CHAPTER 3.0

RESULTS

Results for water quality monitoring and related analyses performed by K&A are reported in this chapter. Select information is discussed here and presented in tables and figures. The compendium of K&A water quality data is found in Appendix C. Seasonal water quality sampling results are compiled in this appendix as: Table C-1 for August 9, 2006; Table C-2 for November 20, 2006; Table C-3 from February 22, 2007; and Table C-4 for April 19, 2007. Field recorded data are included in Tables C-5 to C-8. Sampling results from the September 2006 and July 2007 wet weather events for stormwater inlets and Little Asylum Lake outlet are presented in Table C-9 and C-10 (water quality monitoring data), and C-11 and C-12 (field data), respectively by event. Laboratory analytical reports for all water quality monitoring results are included in Appendix D. Data and analyses conducted by WMU and provided to K&A are included in Appendix E.

3.1 In-lake Water Quality Monitoring Results

In-lake water quality data collected during this study are presented in the following subsections and displayed in tables and figures. Results are generally presented first for Asylum Lake followed by those for Little Asylum Lake.

Temperature and Dissolved Oxygen

Temperature and dissolved oxygen (DO) data collected for each seasonal sampling event are plotted with depth for Asylum Lake in Figures 5-8 and Little Asylum Lake in Figure 9. (Field data are summarized in Appendix C.) The following provides a discussion of these temperature/DO plots.

During the first seasonal sampling on August 9, 2006, the lake was stratified with a pronounced thermocline around 15 feet as evidenced by the sharp decline in temperature and DO concentrations (Figure 5). Temperatures were at or near 25°C above the thermocline then declined sharply to around 6°C below the thermocline. Dissolved oxygen concentrations were roughly 6-7 mg/L above the thermocline, 12 mg/L at the thermocline, and declined drastically to less than 1 mg/L below the thermocline. Anoxic conditions (0.6-0.8 mg/L) were observed at all stations near the bottom. This is commonly observed in eutrophic lakes.

Asylum Lake had undergone fall turnover prior to the November 20, 2006 sampling event evidenced by the near consistent temperature and DO profiles (Figure 6). Temperature at all depths was roughly 6.5°C, while DO levels were roughly 7 mg/L at all depths until a few feet from the bottom. All three sampling locations indicated a significant decline in DO concentrations near the bottom where DO approached 1 mg/L. Anoxic conditions (0.6-0.9 mg/L) were observed at all sites near the bottom in November.

The February 2, 2007 through-the-ice sampling event showed no indication of stratification (Figure 7). The slightly lower temperatures at the surface are indicative of ice cover. The DO profile began at roughly 12-13 mg/L near the surface and declines steadily to around 2 mg/L near the bottom. Stations AS-1 and AS-3 showed signs of anoxic conditions (< 2 mg/L) near the bottom. This suggests there is a strong sediment oxygen demand in Asylum Lake.

By the April 19, 2007 sampling event, Asylum Lake began to show early signs of stratification following spring turnover (Figure 8). A thermocline had not developed at this point, but temperatures were near 7°C at the surface and decreased slightly to between 4-5°C near the bottom. The DO profile indicates high DO concentrations near the surface (>13 mg/L) with a slightly decreasing trend as depth increased. At sites 1 and 2, a marked decreased in DO was observed roughly 10 feet from the bottom where DO concentrations dropped from 13 mg/L to around 5 mg/L. At site 3 there is no marked decrease in DO near the bottom. No anoxic conditions were observed during this sampling event, though the rapid decline in DO during turnover to full temperature stratification supports the suggestion that sediment oxygen demand is high.

In Little Asylum Lake, temperature data from the August 9, 2006 sampling event suggested no signs of stratification with temperature at the surface above 25°C and the same at the bottom (Figure 9). The DO profile decreased from 10 mg/L at the surface to roughly 5 mg/L one foot from the bottom. There was a sharp decrease from 5 mg/L to less than 1 mg/L within the last foot of the water column, indicating some exertion of sediment oxygen demand, though apparently insufficient to create anoxic conditions extending well above the bottom. During the November 20, 2006 sampling event, vertical temperature and DO profiles indicate continued mixing of Little Asylum Lake. Temperature was 5°C and DO was approximately 10 mg/L. On February 2, 2007, the temperature and DO profiles suggested relatively homogenous temperature conditions throughout the water column. Temperature was 1°C at the surface and about 3°C at the bottom. The DO profile shows very low concentrations of 2-3 mg/L down to six feet then an increase to about 7 mg/L at nine feet extending to the bottom. This could be related to plant respiration under ice cover. During the April 19, 2007 sampling event, the temperature profile indicates a developing thermocline between three and six feet (Figure 9). The temperature at the surface was 11°C and below the thermocline 8°C. The DO profile however, shows no indication of a thermocline and is relatively consistent throughout the water column at 13-14 mg/L.

Total Phosphorus, Soluble Reactive Phosphorus and Total Nitrogen

On August 9, 2006, the TP levels in surface waters of Asylum Lake ranged from 13-21.5 µg/L, SRP was very low ranging from 1.9-2.8 µg/L, and TN was recorded at 281-305.8 µg/L (refer to Table C-1 in Appendix C). The representative bottom sample from station AS-2 was very high for TP (565.5 µg/L), SRP (333.9 µg/L), and TN (2,257.3 µg/L). These concentrations strongly suggest sediment release under anoxic conditions and are consistent with the high levels of accumulated phosphorus and nitrogen measured in bottom sediments (see Section 3.2). On November 20, 2006 during fall turnover, the TP level in Asylum Lake was 35.9 µg/L, SRP ranged from 3.6-4 µg/L, and TN ranged from 805-906 µg/L at the surface (Table C-2). Samples collected from the middle of the water column at AS-2 in November were 41.1µg/L for TP, 5.6 µg/L for SRP, and 908 µg/L for TN.

During the February 22, 2007 sampling, the TP level in Asylum Lake ranged from 41.1-60.9 µg/L, SRP was 1.6-5.6 µg/L, and TN was 819-906 µg/L for surface samples (Table C-3). The bottom sample from station AS-2 had a TP concentration of 88.2 µg/L, SRP was 47.7 µg/L, and TN was 1,323 µg/L. Though higher than surface levels, these bottom concentrations did not suggest substantial sediment release as noted under summer temperature stratification in August 2006. This would be expected as fall turnover had likely just occurred and anoxic conditions were not as pronounced in November (Figure 6) compared to August (Figure 5). For April 19, 2007, the TP concentrations in Asylum Lake surface waters were

31.2-32.5 µg/L, SRP was 0.4-0.6 µg/L, and TN was 667-863 µg/L (Table C-4). All samples were taken at mid-depth since the lake appeared generally mixed based on water column temperatures (Figure 8).

During the August 9, 2006 sampling event, the TP concentration in Little Asylum Lake was 50.3 µg/L at the surface and 49.7 µg/L at the bottom; SRP was 7.9 µg/L at the surface and 11.3 µg/L near the bottom; TN was 554.7 µg/L at the surface and 729 µg/L near the bottom (Appendix Table C-1). Temperature data (Figure 9) would suggest that the water column in August was not stratified. This appears to be the case based on similar water quality concentrations at the surface and bottom. On November 20, 2006, the TP concentration measured in Asylum Lake was recorded as 27.6 µg/L, SRP was 0.5 µg/L, and TN was 1,096 µg/L at the surface (Table C-2). During the February 22, 2007 monitoring event, TP was 36.1 µg/L at the surface and 78.1 µg/L near the bottom; SRP was 1.7 µg/L at the surface and 21.2 µg/L near the bottom; TN was 1,380 µg/L at the surface and 1,797 µg/L near the bottom (Table C-3). With ice cover, there is limited vertical mixing. Differences between lower surface water concentrations and higher bottom water concentrations indicate sediment release of phosphorus and nitrogen. On April 19, 2007, the TP concentration was 42.3 µg/L, SRP was 0.7 µg/L, and TN was 832 µg/L at the mid-depth sampling location (Table C-4).

Total Suspended Solids

Total suspended solids (TSS) were detected at low levels below 4 mg/L in surface samples from all sites in Asylum Lake and below 6 mg/L in Little Asylum Lake during this study. These relatively low levels suggest that there is no significant source of sediment loading or re-suspension in the lake. Bottom TSS concentrations were below 6 mg/L for all sites in Asylum and Little Asylum Lakes.

Chlorophyll a

Lake surface chlorophyll *a* levels at open water stations measured for each site in Asylum Lake ranged between 2.4 at AS-3 (August 2006—Appendix Table C-1) and 8.7 µg/L (April 2007—Table C-4). A chlorophyll *a* level of 11.5 µg/L was noted at AS-4 in April of 2007 at the Asylum Lake outlet. These concentrations do not suggest that excessively high levels of algae were present in Asylum Lake during these two sampling periods. Limited field observations confirm that there appeared to be few indications of nuisance algal conditions despite measurable levels of available phosphorus (i.e., SRP).

Chlorophyll *a* levels in Little Asylum Lake were between 3.1 (August 2006) and 4.6 µg/L (April 2007). Even though Little Asylum Lake generally exhibited high concentrations of TP, luxurious rooted plant growth in Little Asylum Lake may out-compete algae for this available phosphorus.

Ammonia-nitrogen and Nitrate-nitrogen

Ammonia-nitrogen was not detected in surface waters of Asylum Lake during August of 2006 (Table C-1). A high level of ammonia-nitrogen was noted in the bottom waters however, at a level of 2.59 mg/L during this same period. This might be expected given the severe anoxia noted during these period of summer stratification and high levels of TN in bottom sediments (see Section 3.2). Ammonia-nitrogen was detected at every surface and bottom water sampling location during the November 2006 (Table C-2) and February 2007 (Table C-3) events at levels ranging from 0.02-0.47 mg/L. Low levels were again noted at all locations sampled in April 2007 (Table C-4) but at a much lower range of concentrations

(0.02-0.09 mg/L). Nitrate-nitrogen was nearly always below the method detection limit of 0.1 mg/L. If detected, it was reported at a level of 0.1 mg/L.

Secchi Depth, Conductivity, and pH

Secchi depth (water clarity) measured on Asylum Lake during the study was generally consistent across sampling sites for each event. The greatest Secchi depth reading was 12.5 feet during the August 9, 2006 sampling (Appendix Table C-5) and the lowest recorded depth was 5.5 feet during the April 19, 2007 spring turnover sampling event (Table C-4). In Little Asylum Lake, the greatest Secchi depth reading was 9.5 feet during the November 20, 2006 sampling and the shallowest depth was 4.5 feet during the August 9, 2006 monitoring.

Conductivity levels in Asylum Lake ranged from 659 to 1,212 µS at all sites and over all sampling occasions. In Little Asylum Lake, conductivity ranged from 669 to 954 µS over all monitoring events. Over all monitoring events and all sites, pH ranged from 6.75 to 8.45 in Asylum Lake. In Little Asylum Lake, pH ranged from 6.4 to 8.08 over all sampling occasions. These pH levels suggest a generally neutral pH of 7.0, or slightly basic condition of pH >7.0.

Major Ions

Sodium and chloride levels in Asylum and Little Asylum Lakes were relatively constant between: a) sampling locations; b) surface and bottom waters; c) both lakes; and, d) over the four seasonal samplings. This suggests that inputs such as road salts in stormwater are relatively minor, and that conditions in both lakes are relatively constant with respect to these ion concentrations. Magnesium and potassium levels were similarly consistent across stations, lakes and seasons. The same was noted for sulfate concentrations, which generally ranged from 12-16 mg/L with one notable exception. For Little Asylum Lake in April 2007, sulfate was measured at a concentration of 38 mg/L. It is uncertain whether this is an invalid result or indicative of some condition associated with organically enriched sediments in this highly productive system (e.g., significant wetlands surrounding open water) manifesting high in-lake levels during or following winter stratification.

Alkalinity levels (as $CaCO_3$) are relatively consistent between the two lakes for individual sampling events with some variability between seasons. Levels suggest a moderately hardwater condition as would be expected from regional geology. Iron was typically below laboratory method detection levels.

Atrazine, Total Petroleum Hydrocarbons, and Mercury

Atrazine and total petroleum hydrocarbons (TPH) were reported as below standard laboratory detection limits during the August and November 2006 sampling events for all samples collected. For this reason, atrazine and TPH were not sampled in subsequent efforts in February and April 2007. More than one-half of the mercury samples collected from Asylum and Little Asylum Lake were reported below the low level laboratory detection limits. Those that were detected ranged from 4.8-27.2 ng/L (parts per trillion). In Asylum Lake, detected mercury concentrations ranged from 4.7-12.5 ng/L; in Little Asylum Lake, these ranged from 12.0-27.2 ng/L. During spring turnover sampling in April 2007, every location sampled in both lakes had a detectable level of mercury.

E. coli

Water quality samples collected in August and November 2006 were tested for *E. coli* bacteria levels. In Asylum Lake, *E. coli* levels ranged from 2.4-3.0 colonies/100 mL in August and 2.0-10.0 colonies/100 mL in November. For Little Asylum Lake, *E. coli* levels ranged from 3.1 colonies/100 mL in August 2006 to 18.0 colonies/100 mL in November 2007. Because of these very low levels, no additional sampling for bacteria counts was undertaken in February or April of 2007.

WMU Water Quality Sampling

Dr. Carla Koretsky of WMU tested water samples collected in August 2006 and April 2007 by K&A for heavy metal concentrations. The water quality report prepared by Dr. Koretsky is included in Appendix E. Results are summarized here. For August 2006, samples were reported as below detections limits for zinc, aluminum, arsenic, molybdenum, lead, selenium, and vanadium (i.e., less than approximately 50 ppb) in all samples. Reported cadmium levels were consistently above the EPA drinking water maximum contaminant level (5 ppb). Dr. Koretsky recommended follow-up analyses to confirm these high levels. Manganese levels were also high in samples collected near the bottom of the lake. Barium levels were slightly above 50 ppb at some sites.

Results for all samples collected in April 2007 were reported as below detection limits for chromium, copper, iron, nickel, cadmium, cobalt, molybdenum and vanadium. All reported concentrations of lead were close to detection limits. Concentrations of barium were higher for filtered samples than unfiltered samples, which Dr. Koretsky concluded might be an artifact from syringe needles or filters used in the field.

3.2 Sediment Sampling Results

Results for sediment nutrient content and mercury sampling are described in this section. These first include data reported by K&A and then by WMU.

Nutrients

High levels of total nitrogen were detected in Asylum Lake sediments at 12,900 mg/kg and in Little Asylum Lake at 54,100 mg/kg. Total phosphorus levels first reported by UFI were deemed unreliable due to laboratory error. Additional samples were necessary for a second analysis. As such, lake bottom sediments were re-sampled on November 20, 2007. Samples were taken at approximately the same locations in Asylum and Little Asylum Lakes as the original samples.

Reported results from UFI showed extremely high TP values for both lakes. These ranged from 0.51-0.59 mg P/g in Asylum Lake and 1.07-1.1 mg P/g in Little Asylum Lake. Confirming that these data were valid, samples sent to the City of Kalamazoo Public Services Laboratory were not substantially different from those reported by UFI. These split samples for Asylum Lake and Little Asylum Lake were 0.44 mg P/g and 1.44 mg P/g, respectively.

Mercury

For the two sites sampled in February 2007 for mercury, these were selected to represent the deepest spot in each lake and to characterize 'worst case' conditions. Mercury was detected in both samples at reported levels of 0.08 mg/kg at AS-2 and 0.09 mg/kg at LA-1.

Given these detections, further sediment sampling was conducted in April 2007 at four sites in Asylum Lake and two sites in Little Asylum Lake (stations AS-1 through AS-4, and LA-1 and LA-2 as shown in Figure 3). All sediment samples were reported below detection limits with the exception of one sample collected at AS-1 which had a concentration of 0.09 mg/kg. All sediment mercury sampling results are reported in Table 3.

Table 3. Asylum and Little Asylum Lake Analytical Results for Mercury Concentrations in Sediment Samples.

Site Location	Date Collected	Sample	Mercury (mg/kg)
AS-2	2/22/2007	A	0.082
LA-1	2/22/2007	A	0.091
AS-1	4/19/2007	A	0.092
AS-1	4/19/2007	B	BDL
AS-2	4/19/2007	A	BDL
AS-2	4/19/2007	B	BDL
AS-3	4/19/2007	A	BDL
AS-3	4/19/2007	B	BDL
AS-4	4/19/2007	A	BDL
AS-4	4/19/2007	B	BDL
LA-1	4/19/2007	A	BDL
LA-1	4/19/2007	B	BDL
LA-2	4/19/2007	A	BDL
LA-2	4/19/2007	B	BDL

BDL=Below detection limit (0.001 mg/kg per A&L Great Lakes Laboratories, Inc.)

WMU Sediment Sampling

Dr. Koretsky tested sediment samples collected in August 2006, February 2007, and April 2007 for heavy metal concentrations (see Appendix E). Results from August 2006 showed significant differences in metal concentrations among the three sites sampled. Samples collected in February 2007 and April 2007 were noted to have a high water content and were very rich in organic matter. Due to the condition of the samples, she stated that associated metal concentrations should be regarded as qualitative estimates only. The summary indicated high concentrations of Mg and Ni might have been due to high reagent concentrations in step 1 of the analytical process used.

3.3 Wet Weather Sampling Results

Wet weather sampling results, especially those of particular note that will largely affect water quality conditions, are reported here. For stormwater inlets, all water quality monitoring data are compiled in Appendix Tables C-9 (September 22, 2006) and C-10 (July 17, 2007). This latter Appendix table also includes water quality data for the one event where outflow from Little Asylum Lake was noted at Station

LA-2. No flow was observed from the SW-3 inlet (i.e., subwatershed #7—Figure 2) to Little Asylum Lake; thus, no results are reported here.

Stormwater Inlet #1

This inlet captures surface water runoff from subwatershed 5 and discharges directly to Asylum Lake (refer to Figures 2 and 3). During the September 22, 2006 monitoring, nutrient concentrations were 498.1 µg/L TP, 6.3 µg/L SRP, and 1,794 µg/L TN. On July 17, 2007, nutrient concentrations were 326 µg/L TP, 135 µg/L SRP, and 1,156 µg/L TN. The TSS concentration measured in September 2006 was 68 mg/L; on July 17, 2007, TSS was 46 mg/L. *E. coli* counts were detected during both events with July 2007 notable at 8,500. Mercury was detected at 5.2 ng/L during the September event, though neither atrazine nor TPH were detected.

Stormwater inlet #2

Inlet #2 drains subwatershed 6 and also discharges directly to Asylum Lake. During the September 22, 2006 monitoring, the measured TP concentration was 99.4 µg/L, SRP was 19.5 µg/L, and TN was 997 µg/L. On July 17, 2007, the TP concentration was 299 µg/L, SRP was 121 µg/L, and TN was 3,117 µg/L. The TSS concentration reported for September 2006 was 3 mg/L, and in July 2007 was 76 mg/L. *E. coli* counts, though lower that from inlet #1, were noted.

Stormwater inlet #4

During the September 2006 monitoring, TP concentration was 327.9 µg/L, SRP was 255.2 µg/L, and TN was 1,994 µg/L. During the sampling event on July 17, 2007, TP concentration was 350 µg/L, SRP was 247 µg/L, and TN was 2,357 µg/L. The TSS concentration reported in 2006 was 4 mg/L and in 2007 was 12 mg/L. Mercury was detected in September 2006 at 6.7 ng/L.

Little Asylum Lake Outlet (LA-2)

The outlet from Little Asylum Lake was dry during all other monitoring events except during the July 2007 wet weather event. During this sampling, TP was 203 µg/L, SRP was 55 µg/L, and TN was 1,230 µg/L. The TSS concentration for the Little Asylum Lake outlet was 20 mg/L. These are comparably much higher than noted in the outlet from Asylum Lake at station AS-4.

Stormwater Inlet/Outlet Pollutant Loads

Using the average nutrient concentrations from the K&A monitoring events for wet weather sampling stations and the Asylum Lake outlet, and measured flow volumes (Table 4), annual discharges of TP, TN and TSS are calculated here. It should be noted that these are very coarse estimates whereby the relative magnitude of differences will be illustrative of potential receiving water/downstream impacts.

From Asylum Lake via the outlet structure, annual average discharges to Little Asylum Lake are computed as 102 lbs TP, 1,674 lbs TN, and 2,365 lbs TSS. The annual discharges from Little Asylum Lake via its outlet structure are comparatively small at 1 lb TP, 6 lbs TN, and 96 lbs TSS.

Annual pollutant loads to Asylum Lake from stormwater inlet #1 are estimated to be 105 lbs TP, 376 lbs TN, and 12,497 lbs TSS using available water quality measurements. The pollutant load from stormwater inlet #2 is estimated to be 56 lbs TP, 578 lbs TN, and 21,359 lbs TSS. Annual pollutant loads to Little

Asylum Lake via stormsewer inlet #4 are estimated to be < 1 lb TP, < 1 lb TN, and 1 lb TSS in comparison.

Table 4. Asylum Lake and Little Asylum Lake K&A Stormwater Inlet and Lake Outlet Monitored Flows.

	Flow (cfs)				
	Stormsewer Inlets			Asylum Lake Outlet	Little Asylum Lake Outlet
Date	#1	#2	#4		
8/9/2006	-	-	-	1.088	-
9/22/2006	-	-	-	11.547	-
11/20/2006	-	-	-	0.270	-
2/22/2007	-	-	-	0.375	-
4/19/2007	-	-	-	1.255	-
7/17/2007	0.623	0.687	0.0001	0.0195	0.0052
10/5/2007	-	-	-	0.792	-

3.4 Modeled Watershed Pollutant Loads

Estimated annual runoff volumes and annual phosphorus, nitrogen and sediment loads (pounds per year) from the contributing subwatersheds to Asylum Lake and Little Asylum Lake are presented in Table 6. These are derived from the empirical loading model. Estimated loads to Asylum Lake include subwatershed 1, 3, 4, 5 and 6 (the latter two including stormwater inlets #1 and #2). Areas included in loads to Little Asylum Lake cover subwatersheds 2, 7 and 8.

Table 6. Annual nutrient and sediment loads, and runoff from Asylum Lake and Little Asylum Lake subwatersheds.

	TP (lbs/year)	TN (lbs/year)	TSS (lbs/year)	Runoff (ac-ft/yr)
Asylum Lake Subwatersheds				
1	162	2,387	47,358	355
3	28	271	9,661	30
4	20	146	6,208	20
5	103	1,010	33,877	117
6	21	252	7,746	31
Total	334	4,066	104,850	553
Little Asylum Lake Subwatersheds				
2	21	340	4,229	74
7	7	59	1,672	6
8	2	25	871	4
Total	30	424	6,772	84

A general comparison of the model predictions to the coarsely estimated annual pollutant loads from limited monitoring data presented above in Section 3.3 can be made here. The wet weather estimated phosphorus load from inlet #1 was 105 lbs/yr; from inlet #2, it was 56 lbs/yr. From Table 6, the corresponding model estimated load for subwatershed 5 was 103 lbs/yr. This matches closely with the inlet 1 estimate. The modeled subwatershed 6 load of 21 lbs/yr is less than the wet weather estimate for inlet #2, though combined model loads for these two are 134 lbs/yr compared to the combined wet weather estimate of 161 lbs/yr. These similar approximations led K&A to conclude that the modeled estimates are sufficient for using projected phosphorus and runoff loads for hydraulic and phosphorus mass balance calculations.

Similar comparisons of nitrogen loads suggest that the model may be overestimating loads, or that the wet weather data extrapolation may be underestimating these. This comparison does not, however, suggest that either estimate renders the other useable. The TSS modeled load is likely an overestimate given the low concentrations of TSS measured in Asylum Lake. Differences here can largely be explained by the EMCs used here that are derived from a national database and not necessarily from a comparable local dataset.

A similar model comparison for Little Asylum Lake to wet weather phosphorus load estimates for stormwater inlet #4 suggest that the model prediction is reasonable, though limited model resolution at this small scale hinders meaningful comparisons.

3.5 Hydraulic Mass Balance

Calculations of Asylum Lake volume and surface area estimated from bathymetric data (Sauck et al., 1991) are 1,004 acre-ft and 46.5 acres, respectively. The more recent bathymetric map provided by WMU from 2006 suggests a volume of 976.9 acre-ft and an area of 47 acres. The lake area estimates differ by 1% and the 1991 volume estimate is 2.7% greater than the 2006 volume. These differences are considered relatively minor in this particular application, especially in the context of likely variability in lake volumes and calculation error. Therefore, the original estimates from Sauck et al. (1991) are used here for the hydraulic mass balance. From the 2006 bathymetric map for Little Asylum Lake, the calculated lake surface area is 8.97 acres with a volume of 40.9 acre-ft.

Based on calculated hydraulic loads, the HRT for Asylum Lake was determined to be 0.71 years, or approximately 260 days. The HRT for Little Asylum Lake was determined to have a much shorter residence time of 0.03 years, or approximately 11 days.

A hydraulic mass balance was calculated for Asylum Lake and Little Asylum Lake using these volume estimates. These water balances are presented separately in Figures 10 and 11, respectively. These estimated volumes of water flowing into and out of the lake are summarized in Table 6. Groundwater was the single largest contributor of water to Asylum Lake (732 ac-ft/yr) with the outfall structure constituting the largest loss of water on an annual basis (1,305 ac-ft/yr). Inputs to Little Asylum Lake differ from Asylum Lake in that a significant volume of lakewater is actually lost to the groundwater. A very limited amount of water leaves Little Asylum Lake via the culvert under Parkview Avenue connecting to Cherry Creek.

Table 6. Asylum Lake and Little Asylum Lake Hydraulic Mass Balances.

	Source/Sink	Volume (ac-ft/yr)
Asylum Lake		
Gains	Direct Rainfall	125
	Subwatersheds 5 & 6	148
	Subwatersheds 1, 3 & 4	405
	Groundwater	732
Losses	Evapotranspiration	-105
	Asylum Lake Outlet	-1,305
Little Asylum Lake		
Gains	Direct Rainfall	24
	Subwatersheds 2, 7 & 8	84
	Inlet	1,305
Losses	Evapotranpirtation	-43
	Little Asylum Lake Outlet	-2
	Groundwater	-1,368

3.6 Phosphorus Mass Balance

The phosphorus mass balances for Asylum and Little Asylum Lakes are presented in Figures 12 and 13, respectively; Table 7 summarizes these values. For Asylum Lake, estimates suggest that the largest estimated load to this system is runoff from the immediately surrounding land in subwatershed 1, plus smaller subwatersheds 3 and 4. Because the modeling approach for calculating runoff does not account for storm sewers, the stormwater load from this larger land coverage is model-estimated to be higher than the runoff load from subwatersheds 5 and 6. This difference may be an artifact of the model as coarsely estimated loads from sampling suggest that storm sewered areas likely have a much greater impact on water quality than diffuse overland runoff from remaining drainage areas that are predominantly pervious/vegetated land cover. Regardless, it is obvious that "manageable" stormwater sources in subwatersheds 5 and 6 dominate external loading of phosphorus to the lake. Moreover, much of what enters Asylum Lake appears to be retained in this lake.

In contrast, the phosphorus load that exits Asylum Lake becomes the largest load to Little Asylum Lake. Overland and storm sewered runoff are relatively minor in comparison. Since very little water exits Little Asylum Lake via the outlet, the vast majority of pollutants also appear to be retained despite the short HRT of 11 days.

Table 7. Asylum Lake and Little Asylum Lake TP Mass Balances.

	Source/Sink	Load (lbs/yr)
Asylum Lake		
Gains	Subwatersheds 1, 3 & 4	210
	Subwatersheds 5 & 6	124
	Atmospheric Deposition	20
Losses	Asylum Lake Outlet	-102
	Settling	-252
Little Asylum Lake		
Gains	Subwatersheds 2, 7 & 8	30
	Atmospheric Deposition	7
	Asylum Lake Outlet	102
Losses	Little Asylum Lake Outlet	-1
	Settling	-138

3.7 Aquatic Plant Survey

Survey results for emergent wetland and rooted aquatic plants in Asylum Lake and Little Asylum Lake are summarized here to highlight findings for both native and invasive plant species (submerged and emergent). Results from these surveys are reported here. Relative densities of submergent, floating and emergent plant species observed in these lakes are provided in Appendix F.

<u>Asylum Lake</u>

Based on the aquatic plant survey conducted on August 9, 2006 at Asylum Lake, *Chara spp.* (muckgrass) was present at the highest cumulative percent cover of the submergent species (34.1). Other observed submergent vegetation included *Ceratophyllum demersum* (coontail) at 11.3%, *Potamogeton illinoensis* (Illinois pondweed) at 10.5%, *Potamogeton pectinatus* (sago pondweed) at 5.1%, *Naja spp.* at 1.4%, and *Utricularia spp.* (bladderwort) at 0.9%. The aquatic plant that represented the highest cumulative percent cover overall was the floating plant, *Nymphaea spp.* (white water lily) at 43.3. Floating leaf pondweed covered approximately 4.1%.

Several emergent aquatic species were observed around Asylum Lake. *Typha spp.* (cattails) had the highest cumulative percent cover of the emergent species at 35.9, while *Scripus spp.* (bulrushes) had a percent coverage of approximately 25.2. Invasive species identified around Asylum Lake were *Myriophyllum spicatum* (Eurasian water milfoil) and Lythrum salacaria (purple loosestrife) at 5.8% and 0.4% cover, respectively.

Little Asylum Lake

During the aquatic plant survey conducted by K&A on August 9, 2006 at Little Asylum Lake, five submergent aquatic species were identified in the littoral zone of the lake. *Ceratophyllum demersum* (coontail) had the highest cumulative percent cover of the submergent plants at 27.5. The other submergent aquatic species observed during the survey were *Chara spp.* (muckgrass) at 16.1%, *Potamogeton pectinatus* (sago pondweed) at 13.5%, *Naja spp.* at 8.7%, and *Utricularia spp.* (bladderwort) at 2.7% cover. Only two floating aquatic species were identified during the survey, *Nymphaea spp.* (white water lily) at approximately 42.7 cumulative percent cover and *Nuphar spp.* (yellow water lily) at 0.1%.

The emergent aquatic plant *Typha spp.* (cattails) has the highest cumulative percent cover of all identified aquatic macrophytes/wetland plants at 80%. A second emergent aquatic species was observed, *Decodon verticillatus* (swamp loosestrife), at 0.3% cover. Two invasive aquatic species were identified around Little Asylum Lake. Similar to Asylum Lake, *Lythrum salacaria* (purple loosestrife) was identified and had a much higher percent cover of approximately 7%. Unlike Asylum Lake, Eurasian water milfoil was not noted in Little Asylum Lake, though the invasive species *Potamogeton crispus* (curly pondweed) was present and had a cumulative percent cover of approximately 0.9.

Invasive Aquatic Species Coverage

Survey locations where the three exotic species were observed in Asylum Lake and Little Asylum Lake are noted on Figure 4. Around Asylum Lake, Eurasian water milfoil was observed at twelve sites (six sites classified as present, three as sparse, and three as common). Purple loosestrife was observed at Asylum Lake at three sites (two sites classified as present and one as sparse) and Little Asylum Lake at twelve sites (five sites classified as present, six sites as sparse, and one site as common). Curly pondweed was also observed in Little Asylum Lake at five sites (three sites classified present and one as sparse).