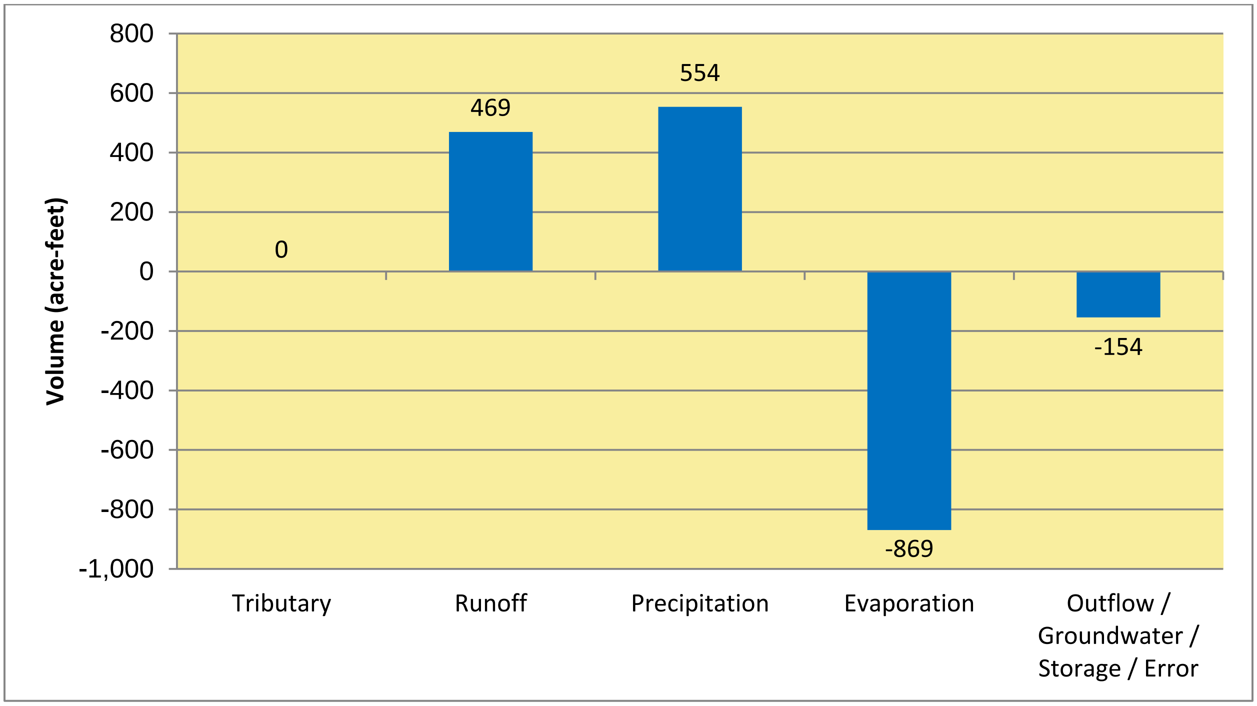
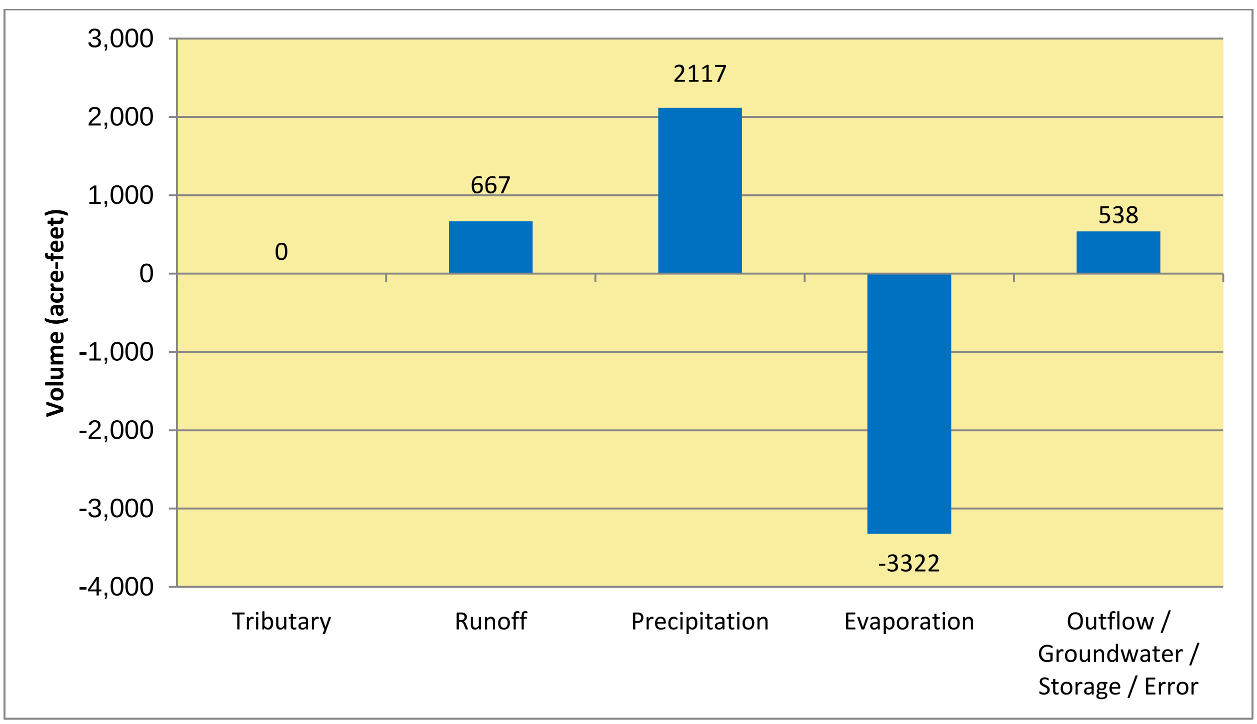


Figure 12. NLF Ecoregion – Shallow Lakes estimated average annual water budget (1997-2010).



3.2 Nutrient Budget

Similar to a water budget, which accounts for the movement of water, a nutrient budget or "mass balance" is an accounting of the amount or "load" of nutrients entering and leaving a lake. Loads are expressed in units of mass per time (e.g., kg/year or lb/year) and estimated by considering the concentration of a substance in the water and the amount of water over a time period. Since phosphorus is the nutrient of primary concern in MN lakes, nutrient budgets were computed for TP. The following sections describe how the various terms of the annual TP budgets were computed for all lakes within the Sand-Axberg chain and the five "example" lakes of the BRW. The TP budgets relied directly on the methods and results of the BRW lake water budgets. The general TP budget for lakes within the BRW was calculated as follows:

In-lake processing (e.g., sedimentation and internal loading) +/– error = tributary load + surface runoff load + atmospheric load – outflow load +/- groundwater load

3.2.1 Surface Inflow

Surface inflow loads were separated between estimated upstream tributary and ungauged (surface water runoff) loads. Similar to the water budget, tributary TP loads were estimated as the outflow load from the lake or lakes directly upstream (discussed in **Section 3.2.3**). This method was used because measured tributary loads to BRW lakes were limited or non-existent. The outflow loads were assumed to contribute directly to the downstream lake with no additional TP inputs or TP losses occurring between the lakes.

To provide an estimate of the surface water runoff load entering each lake, an estimated mean concentration (EMC) of TP was used. TP EMC values were adopted from work performed to support nutrient criteria development for lakes in USEPA Region 8 (HEI 2011b). These values are shown in **Table 4**. A weighted EMC value was computed from the values in **Table 4**, based on LULC characteristics of the contributing watershed of each lake (see **Section 2.0** for BRW lake watershed LULC values). The resultant (weighted) EMC value for each lake was then multiplied by the unit runoff value (see **Section 3.1.1**) and contributing watershed area (**Tables 3 and 5**) to obtain an estimated surface water runoff TP load for each lake. Loads were computed on a daily time step and summarized annually for all lakes in the Sand-Axberg Chain and the five "example" lakes.

Table 6. Total phosphorus estimated mean concentration values used for the TP budgets.

Land use / Land cover classification	Median EMC (mg/L)
Water	0.00
Urban	0.76
Forest	0.15
Pasture & Open	0.27
Cultivated	0.44

3.2.2 Atmospheric Deposition

Atmospheric deposition rates were set equal to those used in the North Central Hardwood Forest (NCHF) Ecoregion in the Minnesota Lake Eutrophication Analysis Procedure (MINLEAP) modeling program. MINLEAP is a program developed by Wilson and Walker (1989) to provide predictive techniques to assess common lake problems based on ecoregion. This program is based on average precipitation, evaporation, and runoff, and uses the general regional patterns (geomorphology, soils, landuse and climatic characteristics) used to describe the ecoregions of Minnesota.

The lakes within the Sand-Axberg chain are located in the NCHF Ecoregion. Therefore, the estimated atmospheric deposition rate of 30 kg/km^2/year was used for these waters. Lakes in the NCHF and the Lake Agassiz Plain (LA) Ecoregion used the same atmospheric deposition load of 30 kg/km^2/year while lakes in the Northern Lakes and Forests (NLF) Ecoregion had an estimated atmospheric load of 15 kg/km^2/year.

3.2.3 Surface Water Outflow

Estimates of annual surface water outflow loads exiting the BRW lakes were computed as the product of the surface water outflow volume (computed in the water budget) and the median in-lake TP concentration from 1997-2010. Median in-lake TP concentrations were used instead of individual years because in-lake concentration data was not available for all lakes for all years from 1997-2010. “Example” lake surface water outflow loads were estimated using the same approach, but relied on the mean in-lake TP concentrations computed in Task 9 of this project (HEI 2011a).

The estimate of surface water outflow loading is based on the estimated surface water outflow value from the water budgets (**Section 3.1.5**). As computed, the surface water outflow value assumes that the net groundwater interaction in the BRW lakes and the water budget error terms are negligible or equal to zero. Since this is not a perfect assumption, the surface water outflow value does have error associated with it. As such, the surface water outflow loading results for the NLF Ecoregion – Shallow Lakes show a (physically impossible) positive number (**Figure 22 and Appendix B**). For use in the next steps of this work (to inform watershed and receiving water models), this error will be taken into consideration. For the purposes of this task, however, the results are presented as is.

3.2.4 In-lake Processes

In-lake processes, including sedimentation and internal loading, were not explicitly accounted for in the nutrient budgets for the Sand-Axberg chain and the five “example” lakes, but were rather estimated (with the error term) as a function of the other terms in the budget equation. A resultant positive value for this term in the budget may indicate that a lake experiences net internal loading. A negative term may indicate that a lake experience net internal losses.

3.2.5 Estimated Total Phosphorus budgets

Using the results from **Sections 3.2.1 through 3.2.4**, the annual and mean annual TP nutrient budgets for 1997-2010 were estimated. Mean annual results for the Sand-Axberg chain are shown in **Figures 13-17** and the “example” lakes are shown in **Figures 18-22**. Yearly results are shown in **Appendix B**.

Figure 13. Axberg Lake average annual total phosphorus budget (1997-2010).

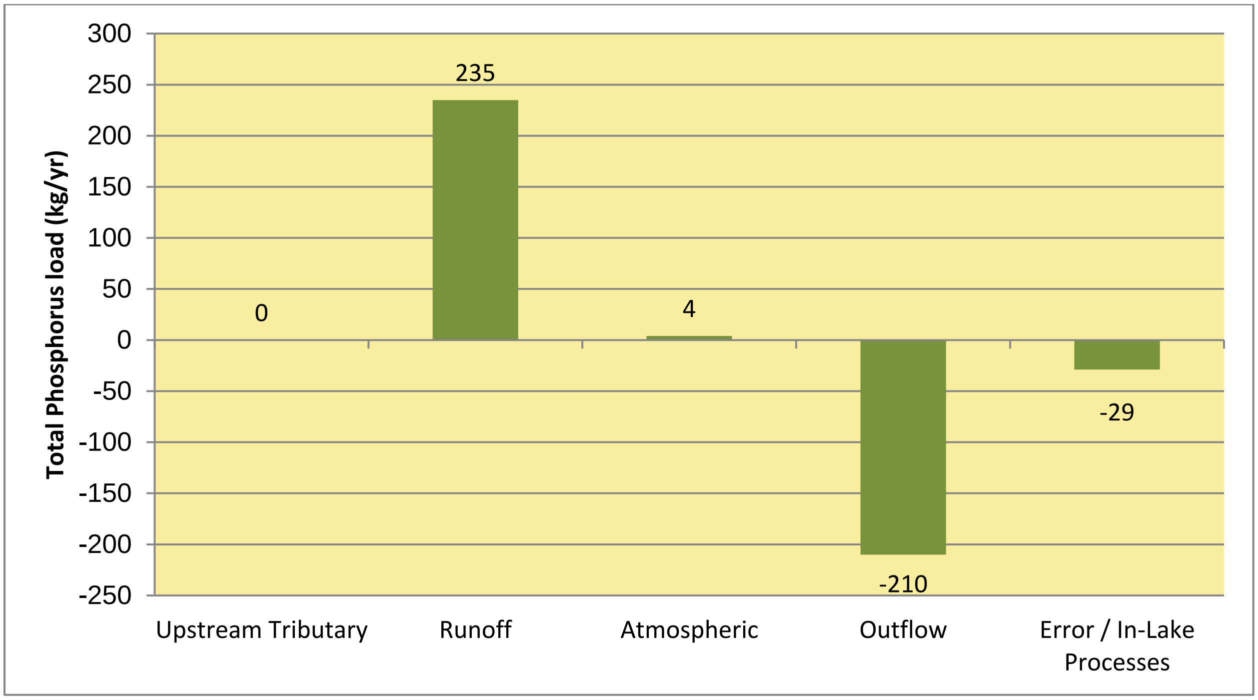


Figure 14. Sand Lake average annual total phosphorus budget (1997-2010).

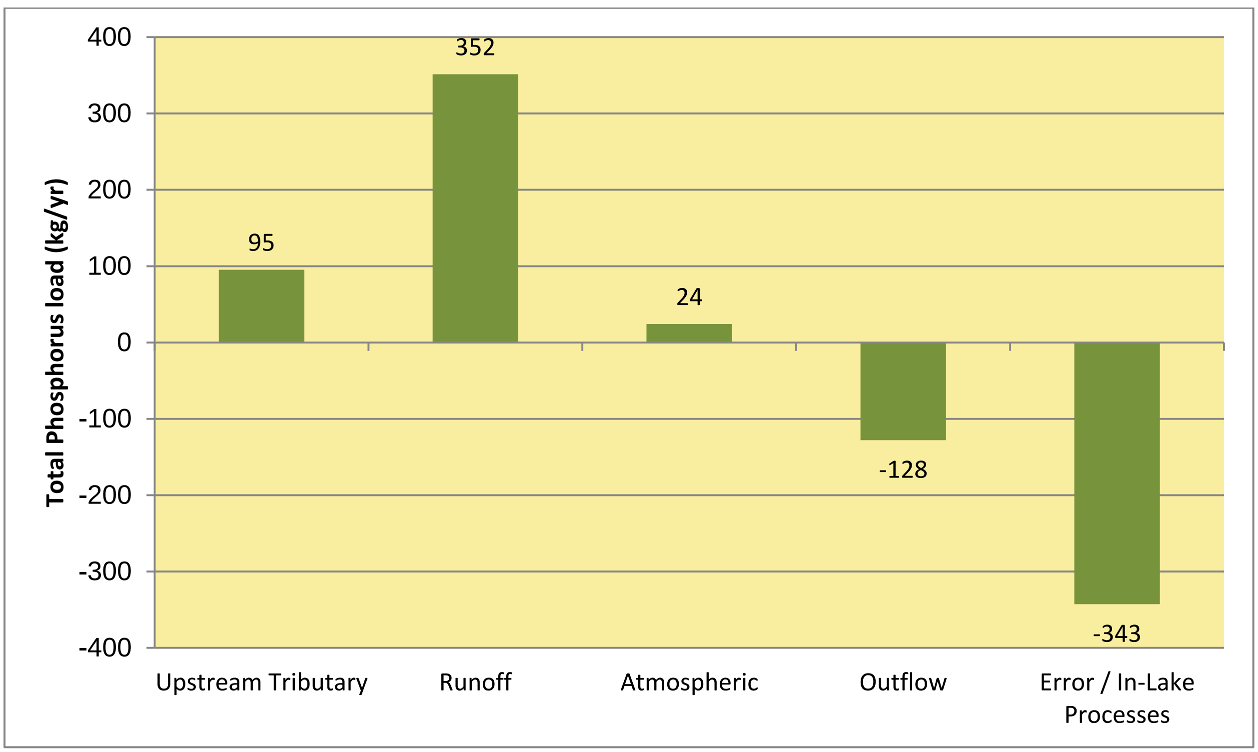


Figure 15. Sorenson Lake average annual total phosphorus budget (1997-2010).

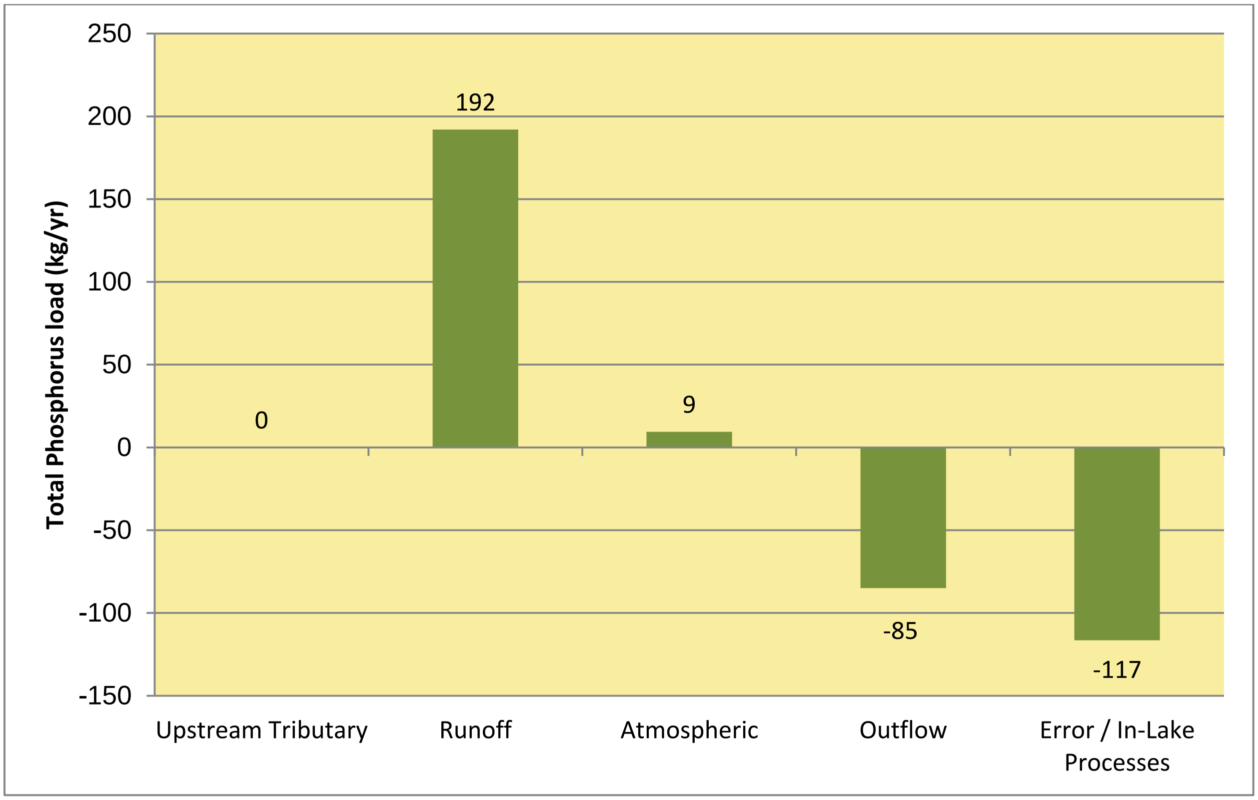


Figure 16. Talac Lake average annual total phosphorus budget (1997-2010).

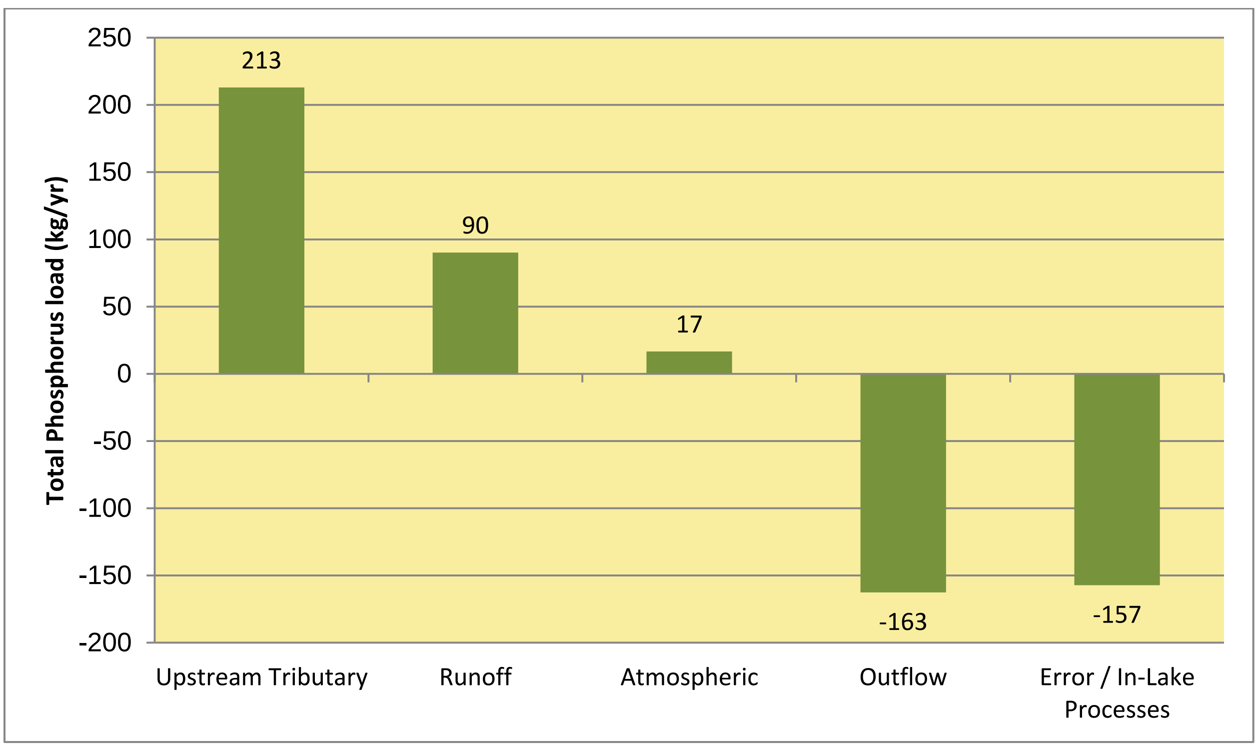


Figure 17. Yort Lake average annual total phosphorus budget (1997-2010).

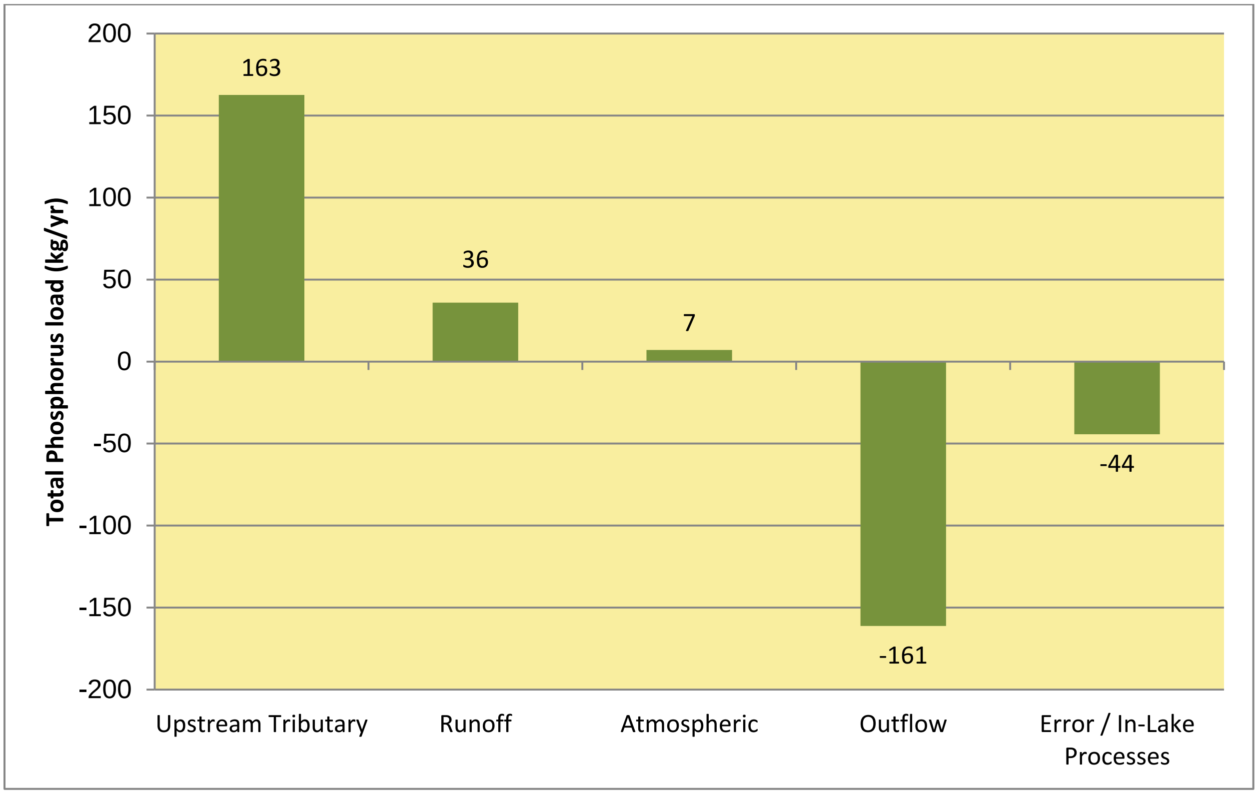


Figure 18. LA Ecoregion Deep Lakes average annual total phosphorus budget (1997-2010).

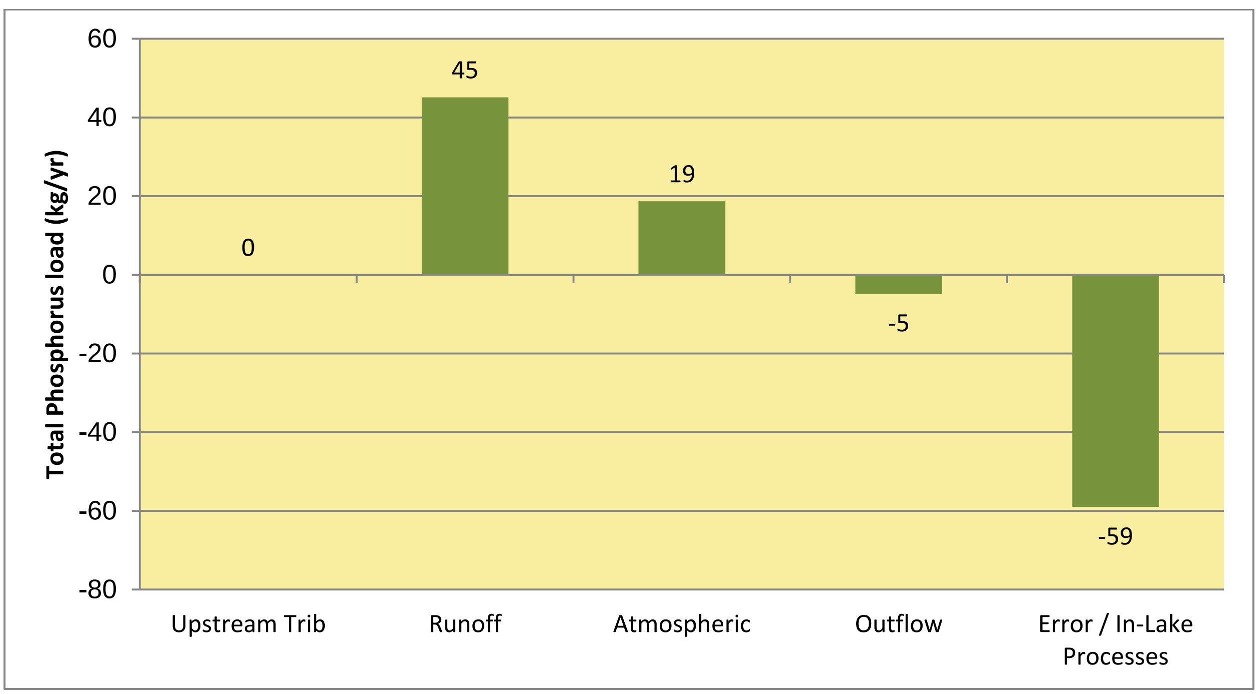


Figure 19. LA Ecoregion Shallow Lakes average annual total phosphorus budget (1997-2010).

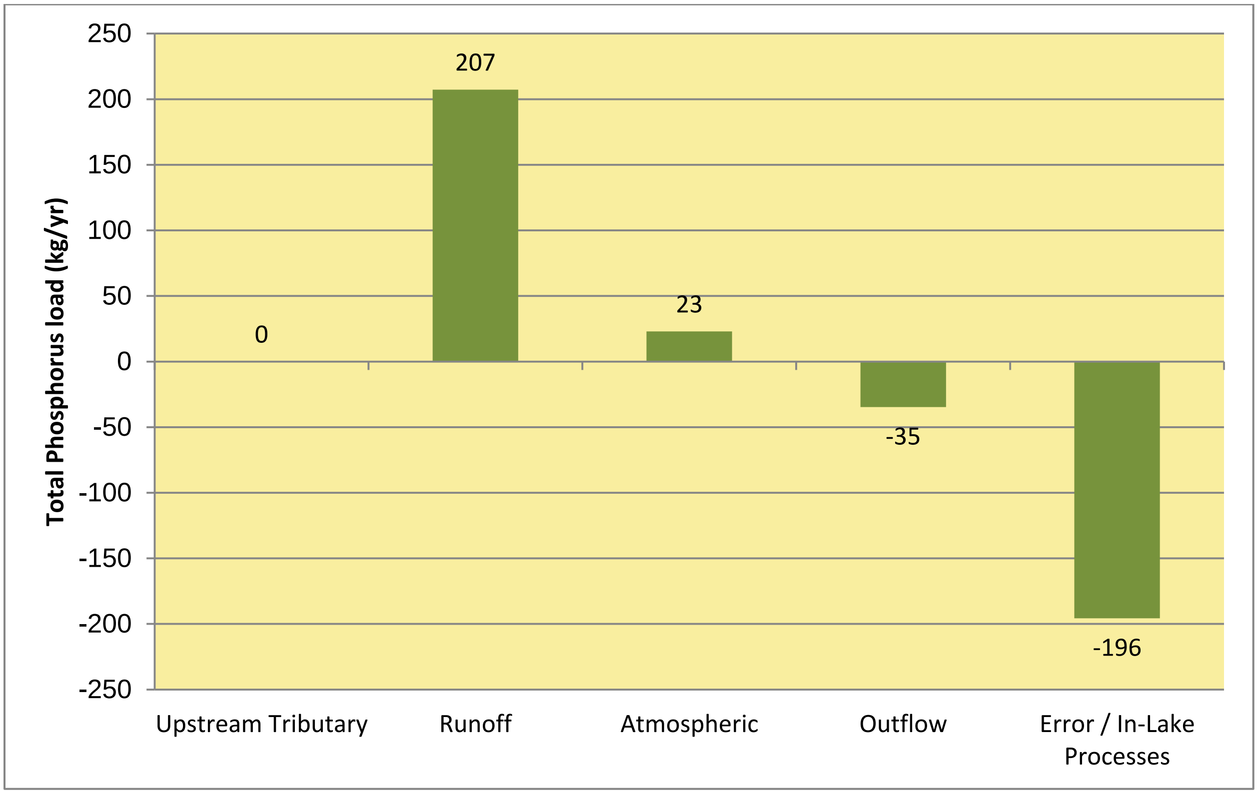


Figure 20. NCHF Ecoregion Deep Lakes average annual total phosphorus budget (1997-2010).

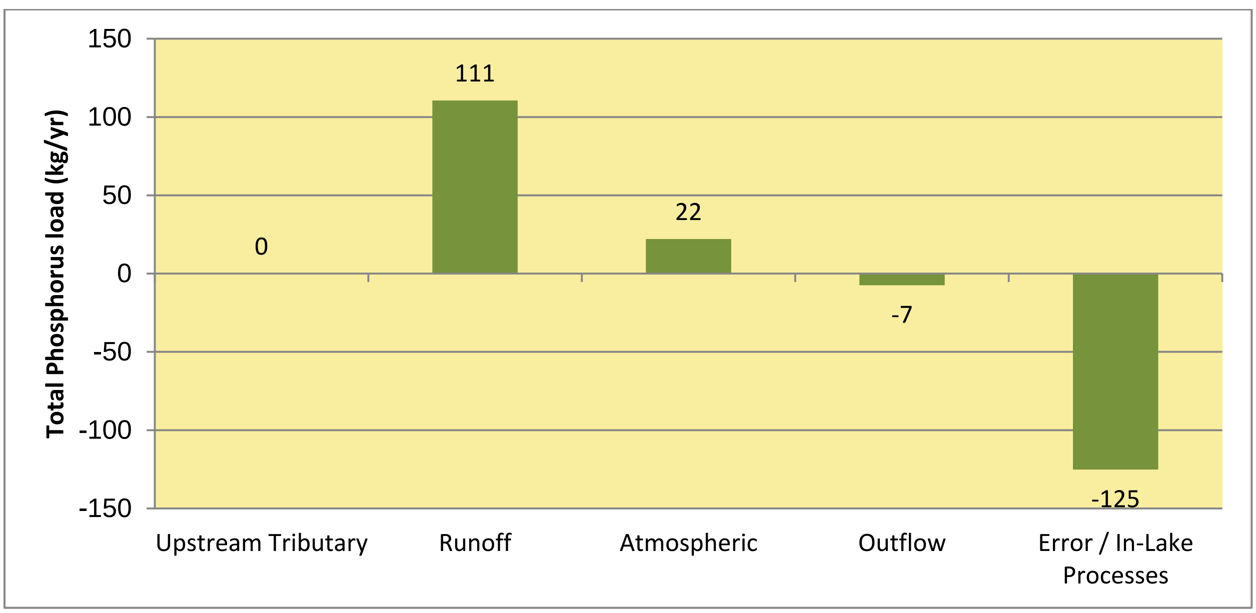


Figure 21. NCHF Ecoregion Shallow Lakes average annual total phosphorus budget (1997-2010).

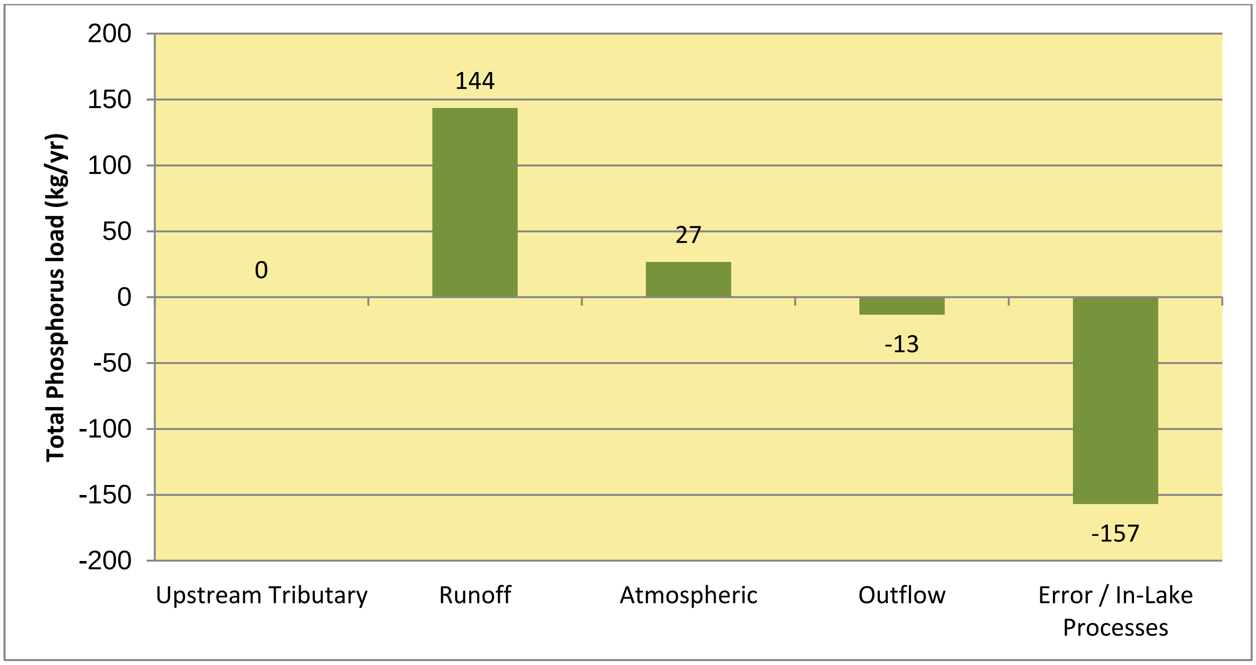
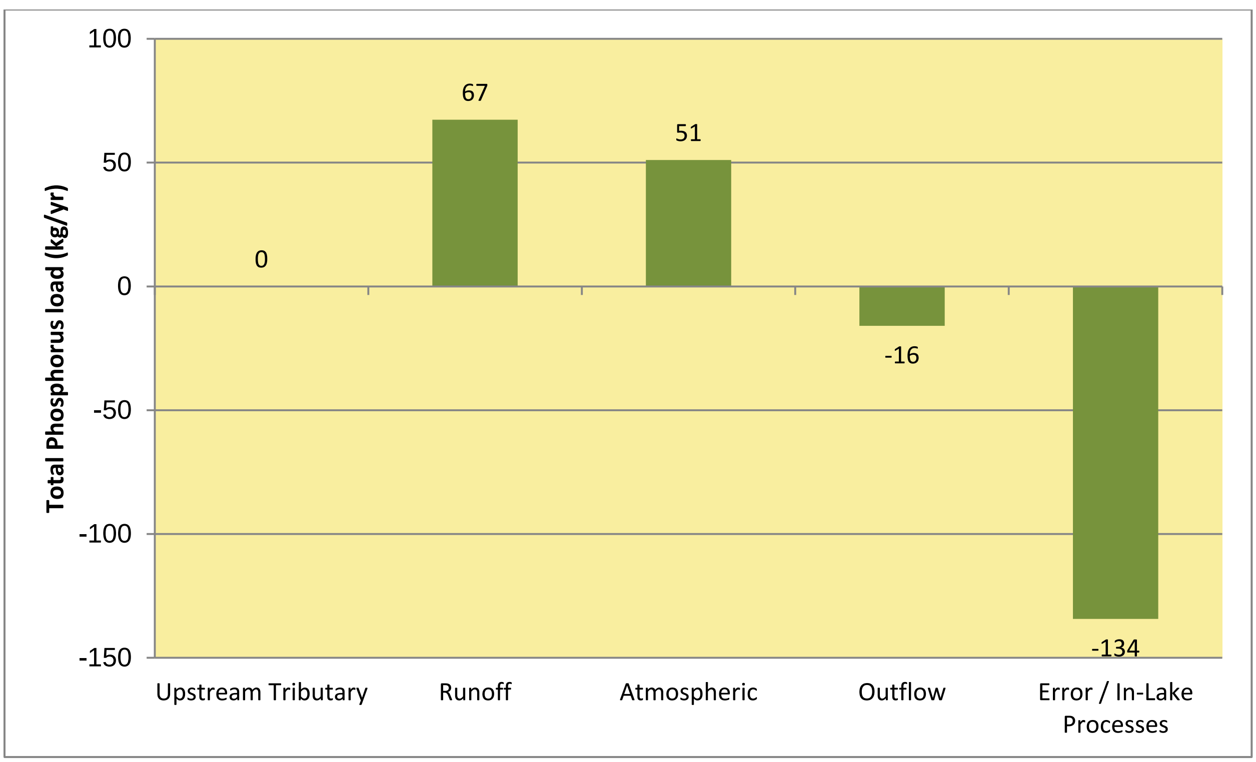


Figure 22. NLF Ecoregion Shallow Lakes average annual total phosphorus budget (1997-2010).



4.0 Summary

Water and TP budgets were computed for the lakes in BRW, with analyses addressing the five lakes in the Sand-Axberg chain and five "example" lakes developed in previous tasks of this project. Results of these budgets will inform watershed and receiving water models to be developed in the next steps in the work. Results present mean annual budgets between the years 1997-2010.

5.0 Works Cited

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Appendix A. Water budgets for lakes within the Sand-Axberg chain-of-lakes and the "example" lakes.

Axberg Lake

Year	Annual Volumes in AF/year							
	Timeframe	Tributary Inflow +	Local Runoff +	Precipitation +	Evaporation -	Change in Storage -	Outflow/ Groundwater/ Error -	Water Balance =0
1997	1/1-12/31	0.00	968.50	97.29	118.89	120.64	826.25	0.00
1998	1/1-12/31	0.00	1049.89	98.01	115.53	51.58	980.79	0.00
1999	1/1-12/31	0.00	861.00	85.69	130.53	-5.30	821.46	0.00
2000	1/1-12/31	0.00	936.44	87.67	123.22	-0.12	901.02	0.00
2001	1/1-12/31	0.00	844.63	74.17	138.15	-26.87	807.52	0.00
2002	1/1-12/31	0.00	494.51	69.27	132.89	9.76	421.14	0.00
2003	1/1-12/31	0.00	317.93	55.99	138.42	-26.92	262.42	0.00
2004	1/1-12/31	0.00	617.33	94.44	124.36	33.88	553.53	0.00
2005	1/1-12/31	0.00	651.88	85.83	135.79	15.00	586.92	0.00
2006	1/1-12/31	0.00	702.56	70.62	134.57	-24.03	662.65	0.00
2007	1/1-12/31	0.00	534.69	80.63	141.61	-1.09	474.79	0.00
2008	1/1-12/31	0.00	702.95	90.20	129.17	48.30	615.68	0.00
2009	1/1-12/31	0.00	1071.69	67.32	119.47	-14.37	1033.90	0.00
2010	1/1-12/31	0.00	1041.07	106.04	139.05	-0.26	1008.32	0.00
Average		**0**	**771.08**	**83.08**	**130.12**	**12.87**	**711.17**	**0**

Sand Lake

Year	Annual Volumes in AF/year							
	Timeframe	Tributary Inflow +	Local Runoff +	Precipitation +	Evaporation -	Change in storage -	Outflow / Groundwater / Error -	Water Balance =0
1997	1/1-12/31	826.25	1157.35	586.70	721.55	729.27	1119.49	0.00
1998	1/1-12/31	980.79	1254.61	591.03	683.15	311.12	1832.17	0.00
1999	1/1-12/31	821.46	1028.90	516.74	781.63	-31.60	1617.07	0.00
2000	1/1-12/31	901.02	1119.04	528.68	739.99	0.05	1808.69	0.00
2001	1/1-12/31	807.52	1009.33	447.25	809.94	-162.35	1616.51	0.00
2002	1/1-12/31	421.14	590.94	417.73	783.02	58.58	588.22	0.00
2003	1/1-12/31	262.42	379.93	337.64	817.52	-162.31	324.77	0.00
2004	1/1-12/31	553.53	737.71	569.47	773.55	204.87	882.30	0.00
2005	1/1-12/31	586.92	778.99	517.57	808.81	91.73	982.93	0.00
2006	1/1-12/31	662.65	839.56	425.86	799.29	-143.69	1272.47	0.00
2007	1/1-12/31	474.79	638.95	486.22	843.61	-6.53	762.88	0.00
2008	1/1-12/31	615.68	840.03	543.93	791.71	291.65	916.28	0.00
2009	1/1-12/31	1033.90	1280.66	405.96	754.43	-86.02	2052.11	0.00
2010	1/1-12/31	1008.32	1244.07	639.45	837.34	-1.11	2055.62	0.00
Average		**711.17**	**921.43**	**501.02**	**781.82**	**78.12**	**1273.68**	**0.00**

Sorenson Lake

Year	Timeframe	Annual Volumes in AF/year						
		Tributary Inflow +	Local Runoff +	Precipitation +	Evaporation -	Change in storage -	Outflow / Groundwater / Error -	Water Balance =0
1997	1/1 - 12/31	0	626.20	229.96	252.21	285.84	318.11	0.00
1998	1/1 - 12/31	0	678.83	231.66	245.67	121.95	542.87	0.00
1999	1/1 - 12/31	0	556.70	202.54	276.48	-12.39	495.15	0.00
2000	1/1 - 12/31	0	605.47	207.22	261.28	0.02	551.40	0.00
2001	1/1 - 12/31	0	546.11	175.31	292.56	-63.63	492.49	0.00
2002	1/1 - 12/31	0	319.74	163.74	281.50	22.96	179.01	0.00
2003	1/1 - 12/31	0	205.56	132.34	296.11	-63.62	105.41	0.00
2004	1/1 - 12/31	0	399.15	223.21	263.76	80.30	278.29	0.00
2005	1/1 - 12/31	0	421.48	202.87	287.60	35.96	300.79	0.00
2006	1/1 - 12/31	0	454.26	166.92	285.42	-56.32	392.08	0.00
2007	1/1 - 12/31	0	345.71	190.58	299.96	-2.56	238.89	0.00
2008	1/1 - 12/31	0	454.51	213.20	273.82	114.32	279.58	0.00
2009	1/1 - 12/31	0	692.92	159.12	253.66	-33.72	632.10	0.00
2010	1/1 - 12/31	0	673.12	250.64	294.85	0.64	628.27	0.00
Average		**0**	**498.55**	**196.38**	**276.06**	**30.70**	**388.17**	**0.00**

Talac Lake

Year	Annual Volumes in AF/year							
	Timeframe	Tributary Inflow +	Local Runoff +	Precipitation +	Evaporation -	Change in storage -	Outflow / Groundwater / Error -	Water Balance =0
1997	1/1-12/31	2150.28	373.98	403.91	511.16	422.17	1994.84	0.00
1998	1/1-12/31	2159.94	405.41	406.89	489.95	214.19	2268.10	0.00
1999	1/1-12/31	2303.84	332.47	355.74	556.58	-21.76	2457.23	0.00
2000	1/1-12/31	2167.91	361.60	363.96	526.40	0.03	2367.04	0.00
2001	1/1-12/31	1080.71	326.15	307.91	581.65	-111.77	1244.89	0.00
2002	1/1-12/31	503.78	190.95	287.59	560.36	40.33	381.63	0.00
2003	1/1-12/31	987.71	122.77	232.44	583.73	-111.74	870.93	0.00
2004	1/1-12/31	1261.23	238.38	392.05	541.58	141.04	1209.04	0.00
2005	1/1-12/31	1573.26	251.72	356.31	576.69	63.15	1541.45	0.00
2006	1/1-12/31	1154.96	271.29	293.18	569.73	-98.92	1248.61	0.00
2007	1/1-12/31	1155.17	206.47	334.74	600.59	-4.50	1100.28	0.00
2008	1/1-12/31	2331.69	271.44	374.47	557.39	200.79	2219.42	0.00
2009	1/1-12/31	2687.71	413.83	279.48	524.28	-59.22	2915.96	0.00
2010	1/1-12/31	1901.95	402.00	440.23	592.84	-0.76	2152.10	0.00
Average		**1672.87**	**297.75**	**344.92**	**555.21**	**48.07**	**1712.25**	**0.00**

Yort Lake

Year	Annual Volumes in AF/year							
	Timeframe	Tributary Inflow +	Local Runoff +	Precipitation +	Evaporation -	Change in Storage -	Outflow / Groundwater / Error -	Water Balance =0
1997	1/1 - 12/31	1994.84	142.88	171.00	208.96	212.55	1887.21	0.00
1998	1/1 - 12/31	2268.10	154.89	172.26	203.05	90.68	2301.53	0.00
1999	1/1 - 12/31	2457.23	127.02	150.61	229.41	-9.21	2514.66	0.00
2000	1/1 - 12/31	2367.04	138.15	154.09	216.56	0.01	2442.70	0.00
2001	1/1 - 12/31	1244.89	124.61	130.36	242.81	-47.32	1304.36	0.00
2002	1/1 - 12/31	381.63	72.96	121.75	233.56	17.07	325.71	0.00
2003	1/1 - 12/31	870.93	46.90	98.41	243.28	-47.31	820.26	0.00
2004	1/1 - 12/31	1209.04	91.07	165.98	218.57	59.71	1187.82	0.00
2005	1/1 - 12/31	1541.45	96.17	150.85	238.65	26.74	1523.07	0.00
2006	1/1 - 12/31	1248.61	103.65	124.12	236.51	-41.88	1281.75	0.00
2007	1/1 - 12/31	1100.28	78.88	141.71	248.90	-1.90	1073.88	0.00
2008	1/1 - 12/31	2219.42	103.71	158.53	227.02	85.00	2169.63	0.00
2009	1/1 - 12/31	2915.96	158.11	118.32	209.98	-25.07	3007.47	0.00
2010	1/1 - 12/31	2152.10	153.59	186.37	244.38	-0.32	2248.01	0.00
Average		**1712.25**	**113.76**	**146.03**	**228.69**	**22.77**	**1720.58**	**0.00**

Lake Agassiz Ecoregion Deep "Example" Lake

Year	Annual Volumes in AF/year						
	Timeframe	Tributary Inflow +	Local Runoff +	Precipitation +	Evaporation -	Outflow/ Net Groundwater / Change in Storage / Error -	Water Balance =0
1997	1/1-12/31	0.00	413.19	454.03	559.59	307.63	0.00
1998	1/1-12/31	0.00	447.91	457.38	534.90	370.39	0.00
1999	1/1-12/31	0.00	367.33	399.89	609.16	158.06	0.00
2000	1/1-12/31	0.00	399.51	409.13	576.07	232.57	0.00
2001	1/1-12/31	0.00	360.35	346.12	635.70	70.76	0.00
2002	1/1-12/31	0.00	210.97	323.27	613.08	-78.83	0.00
2003	1/1-12/31	0.00	135.64	261.29	639.67	-242.75	0.00
2004	1/1-12/31	0.00	263.37	440.70	595.05	109.02	0.00
2005	1/1-12/31	0.00	278.11	400.53	631.33	47.31	0.00
2006	1/1-12/31	0.00	299.74	329.56	624.41	4.88	0.00
2007	1/1-12/31	0.00	228.11	376.27	658.10	-53.71	0.00
2008	1/1-12/31	0.00	299.90	420.93	612.21	108.63	0.00
2009	1/1-12/31	0.00	457.21	314.16	577.29	194.09	0.00
2010	1/1-12/31	0.00	444.15	494.85	650.95	288.06	0.00
Average		**0.00**	**328.96**	**387.72**	**608.39**	**108.29**	**0.00**

Lake Agassiz Ecoregion Shallow "Example" Lake

Year	Annual Volumes in AF/year						
	Timeframe	Tributary Inflow +	Local Runoff +	Precipitation +	Evaporation -	Outflow/ Net Groundwater / Change in Storage / Error -	Water Balance =0
1997	1/1-12/31	0.00	637.73	557.22	686.77	508.18	0.00
1998	1/1-12/31	0.00	691.32	561.33	656.47	596.19	0.00
1999	1/1-12/31	0.00	566.95	490.77	747.61	310.11	0.00
2000	1/1-12/31	0.00	616.62	502.11	707.00	411.73	0.00
2001	1/1-12/31	0.00	556.17	424.78	780.18	200.76	0.00
2002	1/1-12/31	0.00	325.62	396.74	752.42	-30.05	0.00
2003	1/1-12/31	0.00	209.35	320.67	785.06	-255.04	0.00
2004	1/1-12/31	0.00	406.50	540.86	730.29	217.06	0.00
2005	1/1-12/31	0.00	429.24	491.56	774.81	145.99	0.00
2006	1/1-12/31	0.00	462.62	404.46	766.32	100.76	0.00
2007	1/1-12/31	0.00	352.08	461.79	807.67	6.20	0.00
2008	1/1-12/31	0.00	462.88	516.60	751.34	228.13	0.00
2009	1/1-12/31	0.00	705.68	385.56	708.49	382.75	0.00
2010	1/1-12/31	0.00	685.52	607.32	798.89	493.95	0.00
Average		**0.00**	**507.73**	**475.84**	**746.67**	**236.91**	**0.00**

North Central Hardwood Forest Ecoregion Deep "Example" Lake

Year	Annual Volumes in AF/year						
	Timeframe	Tributary Inflow +	Local Runoff +	Precipitation +	Evaporation -	Outflow/ Net Groundwater / Change in Storage / Error -	Water Balance =0
1997	1/1-12/31	0.00	589.27	536.58	661.34	464.51	0.00
1998	1/1-12/31	0.00	638.79	540.54	632.15	547.17	0.00
1999	1/1-12/31	0.00	523.87	472.59	719.92	276.54	0.00
2000	1/1-12/31	0.00	569.76	483.51	680.81	372.46	0.00
2001	1/1-12/31	0.00	513.90	409.05	751.29	171.66	0.00
2002	1/1-12/31	0.00	300.88	382.05	724.55	-41.62	0.00
2003	1/1-12/31	0.00	193.44	308.79	755.98	-253.75	0.00
2004	1/1-12/31	0.00	375.60	520.82	703.24	193.19	0.00
2005	1/1-12/31	0.00	396.62	473.35	746.12	123.86	0.00
2006	1/1-12/31	0.00	427.46	389.48	737.94	79.00	0.00
2007	1/1-12/31	0.00	325.32	444.69	777.75	-7.75	0.00
2008	1/1-12/31	0.00	427.70	497.47	723.52	201.65	0.00
2009	1/1-12/31	0.00	652.05	371.28	682.25	341.08	0.00
2010	1/1-12/31	0.00	633.42	584.83	769.30	448.95	0.00
Average		**0.00**	**469.15**	**458.22**	**719.01**	**208.36**	**0.00**

North Central Hardwood Forest Ecoregion Shallow “Example” Lake

Year	Annual Volumes in AF/year						
	Timeframe	Tributary Inflow +	Local Runoff +	Precipitation +	Evaporation -	Outflow/ Net Groundwater / Change in Storage / Error -	Water Balance =0
1997	1/1-12/31	0.00	589.45	648.62	799.42	438.64	0.00
1998	1/1-12/31	0.00	638.98	653.40	764.14	528.24	0.00
1999	1/1-12/31	0.00	524.03	571.27	870.23	225.06	0.00
2000	1/1-12/31	0.00	569.94	584.47	822.96	331.44	0.00
2001	1/1-12/31	0.00	514.06	494.45	908.15	100.36	0.00
2002	1/1-12/31	0.00	300.97	461.82	875.83	-113.04	0.00
2003	1/1-12/31	0.00	193.50	373.27	913.82	-347.06	0.00
2004	1/1-12/31	0.00	375.72	629.57	850.07	155.22	0.00
2005	1/1-12/31	0.00	396.74	572.18	901.90	67.03	0.00
2006	1/1-12/31	0.00	427.60	470.80	892.02	6.38	0.00
2007	1/1-12/31	0.00	325.42	537.53	940.14	-77.19	0.00
2008	1/1-12/31	0.00	427.83	601.33	874.58	154.58	0.00
2009	1/1-12/31	0.00	652.25	448.80	824.70	276.35	0.00
2010	1/1-12/31	0.00	633.62	706.93	929.92	410.63	0.00
Average		**0.00**	**469.29**	**553.89**	**869.13**	**154.05**	**0.00**

Northern Lakes and Forest Ecoregion Shallow "Example" Lake

Year	Annual Volumes in AF/year						
	Timeframe	Tributary Inflow +	Local Runoff +	Precipitation +	Evaporation -	Outflow / Net Groundwater / Change in Storage / Error -	Water Balance =0
1997	1/1-12/31	0.00	838.26	2479.48	3055.96	261.78	0.00
1998	1/1-12/31	0.00	908.71	2497.77	2921.11	485.37	0.00
1999	1/1-12/31	0.00	745.22	2183.80	3326.65	-397.63	0.00
2000	1/1-12/31	0.00	810.52	2234.26	3145.95	-101.17	0.00
2001	1/1-12/31	0.00	731.05	1890.15	3471.60	-850.40	0.00
2002	1/1-12/31	0.00	428.02	1765.40	3348.06	-1154.64	0.00
2003	1/1-12/31	0.00	275.18	1426.90	3493.29	-1791.21	0.00
2004	1/1-12/31	0.00	534.32	2406.66	3249.59	-308.61	0.00
2005	1/1-12/31	0.00	564.22	2187.30	3447.71	-696.19	0.00
2006	1/1-12/31	0.00	608.09	1799.74	3409.93	-1002.10	0.00
2007	1/1-12/31	0.00	462.79	2054.84	3593.91	-1076.28	0.00
2008	1/1-12/31	0.00	608.43	2298.73	3343.28	-436.12	0.00
2009	1/1-12/31	0.00	927.58	1715.64	3152.60	-509.38	0.00
2010	1/1-12/31	0.00	901.08	2702.41	3554.84	48.65	0.00
Average		**0.00**	**667.39**	**2117.36**	**3322.46**	**-537.71**	**0.00**

Appendix B. Total phosphorus nutrient budgets for lakes within the Sand-Axberg chain-of-lakes and the created "example" lakes.

Axberg Lake

Year	Annual Phosphorus Loading in kg/year					
	Upstream Tributary	Surface Water Runoff	Atmospheric	Surface Water Outflow	Groundwater / Error / In-Lake	Mass Balance
	+	+	+	-	-	=0
1997	0.00	295.13	4.00	244.04	55.08	0.00
1998	0.00	319.93	4.00	289.69	34.24	0.00
1999	0.00	262.37	4.00	242.63	23.74	0.00
2000	0.00	285.36	4.00	266.12	23.23	0.00
2001	0.00	257.38	4.00	238.51	22.87	0.00
2002	0.00	150.69	4.00	124.39	30.30	0.00
2003	0.00	96.88	4.00	77.51	23.37	0.00
2004	0.00	188.12	4.00	163.49	28.62	0.00
2005	0.00	198.64	4.00	173.35	29.29	0.00
2006	0.00	214.09	4.00	195.72	22.37	0.00
2007	0.00	162.93	4.00	140.23	26.69	0.00
2008	0.00	214.21	4.00	181.85	36.36	0.00
2009	0.00	326.57	4.00	305.37	25.19	0.00
2010	0.00	317.24	4.00	297.82	23.42	0.00
Average	**0.00**	**234.97**	**4.00**	**210.05**	**28.91**	**0.00**

Sand Lake

Year	Annual Phosphorus Loading in kg/year					
	Upstream Tributary +	Surface Water Runoff +	Atmospheric +	Surface Water Outflow -	Groundwater / Error / In-Lake -	Mass Balance =0
1997	110.67	441.50	24.15	112.52	463.81	0.00
1998	131.37	478.60	24.15	184.15	449.98	0.00
1999	110.03	392.50	24.15	162.53	364.15	0.00
2000	120.69	426.88	24.15	181.79	389.94	0.00
2001	108.16	385.03	24.15	162.47	354.88	0.00
2002	56.41	225.43	24.15	59.12	246.87	0.00
2003	35.15	144.93	24.15	32.64	171.59	0.00
2004	74.14	281.42	24.15	88.68	291.04	0.00
2005	78.62	297.16	24.15	98.79	301.14	0.00
2006	88.76	320.27	24.15	127.89	305.29	0.00
2007	63.60	243.74	24.15	76.68	254.82	0.00
2008	82.47	320.45	24.15	92.09	334.98	0.00
2009	138.49	488.54	24.15	206.26	444.92	0.00
2010	135.06	474.58	24.15	206.61	427.19	0.00
Average	**95.26**	**351.50**	**24.15**	**128.02**	**342.90**	**0.00**

Sorenson Lake

Year	Annual Phosphorus Loading in kg/year					
	Upstream Tributary +	Surface Water Runoff +	Atmospheric +	Surface Water Outflow -	Groundwater / Error / In-Lake -	Mass Balance =0
1997	0.00	241.21	9.47	69.63	181.04	0.00
1998	0.00	261.48	9.47	118.83	152.11	0.00
1999	0.00	214.43	9.47	108.39	115.52	0.00
2000	0.00	233.22	9.47	120.70	121.99	0.00
2001	0.00	210.36	9.47	107.81	112.02	0.00
2002	0.00	123.16	9.47	39.18	93.44	0.00
2003	0.00	79.18	9.47	23.07	65.57	0.00
2004	0.00	153.75	9.47	60.92	102.30	0.00
2005	0.00	162.35	9.47	65.84	105.98	0.00
2006	0.00	174.98	9.47	85.83	98.62	0.00
2007	0.00	133.16	9.47	52.29	90.34	0.00
2008	0.00	175.07	9.47	61.20	123.34	0.00
2009	0.00	266.91	9.47	138.37	138.01	0.00
2010	0.00	259.28	9.47	137.53	131.22	0.00
Average	**0.00**	**192.04**	**9.47**	**84.97**	**116.53**	**0.00**

Talac Lake

Year	Annual Phosphorus Loading in kg/year					
	Upstream Tributary +	Surface Water Runoff +	Atmospheric +	Surface Water Outflow -	Groundwater / Error / In-Lake -	Mass Balance =0
1997	182.15	113.32	16.63	189.43	122.68	0.00
1998	302.98	122.85	16.63	215.38	227.08	0.00
1999	270.92	100.74	16.63	233.34	154.95	0.00
2000	302.49	109.57	16.63	224.77	203.92	0.00
2001	270.28	98.83	16.63	118.21	267.52	0.00
2002	98.31	57.86	16.63	36.24	136.56	0.00
2003	55.72	37.20	16.63	82.70	26.84	0.00
2004	149.60	72.23	16.63	114.81	123.65	0.00
2005	164.64	76.27	16.63	146.37	111.17	0.00
2006	213.72	82.21	16.63	118.57	193.99	0.00
2007	128.97	62.56	16.63	104.48	103.68	0.00
2008	153.29	82.25	16.63	210.75	41.42	0.00
2009	344.62	125.40	16.63	276.90	209.75	0.00
2010	344.14	121.81	16.63	204.36	278.22	0.00
Average	**212.99**	**90.22**	**16.63**	**162.59**	**157.24**	**0.00**

Yort Lake

Year	Annual Phosphorus Loading in kg/year					
	Upstream Tributary +	Surface Water Runoff +	Atmospheric +	Surface Water Outflow -	Groundwater / Error / In-Lake -	Mass Balance =0
1997	189.43	45.13	7.04	176.88	64.72	0.00
1998	215.38	48.92	7.04	215.71	55.62	0.00
1999	233.34	40.12	7.04	235.69	44.81	0.00
2000	224.77	43.63	7.04	228.94	46.50	0.00
2001	118.21	39.36	7.04	122.25	42.36	0.00
2002	36.24	23.04	7.04	30.53	35.79	0.00
2003	82.70	14.81	7.04	76.88	27.68	0.00
2004	114.81	28.76	7.04	111.33	39.29	0.00
2005	146.37	30.37	7.04	142.75	41.04	0.00
2006	118.57	32.74	7.04	120.13	38.21	0.00
2007	104.48	24.91	7.04	100.65	35.79	0.00
2008	210.75	32.75	7.04	203.35	47.20	0.00
2009	276.90	49.94	7.04	281.88	51.99	0.00
2010	204.36	48.51	7.04	210.70	49.21	0.00
Average	**162.59**	**35.93**	**7.04**	**161.26**	**44.30**	**0.00**

Lake Agassiz Ecoregion Deep "Example" Lake

Year	Annual Phosphorus Loading in kg/year					
	Upstream Tributary +	Surface Water Runoff +	Atmospheric +	Surface Water Outflow -	Groundwater / Error / In-Lake -	Mass Balance =0
1997	0.00	56.67	18.69	13.66	61.71	0.00
1998	0.00	61.43	18.69	16.44	63.68	0.00
1999	0.00	50.38	18.69	7.02	62.06	0.00
2000	0.00	54.79	18.69	10.33	63.16	0.00
2001	0.00	49.42	18.69	3.14	64.97	0.00
2002	0.00	28.94	18.69	-3.50	51.13	0.00
2003	0.00	18.60	18.69	-10.78	48.07	0.00
2004	0.00	36.12	18.69	4.84	49.98	0.00
2005	0.00	38.14	18.69	2.10	54.74	0.00
2006	0.00	41.11	18.69	0.22	59.59	0.00
2007	0.00	31.29	18.69	-2.38	52.36	0.00
2008	0.00	41.13	18.69	4.82	55.00	0.00
2009	0.00	62.71	18.69	8.62	72.78	0.00
2010	0.00	60.92	18.69	12.79	66.82	0.00
Average	**0.00**	**45.12**	**18.69**	**4.81**	**59.00**	**0.00**

Lake Agassiz Ecoregion Shallow “Example” Lake

Year	Annual Phosphorus Loading in kg/year					
	Upstream Tributary +	Surface Water Runoff +	Atmospheric +	Surface Water Outflow -	Groundwater / Error / In-Lake -	Mass Balance =0
1997	0.00	260.40	22.94	74.26	209.08	0.00
1998	0.00	282.28	22.94	87.13	218.10	0.00
1999	0.00	231.50	22.94	45.32	209.12	0.00
2000	0.00	251.78	22.94	60.17	214.55	0.00
2001	0.00	227.10	22.94	29.34	220.70	0.00
2002	0.00	132.96	22.94	-4.39	160.29	0.00
2003	0.00	85.48	22.94	-37.27	145.69	0.00
2004	0.00	165.98	22.94	31.72	157.20	0.00
2005	0.00	175.27	22.94	21.33	176.88	0.00
2006	0.00	188.90	22.94	14.72	197.12	0.00
2007	0.00	143.76	22.94	0.91	165.80	0.00
2008	0.00	189.00	22.94	33.34	178.61	0.00
2009	0.00	288.15	22.94	55.93	255.15	0.00
2010	0.00	279.91	22.94	72.19	230.67	0.00
Average	**0.00**	**207.32**	**22.94**	**34.62**	**195.64**	**0.00**

North Central Hardwood Forest Ecoregion Deep "Example" Lake

Year	Annual Phosphorus Loading in kg/year					
	Upstream Tributary +	Surface Water Runoff +	Atmospheric +	Surface Water Outflow -	Groundwater / Error / In-Lake -	Mass Balance =0
1997	0.00	138.87	22.09	16.61	144.35	0.00
1998	0.00	150.54	22.09	19.57	153.07	0.00
1999	0.00	123.46	22.09	9.89	135.66	0.00
2000	0.00	134.28	22.09	13.32	143.05	0.00
2001	0.00	121.11	22.09	6.14	137.06	0.00
2002	0.00	70.91	22.09	-1.49	94.49	0.00
2003	0.00	45.59	22.09	-9.07	76.76	0.00
2004	0.00	88.52	22.09	6.91	103.70	0.00
2005	0.00	93.47	22.09	4.43	111.13	0.00
2006	0.00	100.74	22.09	2.83	120.01	0.00
2007	0.00	76.67	22.09	-0.28	99.04	0.00
2008	0.00	100.80	22.09	7.21	115.68	0.00
2009	0.00	153.67	22.09	12.20	163.56	0.00
2010	0.00	149.28	22.09	16.06	155.32	0.00
Average	**0.00**	**110.57**	**22.09**	**7.45**	**125.21**	**0.00**

North Central Hardwood Forest Ecoregion Shallow "Example" Lake

Year	Annual Phosphorus Loading in kg/year					
	Upstream Tributary +	Surface Water Runoff +	Atmospheric +	Surface Water Outflow -	Groundwater / Error / In-Lake -	Mass Balance =0
1997	0.00	180.35	26.70	37.87	169.19	0.00
1998	0.00	195.51	26.70	45.60	176.61	0.00
1999	0.00	160.33	26.70	19.43	167.61	0.00
2000	0.00	174.38	26.70	28.61	172.47	0.00
2001	0.00	157.28	26.70	8.66	175.33	0.00
2002	0.00	92.09	26.70	-9.76	128.55	0.00
2003	0.00	59.20	26.70	-29.96	115.87	0.00
2004	0.00	114.96	26.70	13.40	128.26	0.00
2005	0.00	121.39	26.70	5.79	142.31	0.00
2006	0.00	130.83	26.70	0.55	156.98	0.00
2007	0.00	99.57	26.70	-6.66	132.94	0.00
2008	0.00	130.90	26.70	13.34	144.26	0.00
2009	0.00	199.57	26.70	23.86	202.41	0.00
2010	0.00	193.87	26.70	35.45	185.12	0.00
Average	**0.00**	**143.59**	**26.70**	**13.30**	**156.99**	**0.00**

Northern Lakes and Forest Ecoregion Shallow "Example" Lake

Year	Annual Phosphorus Loading in kg/year					
	Upstream Tributary +	**Surface Water Runoff** +	**Atmospheric** +	**Surface Water Outflow** -	**Groundwater / Error / In-Lake** -	**Mass Balance** =0
1997	0.00	84.56	51.04	7.75	127.86	0.00
1998	0.00	91.67	51.04	14.37	128.35	0.00
1999	0.00	75.18	51.04	-11.77	137.99	0.00
2000	0.00	81.76	51.04	-2.99	135.80	0.00
2001	0.00	73.75	51.04	-25.17	149.96	0.00
2002	0.00	43.18	51.04	-34.17	128.39	0.00
2003	0.00	27.76	51.04	-53.02	131.82	0.00
2004	0.00	53.90	51.04	-9.13	114.08	0.00
2005	0.00	56.92	51.04	-20.61	128.56	0.00
2006	0.00	61.34	51.04	-29.66	142.04	0.00
2007	0.00	46.69	51.04	-31.86	129.58	0.00
2008	0.00	61.38	51.04	-12.91	125.33	0.00
2009	0.00	93.57	51.04	-15.08	159.69	0.00
2010	0.00	90.90	51.04	1.44	140.50	0.00
Average	**0.00**	**67.33**	**51.04**	**-15.91**	**134.28**	**0.00**