Updated Assessment of In-Lake Management Techniques for Shawnee Lake

Shawnee State Park, Bedford County, Pennsylvania

Prepared for:

Pennsylvania DCNR
Bureau of State Parks
PO Box 8551
Harrisburg, PA 17105-8551

Prepared by:

Princeton Hydro, LLC

120 East Uwchlan Avenue
Suite 204
Exton, Pennsylvania
(P) 610.524.4220
(F) 610.524.9434
www.princetonhydro.com

Fred Lubnow, Ph.D.
flubnow@princetonhydro.com

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Section 1 Introduction

In 2009, Princeton Hydro conducted an assessment of a variety of in-lake management techniques to determine their potential feasibility for Shawnee Lake, Bedford County, Pennsylvania. A presentation on this assessment was conducted in June of 2009. As part of that presentation it was noted that in order to conduct a complete and objective analysis of in-lake management techniques, the pollutant budget (particularly total phosphorus and total suspended solids) for the lake and watershed would need to be revised.

The Phase I study, conducted approximately 10 years ago, described the lake as being mesotrophic to slightly eutrophic with nuisance densities of submerged aquatic plants being the primary water quality impact. In contrast, after the 2003-04 drawdown water column nutrient concentrations increased, which resulted in a substantial increase in algal biomass and a substantial decline in water clarity. Since this large "alternative stable state" shift in the lake from a clear-water plant dominated state to a turbid algal-dominated state, no revisions to the pollutant load analysis or the lake's Management Plan have been conducted.

In order to better account for these recent changes in the lake and how they may have included existing conditions, Princeton Hydro was hired to revise the assessment of in-lake management techniques. To conduct this revised assessment some updated water quality data had to be collected and analyzed. Thus, in 2009 the Pennsylvania Department of Conservation and Natural Resources (PA DCNR) conducted six in-lake monitoring events from May through October 2009. In addition, the Pennsylvania Department of Environmental Protection (PA DEP) and the Bedford County Conservation District (BCCD) collected a total of six in-stream sampling events, under both baseline and storm event conditions. Finally, the Pennsylvania Fish and Boat Commission provided results of a fishery survey that was conducted at Shawnee Lake in 2008. Collectively, these data were utilized to:

- Update and revise the inter-annual water quality analysis that was conducted for Shawnee Lake during the first assessment in 2009,
- Update and revise the annual hydrologic and pollutant loading budgets,
- Quantify the lake's annual internal phosphorus load, and
- Conduct a revised assessment of in-lake and watershed-based restoration / management techniques.

In addition to the tasks outlined above, the result of this study will be presented to the public in a PowerPoint presentation format. The presentation will review existing water quality conditions in Shawnee Lake as well as the recommendations made to address its water quality and ecological problems.

Section 2 Water Quality Analysis

In the original assessment (2009) the inter-annual water quality data from Shawnee Lake were analyzed and some of the select pieces were graphed for convenience. The graphs focused primarily on data collected from 2006 to 2008. Thus, for this assessment, the data collected in 2009 were simply added to these established graphs.

Figure 1 shows the TP concentrations in the surface water at the dam station from 2006 to 2009. The variability in the 2009 TP concentrations in the surface waters at the dam station was low relative to past monitoring (TP concentrations varying between 0.031 and 0.058 mg/L in 2009).

The mean 2009 TP concentration was 0.047 mg/L, which was slightly lower than the mean values for 2007 and 2008 of 0.052 and 0.050 mg/L, respectively. However, the high TP concentration in 2009 was 0.058 mg/L, while the highest values for 2007 and 2008 were 0.075 and 0.079 mg/L, respectively.

Please note that TP concentrations greater than 0.06 mg/L (the red line shown in Figure 1) typically result in severe algal blooms in freshwater waterbodies. In contrast, based on US EPA criteria, a waterbody is considered eutrophic (highly productive) if the TP concentrations are greater than 0.03 mg/L. Although a highly productive system has a higher risk of experiencing nuisance water quality conditions, moderate to highly productive systems also give rise to successful, warm-water recreational fisheries.

While TP concentrations in the main body of Shawnee Lake occasionally exceeded the 0.06 mg/L threshold, concentrations were usually greater than 0.03 mg/L and in 2009 were equal to or greater than 0.05 mg/L. Although a formal modeling analysis was not be conducted with the more recent data, the recommended goal for the long-term management of Shawnee Lake is to keep the in-lake TP concentrations as close to 0.03 mg/L as possible.

Figure 2 shows the TN concentrations in the surface water at the dam station from 2006 to 2009. Similar to the TP data, variability in the 2009 TN concentrations at the dam stations were low relative to past monitoring (TN concentrations varying between 0.67 and 0.97 mg/L).

Figure 3 shows chlorophyll *a* concentrations in the surface water at the dam station from 2006 to 2009. Chlorophyll *a* concentrations varied between 0.020 and 0.061 mg/L in 2009 with a mean value of 0.047 mg/L. The 2009 mean value was similar to the 2007 and 2008 mean chlorophyll *a* values of 0.057 and 0.047 mg/L, respectively. However, the high chlorophyll *a* concentration of 0.061 mg/L in 2009 was lower than the highest concentrations in 2007 and 2008 of 0.091 and 0.080 mg/L, respectively. The lower

maximum chlorophyll *a* concentration in 2009 may have been due to the slightly higher amount of rain during that year.

From a layperson's perspective, algal blooms are considered a substantial nuisance (impacting recreational usage) when concentrations are equal to or greater than 0.03 mg/L. Five of the six 2009 samples had chlorophyll *a* concentrations greater than 0.06 mg/L (Figure 3). Thus, while surface water TP concentrations in the main body of the lake were not consistently high, chlorophyll *a* concentrations were usually at nuisance levels. This indicates that the algal blooms developed in the western coves and were transported to the main basin through wind and wave action and/or factors other than nutrient supply (i.e. structure of existing food web) drive algal productivity in Shawnee Lake.

Figure 4 shows the TSS concentrations in the surface water at the dam station from 2006 to 2009. TSS concentration in 2009 varied from 2.5 to 18 mg/L with a mean value of 5 mg/L. The mean TSS concentrations in 2007 and 2008 were 14 and 7.5 mg/L, respectively.

TSS concentrations greater than 25 mg/L typically result in conditions that are considered unacceptable to the layperson for recreational use; the water has a highly muddy or turbid appearance. Also, such elevated TSS concentrations have a negative impact on the fishery community, particularly cold water species such as trout. TSS concentrations were consistently less than 15 mg/L over the 2009 sampling season (Figure 4). Thus, at least within the main body of the lake, algal biomass was the main factor impacting water clarity, as opposed to high concentrations of inorganic material.

Figure 5 shows Secchi depth (measured in meters) in the surface water at the dam station from 2006 to 2009. Secchi depth exhibited a small amount of variability in 2009, varying between 0.5 and 0.75 m with a mean of 0.7 m. The amount of variability in Secchi depth was greater in 2007 and 2008. However, the mean Secchi depth in 2007 was lower (0.5 m), while the mean Secchi depth in 2008 was higher (0.8 m) relative to the mean value for 2009.

Typically, for the layperson, when the Secchi depth falls below 1.0 m (3.3 ft) the water is considered unacceptable for recreational use. As cited above, the Secchi depth of Shawnee Lake was consistently less than 0.8 m over the 2009 sampling season (Figure 5). These turbid, aesthetically displeasing conditions were primarily the result of algal biomass and not inorganic sediments. In addition, such consistently turbid conditions severely limits the development of rooted, submerged macrophytes (aquatic plants), which provide cover and food for fish and channel at least some of the nutrients into plants instead of algae.

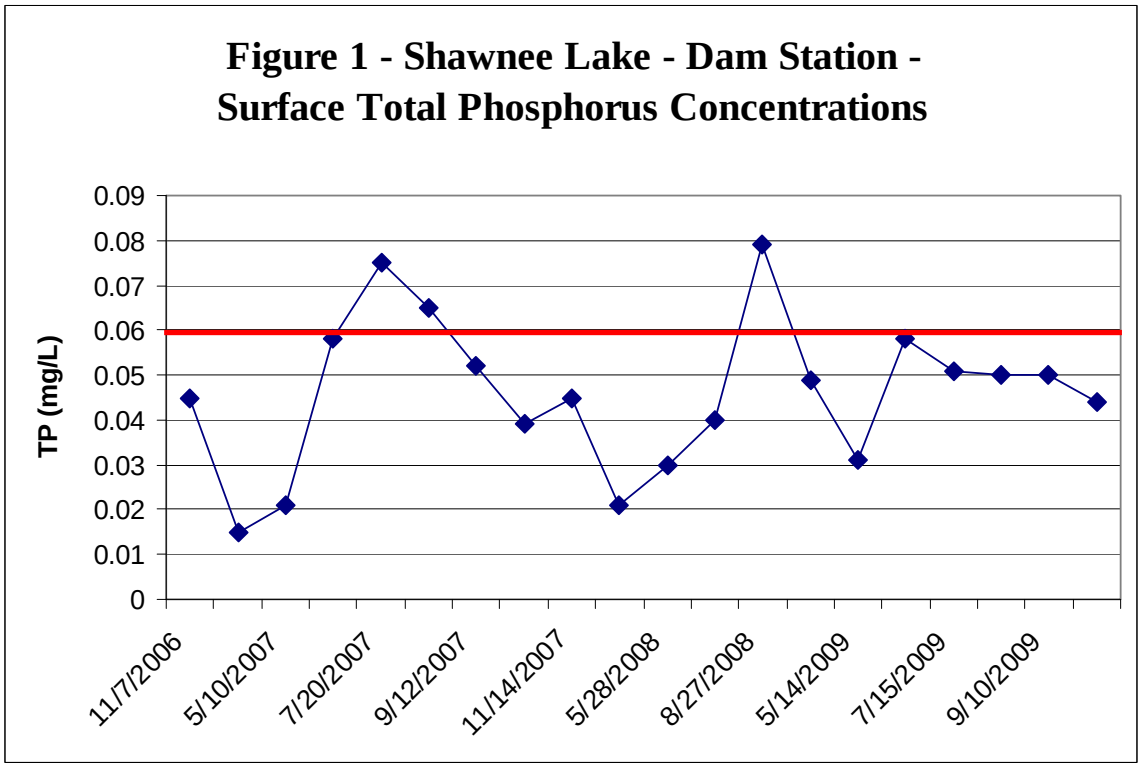


Figure 1 - Shawnee Lake - Dam Station -
Surface Total Phosphorus Concentrations
TP (mg/L)
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
11/7/2006
5/10/2007
7/20/2007
9/12/2007
11/14/2007
5/28/2008
8/27/2008
5/14/2009
7/15/2009
9/10/2009

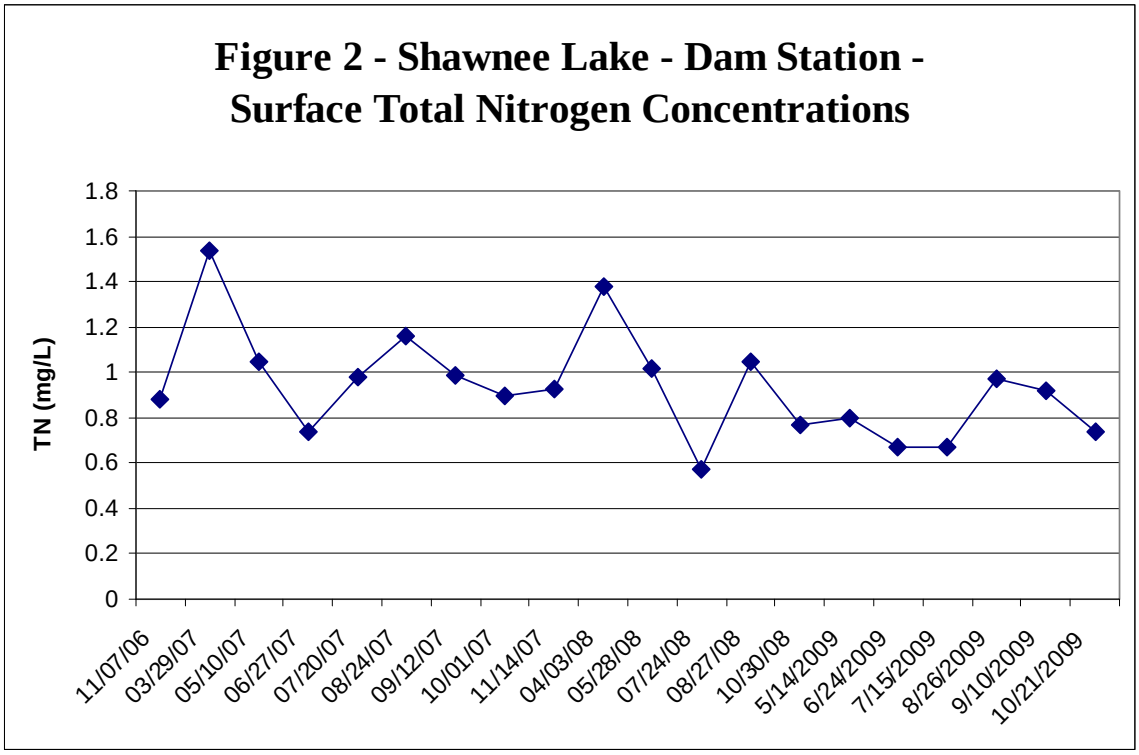


Figure 2 - Shawnee Lake - Dam Station -
Surface Total Nitrogen Concentrations
TN (mg/L)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
11/07/06
03/29/07
05/10/07
06/27/07
07/20/07
08/24/07
09/12/07
10/01/07
11/14/07
04/03/08
05/28/08
07/24/08
08/27/08
10/30/08
5/14/2009
6/24/2009
7/15/2009
8/26/2009
9/10/2009
10/21/2009

Figure 3 - Shawnee Lake - Dam Station - Surface Chlorophyll *a* Concentrations

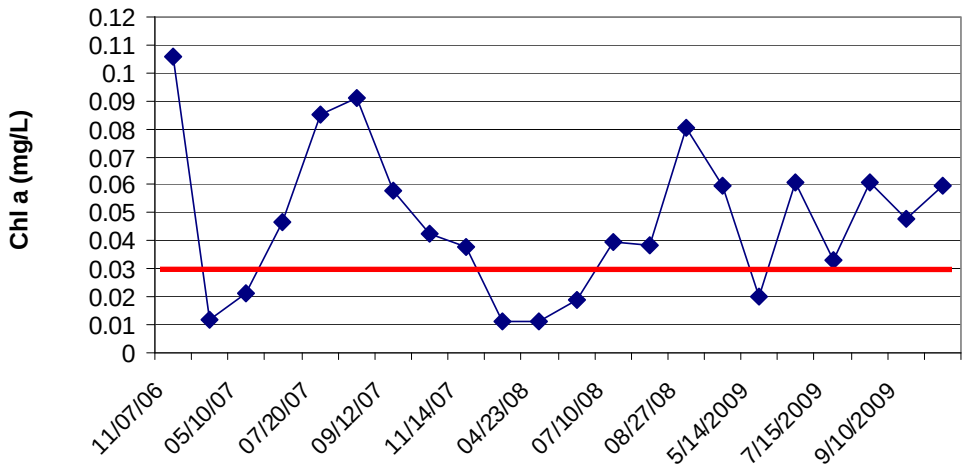
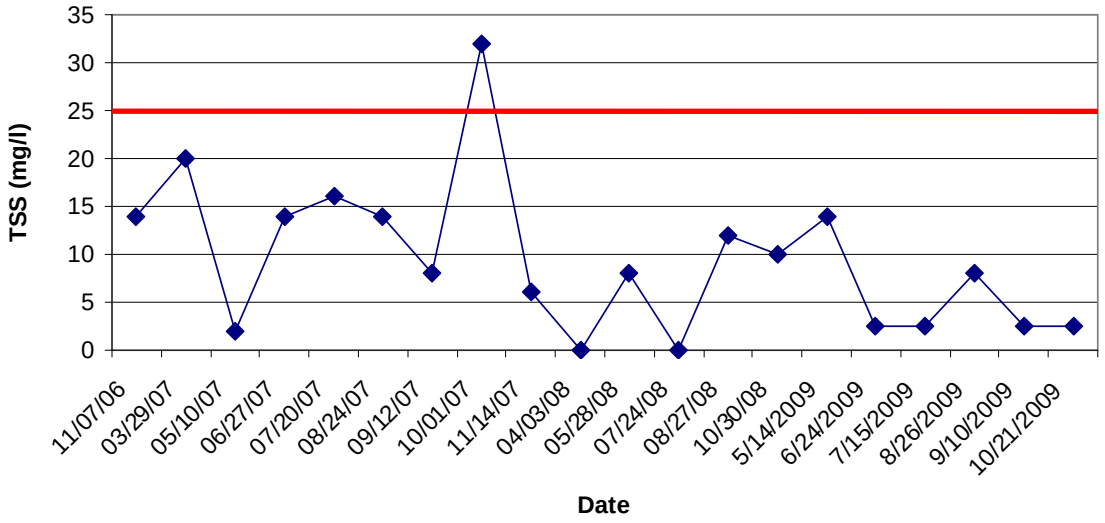


Figure 4 - Shawnee Lake - Dam Station - Surface Total Suspended Solids Concentrations



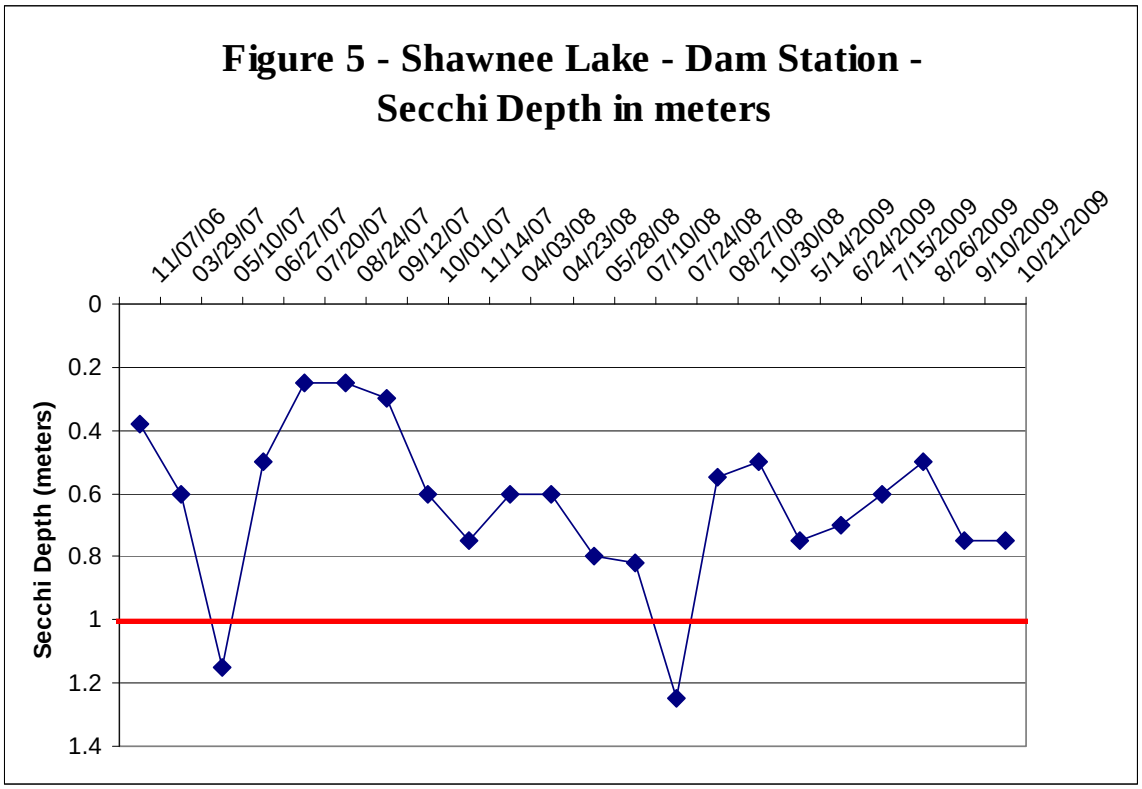


Figure 5 - Shawnee Lake - Dam Station -
Secchi Depth in meters
Secchi Depth (meters)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
11/07/06
03/29/07
05/10/07
06/27/07
07/20/07
08/24/07
09/12/07
10/01/07
11/14/07
04/03/08
04/23/08
05/28/08
07/10/08
07/24/08
08/27/08
10/30/08
5/14/2009
6/24/2009
7/15/2009
8/26/2009
9/10/2009
10/21/2009

Inter Station Variability in Shawnee Lake

In addition to the inter-annual (year to year) assessment, an inter-station (sampling site to sampling site) comparison was done with the 2009 data. This additional analysis, while not part of the original Scope of Work, provided some critical information on the impacts of both external and internal loading.

Based on the inter-station assessment, Station #3 (Treatment Plan; Kegg Run basin) TP concentrations were general higher than Stations #1 (Dam) and #2 (Shawnee Branch) TP concentration during the first half of the 2009 growing season (Figure 6). In contrast, in August 2009 TP concentrations at Stations #2 and #3 were excessive (> 0.08 mg/L), while the Station #1 TP concentration was moderate (0.05 mg/L).

In contrast, Station #2 had the highest TN concentration in four of the six sampling events, while Station #3 has the highest TN concentration in the remaining two (Figure 7).

Early in the growing season, Station #3 had slightly higher chlorophyll *a* concentrations relative to Stations #1 and #2. However, the highest chlorophyll *a* concentrations were observed at Station #2 during the September 209 sampling event (Figure 8).

While the highest chlorophyll *a* concentrations shifted from Station #3 to Station #2 through the 2009 growing season, TSS concentrations at Station #2 were consistently higher than the other two stations through the growing season (Figure 9). In fact, TSS concentrations were consistently greater than 15 mg/L at Station #3, while concentrations at Stations #1 and #2 were consistently below 15 mg/L.

Both algal densities and TSS concentrations impact water clarity. As algal biomass and TSS concentrations increase, water clarity, as measured with a Secchi disk, will decline. The lowest Secchi disk values were measured at Station #3 during the May and August 2009 sampling events (Figure 10).

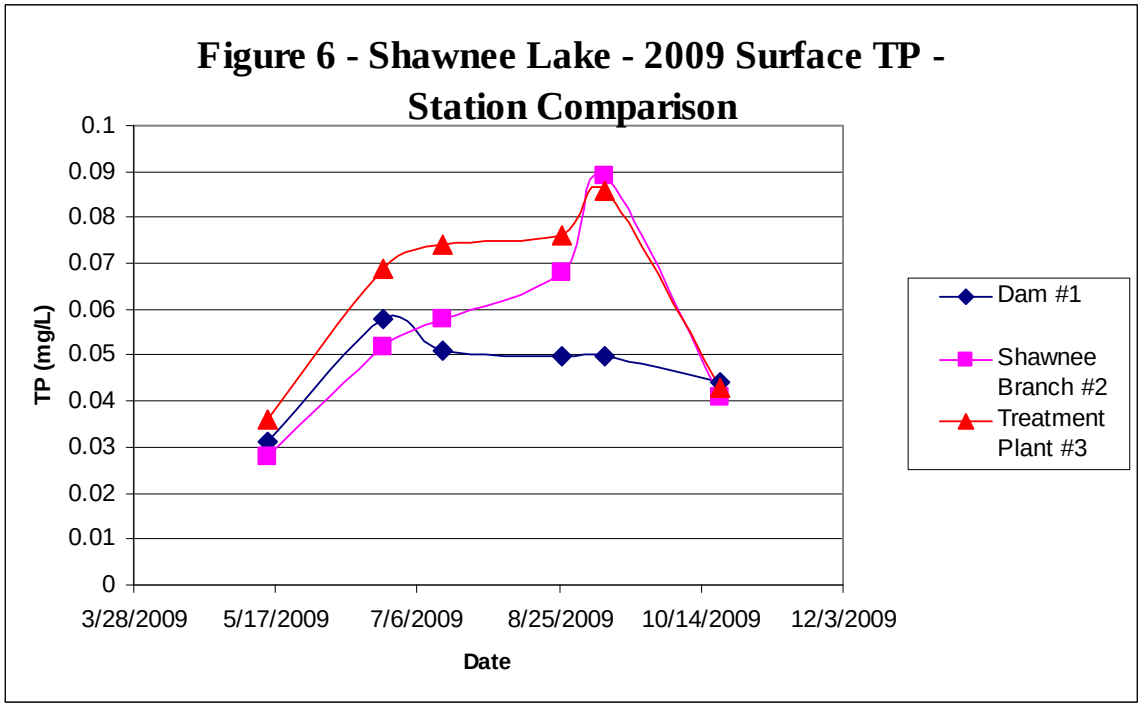


Figure 6 - Shawnee Lake - 2009 Surface TP - Station Comparison
TP (mg/L)
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
3/28/2009
5/17/2009
7/6/2009
8/25/2009
10/14/2009
12/3/2009
Date
Dam #1
Shawnee Branch #2
Treatment Plant #3

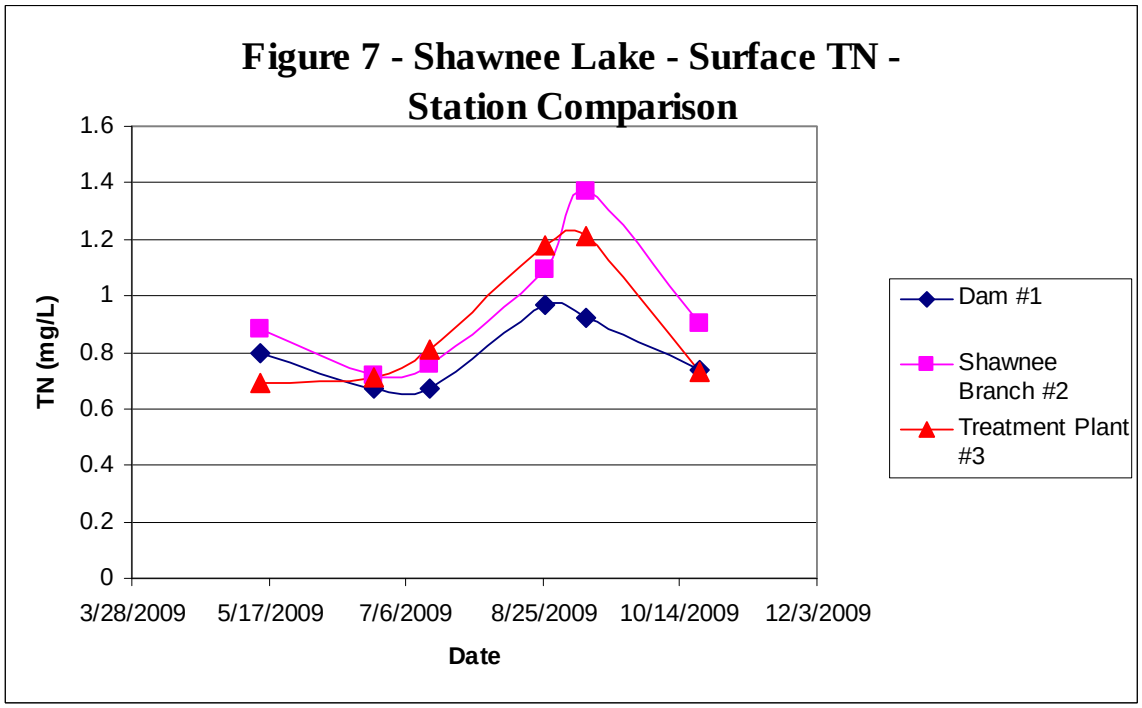


Figure 7 - Shawnee Lake - Surface TN - Station Comparison
TN (mg/L)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
3/28/2009
5/17/2009
7/6/2009
8/25/2009
10/14/2009
12/3/2009
Date
Dam #1
Shawnee Branch #2
Treatment Plant #3

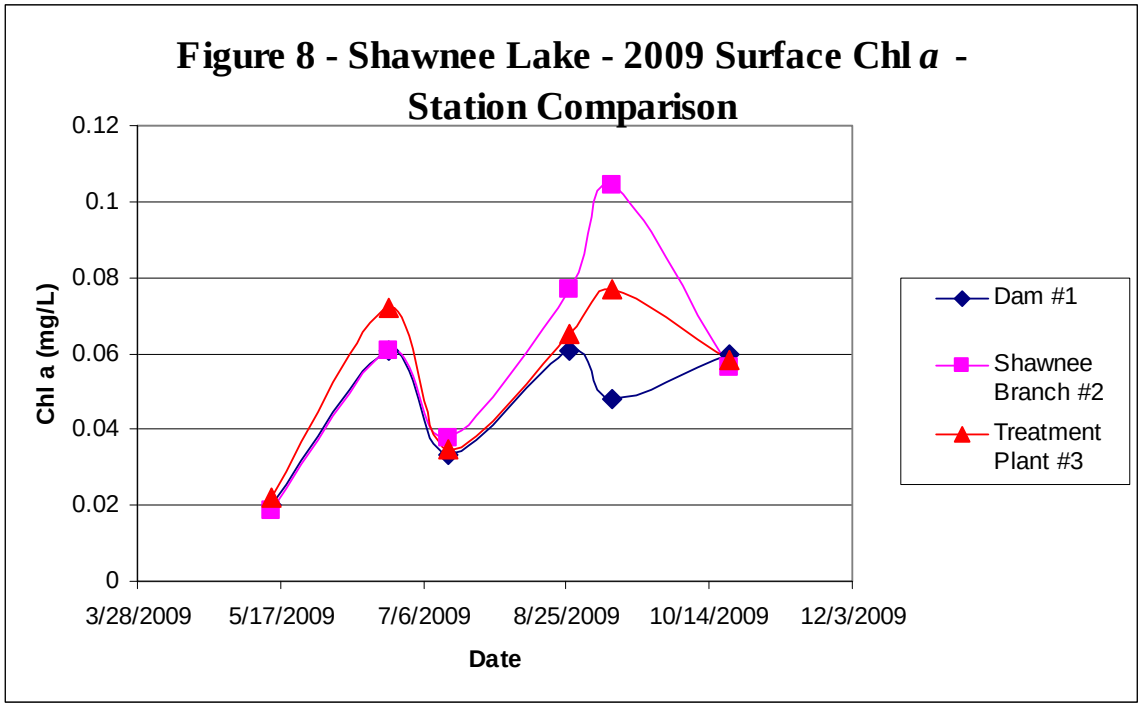


Figure 8 - Shawnee Lake - 2009 Surface Chl *a* - Station Comparison
Chl a (mg/L)
0.12
0.1
0.08
0.06
0.04
0.02
0
3/28/2009
5/17/2009
7/6/2009
8/25/2009
10/14/2009
12/3/2009
Date
Dam #1
Shawnee Branch #2
Treatment Plant #3

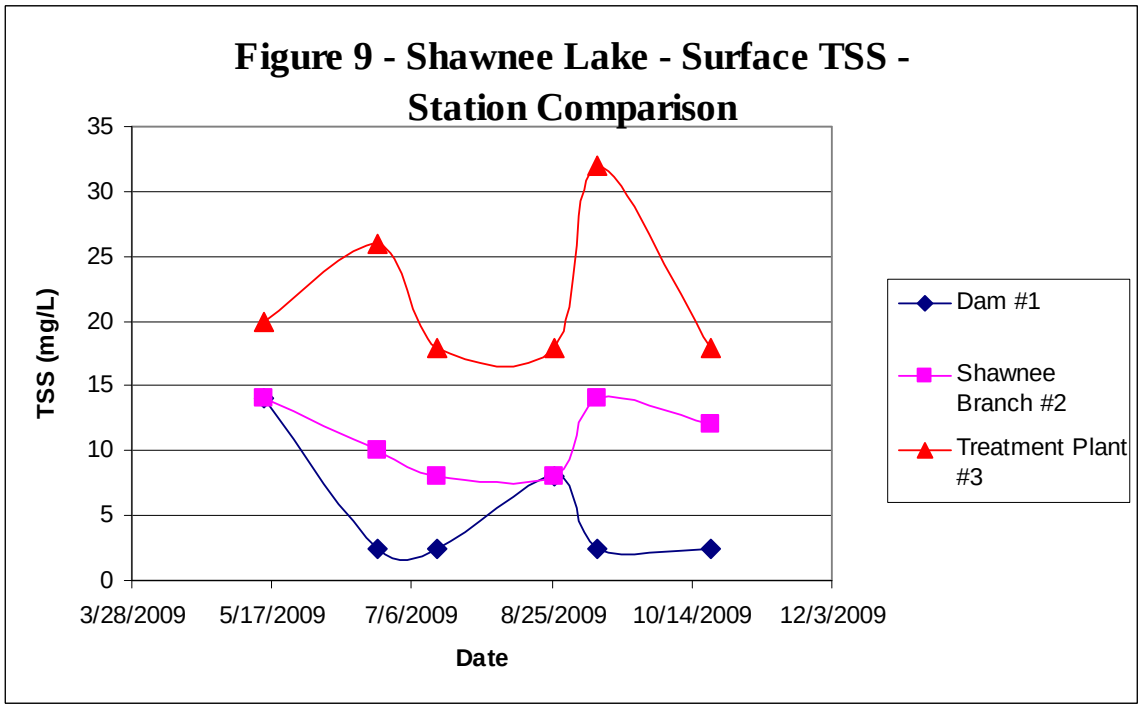


Figure 9 - Shawnee Lake - Surface TSS - Station Comparison
TSS (mg/L)
35
30
25
20
15
10
5
0
3/28/2009
5/17/2009
7/6/2009
8/25/2009
10/14/2009
12/3/2009
Date
Dam #1
Shawnee Branch #2
Treatment Plant #3

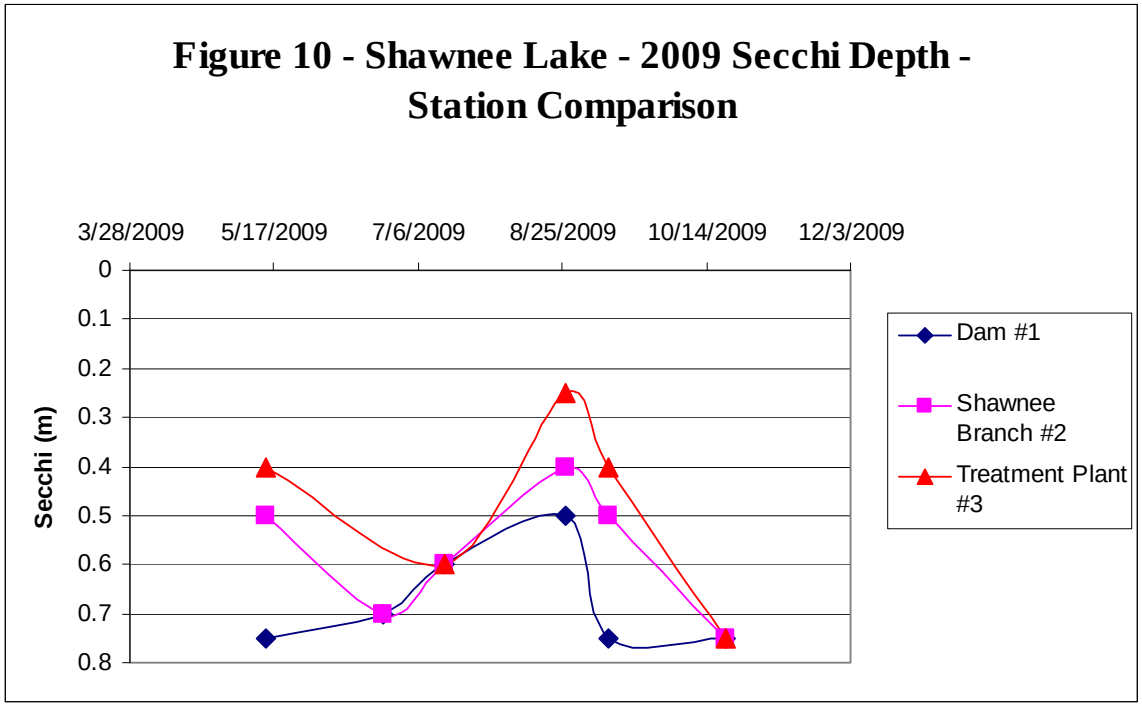


Figure 10 - Shawnee Lake - 2009 Secchi Depth - Station Comparison
3/28/2009
5/17/2009
7/6/2009
8/25/2009
10/14/2009
12/3/2009
Secchi (m)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
Dam #1
Shawnee Branch #2
Treatment Plant #3

Section 3 2009 Updated Hydrologic and Pollutant Load Estimates

Princeton Hydro utilized site specific nutrient and discharge data, in concert with regional hydrologic data obtained through the United States Geologic Survey (USGS) to calculate the monthly and annual hydrologic and pollutant loads entering Shawnee Lake from the Kegg Run and Shawnee Branch sub-watersheds. The resulting sub-watershed pollutant loads were compared to an updated analysis of the lake's internal phosphorus load. In addition, the quantify pollutant loads were also completed to the original modeled calculations conducted by Aqua-Link as part of the 2000-2003 feasibility study.

In order to calculate the watershed based nitrogen, phosphorus and sediment loads generated form the Kegg Run and Shawnee Branch sub-watersheds, Princeton Hydro first delineated the drainage area of each sub-watershed. Specifically, Kegg Run subwatershed encompasses an area of 2,729 ha (6,744 acres) while the Shawnee Branch subwatershed encompasses 4,735 ha (11,700 acres). Princeton Hydro found relatively good agreement between our delineation and that of Aqua-Link with relative percent differences of 0.3% and 0.4% for Kegg Run and Shawnee Branch respectively.

Following the delineation of each sub-watershed Princeton Hydro developed hydrologic budgets for each tributary. First, daily mean discharge values for four (4) USGS gauged tributaries which were within close proximity to Lake Shawnee were compiled. The four tributaries are as follows:

- Wills Creek USGS 01601000
- Dunning Creek USGS 01560000
- Bald Eagle Creek USGS 01557500
- Tonoloway Creek USGS 01613050

Daily discharge values were obtained from January 2009 – December 2009. From these data Princeton Hydro calculated mean monthly discharge for each of the reference gauged tributaries and then normalized this discharge for watershed area. The four normalized monthly discharge values were subsequently averaged with the resulting specific discharge utilized as the regional discharge rate for Kegg Run and the Shawnee Branch. The normalized discharge value was subsequently multiplied by the sub-watershed area for Kegg Run and Shawnee Branch to calculate a monthly hydrologic load for each sub-watershed, the results of which are presented in Table 3.1.

Table 3.1: Lake Shawnee – 2009 Hydrologic Loads

2009 Hydrologic Load		
	Kegg Run	Shawnee Branch
Month	(liters)	(liters)
January	849,010,293	1,472,998,215
February	1,471,568,708	2,553,111,661
March	766,519,529	1,329,880,105
April	1,890,267,486	3,279,536,956
May	2,299,559,361	3,989,641,659
June	1,163,158,766	2,018,032,996
July	234,327,802	406,549,175
August	127,862,895	221,836,905
September	74,208,626	128,748,938
October	556,370,039	965,279,315
November	400,892,922	695,532,862
December	2,356,164,000	4,087,848,398

Following the determination of monthly discharge volumes for each sub-watershed Princeton Hydro determined the 2009 nutrient load. This was accomplished through multiplying total phosphorus, total nitrogen and total suspended solids concentrations which were collected during the May, July, September and November events by the monthly discharge value to obtain a pollutant mass for that month. During those months in which sampling did not occur Princeton Hydro utilized a mean pollutant concentration derived from the four sample dataset. The results of this analysis are presented in Tables 3.2 through 3.4.

Table 3.2: Lake Shawnee – 2009 TN Loads

Lake Shawnee – 2009 TN Loads		
	Kegg Run	Shawnee Branch
Month	(kg/mo)	(kg/mo)
January	454	2,858
February	787	4,953
March	410	2,580
April	1,011	6,362
May	1,219	6,703
June	622	3,915
July	176	992
August	68	430
September	40	220
October	298	1,873
November	128	1,342
December	1,261	7,930
Total	**6,475**	**40,158**

Table 3.3: Lake Shawnee – 2009 TP Loads

Lake Shawnee – 2009 TP Loads		
	Kegg Run	Shawnee Branch
Month	(kg/mo)	(kg/mo)
January	32	43
February	55	75
March	29	39
April	71	97
May	67	128
June	44	60
July	10	12
August	5	7
September	5	4
October	21	28
November	6	17
December	88	121
Total	**431**	**631**

Table 3.4: Lake Shawnee – 2009 TSS Loads

Lake Shawnee – 2009 TSS Loads		
	Kegg Run	Shawnee Branch
Month	(kg/mo)	(kg/mo)
January	6,155	5,745
February	10,669	9,957
March	5,557	5,187
April	13,704	12,790
May	18,396	31,917
June	8,433	7,870
July	586	1,016
August	927	865
September	1,187	322
October	4,034	3,765
November	1,002	1,739
December	17,082	15,943
Total	**87,734**	**97,115**

Table 3.5 compares the 2009 Kegg Run subwatershed hydrologic and pollutant loads calculated by Princeton Hydro to those modeled by Aqua-Link during the 2000-2003 Diagnostic / Feasibility Study. Table 3.6 is a similar comparison for the Shawnee Branch subwatershed.

Table 3.5: Kegg Run – 2000 vs. 2009 Loading Comparison

Kegg Run – 2000 vs. 2009 Load Comparison				
	Hydro Load	TN	TP	TSS
	(L/yr)	(kg/yr)	(kg/yr)	(kg/yr)
2000	1.28×10^{10}	8,385	559	351,605
2009	1.22×10^{10}	6,475	431	87,734
% Change	-4%	-23%	-23%	-75%

Table 3.6: Shawnee Branch – 2000 vs. 2009 Loading Comparison

Shawnee Branch – 2000 vs. 2009 Load Comparison				
	Hydro Load	TN	TP	TSS
	(L/yr)	(kg/yr)	(kg/yr)	(kg/yr)
2000	2.21×10^{10}	16,377	1,128	731,167
2009	2.11×10^{10}	40,158	631	97,115
% Change	-4%	+145%	-44%	-87%

TP loading decreased from 2000 to 2009 by 23% in Kegg Run and 44% in Shawnee Branch, based on the limited dataset utilized to calculate loads. Declines in TSS loading from 2000 to 2009 were more dramatic; a decline of 75% for Kegg Run and 87% for Shawnee Branch. TN loading in Kegg Run also declined from 2000 to 2009 by 23%, however, there was a sharp increase in TN load in Shawnee Branch by 145% during the same period of time (Table 3.6).

It should be noted that the loads calculated during the 2009 season for both sub-watersheds were based on a dataset of four (4) discrete grab samples throughout the entire year. More frequent sampling, over a range of flow regimes, will allow for a more accurate characterization of the watershed load of all nutrient parameters. Furthermore, discharge data was estimated from regional tributaries as there was not a continual discharge record available for either Kegg Run or the Shawnee Branch.

Section 4 Internal Phosphorus Load Quantification

Data from the 2000 Diagnostic / Feasibility Study indicated that Shawnee Lake experiences thermal stratification from June through August. During this monitoring period, dissolved oxygen (DO) concentrations in the hypolimnion were less than 1.0 mg/L. Furthermore, hypolimnetic TP concentrations were higher than those measured in the epilimnetic waters, indicating the potential for internal P loading. In order to model this load Aqua-Link utilized sediment phosphorus release coefficients for both oxic and anoxic (DO < 1 mg/L) conditions. The coefficients utilized for this study were 0.5 mg / m^2 / day under oxic conditions and 2.0 mg / m^2 / day under anoxic conditions.

The original Phase I study assumed 90 days of anoxia and 275 days of oxic conditions. The resulting model predicted that approximately 579 kg / yr of TP was released from the sediments. From the analysis of this study it seems that the modeler assumed the entire lake area experienced anoxic conditions during the 90 day period. This likely resulted in an overestimation of internal load given that the strongest thermal stratification and anoxia occurs near and around the deep dam station. Furthermore, the modeler assumed oxic loading to occur over a period of 275 days. This also likely caused an overestimation of internal P loading as little phosphorus leaches from the sediments during the colder months of the year.

Princeton Hydro revised the internal load estimate of Shawnee Lake as based on *in-situ* data collected during the 2009 season in concert with stage / storage data collected during the bathymetric survey. This information allowed Princeton Hydro to calculate the oxic and anoxic loading of phosphorus within the lake on varying spatial and temporal scales. Specifically, Princeton Hydro first reviewed the *in-situ* data collected by the PADEP which showed the lake to experience anoxic conditions beginning in May at depths equal to and greater than 7 m. Anoxic conditions were the strongest during the August event with DO concentrations < 1.0 mg/L in those waters equal to and deeper than 3 m. Anoxia persisted through the September event at depths of 5 m and greater. During the October event the lake was fully mixed and as such did not experience anoxia. Princeton Hydro assumed oxic loading to only occur during the growing season (May through September) in those areas of the lake which did not experience anoxia. This area was simply the difference between the anoxic area and total lake area. For the calculation of the internal phosphorus load Princeton Hydro utilized the same sediment P load coefficients which were utilized during the 2000 study. Table 4.1 summarizes the internal P load contribution to Shawnee Lake.

Table 4.1: Shawnee Lake – Internal P Load

Month	Oxic	Anoxic	Sum
	(kg/mo)	(kg/mo)	(kg/mo)
May	27.1	3.1	30.3
June	21.9	20.4	42.3
July	22.7	21.1	43.7
August	16.5	45.9	62.4
September	20.5	26.2	46.7
Sum	108.7	116.7	225.4

The total internal phosphorus load for Shawnee Lake is 225.4 kg / yr. This value represents a 61% decrease over that modeled during the 2000 season. The disparity between the 2000 and 2009 modeling data is due to a more refined loading estimate during the 2009 effort as based on recent bathymetric data in concert with alteration of temporal loading trends to more accurately reflect internal P load dynamics.

Section 5 Data Analysis

All of the data collected and presented in Sections 2 through 4 of this report were analyzed within the context of addressing the objectives of this study as listed in Section 1. For convenience, the results of this data analysis are listed below in a bulleted format.

- The 2009 hydrologic loads calculated for Shawnee Branch and Kegg Run were similar to those for calculated as part of the 2000 Phase I study. The difference between the 2009 and 2003 results for each tributary was only approximately 4%.

- The variability in the 2009 TP concentrations in the surface waters at the dam station was low relative to past monitoring (TP concentrations varying between 0.031 and 0.058 mg/L).

- Similar to the TP data, the 2009 TN concentrations at the dam stations were low relative to past monitoring (TN concentrations varying between 0.67 and 0.97 mg/L).

- In an inter-station comparison, Station #3 (Treatment Plant; Kegg Run basin) TP concentrations were generally higher than Station #1 (Dam) and Station #2 (Shawnee Branch) in the first half of the growing season. In early September 2009, TP concentrations in Stations #2 and #3 were excessive (> 0.08 mg/L), while in Station #1 the concentration was moderate (0.05 mg/L).

- Early in the growing season, Station #3 had slightly higher chlorophyll *a* concentrations relative to Stations #1 and #2. The highest chlorophyll *a* concentrations were observed in Station #2 during the September sampling event.

- TSS concentrations were consistently greater than 15 mg/L at Station #3, while concentrations at Stations #1 and #2 were consistently below 15 mg/L. While the Kegg Run in-stream TSS database is small, concentrations were generally low. This provides evidence that the high TSS concentrations in the Kegg Run basin may be due to wind-driven sediment re-suspension and/or a large population of benthic fish (yellow bullheads)

- Of the four Kegg Run sampling events, the one that had a higher TSS (16 mg/L) also had a moderately high TP (0.064 mg/L); this was on 29 September 2010. Thus, watershed-based measures do need to be taken into account.

- For Shawnee Branch, the 2009 annual TP load was approximately 44% lower than the Phase I estimated TP load. Also, the 2009 annual TSS load was approximately 87% lower than the Phase I estimated TSS load. In sharp contrast, the 2009 annual TN load was approximately 2.4 times larger than the Phase I estimated TN load.

- For Kegg Run, the 2009 annual TP and TN loads were both approximately 23% lower than the respective Phase I estimated loads. Also, the 2009 annual TSS load was 75% lower than the Phase I estimated TSS load.

- The 2009 internal phosphorus load estimate was approximately 61% lower than the Phase I load estimate.

Resulting Conclusion in Response to the Data Analysis:

- The 2009 watershed-based pollutant loads (Kegg Run and Shawnee Branch) were lower in magnitude relative to the 2000 loads, with the exception being the TN load originating from the Shawnee Branch. In spite of this general reduction, the external, watershed-based sources still account for the majority of pollutant loading entering Shawnee Lake. For example, the internal phosphorus load for Shawnee Lake is estimated to account for only 17% of the Kegg Run and Shawnee Branch TP loads combined. This means that watershed management and planning should still be an important component of an overall long-term Restoration Plan for Shawnee Lake.

- Kegg Run Cove had excessive TSS concentrations, relative to the other two sections of the lake, in spite of relative low TSS concentrations measured in Kegg Run itself. For example, TSS concentrations off of the Kegg Bridge from May 2009 to April 2010 varied from < 5 to 16 mg/L with a mean value of only 5.7 mg/L. In contrast, TSS concentrations in Kegg Run Cove varied between 18 and 32 mg/L with a mean of 22 mg/L. Based on these contrasting data, the elevated TSS in Kegg Run Cove is probably attributed to sediment re-suspension.

- Two factors may be contributing to the consistently high TSS concentrations in Kegg Run Cove. First, the absence of large stands of aquatic plants allows wind and wave action in shallow waters to easily re-suspend fine particles. Second, the fishery community may be contributing to these conditions. During a 2008 fishery survey of Shawnee Lake, yellow bullhead were the third most abundant species collected. Benthic feeding fishes, such as yellow bullhead and common carp, are well known to increase turbidity in shallow waterbodies through their feeding and spawning activities.

- While TP concentrations in the Kegg Run and Shawnee Branch Coves varied from low to excessive (0.028 – 0.089 mg/L), concentrations at the Dam station were moderate (0.031 – 0.058 mg/L). In spite of these moderate concentrations, nuisance blooms persist. The stratified, still water habitat in the main body of the lake, favors the growth and development of large blue-green algal blooms, particularly during the dry summer months.

- A number of factors may be contributing to the nuisance algal blooms in the main body of Shawnee Lake, in spite of the moderate TP concentrations. First, as previously mentioned, the stratified, still water conditions provide excellent conditions for blue-green algal blooms, since many of these algae can regulate their position in the water column with gas vacuoles. With this ability to migrate through the water column, blue-green algae can move to the surface to out-compete other algae for light and move to the deeper depths to utilize the nutrient-rich waters. Second, the planktonic food web is dominated by fishes that feed on large-bodied, algae-eating zooplankton. Thus, the large number of gizzard shad in the lake keeps large-bodied, algae-eating zooplankton densities low, thus removing this natural form of algae control from the food web.

Section 6 Recommended Strategy for Shawnee Lake

The recommendations described in Appendix A focus on in-lake management actions. While this study updated / revised the watershed-based loads originating from the Kegg Run and Shawnee Lake subwatersheds, no detailed watershed-based assessments or surveys were conducted to identify specific locations for the implementation of specific projects. Instead, this study focused on analyzing the collected data to develop a series of in-lake management actions that are designed to improve the overall water quality, ecological and recreation health of Shawnee Lake. However, it should be emphasized that focusing only on the in-lake issues of concern typically only addresses the "symptoms" of eutrophication.

It is absolutely vital that watershed-based actions also be considered to reduce the pollutant load entering the lake, which tends to be the major "cause" of eutrophication. Thus, it is strongly recommended that the watershed-based portion of the Diagnostic / Feasibility Study's restoration recommendations of 2000 be updated. The fact that the TN load in the Shawnee Branch increased by 145% from 2000 to 2009 indicates that some recent watershed-based activities may be the cause for this increase. In any event, while watershed-based actions will be necessary for the long-term protection and improvement of Shawnee Lake, this report focuses on in-lake management actions. Details on the recommended in-lake management measures are provided in Appendix A.

APPENDIX A

In-Lake Management Measures for Shawnee Lake

I. Reduce the in-lake nutrient concentrations in the western cove

1. Based on the 2009 data, TP and TN concentrations in the coves were higher relative to the Dam sampling station.

2. TSS concentrations were also higher in the coves relative to the Dam sampling stations, particularly the Kegg Run Cove.

3. However, in-stream TP or TSS concentrations or loads were not particularly high entering the lake through the western coves.

4. Thus, the nutrients that fuel algal growth in the coves originate from both the watershed and from the sediments.

5. Dissolved Oxygen (DO) concentrations are low in the bottom waters of the coves but do not typically go anoxic (DO < 1 mg/L).

6. Thus, sediment re-suspension and/or benthic fish feeding activities are contributing to the higher nutrient concentrations in the coves.

RECOMMENDATION - Installation of a series of Floating Wetland Islands at key locations in the coves to contribute toward reducing existing, in-lake nutrient concentrations.

COST - 250 sq ft FWI; purchase, plants, materials, installation, monitoring - $13,000.00 per FWI.

MANAGEMENT ACTION - Install six (6) of the 250 sq ft FWIs in the Kegg Run cove to aid in reducing the available nutrients. May want to conduct a demonstration project of installing only two (2) of the 250 sq ft FWIs at approximately $26,000.00. Also, depending on the level of nutrient removal efficiency, each island may need to be equipped with an aeration system to increase the DO concentration underneath the FWIs. Such aeration systems could be solar based.

NOTES

A smaller FWI (6 sq. ft.) could also be installed along with the larger ones and used to quantify how much phosphorus and nitrogen are sequestered in the islands over the course of one growing season. The small FWI can be weighed after it is planted and installed in the lake for a day or two. At the end of the growing season, the small FWI can be re-weighed and samples collected of the plants and the microbial biomass underneath the island for nutrient analysis. The resulting data for the 6 sq. ft. FWI can then be used to estimate how much phosphorus and nitrogen are stored in the islands over one growing season.

Using other studies, it is estimated that one 250 sq. ft. FWI can remove approximately 10 lbs of total phosphorus (TP) per year. This has the potential of reduce the amount of algal biomass by approximately 11,000 lbs per FWI (1 lbs of TP is estimated to potentially generate 1,100 lbs of wet algae biomass).

Finally, it should be emphasized that the FWIs are to supplement, not replace, watershed-based actions to reduce the pollutant loads entering the lake.

In-Lake Management Measures for Shawnee Lake

II. Biomanipulation Management Actions

Pelagic Habitat

1. Based on the 2008 fishery survey, gizzard shad and yellow bullhead were the 1st and 3rd most common species, respectively.

2. The gizzard shad feed on large, herbivorous zooplankton; the yellow bullhead stir up the bottom sediments.

RECOMMENDATION - Stock the lake with hybrid striped bass to reduce the population of gizzard shad, which in turn would reduce grazing pressure on algae-eating zooplankton. In addition, it would benefit the recreational fishery (put and take fishery).

COST - Excluding the southwest Kegg Run Cove in the calculation due to its shallow depth and at a stocking rate of 10 hybrid striped bass per targeted acre (with 8-12" fish), such a stocking program is expected to cost $12,000.00 (excluding transportation).

MANAGEMENT ACTION - Stock 4,000 hybrid striped bass in Shawnee Lake. It could be done over 2 years to make the annual stocking fee more manageable.

NOTES

It should be noted that PA Fish & Boat Commission are not in favor of stocking hybrid striped bass in Shawnee Lake. Given these current reservations, this in-lake management measure is ranked low relative to the other measures. However, since the lake is relatively turbid, and the fact that gizzard shad are one of the dominant species, hybrid striped bass is the recommended species for the implementation of any biomanipulation program focusing on the lake's pelagic habitat.

Benthic Habitat

3. In addition to the gizzard shad, there is concern that the yellow bullhead may be at least partially responsible for the turbid conditions, particularly in Kegg Run cove where the TSS was consistently greater than 15 mg/L in 2009.
In contrast, TSS concentrations at the other two stations were less than 15mg/L through the 2009 growing season.

RECOMMENDATION - While an aggressive yellow bullhead removal program may aid in reducing the turbidity in the Kegg Run Cove, it is not recommended at this time.

MANAGEMENT ACTION - Any future fishery survey conducted at Shawnee Lake should include a design where the Kegg Run Cove is specifically surveyed to assess its existing population of benthic fishes. In addition, the PA DCNR should work with the Fish and Boat Commission to ensure that any future stocking programs for Shawnee Lake do not include benthic fish species.

In-Lake Management Measures for Shawnee Lake

III. Experimental Treatment to Reduce Turbidity in Part of Kegg Run Cove

1. As shown in the 2009 data, Kegg Run Cove is consistently more turbid than the rest of Shawnee Lake.

2. Based on the data collected, the driving factor for the turbidity does not appear to be solely from watershed-based sources.

3. In addition to benthic fish, re-suspension of settled particulate material in this shallow cove may also be responsible for the turbid conditions.

4. These turbid conditions prevent the establishment of submerged or floating leaved, rooted aquatic plants, which is a preferred condition.

5. Thus, in order to potentially stimulate the growth of aquatic plants, Kegg Run Cove could be treated with a clarifier to temporarily increase water clarity at a critical time of the year such as spring or early summer.

RECOMMENDATION - Consider treating the most western section of Kegg Run Cove with a clarifier (aluminum sulfate) in the spring / early summer to stimulate the growth of submerged / floating leaved aquatic plants. It should be emphasized that this would be experimental in nature and given the flushing rate of the lake, increased water clarity is not anticipated to last more than one growing season.

COST - The most western end of Kegg Run Cove is approximately 41 acres. Based on the lake's alkalinity / hardness values from the Phase I study, it is estimated that the dosage rate of alum would be between 100 to 150 gallons per acre. Conducting this proposed clarification project, with alum is estimated to cost approximately $37,000.00 to $40,000.00. This estimated price range includes purchase and transport of alum, application of alum and some follow up monitoring.

MANAGEMENT ACTION - If this project is to be implemented, an alum feasibility study should be conducted (approximately $3,000.00).

NOTES

Again, it should be emphasized that this proposed treatment would be experimental in nature. However, Princeton Hydro has used water clarifiers such as alum to increase water clarity and result in a substantial increase in rooted aquatic plant densities.

While there is no formal permitting process in the application of nutrient clarifers such as alum, a meenting with both the South Central Regiona office of PA DEP and the Fish & Boat Commission is strongly recommended if this in-lake measure is considered for implementation.

In-Lake Management Measures for Shawnee Lake

IV. Destratifying the Water Column of Shawnee Lake

1. Based on the 2009 data, the internal phosphorus load does not account for a large portion of the lake's annual TP load.

2. However, the lake does strongly stratify, particularly in the main, eastern basin.

3. In addition, there are several genera of blue-green algae that bloom in the lake that can migrate through the water column and/or bloom in deeper waters. Thus, these blue-green algae can out-compete other algae for light and nutrients during the summer.

4. Destratifying the water column will eliminate this blue-green algae habitat.

RECOMMENDATION - Consider aerating the main basin or the entire lake.

COST - Design and installation of a standard aeration system in the main basin is estimated to cost approximately $150,000.00, while installing a system for the entire 445 acres of the lake is estimated to cost approximately $310,000.00.

MANAGEMENT ACTION - Of the two options, aerating the main basin would be the most cost effective approach. While these prices are for a standard aeration system, the use of a solar-based aeration system could be considered.

NOTES

It should be noted that based on the depth and size of the main basin of Shawnee Lake, a solar-based aeration system may not be feasible due to the associated energy demands in keeping it well mixed over most of the growing season. However, a "hybrid" system could reduce electrical costs and may be cost effective relative to the long-term operation of the system.