KANSAS – LOWER REPUBLICAN BASIN TOTAL MAXIMUM DAILY LOAD

Waterbody: Lake Shawnee
Water Quality Impairment: Eutrophication

1. INTRODUCTION AND PROBLEM IDENTIFICATION

Subbasin: Middle Kansas **Counties:** Shawnee

HUC 8: 10270102 **HUC 10 (12):** 09 (02)

Ecoregion: Central Irregular Plains, Osage Cuestas (40b)

Drainage Area: 8.4 square miles

Conservation Pool: Surface Area = 371 acres
Watershed/Lake Ratio: 15:1
Maximum Depth = 14 meters
Mean Depth = 4.3 meters
Storage Volume = 7,256 acre-feet
Estimated Retention Time = 2.7 years
Mean Annual Inflow = 2722 acre-feet
Mean Annual Discharge = 2666 acre-feet
Constructed: 1937

Designated Uses: Primary Contact Recreation Class A; Expected Aquatic Life Support; Domestic Water Supply; Food Procurement; Ground Water Recharge; Industrial Water Supply; Irrigation Use; Livestock Watering Use.

303(d) Listings: Lake Shawnee Eutrophication: 2002, 2004, 2008, 2010 Kansas Lower Republican River Basin Lakes.

Impaired Use: All uses in Lake Shawnee are impaired to a degree by eutrophication

Water Quality Criteria: Nutrients - Narrative: The introduction of plant nutrients into streams, lakes, or wetlands from artificial sources shall be controlled to prevent the accelerated succession or replacement of aquatic biota or the production of undesirable quantities or kinds of aquatic life (KAR 28-16-28e(c)(2)(A)).

The introduction of plant nutrients into surface waters designated for domestic water supply use shall be controlled to prevent interference with the production of drinking water (K.A.R. 28-16-28e(c)(3)(A)).

The introduction of plant nutrients into surface waters designated for primary or secondary contact recreational use shall be controlled to prevent the development of objectionable

concentrations of algae or algal by-products or nuisance growths of submersed, floating, or emergent aquatic vegetation (KAR 28-16-28e(c)(7)(A)).

2. CURRENT WATER QUALITY CONDITION AND DESIRED ENDPOINT

Level of Support for Designated Uses under 2010-303(d): Excessive nutrients are not being controlled and are thus impairing aquatic life, domestic water supply and contributing to objectionable algal blooms that contribute to the Eutrophication and impairment of contact recreation within Lake Shawnee.

Level of Eutrophication: Very Eutrophic, Trophic State Index = 61.2

The Trophic State Index (TSI) is derived from the chlorophyll *a* concentration. Trophic state assessments of potential algal productivity were made based on chlorophyll *a*, nutrient levels, and values of the Carlson Trophic State Index (TSI). Generally, some degree of eutrophic conditions is seen with chlorophyll *a* over 12 µg/L and hypereutrophy occurs at levels over 30 µg/L. The Carlson TSI derives from the chlorophyll *a* concentrations and scales the trophic state as follows:

1. Oligotrophic TSI < 40
2. Mesotrophic TSI: 40 - 49.99
3. Slightly Eutrophic TSI: 50 - 54.99
4. Fully Eutrophic TSI: 55 - 59.99
5. Very Eutrophic TSI: 60 - 63.99
6. Hypereutrophic TSI: $\geq$ 64

Lake Chemistry Monitoring Sites: KDHE Station LM012201 in Lake Shawnee.

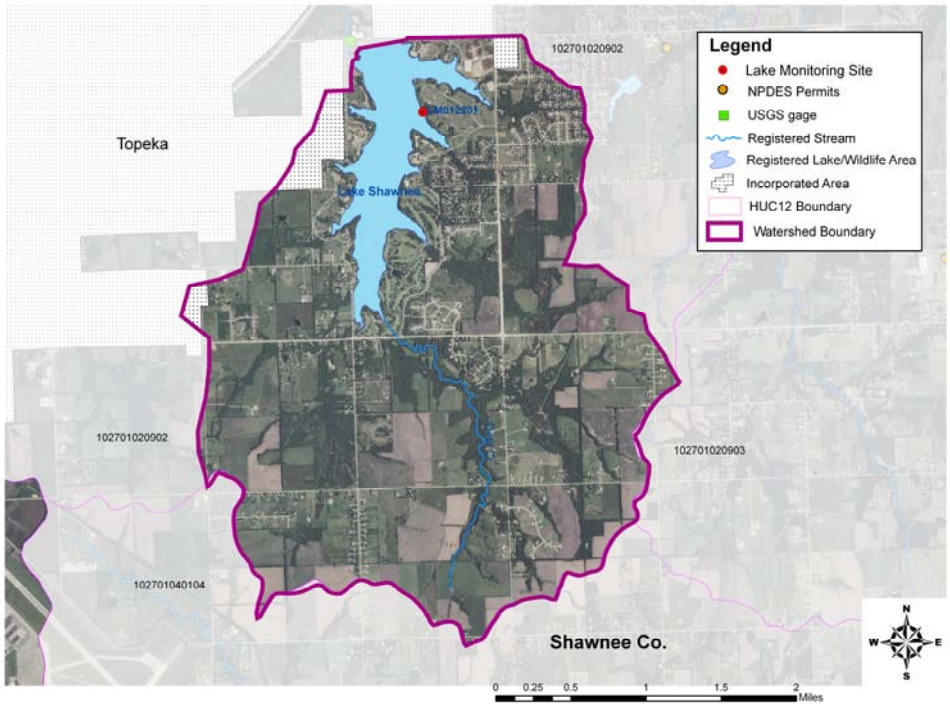
Period of Record Used: 17 surveys conducted by KDHE in calendar years: 1986, 1990, 1995, 1998, 1999, 2000, 2001, 2002, 2003, 2006, and 2009.

Hydrological Conditions: Deer Creek above Lake Shawnee (Figure 1) is the only registered stream directly feeding Lake Shawnee with estimated flow durations listed in Table 1 (Perry et al., 2004). According to the USGS Lake Hydro data, the mean runoff in the watershed is 6.85 inches/year; the mean precipitation in the watershed is 34.2 inches/year and the mean loss due to evaporation for the lake is 47.4 inches/year.

Table 1. Estimated flow-duration values for Deer Creek above Lake Shawnee (Perry et al., 2004). Flow values are in units of cubic-feet per second.

Stream	CUSEGA Segment	Average Flow	2-year Peak	90%	75%	50%	25%	10%
Deer Creek	1027010241	3.76	912	0.0	0.0	0.0	0.59	3.22

Figure 1. Lake Shawnee Watershed.



Current Conditions: Lake Shawnee has chlorophyll *a* concentrations averaging 22.6 µg/L, with a corresponding Trophic State Index (TSI) value of 61.2, for the period of record. Chlorophyll *a* concentrations were measured in samples taken during the summers of 1986, 1990, 1995, 1998, 1999, 2000, 2001, 2002, 2003, 2006 and 2009 (Figure 2). As indicated, the yearly average chlorophyll *a* concentration increased to 38.1 µg/L in 2001 and remained above 25.0 µg/L for the remainder of the period of record (Figure 3).

Figure 2. Chlorophyll *a* concentrations in Lake Shawnee by sampling date.

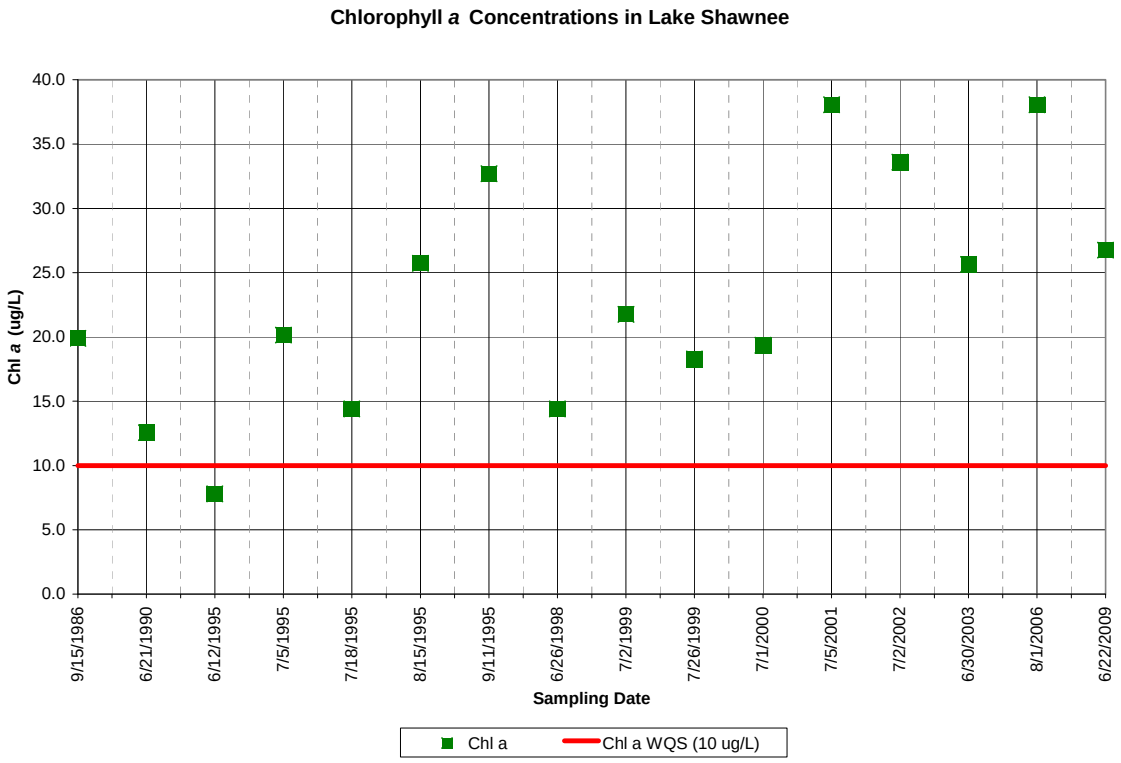
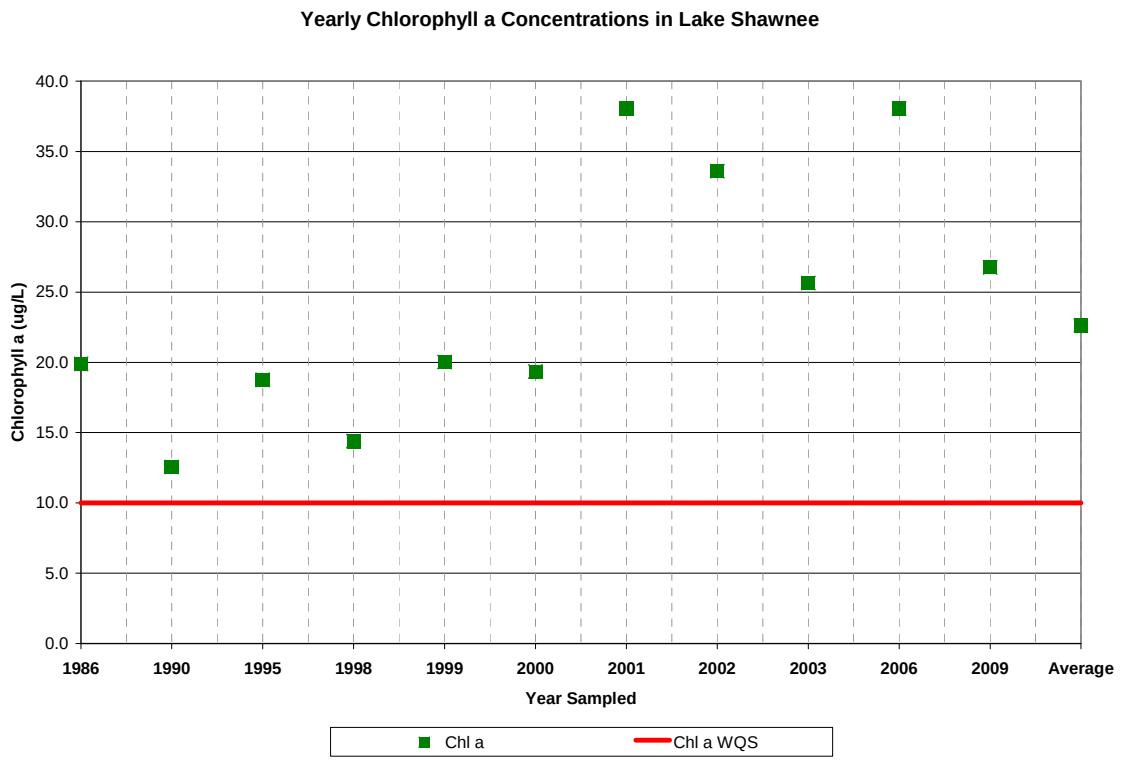
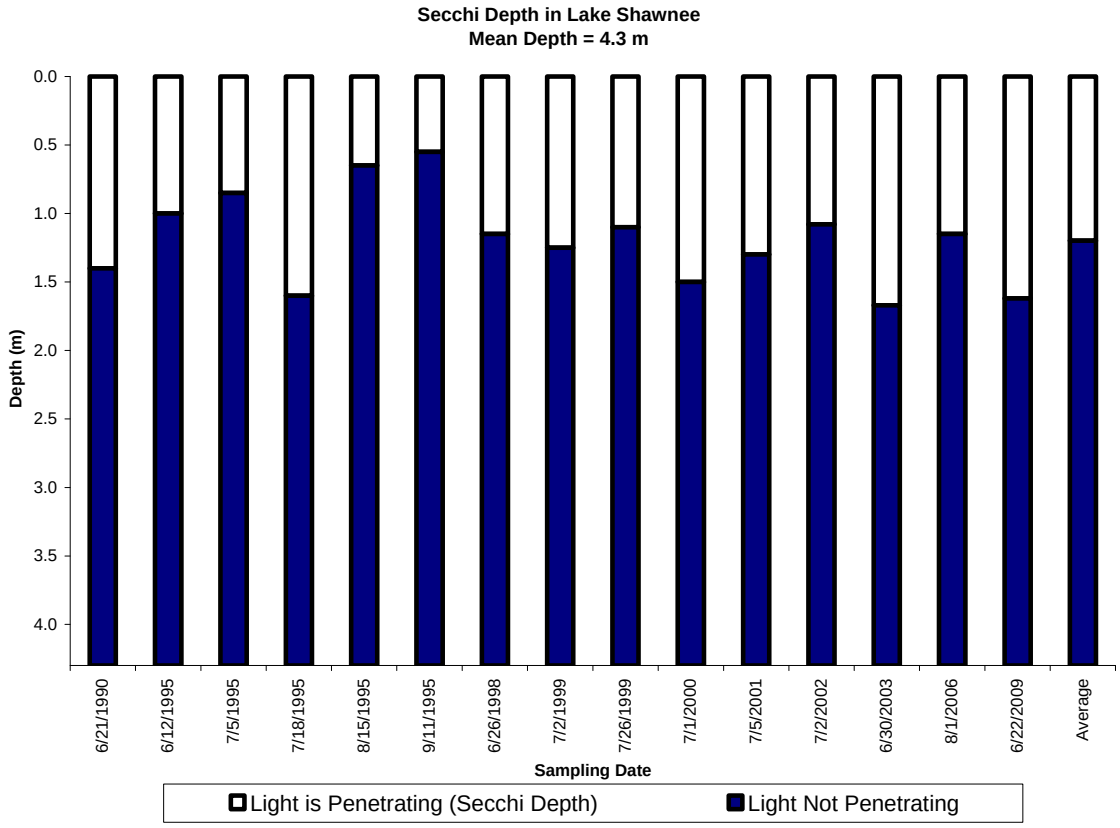


Figure 3. Yearly averages of chlorophyll *a* concentrations in Lake Shawnee.



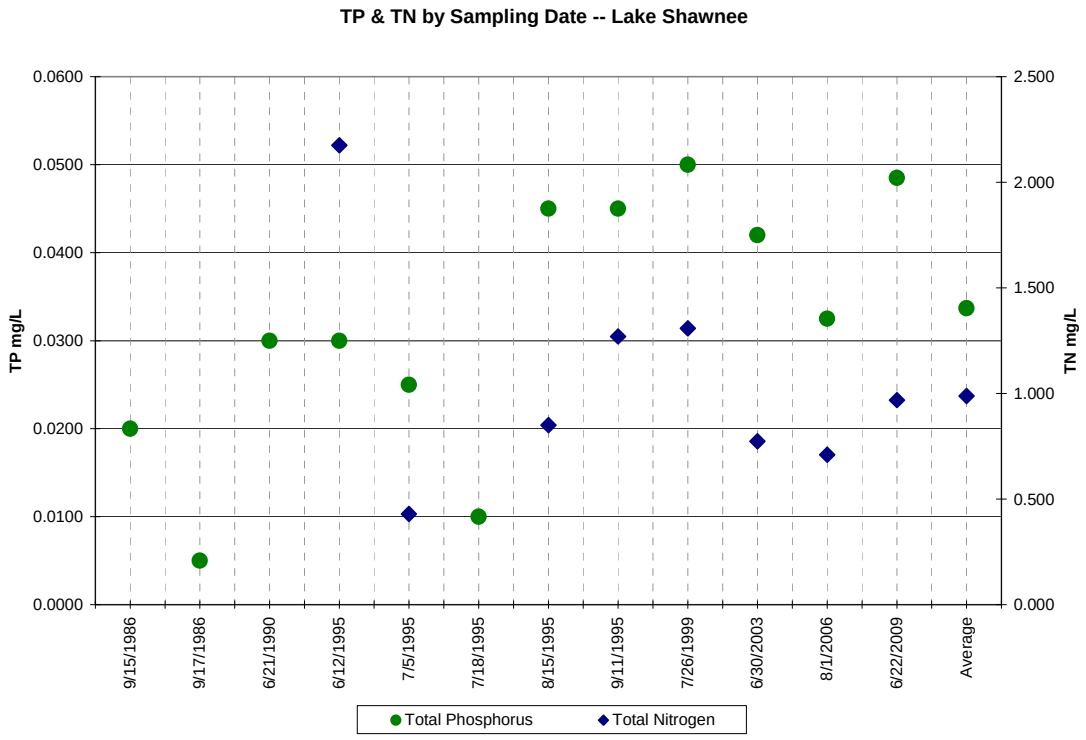
The average Secchi depth in Lake Shawnee is 1.20 meters, with the lowest reading occurring in September of 1995 at 0.55 meters (Figure 4). Turbidity in Lake Shawnee for the period of record averaged 4.58 NTU with a range of 1.95 NTU in 1999 to 9.16 NTU in 2006. Total suspended solids (TSS) ranged from 4.50 mg/L in 1999 to 12.5 mg/L in 2006 with an average of 8.0 mg/L (Table 2).

Figure 4. Secchi Depth in Lake Shawnee for the period of record.



Total phosphorus (TP) concentrations average 33.7 µg/L, ranging from 5.0 µg/L in 1986 to 50.0 ug/L in 1999 while the highest and the lowest recorded total nitrogen concentrations were measured in June and July of 1995 at 2.18 and 0.43 mg/L, respectively (Figure 5). Total nitrogen concentrations average 0.988 mg/L for the period of record (Table 3).

Figure 5. Average Total Phosphorus and Total Nitrogen concentration by sampling date.



A comparison of the average values for samples collected from 1986 to 1999 and 2000 to 2009 reveals an improvement in both total nitrogen (TN) concentration and Secchi depth. However, the chlorophyll *a* concentration increased along with total phosphorus (TP), turbidity and total suspended solids (TSS) concentrations (Table 2).

Table 2. Lake Shawnee data for the period of record.

Sample Date	Chl-a (μg/L)	TN (mg/L)	TP (mg/L)	TN:TP ratio	Secchi Depth (m)	Turbidity (NTU)	TSS (mg/L)
9/15/1986	19.9	*	0.020	*	*	4.90	6.00
9/17/1986	*	*	< 0.01	*	*	*	*
6/21/1990	12.6	*	0.0300	*	1.40	4.55	5.00
6/12/1995	7.8	2.18	0.0300	72.5	1.00	*	*
7/5/1995	20.2	0.430	0.250	17.2	0.850	*	*
7/18/1995	14.4	*	0.0100	*	1.60	2.80	7.00
8/15/1995	25.7	0.850	0.045	18.9	0.650	*	*
9/11/1995	32.7	1.27	0.045	28.2	0.550	*	*
6/26/1998	14.4	*	*	*	1.15	*	*
7/2/1999	21.8	*	*	*	1.25	*	*
7/26/1999	18.3	1.31	0.0500	26.2	1.10	1.95	4.50
Average 1986-1999	***18.1***	***1.10***	***0.031***	***31.3***	***1.07***	***3.55***	***5.57***
7/1/2000	19.4	*	*	*	1.50	*	*
7/5/2001	38.1	*	*	*	1.30	*	*
7/2/2002	33.6	*	*	*	1.08	*	*
6/30/2003	25.7	0.773	0.0420	18.4	1.67	3.80	10.0
8/1/2006	38.1	0.710	0.0325	21.8	1.15	9.16	12.5
6/22/2009	26.8	0.968	0.0485	20.0	1.62	5.15	10.0
Average 2000-2009	***30.2***	***0.817***	***0.041***	***20.8***	***1.39***	***6.21***	***10.8***

*Data not available

Table 3. Yearly averages of Lake Shawnee data.

Year	Chl-a (μg/L)	TN (mg/L)	TP (mg/L)	TN:TP ratio	Secchi Depth (m)	Turbidity (NTU)	TSS (mg/L)
1986	19.9	*	0.0125	*	*	4.90	6.00
1990	12.6	*	0.0300	*	1.40	4.55	5.00
1995	18.8	1.08	0.0310	34.7	0.950	2.8	7.00
1998	14.4	*	*	*	1.15	*	*
1999	20.0	1.31	0.0500	26.2	1.18	1.95	4.50
2000	19.4	*	*	*	1.50	*	*
2001	38.1	*	*	*	1.30	*	*
2002	33.6	*	*	*	1.08	*	*
2003	25.7	0.773	0.0420	18.4	1.67	3.80	10.0
2006	38.1	0.710	0.0325	21.8	1.15	9.16	12.5
2009	26.8	0.968	0.0485	20.0	1.62	5.15	10.0
Average	***22.6***	***0.988***	***0.0337***	***24.2***	***1.20***	***4.58***	***8.00***

*Data not available

The ratio of total nitrogen and total phosphorus has been used to determine which of these nutrients is most likely limiting plant growth in Kansas aquatic ecosystems. Generally, lakes that are nitrogen limited have water column TN:TP ratios < 8 (mass); lakes that are co-limited by nitrogen and phosphorus have water column TN:TP ratios between 9 and 21; and lakes that are phosphorus limited have water column TN:TP ratios > 29 (Dzialowski et al., 2005). The TN:TP ratio in Lake Shawnee indicates the lake is likely co-limited by phosphorus and nitrogen with only one reading in June of 1995 indicating phosphorus limitation (Figure 6).

Figure 6. TN:TP ratio for period of record in Lake Shawnee.

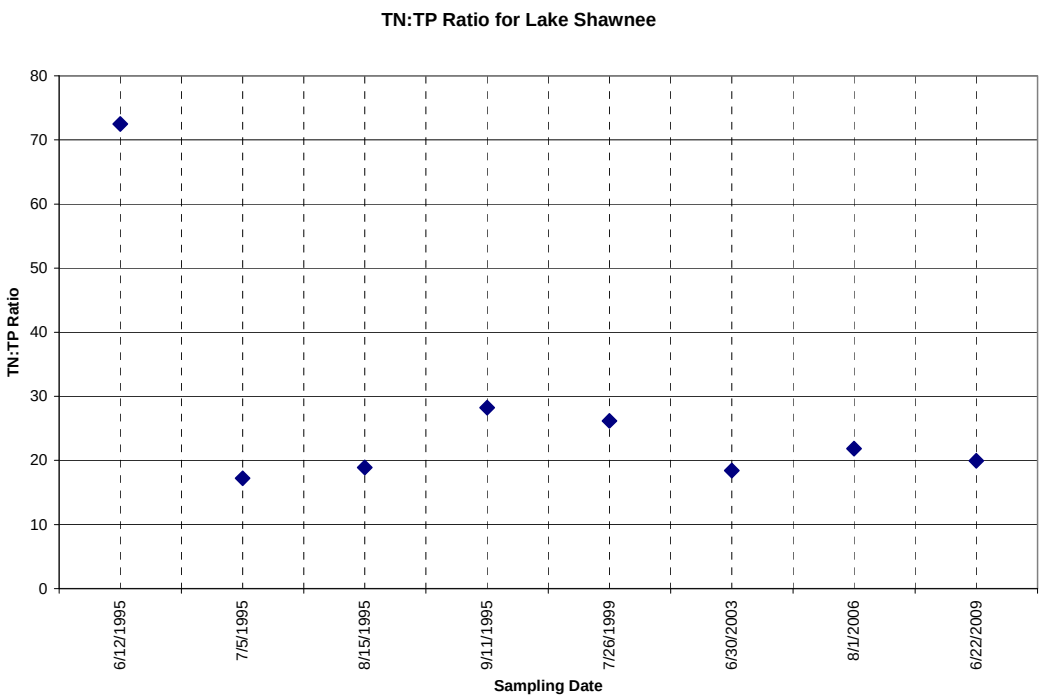


Table 4 lists the six metrics measuring the roles of light and nutrients in Lake Shawnee. Non-algal turbidity (NAT) values <0.4m^{-1} indicates there are very low levels of suspended silt and/or clay. The values between 0.4 and 1.0m^{-1} indicate inorganic turbidity assumes greater influence on water clarity but would not assume a significant limiting role until values exceed 1.0m^{-1}.

Table 4. Lake Shawnee limiting factor metrics.

Sampling Year	Non-algal Turbidity	Light Availability in the Mixed Layer	Partitioning of Light Extinction between Algae & Non-algal Turbidity	Algal use of Phosphorus Supply	Light Availability in the Mixed Layer for a Given Surface Light	Shading in Water Column due to Algae and Inorganic Turbidity	Chl-*a* (μg/L)
	NAT	**Zmix*NAT**	**Chl-a*SD**	**Chl-a/TP**	**Zmix/SD**	**Shading**	
1986	*	*	*	0.944	*	*	19.9
1990	0.401	1.59	17.8	0.418	2.78	5.38	12.6
1995	0.728	2.83	16.5	0.761	4.79	6.83	18.8
1998	0.510	1.98	16.6	*	3.38	5.79	14.4
1999	0.452	1.76	20.1	0.366	3.54	6.11	20.0
2000	0.183	0.712	29.0	*	2.59	5.73	19.4
2001	0	0	49.5	*	2.99	7.13	38.1
2002	0.0859	0.334	36.3	*	3.60	7.13	33.6
2003	0	0	42.8	0.611	2.33	6.01	25.7
2006	0	0	43.8	1.17	3.38	7.31	38.1
2009	0	0	43.3	0.552	2.40	6.12	26.8

*Data not available

The depth of the mixed layer in meters (Z) multiplied by the NAT value assesses light availability in the mixed layer. There is abundant light within the mixed layer of the lake and potentially a high response by algae to nutrient inputs when this value is less than 3. Values greater than 6 would indicate the opposite.

The partitioning of light extinction between algae and non-algal turbidity is expressed as Chl-a*SD (Chlorophyll *a* * Secchi Depth). Inorganic turbidity is not responsible for light extinction in the water column and there is a strong algal response to changes in nutrient levels when this value is greater than 16. Values less than 6 indicate that inorganic turbidity is primarily responsible for light extinction in the water column and there is a weak algal response to changes in nutrient levels.

Values of algal use of phosphorus supply (Chl-a/TP) that are greater than 0.4 indicate a strong algal response to changes in phosphorus levels, where values less than 0.13 indicate a limited response by algae to phosphorus.

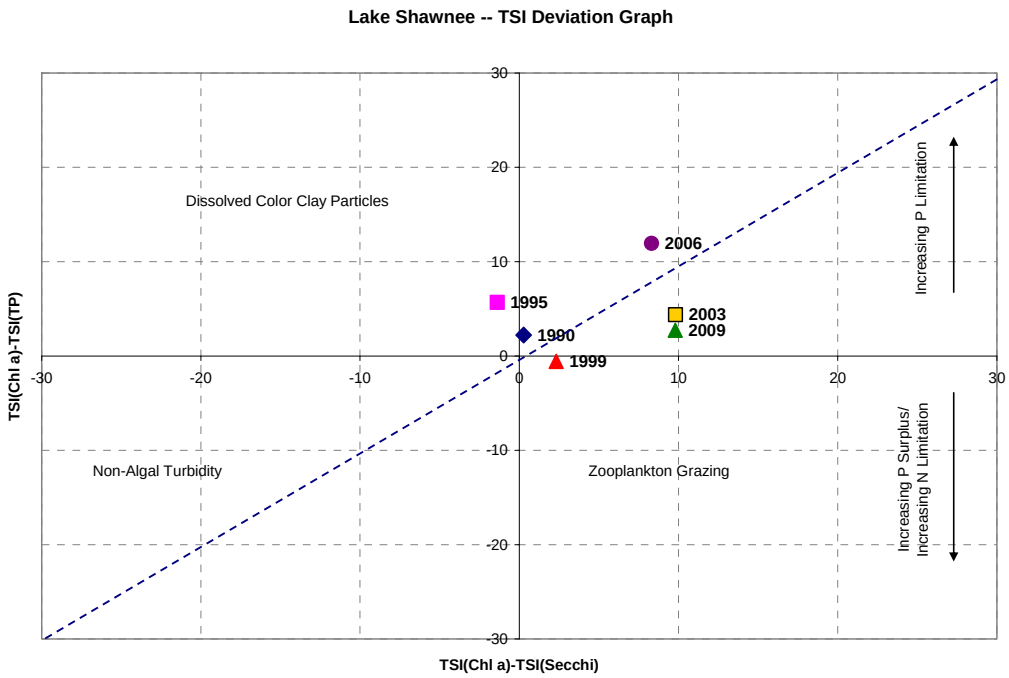
The light availability in the mixed layer for a given surface light is represented as Zmix/SD. Values less than 3 indicate that light availability is high in the mixed zone and there is a high probability of strong algal responses to changes in nutrient levels.

Shading values less than 16 indicate that self-shading of algae does not significantly impede productivity. This metric is most applicable to lakes with maximum depths of less than 5 meters (Carney, 2004).
The above metrics indicate that Lake Shawnee has low levels of inorganic turbidity allowing abundant light into the mixed layer resulting in strong algal response to changes in nutrient levels. Self shading does not appear to be impeding algal productivity in Lake Shawnee.

Another method for evaluating limiting factors is the TSI deviation metrics. Figure 7 (Multivariate Deviation Graph) summarizes the current trophic conditions at Lake Shawnee using a multivariate TSI comparison chart for the period of record. Where TSI(Chl-a) is greater than TSI(TP), the situation indicates phosphorus is limiting chlorophyll *a*, whereas negative values indicate turbidity limits chlorophyll *a*. Where TSI(Chl-a)-TSI(SD) is plotted on the horizontal axis, if the Secchi depth (SD) trophic index is less than the chlorophyll *a* trophic index, then there is dominant zooplankton grazing. Transparency would be dominated by non-algal factors such as color or inorganic turbidity if the Secchi depth index were more than the chlorophyll *a* index. Points near the diagonal line occur in turbid situations where phosphorus is bound to clay particles and therefore turbidity values are closely associated with phosphorus concentrations.

The multivariate TSI comparison chart in Figure 7 shows that all three TSI scores are reasonably close to one another and are fairly consistent over the period of record. All years plot near the diagonal line suggesting phosphorus is bound to clay particles linking turbidity values with phosphorus concentrations.

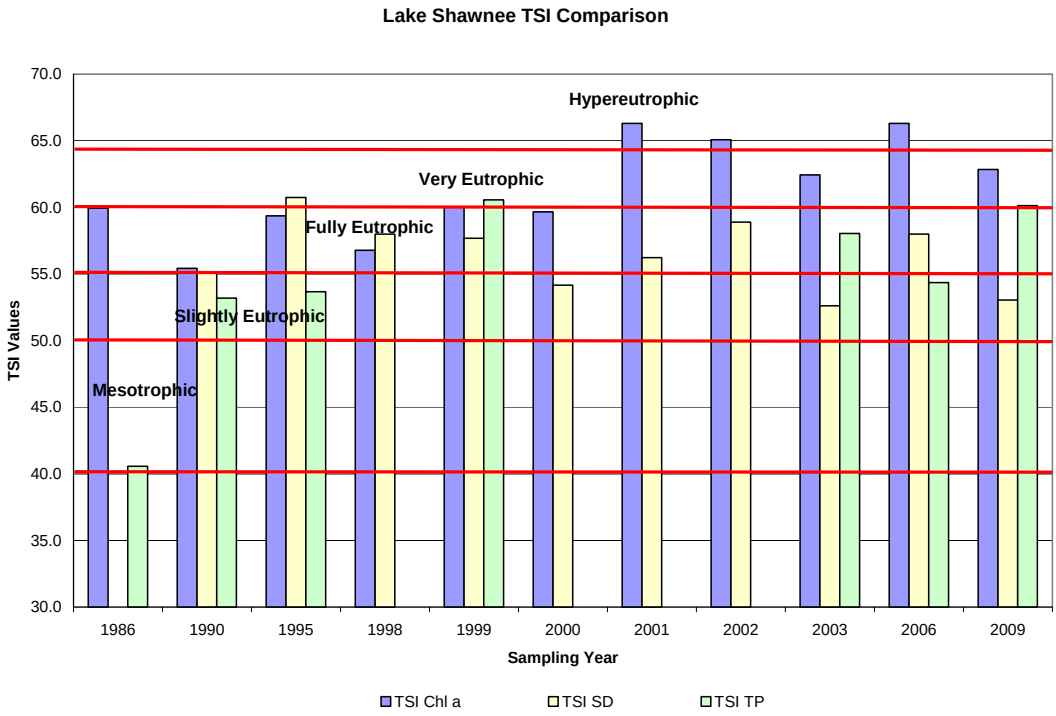
Figure 7. Multivariate TSI comparison chart for Lake Shawnee.



The Carlson Trophic State Indices for chlorophyll *a*, Secchi depth and total phosphorus in Lake Shawnee shown in Figure 8 reveal the steady deterioration of the eutrophic state of the lake over the period of record. Data prior to the year 2000, when averaged, results in indices of 59.4, 57.8 and 53.4 for chlorophyll *a*, Secchi depth and total phosphorus, respectively. The chlorophyll *a* index reached a state of hypereutrophy in 2001 and remained in either a hypereutrophic or very

eutrophic state through 2009 with an average TSI index for sampling years 2000-2009 of 64.0. The total phosphorus index also increased over the period of record with the average TSI for sampling years 2000-2009 reaching 58.1 and the average Secchi depth TSI score decreasing to an average of 55.2 for the same time period.

Figure 8. Lake Shawnee Trophic State Indices.



The median trophic conditions within Lake Shawnee compared to other Federal lakes in the state are summarized in Table 5. The trophic indicators of total nitrogen and chlorophyll *a* do not meet any of the Federal Lake, Central Great Plains Lake or statewide benchmarks. However, Secchi depth and total phosphorus trophic indicator values meet the benchmarks for the Federal and Central Great Plains Lakes while missing the statewide targets.

Table 5. Median trophic indicator values of Lake Shawnee in comparison with other federal lakes and draft nutrient benchmarks in Kansas. The nutrient benchmarks were derived from 47-58 lakes and reservoirs, based on the data collected between 1985-2002 (Dodds et al., 2006).

Trophic Indicator	Lake Shawnee	Federal Lake	Central Great Plains	Statewide Benchmark
Secchi Depth (cm)	120	95	117	129
TN (µg/l)	988	903	695	625
TP (µg/l)	33.7	76	44	23
Chlorophyll *a* (µg/l)	22.6	12	11	8

A comparison with surrounding lakes (Table 6) shows higher levels of chlorophyll *a* and total nitrogen in Lake Shawnee while total phosphorus is similar to the surrounding lakes and Secchi

depth is improved, revealing Lake Shawnee is relatively clear when compared to other lakes in the region.

Table 6. Comparison of 2000 – 2010 Average Conditions at Lake Shawnee & Surrounding Lakes.

Lake	Chlorophyll *a* (μg/L)	Total Phosphorus (μg/L)	Total Nitrogen (μg/L)	Secchi (m)
Lake Shawnee	**30.2**	**41**	**817**	**1.39**
Shawnee Co. SFL*	8.8	26	403	1.24
Lake Jivaro**	4.0	51	724	1.00
Douglas Co SFL*+	11.6	24	855	1.78
Lone Star Lake+	14.8	43	819	1.46
Stowbridge Reservoir +	18.5	45	856	0.93
Osage Co SFL	7.5	31	501	1.67
Average of Surrounding Lakes	***10.8***	***37***	***693***	***1.35***

*Identified by Kansas Biological Survey as Reference Lake in the Central Irregular Plains.
+Identified as Impaired by Eutrophication on 2010 303(d) List or by Existing TMDL.
**Only one sample collected since 2000.

Algal Communities: As seen in Table 7, algal communities in Lake Shawnee have been dominated by blue-green algae, or cyanobacteria, for the period of record. An increasing supply of nutrients, especially phosphorus and possibly nitrogen, will often result in higher growth of blue-green algae because they possess certain adaptations that enable them to out compete true algae (Soil and Water Conservation Society of Metro Halifax, 2007). Several of the cyanobacteria species possess gas vacuoles that allow them to move within the water column vertically. This selective advantage allows for some species to move within the water column to avoid predation and reach optimal primary productivity. Their movement within the water column may influence chlorophyll *a* levels within the lake at various depths during the diel cycle.

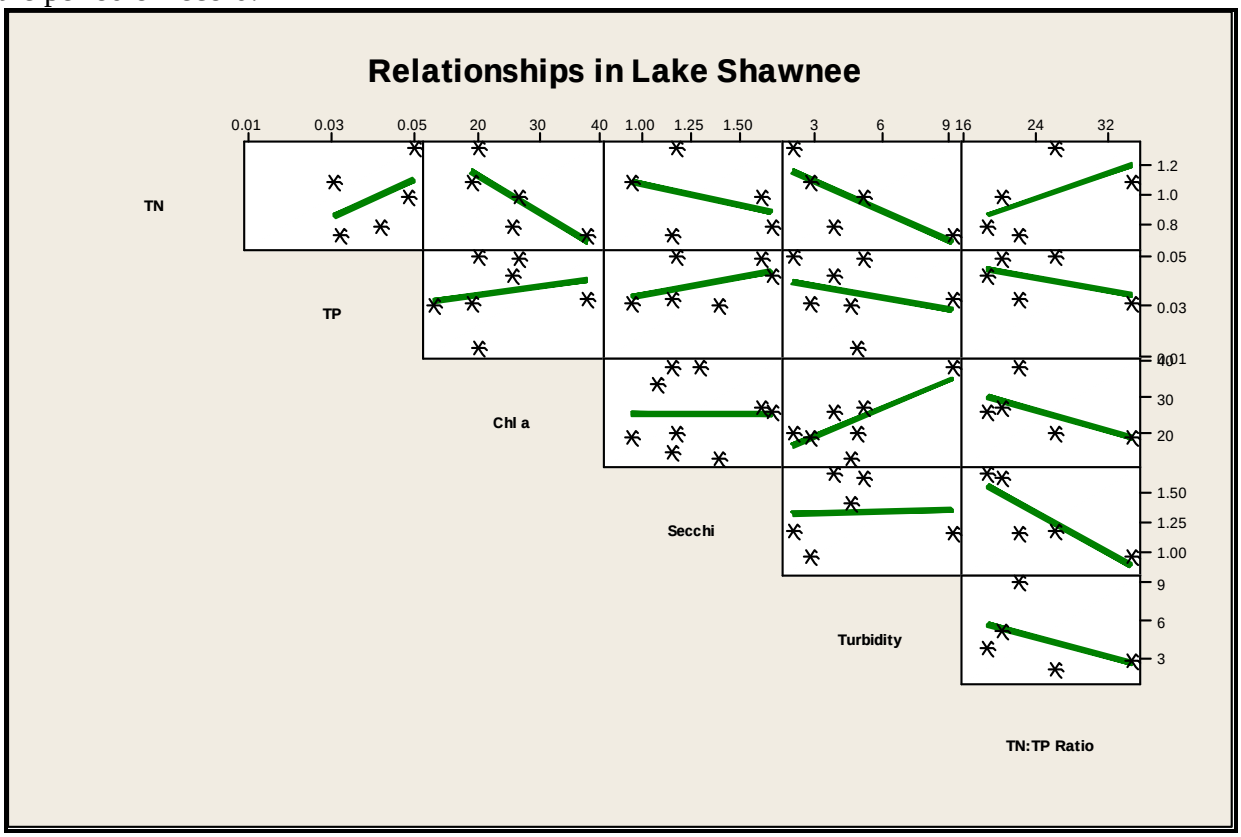
Table 7. Algal communities observed in Lake Shawnee during KDHE sampling years.

Sampling Date	Total Cell Count cells/mL	Percent Composition				Chl-*a* μg/L
		Green	Blue Green	Diatom	Other	
1995	63,500	2	96	0	2	18.8
1999	50,022	0	100	0	0	20.0
2003	44,888	7	90	3	<1	25.7
2006	70,371	4	94	2	<1	38.1
2009	72,198	1	98	1	<1	26.8

Relationships: Within Lake Shawnee there are poor relationships between: total phosphorus and chlorophyll *a*; total phosphorus and turbidity; chlorophyll *a* and Secchi depth and Secchi depth and Turbidity. There is a minor relationship between: total nitrogen and total phosphorus; total nitrogen and Secchi depth; total phosphorus and Secchi depth; and turbidity and TN:TP ratio. There is a moderate relationship between chlorophyll *a* and TN:TP ratio while there is a

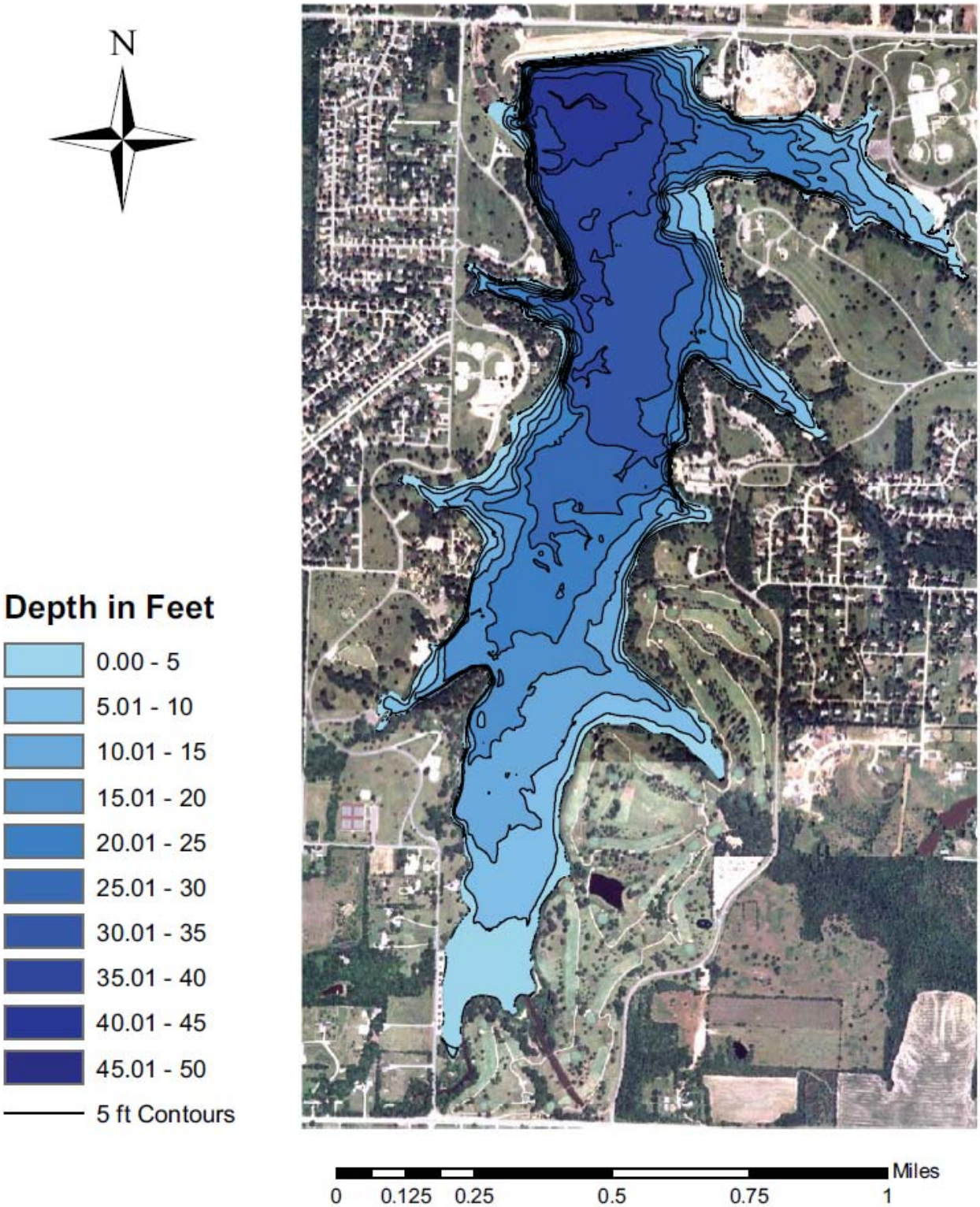
strong relationship between total nitrogen and chlorophyll *a*; total nitrogen and turbidity; chlorophyll *a* and turbidity and between Secchi depth and TN:TP ratio.(Figure 9).

Figure 9. Relationship of Chlorophyll *a*, TN, TP, TN:TP and Secchi Depth in Lake Shawnee for the period of record.



Bathymetric Survey: A bathymetric and sediment survey performed by Kansas Biological Survey in 2009 revealed high percentages of silt and clay in the sediment of Lake Shawnee. Silt and clay make up 68% and 28% of the sediment, respectively, in the southern portion of the lake while nearer the dam the sediment is made up of 30% silt and 62% clay. Sediment and nutrient loads appear to derive from drainage channels on the east and south sides of the lake as the lake is shallower along these edges than the west edge of the lake (Figure 10).

Figure 10. Water depth in Lake Shawnee based on 2009 bathymetric surveys. Depths are based on a pool elevation of 959.8 feet (KBS, 2010).



Stream Data: No water quality data was available for Deer Creek (CUSEGA 1027010241).

Desired Endpoints of Water Quality (Implied Load Capacity) in Lake Shawnee:

In order to improve the trophic condition of Lake Shawnee from its current Very Eutrophic status, the desired endpoint will be to maintain summer chlorophyll *a* average concentrations below 10 μg/L, with the reductions focused on nutrients (TN and TP) entering the lake. The chlorophyll *a* endpoint of 10 μg/L is below the recent average of surrounding lakes and will ensure long-term protection to fully support Primary Contact Recreation within the lake. Based on the BATHTUB reservoir eutrophication model (Appendix A), the total phosphorus entering the lake must be reduced by 65% and the total nitrogen entering the lake must be reduced by 25%. These reductions at the inflow to Lake Shawnee will result in a 55% reduction of total phosphorus, a 17% reduction of total nitrogen, and a 56% reduction of Chlorophyll *a* within the lake (Table 8). Achievement of the endpoint indicates loads are within the loading capacity of the lake, the water quality standards are attained, and full support of the designated uses of the lake has been achieved. Seasonal variation has been incorporated in this TMDL since the peaks of algal growth occur in the summer months. The current average condition for Lake Shawnee utilized in the model input was based on data from 1986-2009 from KDHE at LM012201. Water quality data for the Deer Creek tributary was estimated by adjusting tributary nutrient inputs in the BATHTUB model until the current condition in the lake was generated upon running the model. This resulted in tributary inputs for Deer Creek of 180 μg/L of total phosphorus and 1500 μg/L of total nitrogen. Annual flow of Deer Creek was estimated using the average flow condition of 3.76 cfs or 3.36 hm^3/year (Perry et al., 2004).

Table 8. Lake Shawnee Current average condition and TMDL based on BATHTUB.

	Current Avg. Condition	**TMDL**	**Percent Reduction**
Total Phosphorus – Annual Load (lbs/year)	1,366	478	65%
Total Phosphorus – Daily Load* (lbs/day)	10.1	3.51	65%
Total Phosphorus – Lake Concentration (mg/L)	0.0337	0.0150	55%
Total Nitrogen – Annual Load (lbs/year)	13,469	10,136	25%
Total Nitrogen – Daily Load* (lbs/day)	99.0	74.5	25%
Total Nitrogen – Lake Concentration (mg/L)	0.988	0.818	17%
Chlorophyll *a* Concentration (ug/L)	22.6	10	56%

*See Appendix B for Daily Load Calculations

3. SOURCE INVENTORY AND ASSESSMENT

Point Sources: There is one NPDES permit that falls into the Lake Shawnee watershed (Table 9). This stormwater discharge (MS4) permit requires the implementation of best management practices in order to attenuate the discharge of total phosphorus into the Shawnee County stormwater discharge system's receiving streams and lakes.

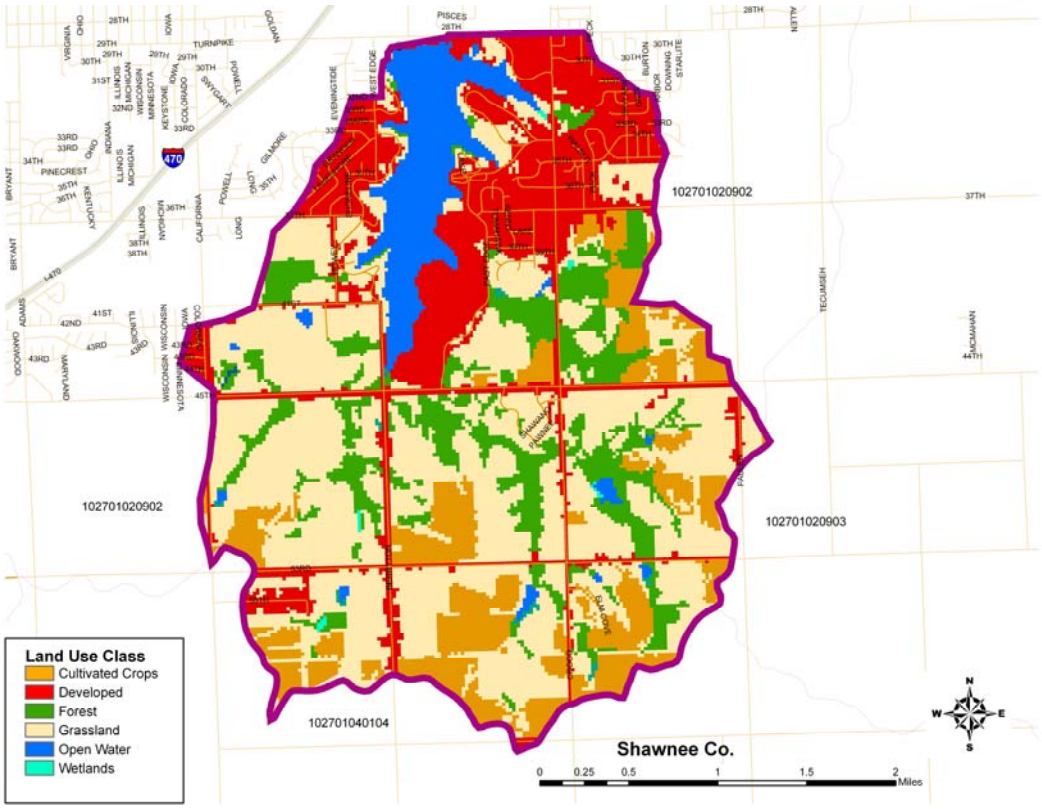
Table 9. Discharge permits in the Lake Shawnee watershed.

Permitee	NPDES Permit #	State Permit #	Type	Expiration Date
Shawnee County	KSR041034	M-KS72SU01	Stormwater	September 30, 2009*

* Permit pending

Land Use: The predominant land uses in the Lake Shawnee watershed are grassland (43.6%) and developed land (22.3%), according to the 2001 National Land Cover Data. Together they account for 65.9% of the total land area in the watershed with the remaining land area composed of cultivated cropland (14.0%), forest (12.6%), open water (7.2%) and wetlands (0.30%) (Figure 11). The Lake Shawnee golf course, at approximately 145 acres, runs adjacent to the southeastern section of Lake Shawnee and is categorized as developed land in Figure 11.

Figure 11. Land use in the Lake Shawnee watershed.



Livestock Waste Management Systems: There are no active permitted or certified confined animal feeding operations (CAFOs) in the Lake Shawnee watershed. According to the USDA National Agricultural Statistics Service, the cattle inventory for Shawnee County was 12,700

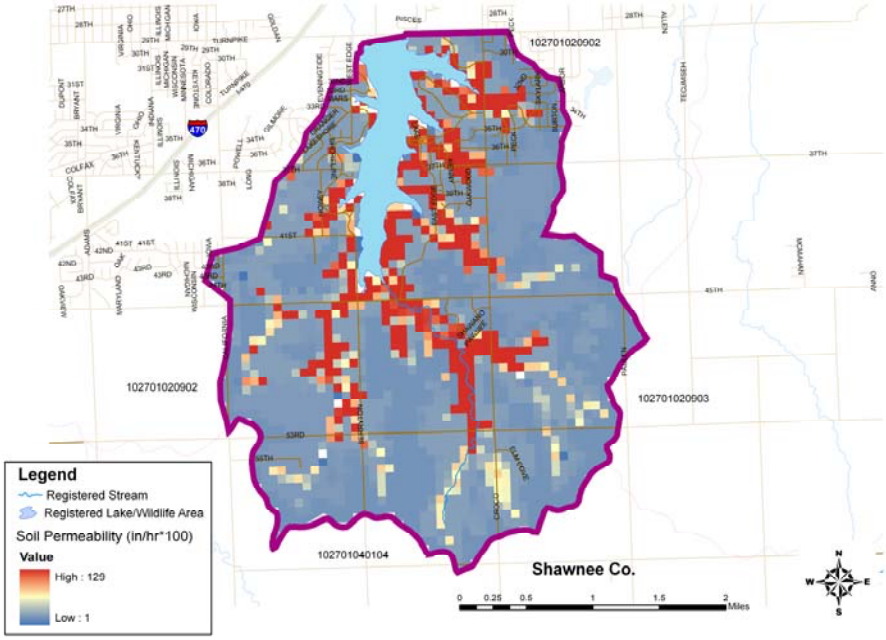
head on January 1, 2010. However, the Lake Shawnee watershed comprises less than 2% of the land area in Shawnee County making it unlikely that livestock operations are a primary contributor of nutrients to the lake.

On-Site Waste Systems: The lower portion of the Lake Shawnee watershed is serviced by the City of Topeka utilities division making it probable the majority of the households in the watershed are connected to municipal sewer service. Any failing on-site septic systems contributing to the nutrient loads in Lake Shawnee are restricted to the rural headwater area of the watershed.

Population: According to the 2000 U.S. Census, the total population of Shawnee County was 169,871 people with the density of the Lake Shawnee watershed approximately 336 people/square mile. The 2010 U.S. Census registered a 4.7% increase in the total population of Shawnee County with a population of 177,934.

Contributing Runoff: The watershed of Lake Shawnee has a mean soil permeability value of 0.36 inches/hour. Permeability ranges from 0.01 inches/hour to 1.29 inches/hour according to NRCS STATSGO database with over 43% of the watershed having a permeability value less than 0.57 inches/hour, which contributes to runoff during extremely low rainfall intensity events. 31% of the Lake Shawnee watershed has a permeability value of 1.29 inches/hour, generating runoff during very low to low rainfall intensities (Figure 12). According to a USGS open-file report (Juracek, 2000), the threshold soil-permeability values are set at 3.43 inches/hour for very high, 2.86 inches/hour for high, 2.29 inches/hour for moderate, 1.71 inches/hour for low, 1.14 inches/hour for very low, and 0.57 inches/hour for extremely low soil-permeability. Runoff is primarily generated as infiltration excess with rainfall intensities greater than soil permeability. As the watersheds' soil profiles become saturated, excess overland flow is produced.

Figure 12. Soil permeability in the Lake Shawnee watershed.



Background and Natural Sources: There is a significant resident goose population on and near Lake Shawnee. Geese may contribute nutrients through fecal deposits in the lake and along the shoreline. Although much of the nutrient load from the geese may settle to the lake bottom as part of the sediment deposition, anaerobic conditions in shallow areas of the lake or re-suspension during times of turnover may introduce available nutrients into the water column. Maintaining deterrents around the lake, such as silhouettes or high grass at the water's edge, may discourage and disperse geese from overloading areas of the lake. Some nutrient loading as organic forms may occur in the fall as a result of leaf litter and macrophyte senescence.

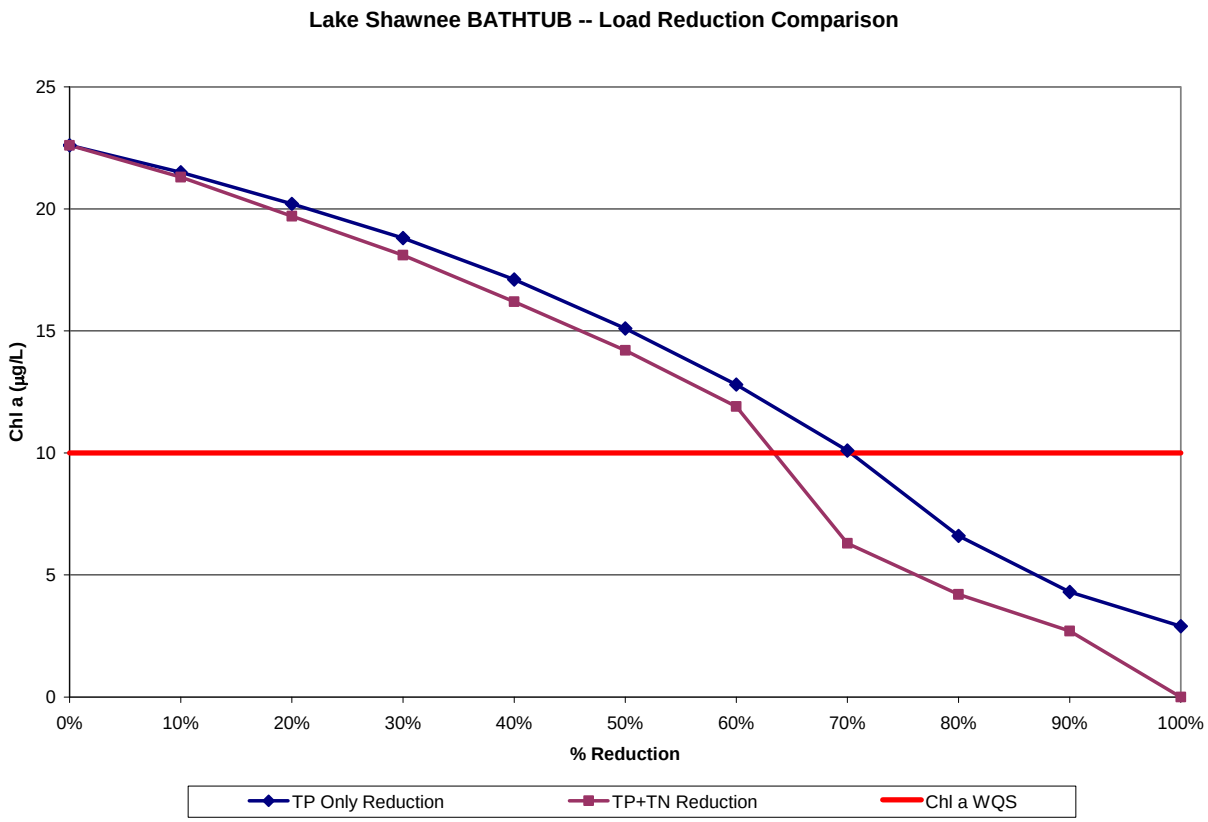
4. ALLOCATION OF POLLUTANT REDUCTION RESPONSIBILITY

Phosphorus and nitrogen are co-limiting nutrients in Lake Shawnee and, as such, both phosphorus and nitrogen will both be allocated under this TMDL. The general inventory of sources within the drainage area of the lake indicates load reductions should be focused on nonpoint source runoff contributions attributed to fertilizer applications and animal waste.

The lake model utilized for the development of the TMDL was BATHTUB. BATHTUB is an empirical receiving water quality model, that was developed by the U.S. Army Corps of Engineers (Walker, 1996), and has been commonly applied in the nation to address many TMDLs relating to issues associated with morphometrically complex lakes and reservoirs (Mankin et al., 2003; Wang et al., 2005). Lake Shawnee was considered one segment for the BATHTUB model. Atmospheric total nitrogen was obtained from the Clean Air Status and Trends Network (CASTNET), which is available at http://www.epa.gov/castnet. The CASTNET station from the Konza Prairie (KS) was used to estimate the atmospheric TN concentration for the model. Total phosphorus atmospheric loading was estimated using the 1983 study of Rast and Lee. Water quality data for the main basin segment was averaged using the 1986-2009 data

from KDHE (LM012201). Model input data for the tributary Deer Creek was estimated by adjusting tributary nutrient inputs in the BATHTUB model until the current condition in the lake was generated upon running the model. The BATHTUB model was calibrated for Lake Shawnee and results (Appendix A) estimate that the lake retains 84% of the TP and 54% of the TN load annually. Based on modeling results, the combined reduction of TP and TN results in reaching the chlorophyll *a* endpoint more readily than reducing TP alone (Figure 13). Hence, a 65% reduction of TP and a 25% reduction of TN within the inflow to Lake Shawnee are necessary to achieve the TMDL endpoint of 10 ug/L of Chlorophyll *a* within Lake Shawnee.

Figure 13. Changes in chlorophyll *a* levels in relation to watershed nutrient reduction.



Point Sources: A wasteload allocation is assigned to the Shawnee County stormwater discharge (MS4) permit for nitrogen and phosphorus under this TMDL (Table 10). As of 2001 (NLCD), 22.3% of the land in the Lake Shawnee watershed was developed (Figure 11); however, Shawnee County recorded a 4.7% growth in population between 2000 and 2010. Therefore, in order to account for the current level of development and to accommodate future development within the watershed, 30% of the total phosphorus and total nitrogen load under this TMDL is allocated as wasteload to the Shawnee County MS4 permit.

Nonpoint Sources: Nonpoint sources are contributors for the nutrient input and impairment in Lake Shawnee. This assessment suggests that fertilizer applied to the lawns and the land in the watershed combined with animal waste runoff are the main contributors to the very eutrophic state of the lake. Load Allocations for Lake Shawnee were calculated using the BATHTUB model (Appendix A).

Table 10. Lake Shawnee TMDL

Description	Allocations (lbs/year)	Allocations (lbs/day)*
Total Phosphorus Atmospheric Load	33.1	0.240
Total Phosphorus Wasteload Allocation	143	1.05
Total Phosphorus Nonpoint Source Load Allocation	253	1.86
Total Phosphorus Margin of Safety	47.8	0.351
Total Phosphorus TMDL	478	3.51
Total Nitrogen Atmospheric Load	2,358	17.3
Total Nitrogen Wasteload Allocation	3,041	22.4
Total Nitrogen Nonpoint Source Load Allocation	3,723	27.3
Total Nitrogen Margin of Safety	1,014	7.45
Total Nitrogen TMDL	10,136	74.5

*See Appendix B for Daily Load Calculations

Defined Margin of Safety: The margin of safety provides some hedge against the uncertainty of variable annual total phosphorus and total nitrogen loads and the chlorophyll *a* endpoint. Therefore, the margin of safety is explicitly set at 10% of the total allocations for total phosphorus and total nitrogen, which compensates for the lack of knowledge about the relationship between the allocated loadings and the resulting water quality. The margin of safety for TP and TN is 0.351 lbs/day and 7.45 lbs/day, respectively, as indicated in Table 10.

State Water Plan Implementation Priority: Because there is a Watershed Restoration and Protection Strategy (WRAPS) group in place to implement this TMDL and because Lake Shawnee has a regional benefit for recreation, this TMDL will be a **High** Priority for implementation.
Unified Watershed Assessment Priority Ranking: This watershed lies within the Middle Kansas Basin (HUC 8: 10270102) with a priority ranking of 4 (High Priority for restoration work).

Priority HUC 12: The entire watershed is within HUC 12: 102701020902.

5. IMPLEMENTATION

Desired Implementation Activities: There is potential that urban, construction and agricultural best management practices will improve the condition of Lake Shawnee.

Some of the recommended urban practices are as follows:

1. Educate watershed residents on appropriate lawn fertilizer application.
2. Install grass buffer strips along drainage channels in the watershed.
3. Promote proper management of construction sites to minimize sediment and nutrient runoff.
4. Investigate feasibility of installing storm water wetlands and ponds in the watershed to remove nutrients prior to entering the lake..
5. Promote installation of porous and concrete grid pavement in the watershed.
6. Promote proper application (right product, right time, right place and right rate) of fertilizer to the golf course.

Some of the recommended agricultural practices are as follows:

1. Implement soil sampling to recommend appropriate fertilizer applications on cultivated cropland.
2. Maintain conservation tillage and contour farming to minimize cropland erosion.
3. Promote and adopt continuous no-till cultivation to increase the amount of water infiltration and minimize cropland soil erosion and nutrient transports.
4. Install grass buffer strips along streams and drainage channels in the watershed.
5. Reduce activities within riparian areas.
6. Implement nutrient management plans to manage manure land applications and runoff potential.
7. Adequately manage fertilizer utilization in the watershed and implement runoff control measures.
8. Utilize state-supported Middle Kansas WRAPS process to coordinate load reduction of nutrients to the lake.

Implementation Program Guidance:

Watershed Management Program – KDHE

a. Support Section 319 project activities conducted under the Middle Kansas Watershed Restoration and Protection Strategy (WRAPS) for Lake Shawnee, including demonstration projects and outreach efforts dealing with erosion and sediment control and nutrient management.
b. Provide technical assistance on practices geared to the establishment of vegetative buffer strips.
c. Provide technical assistance on nutrient management in the vicinity of streams.
d. Incorporate the provisions of this TMDL into WRAPS documents relating to Lake Shawnee.

Water Resource Cost Share and Nonpoint Source Pollution Control Programs – KDA Division of Conservation

a. Apply conservation farming practices and/or erosion control structures, including no-till, terraces and contours, sediment control basins, and constructed wetlands.
b. Provide sediment control practices to minimize erosion and sediment and nutrient transport.
c. Re-evaluate nonpoint source pollution control methods.

NPDES – MS4 – KDHE

a. Encourage Shawnee County to retrofit media filters and wetland channels along flow paths of stormwater coming from developed areas east and south of the lake.
b. Support construction of retention ponds and wetland basins to reduce particulate phosphorus, organic nitrogen and nitrates from stormwater.
c. Promote good housekeeping in developed areas near the lake, including street sweeping and prudent fertilizer use on lawns in residential areas.
d. Establish monitoring of nutrients in east and south arms of lake, focusing on concentrations arriving at lake after rainfall events.

Parkland Maintenance – Shawnee County

a. Promote efficient fertilizer use on fairways of golf course.
b. Develop buffer fringe between golf course and lake.
c. Investigate methods to disperse resident geese population from lakeside areas.

Riparian Protection Program – KDA Division of Conservation

a. Establish, protect or re-establish natural riparian systems, including vegetative filter strips and streambank vegetation.
b. Develop riparian restoration projects
c. Promote wetland construction to assimilate nutrient loadings.

Buffer Initiative Program – KDA Division of Conservation

a. Install grass buffer strips near streams in rural portion of county.
b. Leverage Conservation Reserve Program to hold riparian land out of production.

Extension Outreach and Technical Assistance – Kansas State University

a. Educate agricultural producers on sediment, nutrient, and pasture management.
b. Educate livestock producers on livestock waste management and manure applications and nutrient management planning.
c. Provide technical assistance on livestock waste management systems and nutrient management planning.
d. Provide technical assistance on buffer strip design and minimizing cropland runoff.
e. Encourage annual soil testing to determine capacity of field to hold nutrients.
f. Support outreach efforts by Middle Kansas WRAPS projects and continue to educate residents, landowners, and watershed stakeholders about nonpoint source pollution.

Time Frame for Implementation: Initial implementation will proceed over the years from 2012-2019.

Targeted Participants: Primary participants for implementation will be agricultural producers and construction and new and existing development sites within the Lake Shawnee watershed. A detailed assessment of sources conducted over 2011-2012 should include local assessments by conservation district personnel and county public works to survey, locate, and assess the following within the lake drainage area:

1. Total row crop acreage and fertilizer application rates,
2. Cultivation alongside lake,
3. Livestock use of riparian areas,
4. Fields with manure applications.
5. Golf course fertilizer application rates and runoff potential.
6. Construction sites.
7. New residential development.
8. Existing residential development.

Milestone for 2015: In accordance with the TMDL development schedule for the State of Kansas, the year 2015 marks the next cycle of 303(d) activities in the Kansas-Lower Republican Basin. At that point in time, data from 2012 at site LM012201 at Lake Shawnee will be reexamined to assess improved conditions in the lake.

Delivery Agents: The primary delivery agents for program participation will be the Kansas Department of Health and Environment, the Shawnee County Public Works and Planning Commission, the Kansas Department of Agriculture Division of Conservation, the Natural Resources Conservation Service, the Kansas State University Extension Service, and the Middle Kansas WRAPS. Producer outreach and awareness will be delivered by Kansas State Extension and/or coordinated through Middle Kansas WRAPS teams. Implementation decisions and scheduling will be guided by planning documents prepared through Middle KansasWRAPS projects.

Reasonable Assurances:
Authorities: The following authorities may be used to direct activities in the watershed to reduce pollutants and to assure allocations of pollutant to point and nonpoint sources can be attained.

1. K.S.A. 65-171d empowers the Secretary of KDHE to prevent water pollution and to protect the beneficial uses of the waters of the state through required treatment of sewage and established water quality standards and to require permits by persons having a potential to discharge pollutants into the waters of the state.

2. K.S.A. 2-1915 empowers the State Conservation Commission to develop programs to assist the protection, conservation and management of soil and water resources in the state, including riparian areas.

3. K.A.R. 28-16-69 to 71 implements water quality protection by KDHE through the establishment and administration of critical water quality management areas on a watershed basis.

4. K.S.A 75-5657 empowers the State Conservation Commission to provide financial assistance for local project work plans developed to control nonpoint source pollution.

5. K.S.A. 82a-901, et. seq. empowers the Kansas Water Office to develop a state water plan directing the protection and maintenance of surface water quality for the waters of the state.

6. K.S.A. 82a-951 creates the State Water Plan Fund to finance the implementation of the Kansas Water Plan, including selected Watershed Restoration and Protection Strategies.

7. The Kansas Water Plan and the Kansas-Lower Republican Basin Plan provide the guidance to state agencies to coordinate programs intent on protecting water quality and to target those programs to geographic areas of the state for high priority in implementation.

8. K.S.A. 32-807 authorizes the Kansas Department of Wildlife and Parks to manage lake resources.

Funding: The State Water Plan Fund annually generates $16-18 million and is the primary funding mechanism for implementing water quality protection and pollutant reduction activities in the state through the *Kansas Water Plan*. The state water planning process, overseen by the Kansas Water Office, coordinates and directs programs and funding toward watersheds and water resources of highest priority. Typically, the state allocates at least 50% of the fund to programs supporting water quality protection. Additionally, $2 million has been allocated between the State Water Plan Fund and EPA 319 funds to support implementation of Watershed Restoration and Protection Strategies. This watershed and its TMDL are a High priority consideration for funding.

Effectiveness: Nutrient control has been proven effective through conservation tillage, contour farming and use of grass waterways and buffer strips. In addition, the proper implementation of comprehensive livestock waste management plans has proven effective at reducing nutrient runoff associated with livestock facilities. The key to success will be widespread utilization of conservation farming and proper livestock waste management within the watershed cited in this TMDL.

6. MONITORING

KDHE will continue its 3-year sampling schedule in order to assess the trophic state of Lake Shawnee. Based on the sampling results, the 303(d) listing will be evaluated in 2020. Should impairment status continue, the desired endpoints under this TMDL will be refined and more

intensive sampling will be conducted over the period 2015-2020 to assess progress in this implementation.

7. FEEDBACK

Public Notice: An active Internet Web site was established at www.kdheks.gov/tmdl/ to convey information to the public on the general establishment of TMDLs and specific TMDLs for the Kansas-Lower Republican Basin.

Public Hearing: A Public Hearing on this TMDL was held on August 31, 2011 in Topeka to receive comments.

Basin Advisory Committee: The Kansas-Lower Republican Basin Advisory Committee met to discuss the TMDLs in the basin on September 30, 2010 in Lawrence, March 17, 2011 in Manhattan, June 16, 2011 in Lawrence and September 29, 2011 in Topeka.

Watershed Restoration and Protection Strategy Group: This TMDL was reviewed in Westmoreland on August 30, 2011 by the Middle Kansas Subbasin WRAPS group.

Milestone Evaluation: In 2015, evaluation will be made as to the degree and impact of implementation which has occurred within the watershed. Subsequent decisions will be made regarding the implementation approach, priority of allotting resources for implementation and the need for additional or follow up implementation in this watershed at the next TMDL cycle for this basin in 2015 with consultation from local stakeholders and WRAPS members.

Consideration for 303d Delisting: Lake Shawnee will be evaluated for delisting under Section 303d, based on the monitoring data over 2011-2019. Therefore, the decision for delisting will come about in the preparation of the 2020-303d list. Should modifications be made to the applicable water quality criteria during the implementation period, consideration for delisting, desired endpoints of this TMDL and implementation activities might be adjusted accordingly.

Incorporation into Continuing Planning Process, Water Quality, Management Plan and the Kansas Water Planning Process: Under the current version of the Continuing Planning Process, the next anticipated revision would come in 2012, which will emphasize implementation of WRAPS activities. At that time, incorporation of this TMDL will be made into the WRAPS. Recommendations of this TMDL will be considered in the Kansas Water Plan implementation decisions under the State Water Planning Process for Fiscal Years 2012-2020.

Developed December 2, 2011

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Appendix A. BATHTUB Model Summary

Model Inputs

Current Condition, Lake Shawnee

Global Variables	Mean	CV
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.869	0.2
Evaporation (m)	1.2	0.3
Storage Increase (m)	0	0.0

Atmos. Loads (kg/km²-yr)	Mean	CV
Conserv. Substance	0	0.00
Total P	10	0.50
Total N	713	0.50
Ortho P	10	0.50
Inorganic N	713	0.50

Model Options	Code	Description
Conservative Substance	0	NOT COMPUTED
Phosphorus Balance	2	2ND ORDER, DECAY
Nitrogen Balance	2	2ND ORDER, DECAY
Chlorophyll-a	1	P, N, LIGHT, T
Secchi Depth	1	VS. CHLA & TURBIDITY
Dispersion	1	FISCHER-NUMERIC
Phosphorus Calibration	1	DECAY RATES
Nitrogen Calibration	1	DECAY RATES
Error Analysis	1	MODEL & DATA
Availability Factors	0	IGNORE
Mass-Balance Tables	1	USE ESTIMATED CONCS
Output Destination	2	EXCEL WORKSHEET

Segment Morphometry

		Outflow		Area	Depth	Length	Mixed Depth (m)		Hypol Depth		Non-Algal Turb (m⁻¹)		Internal Loads (mg/m2-day) Conserv.		Total P		Total N	
Seg	Name	Segment	Group	km²	m	km	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Lake Shawnee	0	1	1.5	4.3	2.99	4.1	0.12	4	0	0.27	0.2	0	0	0	0	0	0

Segment Observed Water Quality

	Conserv		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	0	0	33.7	0	988	0	22.6	0	1.2	0	874	0	25	0	0	0	0	0

Segment Calibration Factors

	Dispersion Rate		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0

Tributary Data

				Dr Area	Flow (hm³/yr)		Conserv.		Total P (ppb)		Total N (ppb)		Ortho P (ppb)		Inorganic N (ppb)	
Trib	Trib Name	Segment	Type	km²	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Deer Cr	1	1	21.8	3.36	0.1	0	0	180	0.2	1500	0	20	0	600	0

Model Coefficients	Mean	CV
Dispersion Rate	1.000	0.70
Total Phosphorus	1.129	0.45
Total Nitrogen	0.872	0.55
Chl-a Model	1.584	0.26
Secchi Model	1.000	0.10
Organic N Model	1.000	0.12
TP-OP Model	1.000	0.15
HODv Model	1.000	0.15
MODv Model	1.000	0.22
Secchi/Chla Slope (m²/mg)	0.025	0.00
Minimum Qs (m/yr)	0.100	0.00
Chl-a Flushing Term	1.000	0.00
Chl-a Temporal CV	0.620	0
Avail. Factor - Total P	0.330	0
Avail. Factor - Ortho P	1.930	0
Avail. Factor - Total N	0.590	0
Avail. Factor - Inorganic N	0.790	0

Model Output – Current Condition
Lake Shawnee

Segment:	1	Lake Shawnee				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	33.7	0.27	34.8%	33.7		34.8%
TOTAL N MG/M3	988.0	0.24	49.1%	988.0		49.1%
C.NUTRIENT MG/M3	30.4	0.23	42.0%	30.4		42.0%
CHL-A MG/M3	22.6	0.35	87.3%	22.6		87.3%
SECCHI M	1.2	0.26	55.4%	1.2		55.5%
ORGANIC N MG/M3	692.6	0.29	77.1%	874.0		88.5%
TP-ORTHO-P MG/M3	42.5	0.37	64.3%	25.0		42.4%
HOD-V MG/M3-DAY	285.2	0.23	96.1%			
MOD-V MG/M3-DAY	193.2	0.32	92.9%			
ANTILOG PC-1	395.3	0.51	64.2%	429.3		66.6%
ANTILOG PC-2	13.9	0.13	92.8%	14.4		93.8%
(N - 150) / P	24.9	0.34	71.2%	24.9		71.2%
INORGANIC N / P	295.4	0.90	99.0%	13.1		20.5%
TURBIDITY 1/M	0.3	0.20	17.8%	0.3	0.20	17.8%
ZMIX * TURBIDITY	1.1	0.23	8.9%	1.1	0.23	8.9%
ZMIX / SECCHI	3.4	0.28	28.4%	3.4	0.12	28.3%
CHL-A * SECCHI	27.1	0.17	91.6%	27.1		91.6%
CHL-A / TOTAL P	0.7	0.27	97.3%	0.7		97.3%
FREQ(CHL-a>10) %	84.3	0.16	87.3%	84.3		87.3%
FREQ(CHL-a>20) %	45.5	0.50	87.3%	45.5		87.3%
FREQ(CHL-a>30) %	22.2	0.77	87.3%	22.2		87.3%
FREQ(CHL-a>40) %	10.9	0.99	87.3%	10.9		87.3%
FREQ(CHL-a>50) %	5.6	1.17	87.3%	5.6		87.3%
FREQ(CHL-a>60) %	3.0	1.32	87.3%	3.0		87.3%
CARLSON TSI-P	54.9	0.07	34.8%	54.9		34.8%
CARLSON TSI-CHLA	61.2	0.06	87.3%	61.2		87.3%
CARLSON TSI-SEC	57.4	0.07	44.6%	57.4		44.5%

Model Output – Current Condition
Overall Water and Nutrient Balances
Current Condition, Lake Shawnee

Overall Water & Nutrient Balances

Overall Water Balance — Averaging Period = 1.00 years

Trb	Type	Seq	Name	Area km^2	Flow hm^3/yr	Variance $(hm3/yr)^2$	CV -	Runoff m/yr
1	1	1	Deer Cr	21.8	3.4	1.13E-01	0.10	0.15
PRECIPITATION				1.5	1.3	6.80E-02	0.20	0.87
TRIBUTARY INFLOW				21.8	3.4	1.13E-01	0.10	0.15
***TOTAL INFLOW				23.3	4.7	1.81E-01	0.09	0.20
ADVECTIVE OUTFLOW				23.3	2.9	4.72E-01	0.24	0.12
***TOTAL OUTFLOW				23.3	2.9	4.72E-01	0.24	0.12
***EVAPORATION					1.8	2.92E-01	0.30	

Overall Mass Balance Based Upon Component: Predicted TOTAL P — **Outflow & Reservoir Concentrations**

Trb	Type	Seq	Name	Load kg/yr	%Total	Load Variance $(kg/yr)^2$	%Total	CV	Conc mg/m^3	Export $kg/km^2/yr$
1	1	1	Deer Cr	604.8	97.6%	1.83E+04	99.7%	0.22	180.0	27.7
PRECIPITATION				15.0	2.4%	5.63E+01	0.3%	0.50	11.5	10.0
TRIBUTARY INFLOW				604.8	97.6%	1.83E+04	99.7%	0.22	180.0	27.7
***TOTAL INFLOW				619.8	100.0%	1.83E+04	100.0%	0.22	132.9	26.6
ADVECTIVE OUTFLOW				96.5	15.6%	7.86E+02		0.29	33.7	4.1
***TOTAL OUTFLOW				96.5	15.6%	7.86E+02		0.29	33.7	4.1
***RETENTION				523.3	84.4%	1.53E+04		0.24		

Overflow Rate (m/yr)	1.9	Nutrient Resid. Time (yrs)	0.3507
Hydraulic Resid. Time (yrs)	2.2525	Turnover Ratio	2.9
Reservoir Conc (mg/m3)	34	Retention Coef.	0.844

Overall Mass Balance Based Upon Component: Predicted TOTAL N — **Outflow & Reservoir Concentrations**

Trb	Type	Seq	Name	Load kg/yr	%Total	Load Variance $(kg/yr)^2$	%Total	CV	Conc mg/m^3	Export $kg/km^2/yr$
1	1	1	Deer Cr	5040.0	82.5%	2.54E+05	47.0%	0.10	1500.0	231.2
PRECIPITATION				1069.5	17.5%	2.86E+05	53.0%	0.50	820.5	713.0
TRIBUTARY INFLOW				5040.0	82.5%	2.54E+05	47.0%	0.10	1500.0	231.2
***TOTAL INFLOW				6109.5	100.0%	5.40E+05	100.0%	0.12	1310.1	262.2
ADVECTIVE OUTFLOW				2829.1	46.3%	4.42E+05		0.23	988.0	121.4
***TOTAL OUTFLOW				2829.1	46.3%	4.42E+05		0.23	988.0	121.4
***RETENTION				3280.4	53.7%	5.28E+05		0.22		

Overflow Rate (m/yr)	1.9	Nutrient Resid. Time (yrs)	1.0431
Hydraulic Resid. Time (yrs)	2.2525	Turnover Ratio	1.0
Reservoir Conc (mg/m3)	988	Retention Coef.	0.537

Model Output with 67% TP and 25% TN Concentration Reductions at Inflow
TMDL BATHTUB, Lake Shawnee

Segment:	1	Lake Shawnee				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	15.0	0.26	9.9%	33.7		34.8%
TOTAL N MG/M3	818.8	0.24	37.6%	988.0		49.1%
C.NUTRIENT MG/M3	14.5	0.25	13.0%	30.4		42.0%
CHL-A MG/M3	10.0	0.40	53.1%	22.6		87.3%
SECCHI M	1.9	0.23	77.7%	1.2		55.5%
ORGANIC N MG/M3	404.6	0.25	37.8%	874.0		88.5%
TP-ORTHO-P MG/M3	20.0	0.38	33.6%	25.0		42.4%
HOD-V MG/M3-DAY	189.4	0.25	88.7%			
MOD-V MG/M3-DAY	128.3	0.33	81.4%			
ANTILOG PC-1	107.5	0.51	26.5%	429.3		66.6%
ANTILOG PC-2	11.6	0.18	86.9%	14.4		93.8%
(N - 150) / P	44.5	0.34	92.1%	24.9		71.2%
INORGANIC N / P	414.2	0.48	99.6%	13.1		20.5%
TURBIDITY 1/M	0.3	0.20	17.8%	0.3	0.20	17.8%
ZMIX * TURBIDITY	1.1	0.23	8.9%	1.1	0.23	8.9%
ZMIX / SECCHI	2.1	0.25	8.3%	3.4	0.12	28.3%
CHL-A * SECCHI	19.2	0.26	81.4%	27.1		91.6%
CHL-A / TOTAL P	0.7	0.27	97.2%	0.7		97.3%
FREQ(CHL-a>10) %	37.6	0.64	53.1%	84.3		87.3%
FREQ(CHL-a>20) %	7.6	1.21	53.1%	45.5		87.3%
FREQ(CHL-a>30) %	1.8	1.58	53.1%	22.2		87.3%
FREQ(CHL-a>40) %	0.5	1.86	53.1%	10.9		87.3%
FREQ(CHL-a>50) %	0.2	2.08	53.1%	5.6		87.3%
FREQ(CHL-a>60) %	0.1	2.27	53.1%	3.0		87.3%
CARLSON TSI-P	43.2	0.09	9.9%	54.9		34.8%
CARLSON TSI-CHLA	53.2	0.07	53.1%	61.2		87.3%
CARLSON TSI-SEC	50.6	0.07	22.3%	57.4		44.5%

Model Output with 67% TP and 25% TN Concentration Reductions at Inflow
TMDL BATHTUB, Lake Shawnee

Overall Water & Nutrient Balances

Overall Water Balance — Averaging Period = 1.00 years

Trb	Type	Seq	Name	Area km^2	Flow hm^3/yr	Variance (hm3/yr)^2	CV -	Runoff m/yr
1	1	1	Deer Cr	21.8	3.4	1.13E-01	0.10	0.15
PRECIPITATION				1.5	1.3	6.80E-02	0.20	0.87
TRIBUTARY INFLOW				21.8	3.4	1.13E-01	0.10	0.15
***TOTAL INFLOW				23.3	4.7	1.81E-01	0.09	0.20
ADVECTIVE OUTFLOW				23.3	2.9	4.72E-01	0.24	0.12
***TOTAL OUTFLOW				23.3	2.9	4.72E-01	0.24	0.12
***EVAPORATION					1.8	2.92E-01	0.30	

Overall Mass Balance Based Upon Component: Predicted TOTAL P — Outflow & Reservoir Concentrations

Trb	Type	Seq	Name	Load kg/yr	%Total	Load Variance (kg/yr)^2	%Total	CV	Conc mg/m^3	Export kg/km^2/yr
1	1	1	Deer Cr	201.6	93.1%	2.03E+03	97.3%	0.22	60.0	9.2
PRECIPITATION				15.0	6.9%	5.63E+01	2.7%	0.50	11.5	10.0
TRIBUTARY INFLOW				201.6	93.1%	2.03E+03	97.3%	0.22	60.0	9.2
***TOTAL INFLOW				216.6	100.0%	2.09E+03	100.0%	0.21	46.4	9.3
ADVECTIVE OUTFLOW				43.0	19.9%	1.49E+02		0.28	15.0	1.8
***TOTAL OUTFLOW				43.0	19.9%	1.49E+02		0.28	15.0	1.8
***RETENTION				173.6	80.1%	1.68E+03		0.24		

Overflow Rate (m/yr)	1.9	Nutrient Resid. Time (yrs)	0.4477
Hydraulic Resid. Time (yrs)	2.2525	Turnover Ratio	2.2
Reservoir Conc (mg/m3)	15	Retention Coef.	0.801

Overall Mass Balance Based Upon Component: Predicted TOTAL N — Outflow & Reservoir Concentrations

Trb	Type	Seq	Name	Load kg/yr	%Total	Load Variance (kg/yr)^2	%Total	CV	Conc mg/m^3	Export kg/km^2/yr
1	1	1	Deer Cr	3528.0	76.7%	1.24E+05	30.3%	0.10	1050.0	161.8
PRECIPITATION				1069.5	23.3%	2.86E+05	69.7%	0.50	820.5	713.0
TRIBUTARY INFLOW				3528.0	76.7%	1.24E+05	30.3%	0.10	1050.0	161.8
***TOTAL INFLOW				4597.5	100.0%	4.10E+05	100.0%	0.14	985.8	197.3
ADVECTIVE OUTFLOW				2344.6	51.0%	2.88E+05		0.23	818.8	100.6
***TOTAL OUTFLOW				2344.6	51.0%	2.88E+05		0.23	818.8	100.6
***RETENTION				2252.9	49.0%	3.47E+05		0.26		

Overflow Rate (m/yr)	1.9	Nutrient Resid. Time (yrs)	1.1487
Hydraulic Resid. Time (yrs)	2.2525	Turnover Ratio	0.9
Reservoir Conc (mg/m3)	819	Retention Coef.	0.490

Appendix B. Conversion to Daily Loads as Regulated by EPA Region VII

The TMDL has estimated annual average loads for TN and TP that if achieved should meet the water quality targets. A recent court decision often referred to as the "Anacostia decision" has dictated that TMDLs include a "daily" load (Friend of the Earth, Inc v. EPA, et al.).

Expressing this TMDL in daily time steps could be misleading to imply a daily response to a daily load. It is important to recognize that the growing season mean chlorophyll *a* is affected by many factors such as: internal lake nutrient loading, water residence time, wind action and the interaction between light penetration, nutrients, sediment load and algal response.

To translate long-term averages to maximum daily load values, EPA Region 7 has suggested the approach describe in the Technical Support Document for Water Quality Based Toxics Control (EPA/505/2-90-001)(TSD).

Maximum Daily Load (MDL) = (Long-Term Average Load) * $e^{[Z\sigma - 0.5\sigma^2]}$

where $\sigma^2 = \ln(CV^2 + 1)$

CV = Coefficient of variation = Standard Deviation / Mean

Z = 2.326 for 99th percentile probability basis

LTA= Long Term Average
LA= Load Allocation
MOS= Margin of Safety

Parameter	LTA lbs/year	CV	$e^{[Z\sigma - 0.5\sigma^2]}$	MDL lbs/day	Atm LA lbs/day	LA lbs/day	WLA lbs/day	MOS (10%) lbs/day
TP	478	0.5	2.68	3.51	0.240	2.11	1.05	0.351
TN	10,136	0.5	2.68	74.5	17.3	44.7	22.4	7.45

Maximum Daily Load Calculation

Annual TP Load = 478 lbs/yr

Maximum Daily TP Load = [(478 lbs/yr)/(365 days/yr)]*$e^{[2.326*(0.472) - 0.5*(0.472)^2]}$
= 3.51 lbs/day

Annual TN Load = 10,136 lbs/yr

Maximum Daily TN Load = [(10,136 lbs/yr)/(365 days/yr)]*$e^{[2.326*(0.472) - 0.5*(0.472)^2]}$
= 74.5 lbs/day

Margin of Safety (MOS) for Daily Load

Annual TP MOS = 47.8 lbs/yr

Daily TP MOS = [(47.8 lbs/yr)/(365 days/yr)]*$e^{[2.326*(0.472)-0.5*(0.472)^2]}$
= 0.351 lbs/day

Annual TN MOS = 8,369 lbs/yr

Daily TN MOS = [(1,014 lbs/yr)/(365 days/yr)]*$e^{[2.326*(0.472)-0.5*(0.472)^2]}$
= 7.45 lbs/day

Source- *Technical Support Document for Water Quality-based Toxics Control (EPA/505/2-90-001)*