VERDIGRIS BASIN TOTAL MAXIMUM DAILY LOAD

Waterbody/Assessment Unit (AU): Big Hill Lake

Water Quality Impairment: Eutrophication

1. INTRODUCTIONS AND PROBLEM IDENTIFICATION

Subbasin:	Middle Verdigris
County:	Labette
HUC 8:	11070103
HUC 11 (HUC 14):	11070103010 (060)
Ecoregion:	Central Irregular Plains, Osage Cuestas (40b)
Drainage Area:	Approximately 35.4 square miles
Conservation Pool:	Surface Area = 1240 acres (1.94 square miles) Watershed/Lake Ratio = 18:1 Maximum Depth = 16.0 meters Mean Depth = 6.5 meters Storage Volume = 27784 acre-feet Estimated Retention Time = ~1.58 years Mean Annual Inflow = 10,337 cfs (1995-2006) Mean Annual Discharge = 7,958 cfs (1995-2006) Year Constructed: 1981
Designated Uses:	Primary Contact Recreation (A), Expected Aquatic Life Support; Domestic Water Supply; Food Procurement; Industrial Water Supply; Irrigation Use; Livestock Watering Use
303(d) Listings:	2004 & 2006 Verdigris River Basin Lakes
Impaired Use:	All uses are impaired to a degree by eutrophication
Water Quality Standard:	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 (K.A.R. 28-16-28e(c)(2)(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 (K.A.R. 28-16-28e(c)(7)(A)).

2. CURRENT WATER QUALITY CONDITION AND DESIRED ENDPOINT

Level of Eutrophication: Fully Eutrophic, Trophic State Index = 55.5

The Trophic State Index (TSI) is derived from the chlorophyll *a* concentration (Chl-a). Trophic state assessments of potential algal productivity were made based on chlorophyll *a* concentrations, nutrient levels and values of the Carlson Trophic State Index (TSI). Generally, some degree of eutrophic condition is seen with chlorophyll *a* concentrations over 12 ppb and hypereutrophy occurs at levels over 30 ppb. 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 LM031001 in Big Hill Lake.

Period of Record Used: Nine surveys conducted by KDHE in calendar years, 1982, 1986, 1989, 1992, 1995, 1998, 2001, 2004 and 2007. Sampling data was also utilized from a survey conducted by the U.S. Army Corps of Engineers during calendar year 1992 and from a survey conducted by the Kansas Biological Survey (KBS) during calendar year 2006. Daily inflow and discharge data for 1995-2006 was obtained from the U.S. Army Corps of Engineers.

Hydrological Conditions: Big Hill Creek above Big Hill Lake is the only registered stream directly feeding Big Hill Lake. The median flow of Big Hill Creek above the reservoir is 3.68 cfs, the 10% exceedance flow is 37.2 cfs, and the mean flow is 27.1 cfs. Big Hill Creek below the reservoir, which is influenced by reservoir releases, has a median flow of 0.88 cfs, with a 10% exceedance flow of 69.0 cfs and a mean flow of 29.3 cfs (Perry, 2004).

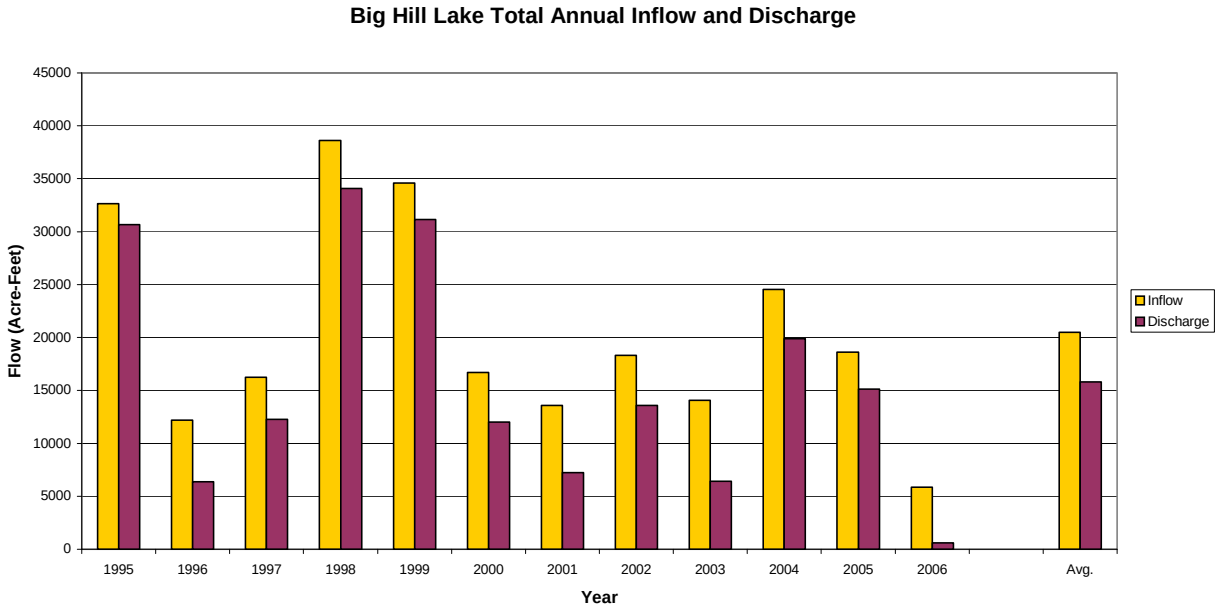
According to the USGS Lake Hydro data, the mean runoff in the watershed is 9.64 inches/year; the mean precipitation in the watershed is 37.9 inches per year; and the mean loss due to evaporation for the Lake is 51.5 inches per year. The calculated mean annual outflow for the lake is 15,800 acre-feet per year.

Table 1 summarizes the total inflow and outflow, and rainfall data for Big Hill Lake for the 90-day period prior to the specified sampling date. The data suggest that the sampling years of 1998 and 2001 were dry throughout the 90-day period preceding the sampling date. As Figure 1 illustrates, the total annual inflow and discharge for the years of: 1995, 1998, 1999, and 2004 generally indicate these are considered wet years.

Table 1. Summary of select reservoir data for Big Hill Lake, for 90 days preceding the KDHE Sampling Date (source: U. S. Army Corps of Engineers).

Sample Date	90 day prior Inflow (cfs)	90 day prior Release (cfs)	90 day prior Rainfall (inches)	90 day prior Avg. Lake Elevation
7/31/1995	12080	11612	23.92	858.78
8/23/1998	967	236	10.24	857.93
7/31/2001	1700	593	10.06	857.76
7/13/2004	5828	4939	12.25	858.41

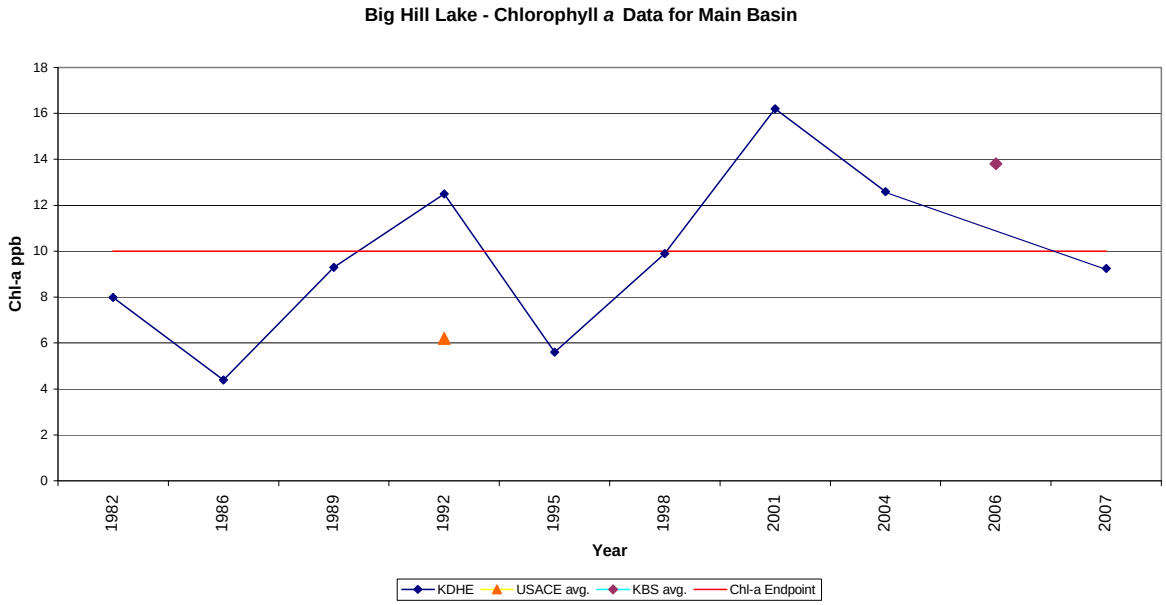
Figure 1. Annual total inflow and discharge measured at Big Hill Lake during 1995-2006.



Current Conditions: Big Hill Lake is a Public Water Supply serving numerous rural residences and small communities via Public Wholesale Water Supply District #4. Of the 24 federal reservoirs in Kansas, Big Hill Lake was identified as the "Top Tier" reservoir for outdoor recreation in 2005 by the Kansas Water Office as part of a background paper on *Economic Development Opportunities at Federal Reservoirs in Kansas.*

Over the period of record for KDHE data, Big Hill Lake had a chlorophyll *a* (chl-*a)* concentration averaging 9.8 ppb. Chlorophyll *a* annual concentrations were greater than 12 ppb in 1992, 2001, and 2004, with a maximum of 16.2 ppb occurring in 2001. The chlorophyll *a* concentration average for KDHE samples obtained from 1992 to 2007 is 11.0 ppb.

Figure 2. Chlorophyll *a* Concentrations in Big Hill Lake



The average secchi depth is 1.55 meters, with the three lowest secchi depth readings ($\leq$1.55) occurring during the years with chl-*a* detections above 12 ppb. The average turbidity value in Big Hill Lake is 3.35 NTU, ranging from a low of 2 NTU (1995 & 1998) to a high of 6.5 NTU (1982).

The average total nitrogen (TN) and total phosphorus (TP) concentrations are 0.61 mg/L and 0.048 mg/L, respectively. The total phosphorus concentrations for samples obtained at 0.5 meters have generally been stable and relatively low. The maximum TP concentration of 0.23 mg/L was detected in 1982. Since this time, TP has averaged 0.024 mg/L. The TN concentration over the period of record is primarily influenced by the Kjeldahl Nitrogen content, which averages 0.53 mg/L. Data for calculating TN is not available prior to the 1992 sampling event.

The ratio of total nitrogen and total phosphorus is a common ratio utilized to determine which of these nutrients is likely limiting plant growth in Kansas aquatic ecosystems. Typically, lakes that are nitrogen limited have a water column TN:TP ratio < 8 (mass); lakes that are co-limited by nitrogen and phosphorus have a TN:TP ratio between 9 and

21; and lakes that are P limited have a water column TN:TP ratio > 29 (Dzialowski et al., 2005). Big Hill Lake is consistently found to be phosphorus limited.

Table 2. KDHE sampling results from Big Hill Lake.

Sample Date	Sample Time	Chl-a (µg/L)	TN (mg/L)	TP (mg/L)	TN:TP ratio	Secchi Depth (m)	Turbidity (NTU)
9/20/1982	NA	7.98	NA	0.23	NA	NA	6.5
8/18/1986	1130	4.4	NA	0.025	NA	NA	2.1
6/7/1989	1400	9.3	NA	<0.01	NA	1.7	2.65
8/11/1992	1215	12.5	0.28	<0.05	11.2	1	3.3
7/31/1995	1805	5.6	0.792	0.02	39.6	1.6	2
6/23/1998	0910	9.9	0.806	0.022	36.6	2.06	2
7/31/2001	0830	16.2	0.422	0.033	13.0	1.4	3.55
7/13/2004	0845	12.6	0.578	0.022	26.3	1.55	4.23
7/30/2007	1145	9.25	0.775	0.02	38.75	1.86	3.8
Average	All Data	9.75	0.610	0.045	24.2	1.55	3.35
Average-1992-2007	**Recent Data**	**11.0**	**0.610**	**0.024**	**24.2**	**1.58**	**3.14**

The U.S. Army Corps of Engineers (USACE) sampled Big Hill Lake throughout 1992. The USACE collected samples at 0.5 meters from three locations within the lake: the dam site, Timber Hill recreation area in the central part of the lake, and the upper lake at the Highway 160 bridge. The data from the damsite location should be comparable to the KDHE data since this is approximately the same location where KDHE collects their samples within Big Hill Lake. The study conducted by the USACE indicated that the mean total nitrogen concentrations were consistent throughout the lake. The mean total phosphorus and chlorophyll *a* concentrations were higher at the upper end of the lake and declined towards the damsite location.

Table 3. 1992 USACE summary of nutrient concentrations at 0.5m in Big Hill Lake.

USACE Sample Location	Mean Total N mg/L	Mean Total Phos mg/L	Mean Chl-a µg/L
Damsite	1.18	0.03	6.2
Timber Hill (Middle Lake)	1.20	0.041	6.8
Hwy 160 Bridge (Upper Lake)	1.20	0.108	9.2

Table 4. U.S. Army Corps of Engineers data from Damsite sampling location.

Sample Date	Sample Time	Chl-a (µg/L)	TN (mg/L)	TP (mg/L)	TN:TP ratio	Secchi Depth (m)
5/27/1992	1515	<5	1.16	NA	NA	1.4
6/16/1992	1500	<5	1.22	NA	NA	1.55
7/1/1992	1415	<5	1.34	NA	NA	1.5
7/15/1992	1135	10.3	1.89	NA	NA	0.8
7/29/1992	1135	<5	0.77	0.027	28.5	1
8/13/1992	1430	6.7	0.72	0.033	21.8	1.1
Avg.		**6.2**	**1.18**	**0.030**	**25.2**	**1.23**

The Kansas Biological Survey sampled Big Hill Lake in 2006. It is evident by their data results that the trophic status of Big Hill Lake has declined since the 1992 sampling event conducted by the USACE. The KBS sampled at a depth of 1.5 meters at three locations throughout the lake, which KBS categorized as riverine, transitional, and main basin.

Table 5. 2006 Summary of KBS data collection at Big Hill Lake.

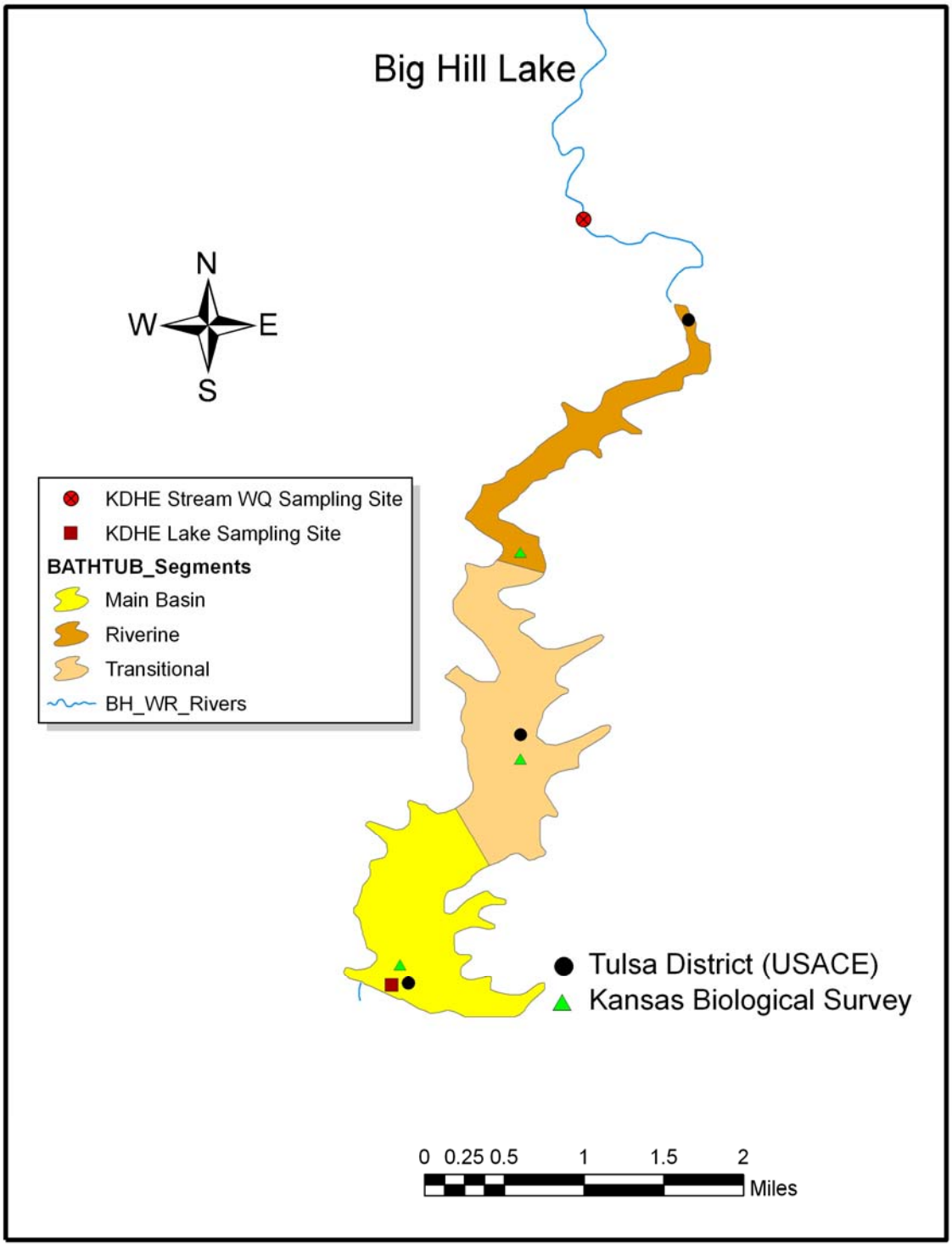
Location	Mean Total N (mg/L)	Mean Total P (mg/L)	Mean Chl-a (µg/L)	Mean Secchi Depth (meters)
Main Basin	0.54	0.022	13.8	1.38
Transitional	0.55	0.025	15.1	1.31
Riverine	0.60	0.028	14	1.36

As seen in Tables 5 and 6, the results from the KBS sampling events are much different from the USACE sampling results for total nitrogen and chlorophyll *a*. However, both data sets indicate that the total nitrogen concentrations within the lake are consistent; total phosphorus concentrations increase slightly towards the upper end of the lake; and the TN:TP ratios are similar for both data sets. As indicated in Figure 1, the 2006 sampling year was completed in drought conditions, which may account for significant discrepancies in the observed total nitrogen and chlorophyll *a* values between the 1992 USACE and the 2006 KBS sampling events. In addition, the dynamics of the internal lake conditions change over time as is indicated by the increasing trend of chlorophyll *a* within Big Hill Lake.

Table 6. KBS data from main basin sampling location.

Sample Date	Chl-a (µg/L)	TN (mg/L)	TP (mg/L)	TN:TP ratio	Secchi Depth (m)
6/27/06	8.5	0.51	0.020	25.5	1.60
7/12/06	12.0	0.46	0.017	27.1	1.20
7/24/06	15.7	0.63	0.023	27.4	1.30
8/8/06	19.1	0.55	0.025	22.0	1.40
Avg.	**13.8**	**0.54**	**0.022**	**25.5**	**1.38**

Figure 3. Big Hill Lake Sampling Locations and BATHTUB Segmentation.



Comparing the data averages between the USACE, KDHE, and KBS indicates that total phosphorus, TN:TP ratios, and the secchi depth readings have been stable throughout the years. The KDHE and KBS data sets are much more similar for chlorophyll *a* and total nitrogen concentrations. This may be due to the hydrological conditions apparent in Big Hill Lake during 1992, and the fact that chlorophyll *a* concentrations have slightly increased within the lake over time.

Table 7. USACE, KDHE, and KBS data averages for main basin in Big Hill Lake.

Agency	Period of Record	Chl-a (µg/L)	TN (mg/L)	TP (mg/L)	TN:TP ratio	Secchi Depth (m)
USACE	1992	6.2	1.18	0.030	25.2	1.23
KBS	2006	13.8	0.54	0.022	25.5	1.38
KDHE	1992-2007	11.0	0.610	0.024	24.2	1.58

The majority of data collected by KDHE indicates that nutrient concentrations are relatively low, but the TN:TP ratios point towards phosphorus having a strong influence on algal growth within the main basin of the lake near the dam.

As seen in Figures 4 and 5, the amount of water flowing into the lake has an effect on chlorophyll *a* levels within the lake. The years with less water inflowing into the lake were more likely to experience chlorophyll *a* levels above 10 ppb. When looking at the inflow for the 90-day period prior to the sample date, the observed chlorophyll *a* values also tend to be higher when there is less flow during this period. These figures suggest that chlorophyll *a* values are likely to be higher during drier years and/or when the inflow into the lake is minimal for the 90-day period prior to the sampling date. As seen in Figure 6, the total phosphorus concentrations are slightly higher for samples that have chlorophyll *a* concentrations greater than 10 ppb. The amount of inflow coming into the lake within the 90-day period prior to the sampling date does not consistently influence the total phosphorus concentrations within the lake. As previously noted, the total phosphorus concentrations are generally consistent within the lake during the period of record.

Figure 4. Chlorophyll *a* concentrations plotted against annual inflow for Big Hill Lake.

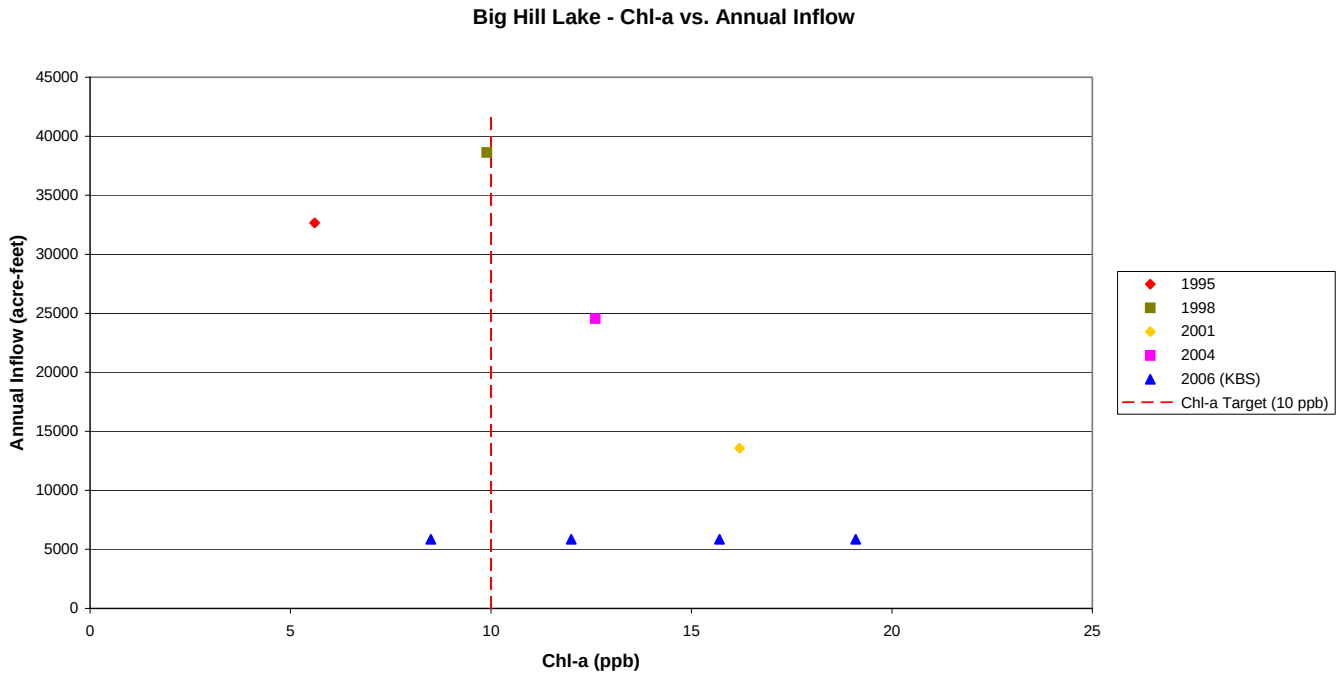


Figure 5. Chlorophyll *a* concentrations plotted against the inflow during the 90 days preceding the sampling date.

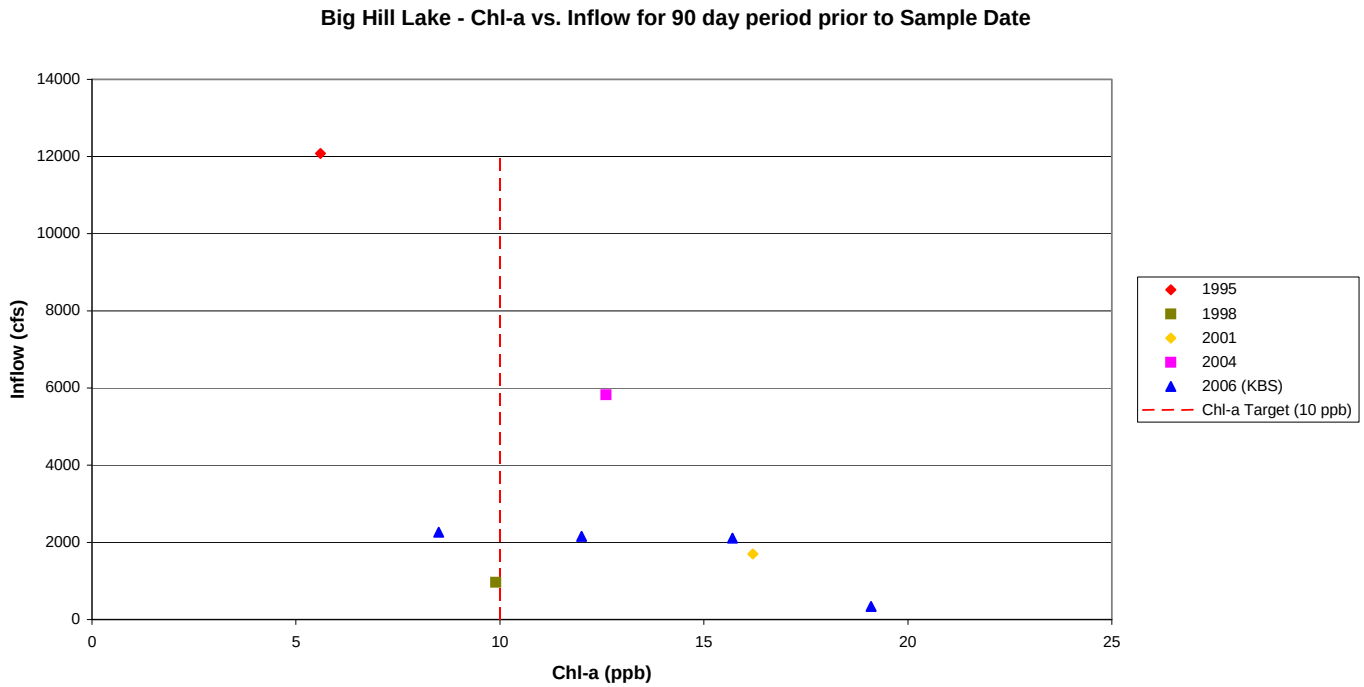
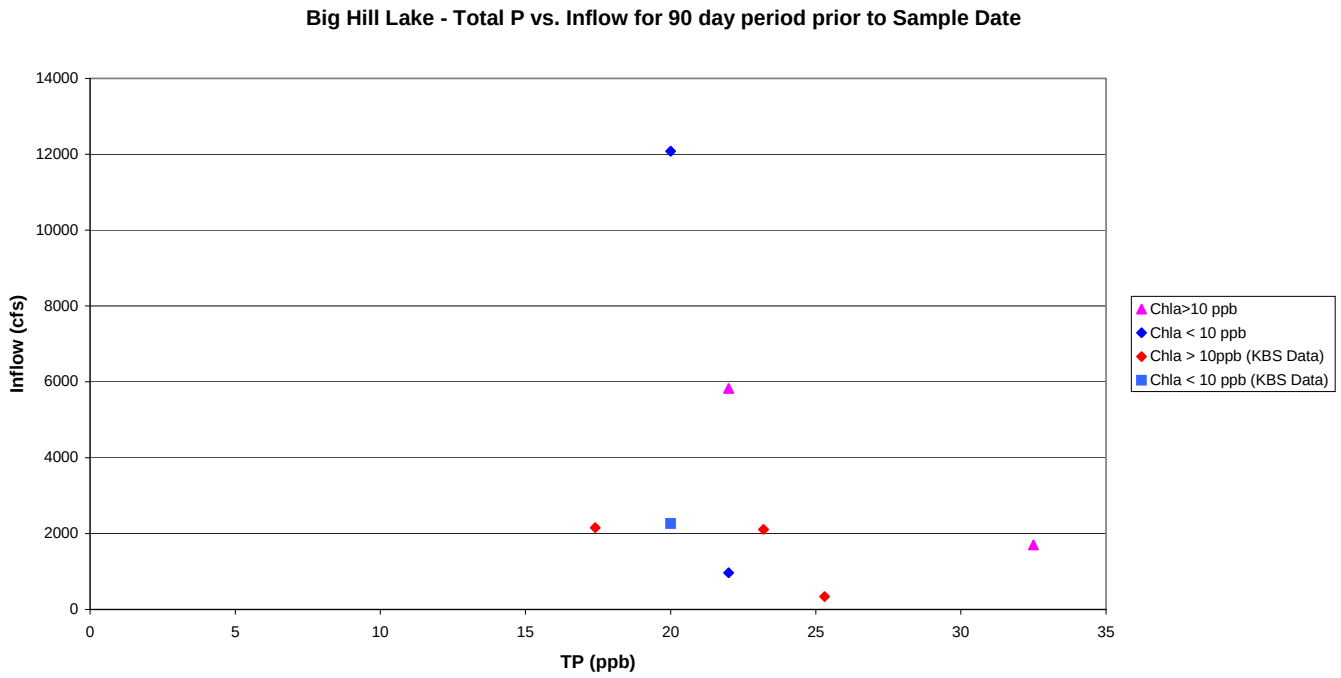


Figure 6. Total phosphorus concentrations for KDHE and KBS samples in Big Hill Lake vs. lake inflow for 90-day period prior to sample date.



The lake stratification profile for the KDHE sampling event conducted on July 13, 2004 at Big Hill Lake is illustrated in Figure 7. The dissolved oxygen (DO) concentrations and temperature readings throughout the water column conclude the lake typically stratifies at a depth around 6 meters.

Figure 7. Big Hill Lake Dissolved Oxygen and Temperature profile during the July 13, 2004 sampling event.

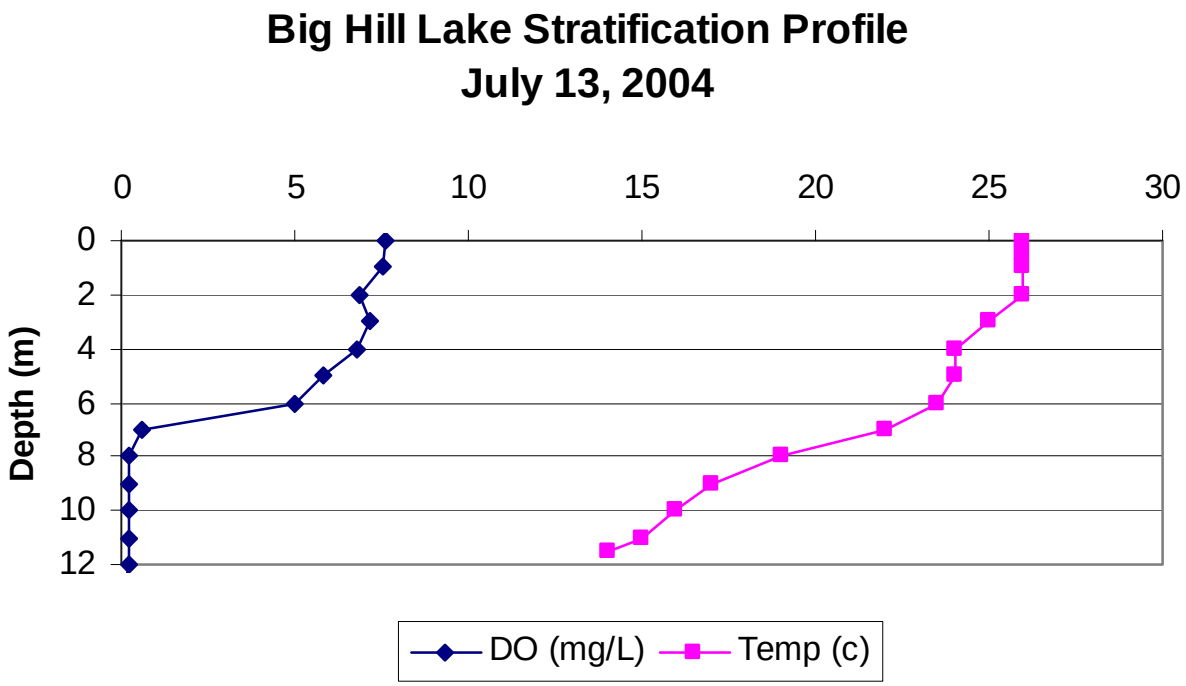


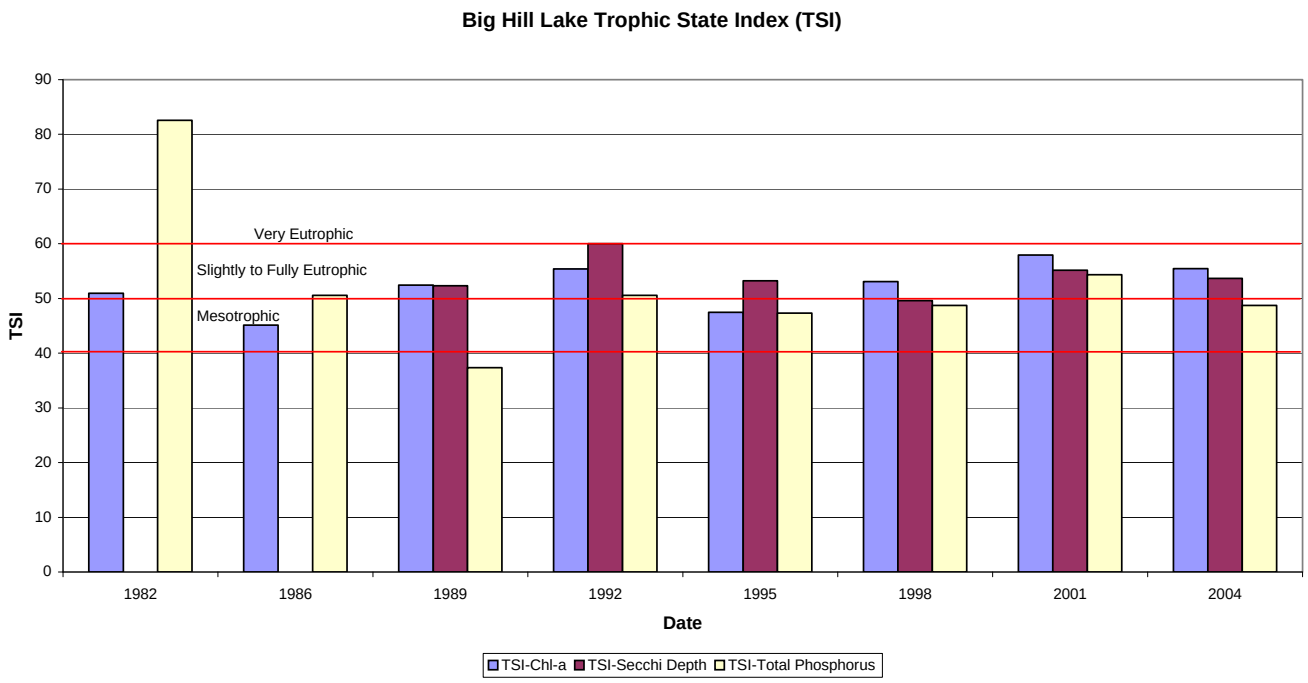
Table 8. Limiting factor determinations for Big Hill Lake.

Year	TN/TP	Non-algal Turbidity	Light Availability in the Mixed Layer	Partioning 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
		NAT	Zmix*NAT	Chl-a*SD	Chl-a/TP	Zmix/SD	Shading
1989		0.36	1.69	15.81	0.93	2.8	
1992	11.2	0.69	3.27	12.5	0.5	4.75	
1995	39.6	0.49	2.30	8.96	0.28	2.97	
1998	36.6	0.24	1.31	20.4	0.45	2.67	7.77
2001	13.0	0.31	1.47	22.7	0.50	3.39	7.37
2004	26.3	0.33	1.57	19.53	0.57	3.06	6.9
2007	38.75	0.31	1.46	17.21	0.46	2.55	

Table 8 lists six metrics measuring the roles of light and nutrients in Big Hill Lake. Non-algal turbidity (NAT) values < 0.4 m^{-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}.

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 < 3. Values greater than 6 would indicate the opposite.

Figure 8. Trophic State Indices in Big Hill Lake for KDHE sampling year.



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 > 16. Values < 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 < 0.13 indicate a limited response by algae to phosphorus.

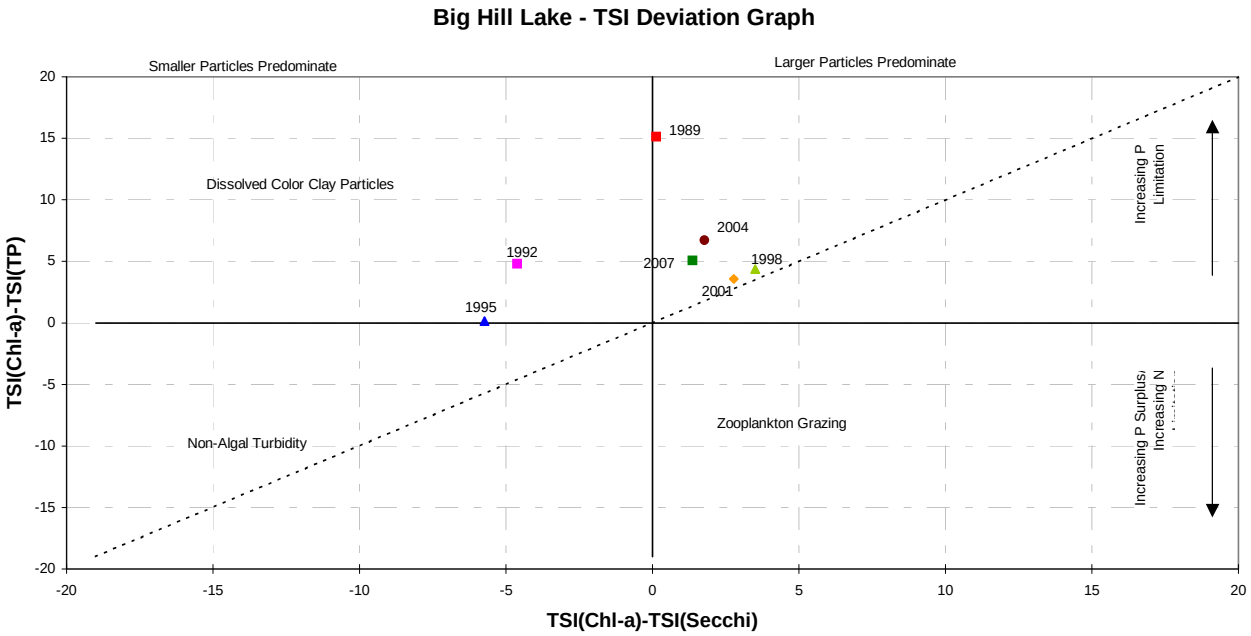
The light availability in the mixed layer for a given surface light is represented as Zmix/SD. Values < 3 indicate that light availability is high in the mixed zone and there is a high probability of strong algal responses to changes in nutrient levels.

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. (Lake and Wetland Monitoring Program 2004 Annual Report, Carney, 2004)

The above metrics conclude that Big Hill Lake generally has low levels of inorganic turbidity (suspended silt/clay particles), there is abundant light availability in the mixed layer, inorganic turbidity does not limit light in the water column, there is a moderate response of algae communities to increases in nutrient levels, and there is a strong algal response to changes in phosphorus levels. According to these metrics, Big Hill Lake is phosphorus limited throughout most sampling years.

Figure 9. Multivariate TSI comparison chart for Big Hill Lake.



Another method for evaluating limiting factors is the TSI deviation metrics. Figure 9 (Multivariate Figure) summarizes the current trophic conditions at Big Hill Lake using a multivariate TSI comparison chart for data obtained by KDHE throughout 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, than 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. For the years plotted in Figure 9, Big Hill Lake is generally clear and primarily limited by phosphorus.

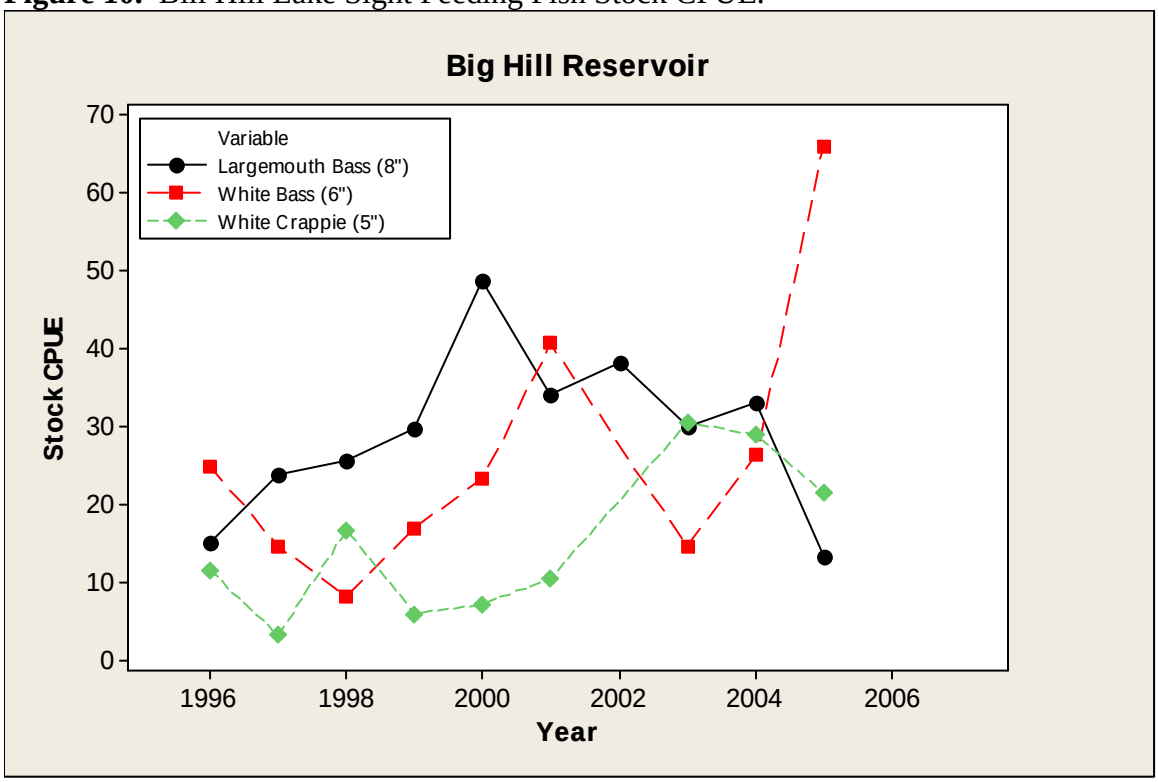
Table 9. Algal Communities Observed in Big Hill Lake, KDHE data.

Sampling Date	Total Cell Count cells/µL	Percent Composition				Chl-a	TN/TP	TP
		Green	Blue Green	Diatom	Other			
6/7/1989		27	11	17	45	9.3	NA	<0.01
8/11/1992	47.4	8	92	0	0	12.5	11.2	<0.05
7/31/1995	12.66	17	77	5	1	5.6	39.6	0.02
6/23/1998	19.0	5	84	7	4	9.9	36.6	0.022
7/31/2001	59.34	<1	99	<1	<1	16.2	13.0	0.033
7/13/2004	38.30	1	98	1	<1	12.6	26.3	0.022
7/30/07							38.75	0.02

Algal Community Structure: As seen in Table 9, the total cell counts of the algal community in Big Hill Lake are composed mainly of cyanobacteria (Blue-Green Algae). 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.

Fish Population: Big Hill Lake offers sport-fishing opportunities throughout the year. The USACE states "Big Hill Lake is considered a trophy fishing lake" and "has developed into one of the most productive and popular fishing spots in the area". According to the Kansas Department of Wildlife and Parks fish survey, the number of adult fish Captured Per Unit Time Effort (CPUE) shows that sight-feeding White Bass and White Crappie have generally been increasing, while Largemouth Bass have remained fairly stable with the exception of a recent decline in 2005. Bottom-feeding fish tend to be dominated by inconsistent Gizzard Shad populations. Channel Catfish populations have generally been low.

Figure 10. Bill Hill Lake Sight Feeding Fish Stock CPUE.



Big Hill Lake tends to have higher chlorophyll *a* values during drier conditions, as indicated by lake inflow. Therefore chlorophyll *a* levels are closely associated with hydrologic conditions and nutrient flux from the watershed. Higher chlorophyll *a* values within Big Hill Lake are associated with slightly lower TN:TP ratios than samples with lower chlorophyll *a* detections, which suggests slight increases in total phosphorus concentrations have an impact on the trophic state of the lake.

Table 10 summarizes median trophic conditions within Big Hill Lake in relation to other federal lakes in the state. The trophic indicator values within Big Hill Lake meet or exceed the statewide benchmarks for secchi depth and total phosphorus. The median total nitrogen concentration is slightly higher than the statewide benchmark, but better than other Federal and Central Great Plains Lakes within the state. The median chlorophyll *a* value within Big Hill Lake is considerably higher than the statewide benchmark and slightly lower than median values observed in other federal lakes within Kansas.

Table 10. Median trophic indicator values of Big Hill Lake (KDHE data 1992-2007) in comparison with other federal lakes and draft lake nutrient benchmarks in Kansas. The nutrient benchmarks were derived from 47-58 lakes and reservoirs, based on the data collected between 1985 and 2002.

Trophic Indicator	Big Hill Lake	Federal Lakes	Central Great Plains	Flint Hills	Statewide Benchmark
Secchi depth (cm)	158	95	117	149	129
TN (µg/L)	677	903	695	301	625
TP (µg/L)	22	76	44	19	23
Chlorophyll *a* (µg/L)	11.2	12	11	5	8

Interim Endpoints of Water Quality (Implied Load Capacity) at Big Hill Lake:

In order to improve the trophic condition of Big Hill Lake from its current Fully Eutrophic status, the desired endpoint will be to maintain summer chlorophyll *a* concentrations below 10 µg/L, with the reductions focused on phosphorus loadings in the lake. The chlorophyll *a* endpoint of 10 µg/L is the statewide goal for lakes serving as Public Water Supplies, which will also ensure long-term protection to fully support Primary Contact Recreation within the lake. Achievement of this endpoint should also result in a secchi disk depth greater than 1.6 m within the main basin of the lake. In addition, current annual and daily average nitrogen loads should not be increased.

Based on the BATHTUB reservoir eutrophication model (see Appendix A), the total phosphorus concentrations entering the lake must be reduced by 35%, which translates into a 25% total phosphorus concentration reduction in the main basin of the lake, to achieve this endpoint. Achievement of the endpoints 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 calculated in the model was based on selected 1992 data from the USACE, 2006 data from the KBS and available KDHE data from the sampling years from 1992 –2007.

Table 11. Current Conditions and Reductions for Big Hill Lake Inflow based on BATHTUB Modeling.

Lake Inflow	Current Avg. Condition	TMDL	Percent Reduction
Total Phosphorus Annual Load (lbs/year)	4366	2919	33 %
Total Phosphorus Daily Load (lbs/day)*	18.54	12.4	33%
Total Phosphorus Concentration (µg/L)	108	70	35%
Total Nitrogen Annual Load (lbs/year)	64,507	64,507	0%
Total Nitrogen Daily Load (lbs/day)*	402	402	0%
Total Nitrogen Concentration (µg/L)	1200	1200	0%

* - See Appendix B for Daily Load Calculations

Table 12. Current Conditions and translating reductions and concentrations with TMDL in place for the main basin of Big Hill Lake.

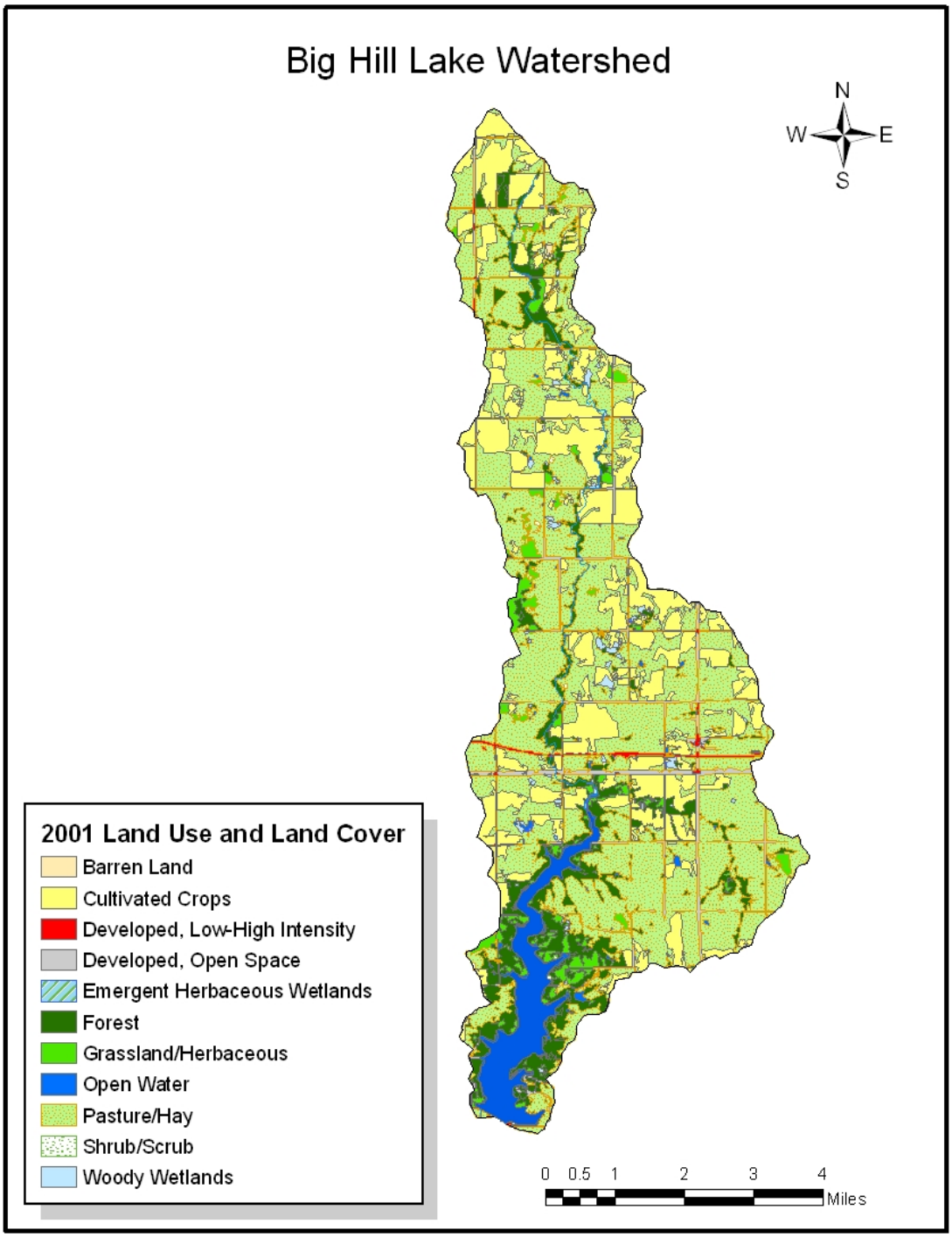
Main Basin Concentrations	Current Avg. Condition	TMDL Estimated Concentration (BATHTUB)	Percent Reduction
Total Phosphorus Concentration (µg/L)	24.0	18.0	25 %
Total Nitrogen Concentration (µg/L)	610	610	0%
Chlorophyll *a* (µg/L)	11.0	< 10	10%
Secchi Depth (m)	1.6	> 1.6	

3. SOURCE INVENTORY AND ASSESSMENT

Land Use: The predominant land cover in the watershed around Big Hill Lake includes 52% pasture, 22% cropland, and 11% forest. The remaining land uses within the watershed contain: 5% open water (to include Big Lake), 4% developed open space, 1% developed low-high intensity, 3% grassland, and 1% woody wetlands.

Utilizing the 2001 NLCD, an assessment of land use within 100 feet of riparian areas within the watershed was conducted. The Kansas Surface Water Register, based on the 1:100,000 scale, was used to assess land use near larger, perennial streams, and the 1:24,000 high resolution NHD was used to assess land use around all streams, including headwater streams. The riparian land use analysis concludes that riparian areas within the Big Hill Lake watershed are generally well protected. The registered streams land use riparian area consists of 64% forested land, 22% permanent grass, and 8% cropland. The NHD land use riparian area consists of 55% permanent grass, 31% forested land, and 7% cropland.

Figure 11. Big Hill Lake Watershed Land Use Map.



There is not any permitted or registered confined animal feeding operations (CAFOs) located within the watershed. Smaller animal feeding operations with less than 300 animal units may be operating within the watershed. Animal waste from any facility with livestock may add to the nutrient load going into Big Hill Lake. According to the 2006-2007 Kansas Agricultural Farm Facts, there are 61,600 and 42,200 head of cattle in Labette and Neosho Counties respectively. Grazing densities within the watershed are estimated at approximately 84 head of cattle per square mile.

Nutrients within the Big Hill Lake watershed may be attributed to fertilizer or manure application to the agricultural lands being utilized for pasture, hay or cropland production. Of particular concern are lands near the riparian areas that are subject to fertilizer applications.

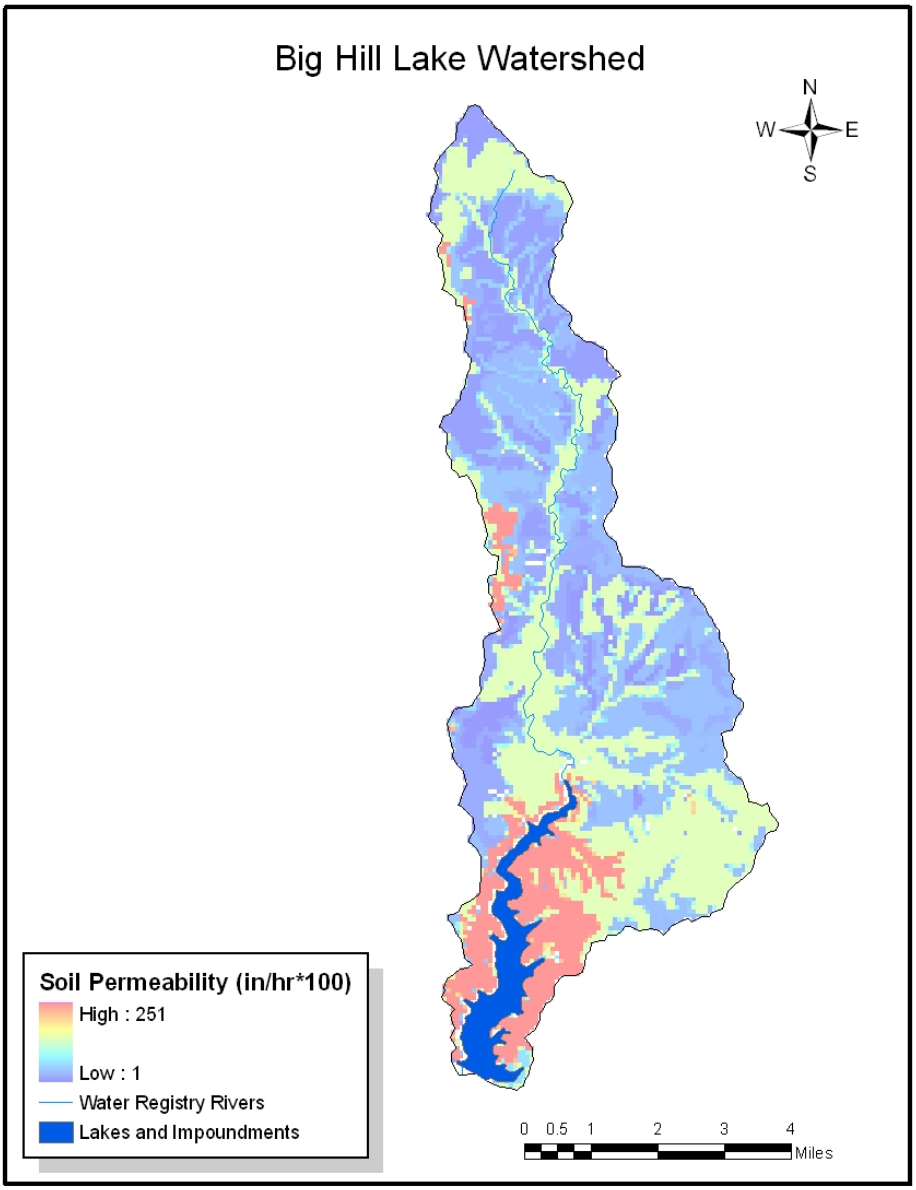
On-Site Waste Systems: The Big Hill Lake watershed is a rural agricultural area. It can be assumed that all of the rural residences in the watershed are not connected to public sewer systems. Failing on-site septic systems may contribute significant nutrient loadings and aggravate eutrophication problems. According to the 2000 census data from the U.S. Census Bureau, the population within the watershed is approximately 618 people (17.4 people/square mile).

NPDES: There are no NPDES permitted facilities within the watershed.

Contributing Runoff: The watershed of Big Hill Lake has a mean soil permeability value of 0.86 inches/hour, ranging from .01 inches/hour to 2.51 inches/hour according to NRCS STATSGO database. About 53% of the watershed has a permeability value less than 0.57 inches/hour, which contributes to runoff during extremely low rainfall intensity events. 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. As seen in Figure 12, the majority of the nonpoint source nutrient runoff will be contributed to the upper portions of the Big Hill Lake watershed.

Background: As mentioned, forested land occupies a large portion of the riparian area within the watershed. Leaf litter and wastes derived from natural wildlife may add to the nutrient load. Atmospheric deposition and seepage from geological formations (i.e. soil and bedrock) may also contribute to the nutrient loads. The suspension of sediment and nutrients within the lake may be influenced by the wind.

Figure 12. Big Hill Lake Soil Permeability Map.



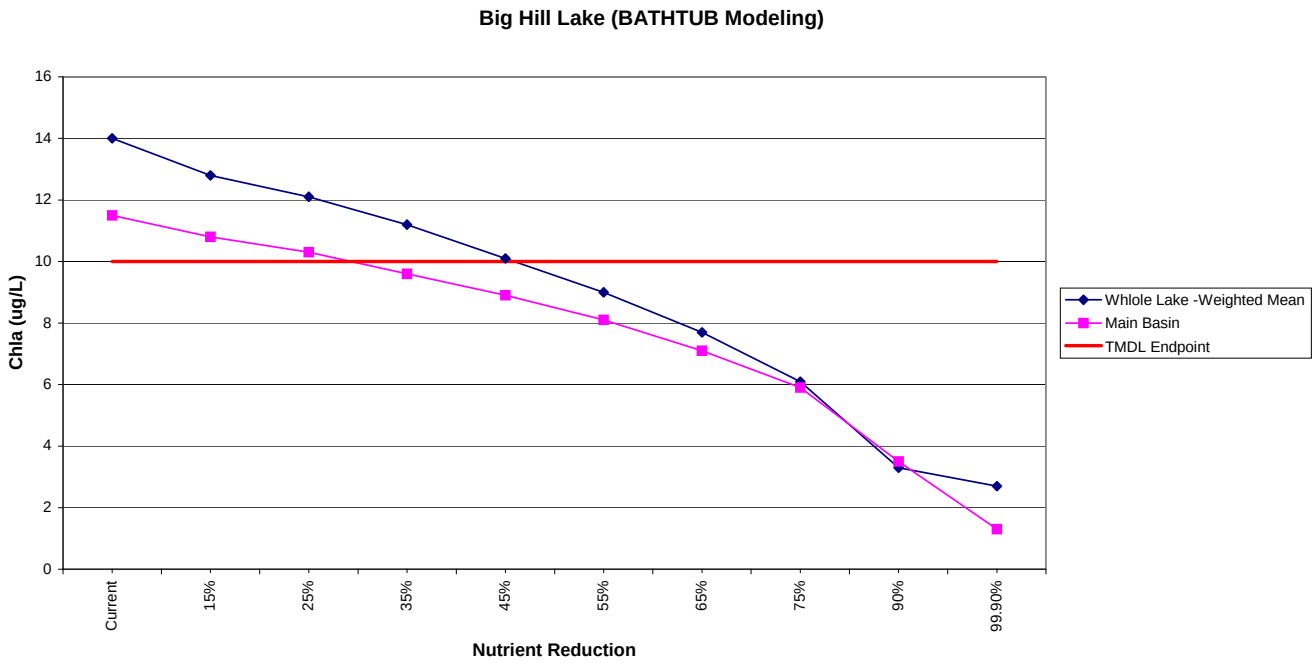
4. ALLOCATION OF POLLUTANT REDUCTION RESPONSIBILITY

Phosphorus is the primary limiting nutrient in the main basin of Big Hill Lake. Phosphorus and nitrogen will both be allocated under this TMDL. Load reductions should be focused on phosphorus since it is the primary limiting factor in the main basin of the lake. Reductions are not initially necessary for nitrogen under this TMDL, but allocations will be made to ensure nitrogen loads do not increase. 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 smaller livestock facilities and fertilizer applicators.

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 th enation to address many TMDLs relating to issues associated with morphometrically complex lakes and reservoirs (Mankin et al., 2003; Wang et al., 2005).

Big Hill Lake was segmented into three sections for the BATHTUB model, which included the upper lake (riverine area), middle lake (transitional area), and the Big Hill dam site (main basin). Atmospheric total nitrogen was obtained from the Clean Air Status and Trends Network (CASTNET), which is available at http://www.epa.gov/castnet/site.html. The CASTNET stations from the Konza Prairie (KS) and Cherokee Nation (OK) were averaged 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 from the main basin segment was averaged using the 1992-2007 data from KDHE. Model input data for the lake inflow tributary was estimated using averages from the USACE 1992 data from the Hwy 160 sampling point near the lake inlet, since this data reflects higher nutrient concentrations that most likely are representative of the inflowing stream as determined through best professional judgment. The input data for the upper and middle lake segments was taken from averages from the KBS 2006 data from the riverine and transitional sampling locations. The BATHTUB model was calibrated for the main basin and results (see Appendix A) estimate that the lake retains 73% of the TP and 55% of the TN load annually. A 35% TP reduction is necessary to achieve the endpoint of this TMDL for the main basin of Big Hill Lake.

Figure 13. Changes in Chlorophyll *a* in relation to TP loading reduction from the watershed.



Point Sources: A current Wasteload Allocation of zero is assigned for nitrogen and phosphorus under this TMDL because of the lack of point sources in the watershed. Should future sources be proposed in the watershed, the current wasteload allocations will be revised by adjusting current load allocations to account for the presence and impact of these new point source dischargers.

Nonpoint Sources: Nonpoint sources are the main contributor for the nutrient input and impairment in Big Hill Lake. Background levels may be attributed to nutrient recycling and leaf litter. The assessment suggest that runoff transporting nutrient loads associated with animal wastes and cultivated crops where fertilizer has been applied, to include pasture and hay, contribute to the fully eutrophic condition of the lake. Load Allocations for Big Hill Lake were calculated using the BATHTUB model (see Appendix A).

Table 13. Big Hill Lake Load Allocations

Description	Load Allocation (lbs/year)	**Load Allocation (lbs/day)***
TP Atmospheric Deposition	242	1.03
TP Nonpoint Source Load	2385	10.13
TP Margin of Safety	292	1.24
TP – Load Allocation	**2919**	**12.4**
TN Atmospheric Deposition	9812	61
TN Nonpoint Source Load	48245	301
TN Margin of Safety	6450	40
TN- Load Allocation	**64507**	**402**

* Refer to 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 original calculated total phosphorus and total nitrogen load allocations, which compensates for the lack of knowledge about the relationship between the allocated loadings and the resulting water quality. The margin of safety is expressed in Table 13.

State Water Plan Implementation Priority: Immediate actions by the stakeholders within the Big Hill Lake watershed are very likely to improve the trophic status of the lake with moderate efforts. Furthermore, since Big Hill Lake is utilized as a public water supply and for primary contact recreation, this TMDL will be a **High** Priority implementation.

Unified Watershed Assessment Priority Ranking: The Big Hill Lake watershed lies within the Middle Verdigris Subbasin (HUC 8: 11070103) with a priority ranking of 26 (Medium Priority for restoration work).

Priority HUC 11s: The HUC 11 encompasses the entire watershed and thus should take priority.

5. IMPLEMENTATION

Desired Implementation Activities: There is a very good potential that agricultural best management practices will improve the condition of Big Hill Lake. 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 Verdigris Basin WRAPS process to coordinate load reduction of nutrients to the lake.

Implementation Program Guidance:

Watershed Management Program – KDHE

a. Support new and ongoing Section 319 implementation and demonstration activities conducted under Verdigris Basin WRAPS projects focused on Big Hill Lake, 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. Support Watershed Restoration and Protection Strategy (WRAPS) efforts for Big Hill Lake.
e. Incorporate the provisions of this TMDL into WRAPS documents relating to Big Hill Lake.

Water Resource Cost Share and Nonpoint Source Pollution Control Programs – SCC

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.

Riparian Protection Program – SCC

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

Buffer Initiative Program – SCC

a. Install grass buffer strips near streams.
b. Leverage Conservation Reserve Enhancement 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 Verdigris Basin 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 2008-2015. Additional implementation may be required over 2016-2018 to achieve the endpoints of this TMDL.

Targeted Participants: Primary participants for implementation will be agricultural producers and stakeholders within the Big Hill Lake watershed. A detailed assessment of sources conducted over 2008-2009 should include local assessments by conservation district personnel and county extension agents to survey, locate, and assess the following within the lake drainage area:

1. Total row crop acreage
2. Cultivation alongside lake
3. Livestock use of riparian areas
4. Fields with manure applications

Milestone for 2013: The year 2013 marks the midpoint of the ten-year implementation window for the watershed. At that point in time, sampled data from Big Hill Lake will be reexamined to assess improved conditions in the lake. Should the impairment remain, adjustments to source assessment, allocation, and implementation activities may occur.

Delivery Agents: The primary delivery agents for program participation will be the Kansas Department of Health and Environment, the State Conservation Commission, the Natural Resources Conservation Service, the Kansas State University Extension Service, and the Verdigris Basin WRAPS teams. Producer outreach and awareness will be delivered by Kansas State Extension and/or coordinated through Verdigris Basin WRAPS teams. Implementation decisions and scheduling will be guided by planning documents prepared through Verdigris Basin WRAPS 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 Verdigris 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 Big Hill Lake. Based on the sampling results, the improved state of the lake will be evaluated in 2016. Should impairment status continue, the desired endpoints under this TMDL will be refined and more intensive sampling will be conducted over the period 2016-2018 to assess progress in this TMDL's implementation.

7. FEEDBACK

Public Meetings: Public Meetings to discuss TMDLs in the Verdigris Basin have been held since 2002. An active Internet Web site was established at http://www.kdheks.gov/tmdl/index.htm to convey information to the public on the general establishment of TMDLs in the Verdigris Basin and these specific TMDLs.

Public Hearing: A Public Hearing on these Verdigris Basin TMDLs will be held in Neodesha on July 23, 2008.

Basin Advisory Committee: The Verdigris Basin Advisory Committee met to discuss these TMDLs on September 25, 2007 in Eureka, February 27, 2008 in Independence, and on July 23, 2008 in Neodesha.

Milestone Evaluation: In 2013, evaluation will be made as to implementation of management practices to minimize the nonpoint source runoff contributing to this impairment. 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 2013 with consultation from the Verdigris Basin WRAPS teams.

Consideration for 303d Delisting: Big Hill Lake will be evaluated for delisting under Section 303d, based on the monitoring data over 2008-2015. Therefore, the decision for delisting will come about in the preparation of the 2016-303d 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 2008, 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 2008-2015.

Developed April 15, 2009

Bibliography

Carney, E.. 1992, 1995, 1998, 2001, 2004. Lake and Wetland Monitoring Program Annual Report/ Summary. Kansas Department of Health and Environment.

Dzialowski, A.R., S.H. Wang, N.C. Lim, W.W. Spotts and D.G. Huggins. 2005; Nutrient Limitation of Phytoplankton Growth in Central Plains Reservoirs, USA; Journal of Plankton Research; 27 (6): 587-595.

Mankin, K.R., S. Wang, J.K Koelliker, D.G. Huggins and F. deNoyelles, Jr., 2003. Watershed lake water quality modeling: verification and application. Journal of Soil and Water Conservation 58(4): 188-196.

Perry, C.A., D.M. Wolock and J.C. Artman, 2004. Estimates of Flow Duration, Mean Flow, and Peak-Discharge Frequency Values for Kansas Stream Location, USGS Scientific Investigations Report 2004-5033.

Soil and Water Conservation Society of Metro Halifax. 2007. The Blue-Green Algae (Cyanobacteria). Accessed on October 15, 2007 at http://lakes.chebucto.org/cyano.html.

Walker, W.W. Jr., 1996. Simplified prcedures for eutrophication assessment and prediction: user manual. Instructional Report W-96-2. U.S. Army Engineer Waterways Experiment Station. Vicksburg, MS.

Wang, S.H., D.G. Huggins, L. Frees, C.G. Volkman, N.C. Lim, D.S. Baker, V. Smith and F. deNoyelles, Jr., 2005. An integrated modeling approach to total watershed management: water quality and watershed management of Cheney Reservoir, Kansas, USA. Water and Air and Soil Pollution 164: 1-19.

Appendix A. BATHTUB Model Summary

Input Files – Current Condition

Global Variables	Mean	CV
Averaging Period (yrs)	1	0.0
Precipitation (m)	1.143	0.0
Evaporation (m)	1.3081	0.0
Storage Increase (m)	0	0.0

Atmos. Loads (kg/km^2-yr	Mean	CV
Conserv. Substance	0	0.00
Total P	10	0.10
Total N	665	0.14
Ortho P	10	0.10
Inorganic N	665	0.14

Model Options	Code	Description
Conservative Substance	0	NOT COMPUTED
Phosphorus Balance	1	2ND ORDER, AVAIL P
Nitrogen Balance	1	2ND ORDER, AVAIL N
Chlorophyll-a	1	P, N, LIGHT, T
Secchi Depth	1	VS. CHLA & TURBIDITY
Dispersion	1	FISCHER-NUMERIC
Phosphorus Calibration	2	CONCENTRATIONS
Nitrogen Calibration	2	CONCENTRATIONS
Error Analysis	1	MODEL & DATA
Availability Factors	1	USE FOR MODEL 1 ONLY
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	km^2	m	km	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Upper Lake	2	1	0.92	1.7	3.3	1.7	0.12	0	0	0.41	0	0	0	0	0	0	0
2	Middle Lake	3	1	2.1	5.35	3.1	4.8	0.12	7	0	0.53	0	0	0	0	0	0	0
3	Big Hill Dam	0	1	1.83	10.54	1.9	6	0.12	7	0	0.4	0.4	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	28	0.16	600	0.25	14	0.4	1.31	0.2	560	0.25	20	0.2	0	0	0	0
2	0	0	25	0.13	550	0.12	15.1	0.4	1.36	0.1	500	0.12	19.6	0.16	0	0	0	0
3	0	0	24	0.2	610	0.36	11	0.35	1.58	0.23	400	0.5	20	0.5	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	0.0	0.5	0.0	0.5	0.60	0.5	1	0	1	0	1	0	1	0	1	0
2	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0
3	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0

Tributary Data

				Dr Area	Flow (hm^3/yr)		Conserv.		Total P (ppb)		Total N (ppb)		Ortho P (ppb)		Inorganic N (ppb)	
Trib	Trib Name	Segment	Type	km^2	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Trib 1	1	1	91.78	25.2	0	0	0	108	0.5	1200	0.5	20	0	350	0.5

Model Coefficients	Mean	CV
Dispersion Rate	1.000	0.70
Total Phosphorus	0.850	0.45
Total Nitrogen	1.100	0.55
Chl-a Model	1.700	0.26
Secchi Model	1.100	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 (m^2/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

Predicted vs. Observed

Big Hill Lake Area Weighted Mean

Predicted & Observed Values Ranked Against CE Model Development Dataset

Segment: 4 Area-Wtd Mean

	Predicted Values--->			Observed Values--->		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	26.6	0.49	25.7%	25.2	0.16	23.8%
TOTAL N MG/M3	602.5	0.63	21.3%	582.1	0.24	19.8%
C.NUTRIENT MG/M3	21.7	0.42	26.7%	20.6	0.19	24.6%
CHL-A MG/M3	13.9	0.55	69.4%	13.3	0.38	67.6%
SECCHI M	1.4	0.26	62.9%	1.4	0.17	64.5%
ORGANIC N MG/M3	507.7	0.36	55.4%	473.6	0.27	49.9%
TP-ORTHO-P MG/M3	31.4	0.46	52.0%	19.8	0.30	33.1%
ANTILOG PC-1	211.3	0.78	45.5%	189.8	0.16	42.3%
ANTILOG PC-2	11.0	0.22	84.7%	11.0	0.18	84.7%
(N - 150) / P	17.1	0.96	50.4%	17.2	0.24	50.7%
INORGANIC N / P	94.8	3.43	87.8%	24.8	2.76	42.8%
TURBIDITY 1/M	0.5	0.13	37.3%	0.5	0.13	37.3%
ZMIX * TURBIDITY	2.1	0.19	30.9%	2.1	0.19	30.9%
ZMIX / SECCHI	3.3	0.26	27.1%	3.2	0.14	24.8%
CHL-A * SECCHI	18.9	0.33	80.9%	18.9	0.26	80.9%
CHL-A / TOTAL P	0.5	0.43	93.8%	0.5	0.26	94.1%
FREQ(CHL-a>10) %	57.6	0.56	69.4%	55.4	0.25	67.6%
FREQ(CHL-a>20) %	18.6	1.25	69.4%	17.0	0.57	67.6%
FREQ(CHL-a>30) %	6.3	1.78	69.4%	5.6	0.83	67.6%
FREQ(CHL-a>40) %	2.4	2.21	69.4%	2.0	1.04	67.6%
FREQ(CHL-a>50) %	1.0	2.57	69.4%	0.8	1.22	67.6%
FREQ(CHL-a>60) %	0.5	2.89	69.4%	0.4	1.38	67.6%
CARLSON TSI-P	51.3	0.13	25.7%	50.7	0.03	23.8%
CARLSON TSI-CHLA	56.3	0.09	69.4%	55.9	0.04	67.6%
CARLSON TSI-SEC	55.4	0.07	37.1%	54.9	0.03	35.5%

Predicted vs. Observed

Big Hill Lake Main Basin

Segment:	**3**	**Big Hill Dam**				
	Predicted Values--->			**Observed Values--->**		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	22.4	0.47	19.9%	24.0	0.20	22.1%
TOTAL N MG/M3	546.5	0.60	17.2%	610.0	0.36	21.9%
C.NUTRIENT MG/M3	18.5	0.41	20.6%	20.3	0.26	24.1%
CHL-A MG/M3	11.5	0.52	60.3%	11.0	0.35	58.1%
SECCHI M	1.6	0.30	69.8%	1.6	0.23	69.2%
ORGANIC N MG/M3	448.7	0.32	45.7%	400.0	0.50	37.0%
TP-ORTHO-P MG/M3	25.8	0.43	43.7%	20.0	0.50	33.5%
ANTILOG PC-1	151.8	0.71	35.7%	151.3	0.32	35.6%
ANTILOG PC-2	10.9	0.28	84.3%	10.1	0.30	80.6%
(N - 150) / P	17.7	0.94	52.5%	19.2	0.52	57.0%
INORGANIC N / P	97.8	2.94	88.5%	52.5	3.42	71.7%
TURBIDITY 1/M	0.4	0.40	31.6%	0.4	0.40	31.6%
ZMIX * TURBIDITY	2.4	0.42	36.3%	2.4	0.42	36.3%
ZMIX / SECCHI	3.7	0.32	33.9%	3.8	0.25	34.8%
CHL-A * SECCHI	18.4	0.42	79.7%	17.4	0.42	77.4%
CHL-A / TOTAL P	0.5	0.41	93.5%	0.5	0.40	90.9%
FREQ(CHL-a>10) %	46.5	0.71	60.3%	43.8	0.50	58.1%
FREQ(CHL-a>20) %	11.4	1.43	60.3%	10.1	1.00	58.1%
FREQ(CHL-a>30) %	3.1	1.92	60.3%	2.7	1.34	58.1%
FREQ(CHL-a>40) %	1.0	2.28	60.3%	0.8	1.60	58.1%
FREQ(CHL-a>50) %	0.4	2.58	60.3%	0.3	1.81	58.1%
FREQ(CHL-a>60) %	0.1	2.83	60.3%	0.1	1.99	58.1%
CARLSON TSI-P	49.0	0.14	19.9%	50.0	0.06	22.1%
CARLSON TSI-CHLA	54.5	0.09	60.3%	54.1	0.06	58.1%
CARLSON TSI-SEC	53.2	0.08	30.2%	53.4	0.06	30.8%

Model Output
Overall Water and Nutrient Balances - Current Condition

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	Trib 1	91.8	25.2	0.00E+00	0.00	0.27
PRECIPITATION				4.8	5.5	0.00E+00	0.00	1.14
TRIBUTARY INFLOW				91.8	25.2	0.00E+00	0.00	0.27
***TOTAL INFLOW				96.6	30.7	0.00E+00	0.00	0.32
ADVECTIVE OUTFLOW				96.6	24.4	0.00E+00	0.00	0.25
***TOTAL OUTFLOW				96.6	24.4	0.00E+00	0.00	0.25
***EVAPORATION					6.3	0.00E+00	0.00	

Overall Mass Balance Based Upon Component: Predicted AVAILABLE 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	Trib 1	1870.8	94.5%	2.02E+05	99.9%	0.24	74.2	20.4
PRECIPITATION				109.6	5.5%	1.20E+02	0.1%	0.10	19.8	22.6
TRIBUTARY INFLOW				1870.8	94.5%	2.02E+05	99.9%	0.24	74.2	20.4
***TOTAL INFLOW				1980.5	100.0%	2.02E+05	100.0%	0.23	64.4	20.5
ADVECTIVE OUTFLOW				545.3	27.5%	6.53E+04		0.47	22.4	5.6
***TOTAL OUTFLOW				545.3	27.5%	6.53E+04		0.47	22.4	5.6
***RETENTION				1435.1	72.5%	2.09E+05		0.32		

Overflow Rate (m/yr)	5.0	Nutrient Resid. Time (yrs)	0.4315
Hydraulic Resid. Time (yrs)	1.3151	Turnover Ratio	2.3
Reservoir Conc (mg/m3)	27	Retention Coef.	0.725

Overall Mass Balance Based Upon Component: Predicted AVAILABLE 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	Trib 1	24809.4	84.8%	1.54E+08	99.7%	0.50	984.5	270.3
PRECIPITATION				4450.8	15.2%	3.88E+05	0.3%	0.14	802.9	917.7
TRIBUTARY INFLOW				24809.4	84.8%	1.54E+08	99.7%	0.50	984.5	270.3
***TOTAL INFLOW				29260.2	100.0%	1.54E+08	100.0%	0.42	951.8	302.8
ADVECTIVE OUTFLOW				13334.9	45.6%	6.44E+07		0.60	546.5	138.0
***TOTAL OUTFLOW				13334.9	45.6%	6.44E+07		0.60	546.5	138.0
***RETENTION				15925.4	54.4%	1.38E+08		0.74		

Overflow Rate (m/yr)	5.0	Nutrient Resid. Time (yrs)	0.6607
Hydraulic Resid. Time (yrs)	1.3151	Turnover Ratio	1.5
Reservoir Conc (mg/m3)	603	Retention Coef.	0.544

Model Output with 35% TP Concentration Reductions at Inflow

Predicted vs. Observed

Big Hill Lake Area-Weighted Mean

Predicted & Observed Values Ranked Against CE Model Development Dataset

Segment: 4 Area-Wtd Mean

	Predicted Values--->			Observed Values--->		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	20.4	0.49	17.1%	25.2	0.16	23.8%
TOTAL N MG/M3	602.5	0.63	21.3%	582.1	0.24	19.8%
C.NUTRIENT MG/M3	17.9	0.42	19.4%	20.6	0.19	24.6%
CHL-A MG/M3	11.2	0.56	58.8%	13.3	0.38	67.6%
SECCHI M	1.5	0.25	67.1%	1.4	0.17	64.5%
ORGANIC N MG/M3	445.8	0.34	45.2%	473.6	0.27	49.9%
TP-ORTHO-P MG/M3	26.6	0.44	45.0%	19.8	0.30	33.1%
ANTILOG PC-1	152.2	0.76	35.8%	189.8	0.16	42.3%
ANTILOG PC-2	10.3	0.24	81.4%	11.0	0.18	84.7%
(N - 150) / P	22.2	0.96	65.3%	17.2	0.24	50.7%
INORGANIC N / P	156.7	2.28	95.3%	24.8	2.76	42.8%
TURBIDITY 1/M	0.5	0.13	37.3%	0.5	0.13	37.3%
ZMIX * TURBIDITY	2.1	0.19	30.9%	2.1	0.19	30.9%
ZMIX / SECCHI	3.1	0.24	22.8%	3.2	0.14	24.8%
CHL-A * SECCHI	16.7	0.37	75.7%	18.9	0.26	80.9%
CHL-A / TOTAL P	0.5	0.35	94.7%	0.5	0.26	94.1%
FREQ(CHL-a>10) %	44.4	0.77	58.8%	55.4	0.25	67.6%
FREQ(CHL-a>20) %	10.7	1.56	58.8%	17.0	0.57	67.6%
FREQ(CHL-a>30) %	3.0	2.12	58.8%	5.6	0.83	67.6%
FREQ(CHL-a>40) %	1.0	2.56	58.8%	2.0	1.04	67.6%
FREQ(CHL-a>50) %	0.4	2.92	58.8%	0.8	1.22	67.6%
FREQ(CHL-a>60) %	0.1	3.23	58.8%	0.4	1.38	67.6%
CARLSON TSI-P	47.5	0.14	17.1%	50.7	0.03	23.8%
CARLSON TSI-CHLA	54.2	0.10	58.8%	55.9	0.04	67.6%
CARLSON TSI-SEC	54.1	0.07	32.9%	54.9	0.03	35.5%

Model Output with 35% TP Concentration Reductions at Inflow

Big Hill Lake Main Basin

Segment:	**3**	**Big Hill Dam**				
	Predicted Values--->			**Observed Values--->**		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	18.0	0.47	13.8%	24.0	0.20	22.1%
TOTAL N MG/M3	546.5	0.60	17.2%	610.0	0.36	21.9%
C.NUTRIENT MG/M3	15.8	0.40	15.4%	20.3	0.26	24.1%
CHL-A MG/M3	9.6	0.53	51.3%	11.0	0.35	58.1%
SECCHI M	1.7	0.30	72.9%	1.6	0.23	69.2%
ORGANIC N MG/M3	406.8	0.31	38.2%	400.0	0.50	37.0%
TP-ORTHO-P MG/M3	22.5	0.43	38.2%	20.0	0.50	33.5%
ANTILOG PC-1	117.2	0.70	28.7%	151.3	0.32	35.6%
ANTILOG PC-2	10.3	0.30	81.6%	10.1	0.30	80.6%
(N - 150) / P	22.1	0.94	65.0%	19.2	0.52	57.0%
INORGANIC N / P	139.8	2.20	94.0%	52.5	3.42	71.7%
TURBIDITY 1/M	0.4	0.40	31.6%	0.4	0.40	31.6%
ZMIX * TURBIDITY	2.4	0.42	36.3%	2.4	0.42	36.3%
ZMIX / SECCHI	3.5	0.32	29.7%	3.8	0.25	34.8%
CHL-A * SECCHI	16.5	0.46	75.3%	17.4	0.42	77.4%
CHL-A / TOTAL P	0.5	0.35	94.3%	0.5	0.40	90.9%
FREQ(CHL-a>10) %	35.6	0.89	51.3%	43.8	0.50	58.1%
FREQ(CHL-a>20) %	6.8	1.67	51.3%	10.1	1.00	58.1%
FREQ(CHL-a>30) %	1.6	2.19	51.3%	2.7	1.34	58.1%
FREQ(CHL-a>40) %	0.5	2.58	51.3%	0.8	1.60	58.1%
FREQ(CHL-a>50) %	0.2	2.89	51.3%	0.3	1.81	58.1%
FREQ(CHL-a>60) %	0.1	3.15	51.3%	0.1	1.99	58.1%
CARLSON TSI-P	45.8	0.15	13.8%	50.0	0.06	22.1%
CARLSON TSI-CHLA	52.8	0.10	51.3%	54.1	0.06	58.1%
CARLSON TSI-SEC	52.2	0.08	27.1%	53.4	0.06	30.8%

Model Output with 35% TP Concentration Reductions at Inflow

Overall Water and Nutrient Balances – Reflects TP Load Reductions

Overall Water & Nutrient Balances

Overall Water Balance — **Averaging Period = 1.00 years**

Trb	Type	Seg	Name	Area km^2	Flow hm^3/yr	Variance (hm3/yr)^2	CV -	Runoff m/yr
1	1	1	Trib 1	91.8	25.2	0.00E+00	0.00	0.27
PRECIPITATION				4.8	5.5	0.00E+00	0.00	1.14
TRIBUTARY INFLOW				91.8	25.2	0.00E+00	0.00	0.27
***TOTAL INFLOW				96.6	30.7	0.00E+00	0.00	0.32
ADVECTIVE OUTFLOW				96.6	24.4	0.00E+00	0.00	0.25
***TOTAL OUTFLOW				96.6	24.4	0.00E+00	0.00	0.25
***EVAPORATION					6.3	0.00E+00	0.00	

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

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance (kg/yr)^2	%Total	CV	Conc mg/m^3	Export kg/km^2/yr
1	1	1	Trib 1	1214.4	91.7%	8.47E+04	99.9%	0.24	48.2	13.2
PRECIPITATION				109.6	8.3%	1.20E+02	0.1%	0.10	19.8	22.6
TRIBUTARY INFLOW				1214.4	91.7%	8.47E+04	99.9%	0.24	48.2	13.2
***TOTAL INFLOW				1324.0	100.0%	8.48E+04	100.0%	0.22	43.1	13.7
ADVECTIVE OUTFLOW				438.1	33.1%	4.21E+04		0.47	18.0	4.5
***TOTAL OUTFLOW				438.1	33.1%	4.21E+04		0.47	18.0	4.5
***RETENTION				885.9	66.9%	9.55E+04		0.35		

Overflow Rate (m/yr)	5.0	Nutrient Resid. Time (yrs)	0.4934
Hydraulic Resid. Time (yrs)	1.3151	Turnover Ratio	2.0
Reservoir Conc (mg/m3)	20	Retention Coef.	0.669

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

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance (kg/yr)^2	%Total	CV	Conc mg/m^3	Export kg/km^2/yr
1	1	1	Trib 1	24809.4	84.8%	1.54E+08	99.7%	0.50	984.5	270.3
PRECIPITATION				4450.8	15.2%	3.88E+05	0.3%	0.14	802.9	917.7
TRIBUTARY INFLOW				24809.4	84.8%	1.54E+08	99.7%	0.50	984.5	270.3
***TOTAL INFLOW				29260.2	100.0%	1.54E+08	100.0%	0.42	951.8	302.8
ADVECTIVE OUTFLOW				13334.9	45.6%	6.44E+07		0.60	546.5	138.0
***TOTAL OUTFLOW				13334.9	45.6%	6.44E+07		0.60	546.5	138.0
***RETENTION				15925.4	54.4%	1.38E+08		0.74		

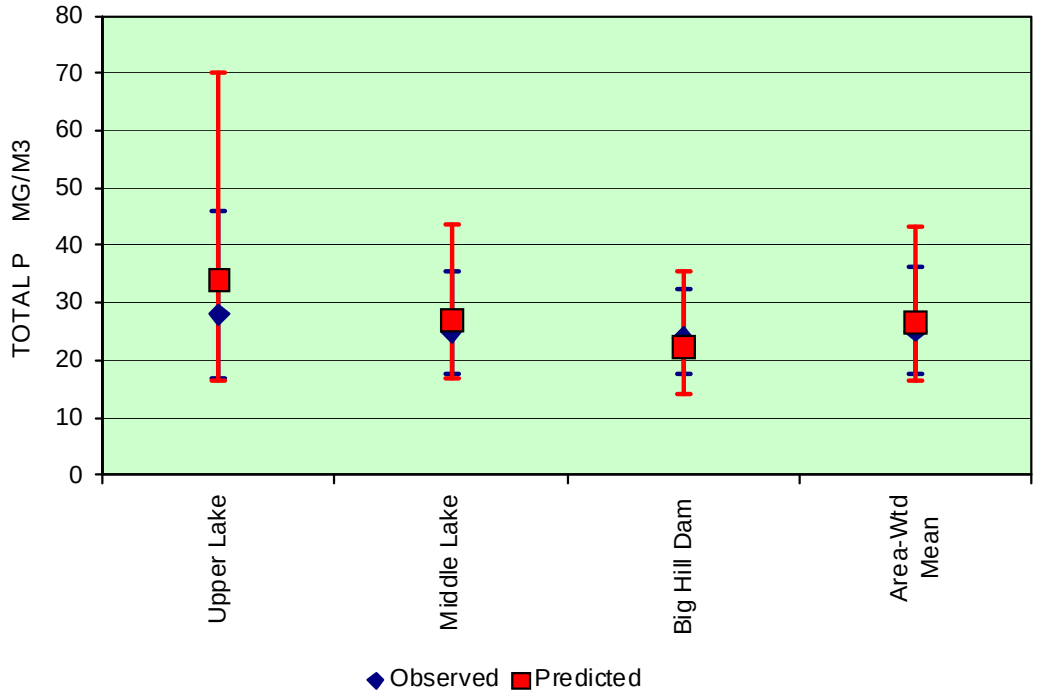
Overflow Rate (m/yr)	5.0	Nutrient Resid. Time (yrs)	0.6607
Hydraulic Resid. Time (yrs)	1.3151	Turnover Ratio	1.5
Reservoir Conc (mg/m3)	603	Retention Coef.	0.544

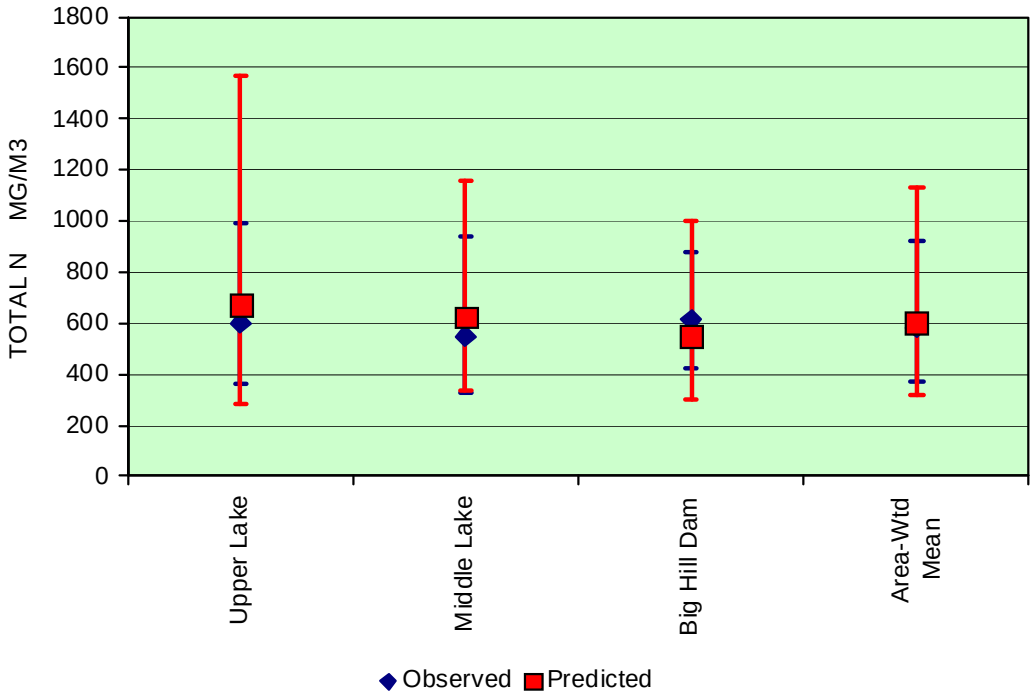
Goodness of Fit (Calibration/Validation)

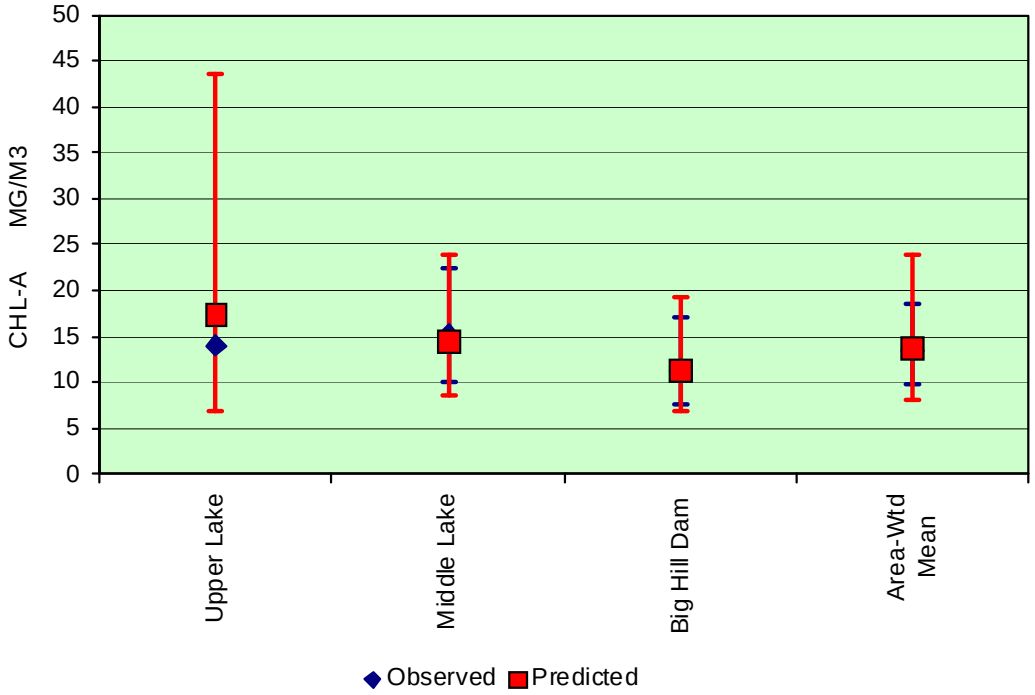
T= Student's t-Statistic testing for significant difference between Observed & Predicted Means using three alternative measures of error: observed error only, T(1); error typical of model development data set, T(2); and observed and predicted error, T(3). Tests of model applicability are normally based upon T(2) and T(3). However, if an appropriate sedimentation model is selected, T(1) can be then used as a basis for deciding whether calibration is appropriate.

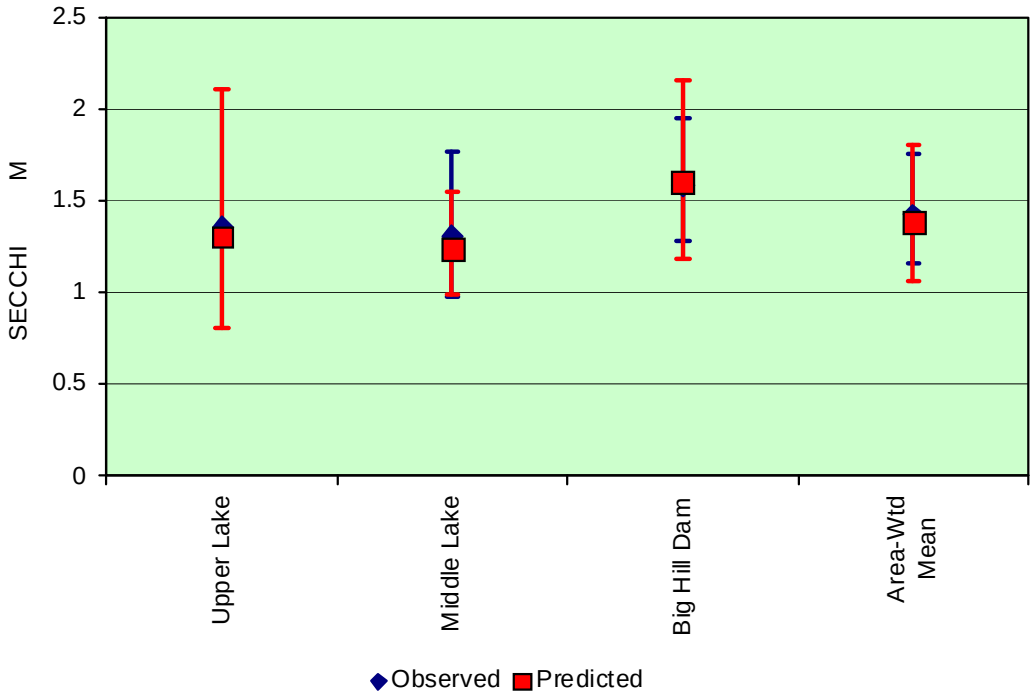
The BATHTUB model was calibrated for the main basin (Big Hill Dam) and calibrated for TP, TN, Chlorophyll *a*, and Secchi Depth. The appropriate model options within BATHTUB were selected and the calibration factors were adjusted to calibrate the simulated values closer to the observed values (for the calibrated parameters) for the main basin. Organic N and Organic P values are inputs to the BATHTUB model. KDHE does not directly measure Organic N, however this is calculated from TKN-NH3 for the KDHE data. KBS did measure Organic N and Organic P. Total P – Ortho P was estimated as KDHE does have Ortho P data but it is all below the detection limit.

BATHTUB Modeling Results: Error bar plots (mean $\pm$ standard deviation of TN < TP, Chla, Secchi depth parameters estimated by BATHTUB model.




1800
1600
1400
1200
1000
800
600
400
200
0
TOTAL N MG/M3
Upper Lake
Middle Lake
Big Hill Dam
Area-Wtd Mean
Observed
Predicted


50
45
40
35
30
25
20
15
10
5
0
CHL-A MG/M3
Upper Lake
Middle Lake
Big Hill Dam
Area-Wtd Mean
Observed
Predicted


2.5
2
1.5
1
0.5
0
SECCHI M
Upper Lake
Middle Lake
Big Hill Dam
Area-Wtd Mean
Observed
Predicted

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	CV	$e^{[Z\sigma - 0.5\sigma^2]}$	MDL	LA	MOS (10%)
TP	2919 lbs/yr	0.2	1.55	12.40 lbs/day	11.16 lbs/day	1.24 lbs/day
TN	64,507 lbs/yr	0.4	2.273	402 lbs/day	361.8 lbs/day	40.2 lbs/day

Maximum Daily Load Calculation

Annual TP Load = 2919 lbs/yr

Maximum Daily TP Load = [(2919 lbs/yr)/(365 days/yr)]*$e^{[2.326*(0.198)-0.5*(0.198)^2]}$
= 12.40 lbs/day

Annual TN Load = 64,507 lbs/yr

Maximum Daily TN Load = [(64507 lbs/yr)/(365 days/yr)]*$e^{[2.326*(0.385)-0.5*(0.385)^2]}$
= 402 lbs/day

Margin of Safety (MOS) for Daily Load

Annual TP MOS = 292 lbs/yr

Daily TP MOS = [(292 lbs/yr)/(365 days/yr)]*$e^{[2.326*(0.198)-0.5*(0.198)^2]}$
= 1.56 lbs/day

Annual TN MOS = 6450 lbs/yr

Daily TN MOS = [(6450 lbs/yr)/(365 days/yr)]*$e^{[2.326*(0.385)-0.5*(0.385)^2]}$
= 40.2 lbs/day

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