VERDIGRIS BASIN TOTAL MAXIMUM DAILY LOAD

Waterbody / Assessment Unit (AU): Elk City Lake

Water Quality Impairment: Eutrophication bundled with Siltation

1. INTRODUCTIONS AND PROBLEM IDENTIFICATION

Subbasin:	Elk
County:	Montgomery
HUC 8 (HUC 11):	11070104 (010, 020, 030)
Ecoregion:	Central Irregular Plains, Osage Cuestas (40b); Central Oklahoma / Texas, Cross Timbers (29a)
Drainage Area:	634 Square Miles
Conservation Pool:	Surface Area = 4400 acres (6.875 square miles) Watershed / Lake Ratio = 86:1 Maximum Depth = 8.0 meters Mean Depth = 3.2 meters Storage Volume = 46,053 acre-feet Estimated Retention Time = ~0.19 years Mean Annual Discharge = 365,052 ac-ft/yr Year Constructed: 1966
Designated Uses:	Primary Contact Recreation (A); Expected Aquatic Life Support; Domestic Water Supply; Food Procurement; Ground Water Recharge; Industrial Water Supply; Irrigation Use; Livestock Watering Use.
303(d) Listings:	2002, 2004, & 2008 Verdigris River Basin Lakes
Impaired Use:	All uses are impaired to a degree by eutrophication
Water Quality Standard:	Nutrients – Narratives: 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)).

Suspended Solids – Narrative: Suspended solids added to surface waters by artificial sources shall not interfere with the behavior, reproduction, physical habitat or other factors related to the survival and propagation of aquatic or semi-aquatic or terrestrial wildlife (K.A.R. 28-16-28e(c)(2)(B)).

2. CURRENT WATER QUALITY CONDITION AND DESIRED ENDPOINT

Level of Eutrophication:

Recent Average (1995-2007): Trophic State Index = 60.5, Very Eutrophic
Chlorophyll *a* = 22.64

Current Condition (2007): Trophic State Index = 64.9, Hypereutrophic
Chlorophyll *a* = 33.0

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

Level of Siltation Impairment: Elk City Lake has high inorganic turbidity and high levels of siltation.

Lake Chemistry Monitoring Sites: KDHE Station LM025001 in Elk City Lake.
Period of Record Used: Ten surveys conducted by KDHE in calendar years; 1976, 1979, 1986, 1989, 1992, 1995, 1998, 2001, 2004, and 2007.

Lake Inflow and Outflow Data: U.S. Army Corps of Engineers, Tulsa District Office
Period of Record Used: 1995-2007.

Stream Chemistry Monitoring Sites (Period of Record Used):
Station 573 on Elk River near Elk City, fixed site (1990-2007)

Hydrologic Conditions: The Elk River, Card Creek, and Chetopa Creek flow into Elk City Lake. The estimated flow durations and mean flows of these streams are illustrated in Table 1a (Perry, 2004). The location of the inflowing stream segments and USGS information provided in Table 1a is also available on the web at: http://ks.water.usgs.gov/studies/strmstats/ks/mg/index.php?test=flowdur.

Table 1a. Elk City Lake receiving streams Estimated Flow (Q) durations in cfs as calculated by USGS using multiple regression techniques (Perry, 2004).

Inflow	USGS Site ID	CUSEGA	90%	75%	50%	25%	10%	Mean Q	Mean Q in hm^3/year	Drainage Area $mile^2$
Elk River	4967	110701041	4.95	15.2	72.8	247	736	400	357	583
Card Cr	5071	1107010419	0	0.93	3.53	9.48	22.5	14.9	13.3	14.5
Chetopa Cr	5082	1107010418	0	0	0.55	3.15	11.3	10.5	9.38	13.2

According to the USGS Lake Hydro data, the mean runoff in the watershed is 8.0 inches/year; the mean precipitation in the watershed is 36.8 inches/year and the mean loss due to evaporation for the Lake is 53.1 inches/year. The U.S. Corps of Engineers (USACE) data indicates the calculated mean annual outflow for the lake is 365,052 acre-feet and the mean annual inflow is 381,577 acre-feet over the period from 1995-2007.

Figure 1. Summary of Elk City annual inflow and outflow (USACE).

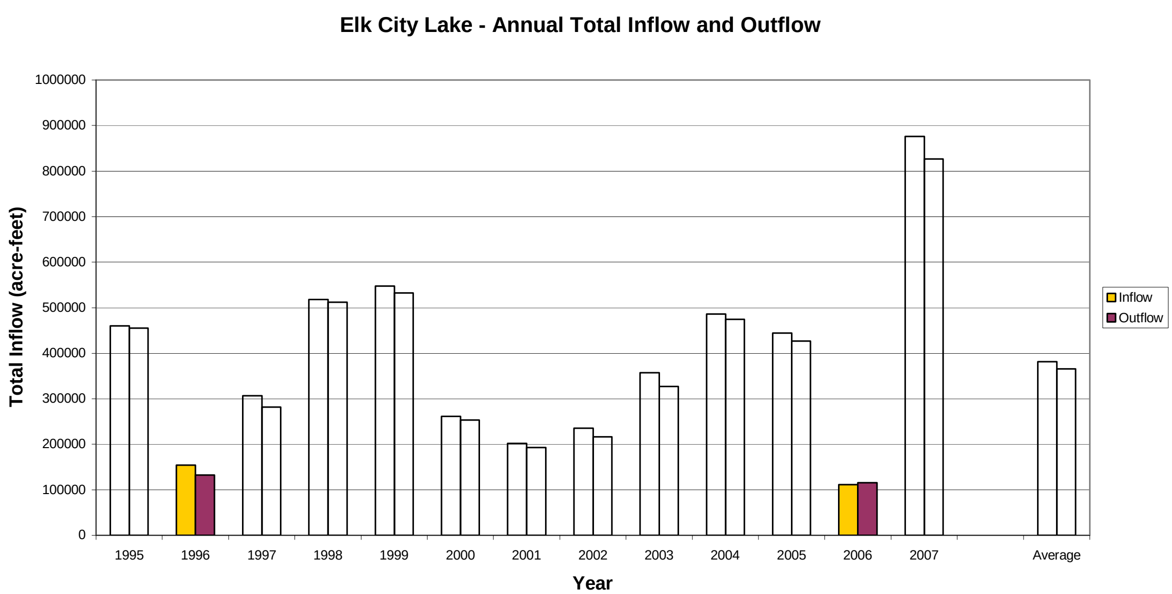
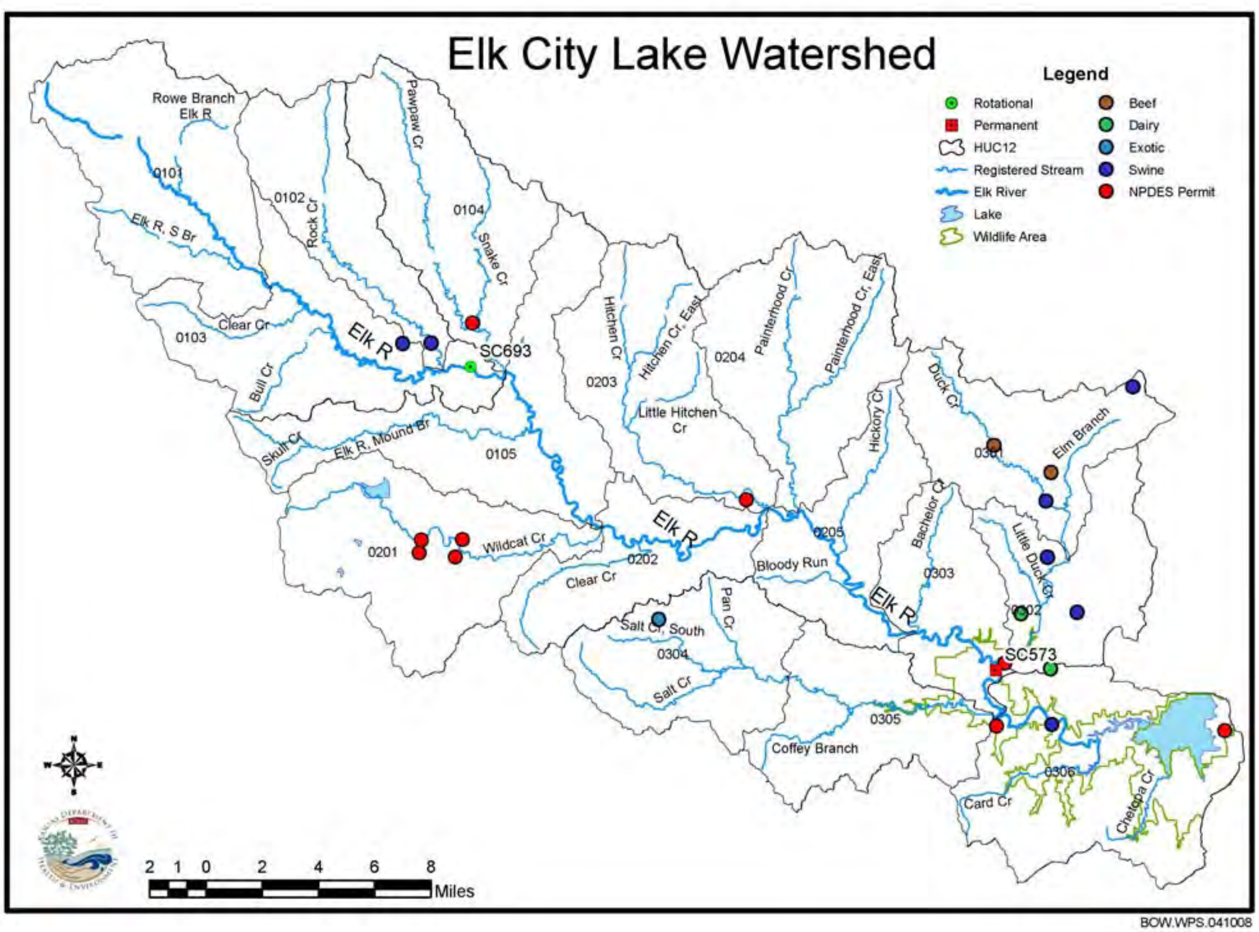


Table 1b. KDHE Stream Chemistry Data averages within the Elk City Lake watershed for the years that coincided with the years Elk City Lake was sampled.

Stream Station	Total P (µg/L)	Total N (µg/L)	Ortho P (µg/L)	TKN (µg/L)	TSS (mg/L)	Turbidity (NTU)
SC573, Elk River	91	827	10	540	62	37

* - Ortho P concentrations are estimated as data was below the detection limits

Figure 2. Elk City Lake Watershed area base map.



Current Conditions: The chlorophyll *a* (chl-a) concentration average over the period of record is 14.1 µg/L. Annual concentration averages exceeded 10 µg/L in the sampling years of 1995, 2001, 2004, and 2007, with the maximum yearly average of 33.0 µg/L occurring in 2007. The more recent chlorophyll *a* concentration average for KDHE samples obtained from 1995-2007 is 22.6 µg/L.

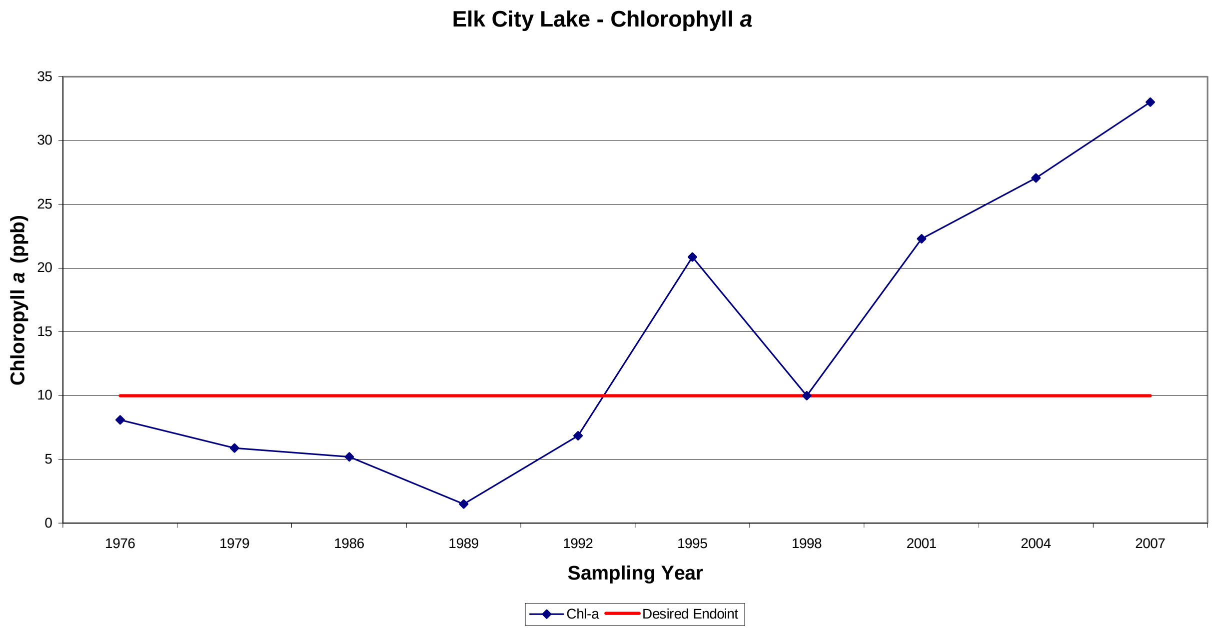
The average secchi depth is 0.33 meters, with the lowest reading of 0.2 occurring in 1989 and a maximum depth reading of 0.49 meters occurring in 2004. The average turbidity value in Elk City Lake is 43.05 NTU, ranging from a low of 15.5 NTU in 2001 to a high of 94 NTU in 1989. The turbidity average has decreased to 30.19 NTU for samples obtained since 1995. The average Total Suspended Solids concentration within Elk City Lake is 32.2 mg/L over the entire period of record with a more recent average of 28.2 mg/L for samples obtained since 1995.

The average total nitrogen (TN) and total phosphorus (TP) concentrations are 0.73 mg/L and 0.085 mg/L, respectively. The maximum TP concentration of 0.175 mg/L was detected in 1989. Data for calculating TN is not available prior to the 1992 sampling event and a maximum TN detection of 0.73 mg/L occurred in 1998.

Table 2. KDHE Sampling results from Elk City Lake.

Sample Date	Sample Time	Chl-a (µg/L)	TN (mg/L)	TP (mg/L)	TN:TP ratio	Secchi Depth (m)	Turbidity (NTU)
6/17/1976	NA	8.1	NA	NA	NA	NA	44
6/4/1979	NA	5.9	NA	0.05	NA	NA	46
8/18/1986	1340	5.2	NA	0.09	NA	NA	41.5
6/7/1989	1015	1.5	NA	0.175	NA	0.2	94
8/11/1992	0930	6.9	0.36	0.1	3.6	NA	54
7/31/1995	1325	20.9	1.02	0.075	13.62	0.35	17
6/22/1998	1720	10.0	1.47	0.097	15.19	0.22	34
7/23/2001	1715	22.3	0.14	0.052	2.60	0.37	15.5
8/9/2004	1620	27.1	0.50	0.049	10.28	0.49	37.9
9/4/2007	1535	33.0	0.92	0.081	11.45	0.34	46.55
Average – All Data		14.1	0.73	0.085	9.46	0.33	43.05
Avg. 1995-2007		22.6	0.81	0.071	10.63	0.35	30.19

Figure 3. Chlorophyll *a* concentrations at Elk City Lake for years sampled by KDHE.



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). Elk City Lake was nitrogen limited in 1992 and 2001; and co-limited by nitrogen and phosphorus for the sampling years of 1995, 1998, 2004, and 2007. Chlorophyll *a* concentrations averaged 14.6 µg/L (years of 1992 and 2001) when the lake was limited by nitrogen and 22.7 µg/L (years of 1995, 1998, 2004, and 2007) when the lake displayed co-limiting characteristics.

Table 3 lists six metrics measuring the roles of light and nutrient in Elk City 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 1.0 m^{-1} indicate inorganic turbidity assumes greater influence on water clarity but would not assume a significant limiting role until values exceed 1.0 m^{-1}.

The depth of the mixed layer in meters (Z) multiplied by the NAT values 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, as seen in Elk City Lake, 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 > 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.

Table 3. Limiting factor determinations for Elk City 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		4.99	15.95	0.3	0.01	16	
1992	3.6				0.069		
1995	13.65	2.86	9.14	7.30	0.28	9.14	
1998	15.2	4.54	14.54	2.2	0.10	14.55	9.76
2001	2.60	2.7	10.26	8.25	0.43	10.27	9.69
2004	10.28	2.04	8.57	13.25	0.55	8.57	9.68
2007	11.45	2.94	11.17	11.22	0.41	11.18	

Values of algal use of phosphorus supply (Chl-a/TP) that are greater than 0.4 indicates a strong algal response to changes in phosphorus levels, where values < 0.13 indicates 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 (Carney, 2004).

The above metrics conclude that Elk City Lake generally has high levels of inorganic turbidity (suspended silt/clay particles), there is a lack of light availability in the mixed layer, inorganic turbidity limits light in the water column, and self-shading of algae does not significantly impede productivity. Two of the metrics (Zmix*NAT and Chl-a*SD) indicate there is a low to moderate response by algae to nutrient inputs, however the Chl-a/TP metric indicates a moderate to strong response to changes in phosphorus levels. According to these metrics Elk City Lake is typically limited by light, nitrogen, and phosphorus (co-limited).

Another method for evaluating limiting factors is the TSI deviation metrics. Figure 4 (Multivariate Deviation Graph) summarizes the current trophic conditions at Elk City Lake using a multivariate TSI comparison chart for data obtained by KDHE throughout the period of record for years when the secchi depth was measured. Where TSI(Chl-a) is greater than TSI(TP), the situation indicates phosphorus is limiting chlorophyll *a*, wherea 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 4, Elk City Lake is generally limited by non-algal turbidity, light, nitrogen, and phosphorus.

Figure 4. Multivariate TSI comparison chart for Elk City Lake.

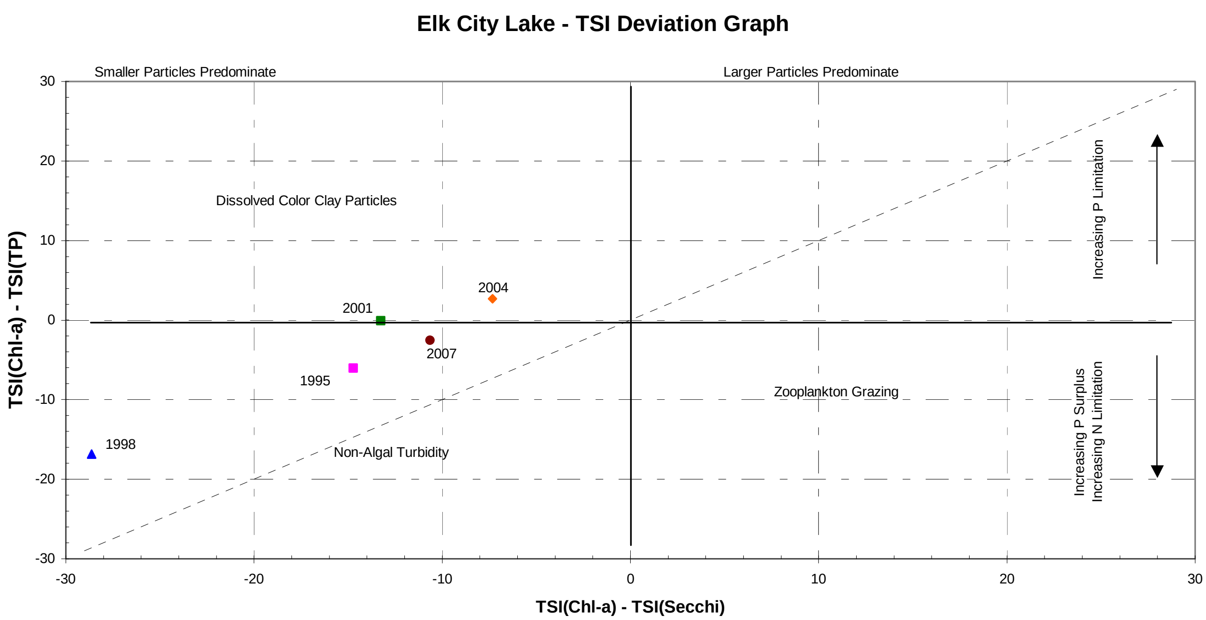
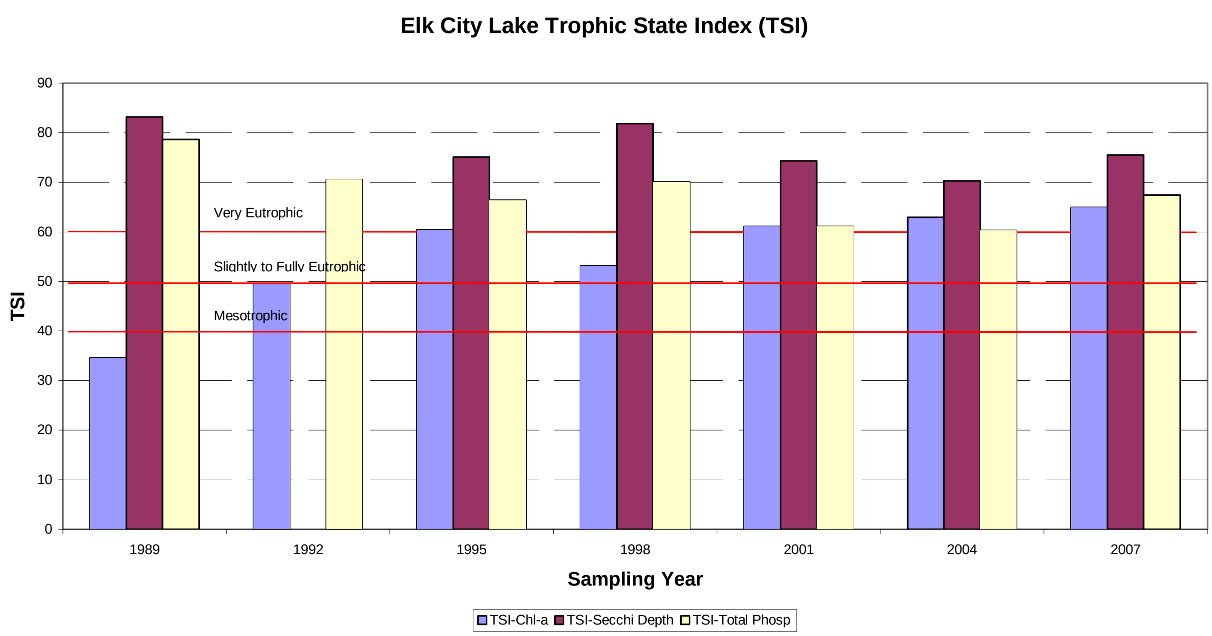


Table 4 summarizes median trophic conditions within Elk City Lake in relation to other federal lakes in the state. The median trophic indicator values within Elk City Lake do not meet any of the statewide benchmarks and is considerably worse than other lakes within the Central Great Plains ecoregion. In comparison to other federal lakes, the median nutrient concentrations are similar but the median secchi depth and chlorophyll *a* values are significantly worse.

Table 4. Median trophic indicator values of Elk City Lake (KDHE data 1995-2007) 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 and 2002 (Dodds et al., 2006).

Trophic Indicator	**Elk City Lake**	Federal Lakes	Central Great Plains	Statewide Benchmark
Secchi Depth (cm)	**35**	95	117	129
TN (µg/L)	**921.5**	903	695	625
TP (µg/L)	**75.0**	76	44	23
Chl-a (µg/L)	**22.3**	12	11	8

Figure 5. Trophic State Indices in Elk City Lake for KDHE sampling years.



Common water quality patterns observed in Elk City Lake are shown in Figures 6, 7, 8, and 9. In general there are negative relationships between; Turbidity and chlorophyll *a*; turbidity and secchi depth; chlorophyll *a* and total phosphorus; secchi depth and total nitrogen; and total phosphorus and secchi depth. There are positive relationships between: turbidity and total phosphorus; chlorophyll *a* and secchi depth; total phosphorus and total nitrogen; and total nitrogen and the TN:TP ratio. The relationships between turbidity and total phosphorus and the between chlorophyll *a* and total phosphorus help illustrate the complexity of the impairment issues governing Elk City Lake. The data suggests that higher total phosphorus concentrations result in higher turbidity, which contributes to the siltation impairment of the lake. Whereas, the lower total phosphorus concentrations and lower turbidity in the lake results in higher chlorophyll *a* concentrations, which contributes to the eutrophication impairment of the lake. As light penetrates the lake during less turbid conditions the algal production increases, which reflects primary algal production activities that contribute to the eutrophication of the lake. When runoff or wet conditions prevail, turbid conditions would likely exist causing microbial processes to govern Elk City Lake's water quality.

Figure 6. Common Water Quality relationships between Turbidity and other common parameters (1976-2007). LN indicates data was natural log transformed.

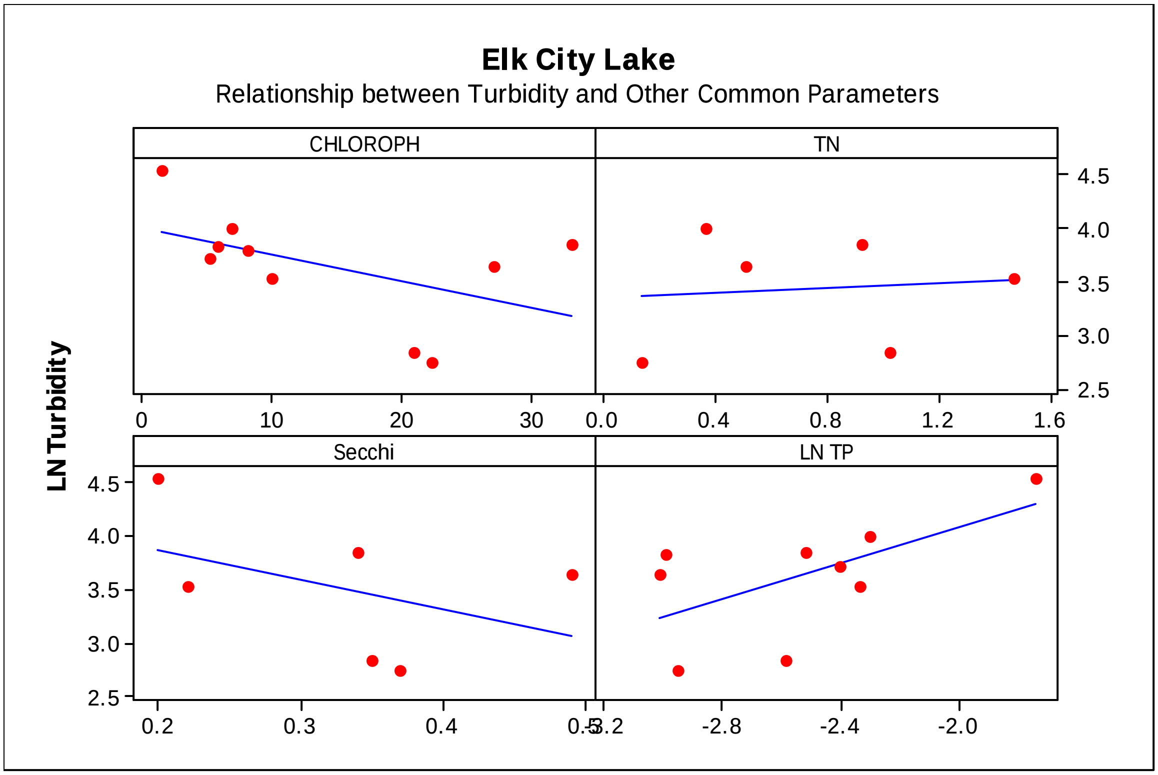


Figure 7. Common Water Quality relationships between Chlorophyll *a* and other common parameters (1979-2007). LN indicates data was natural log transformed.

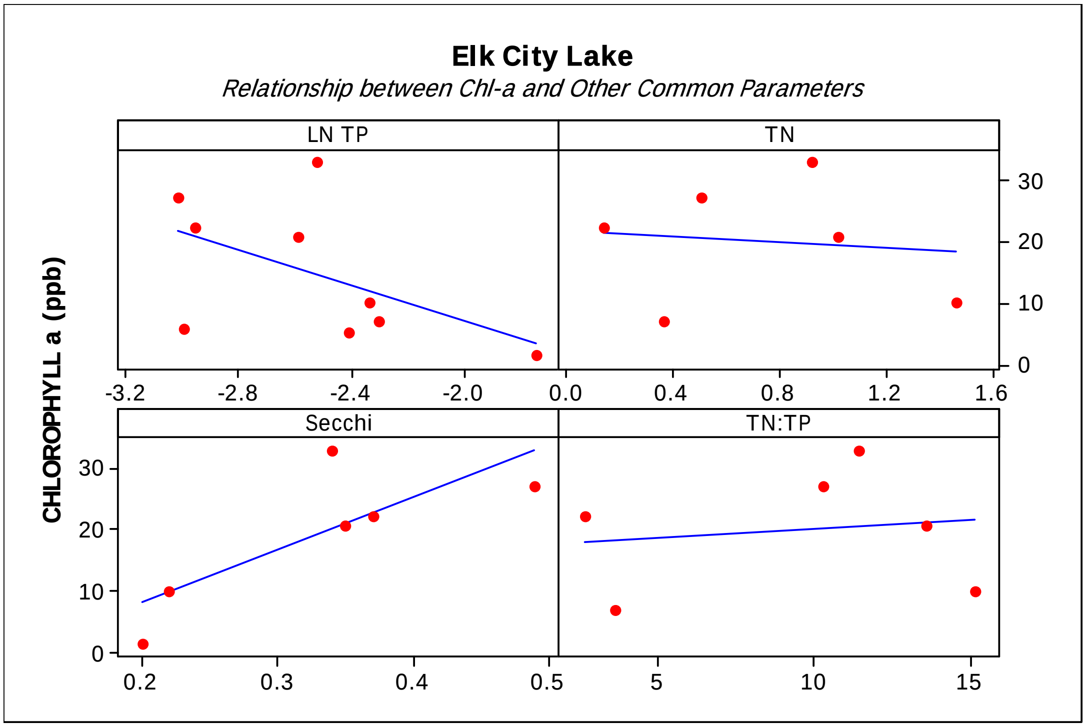


Figure 8. Common Water Quality relationships between secchi depth and other common parameters (1995-2007).

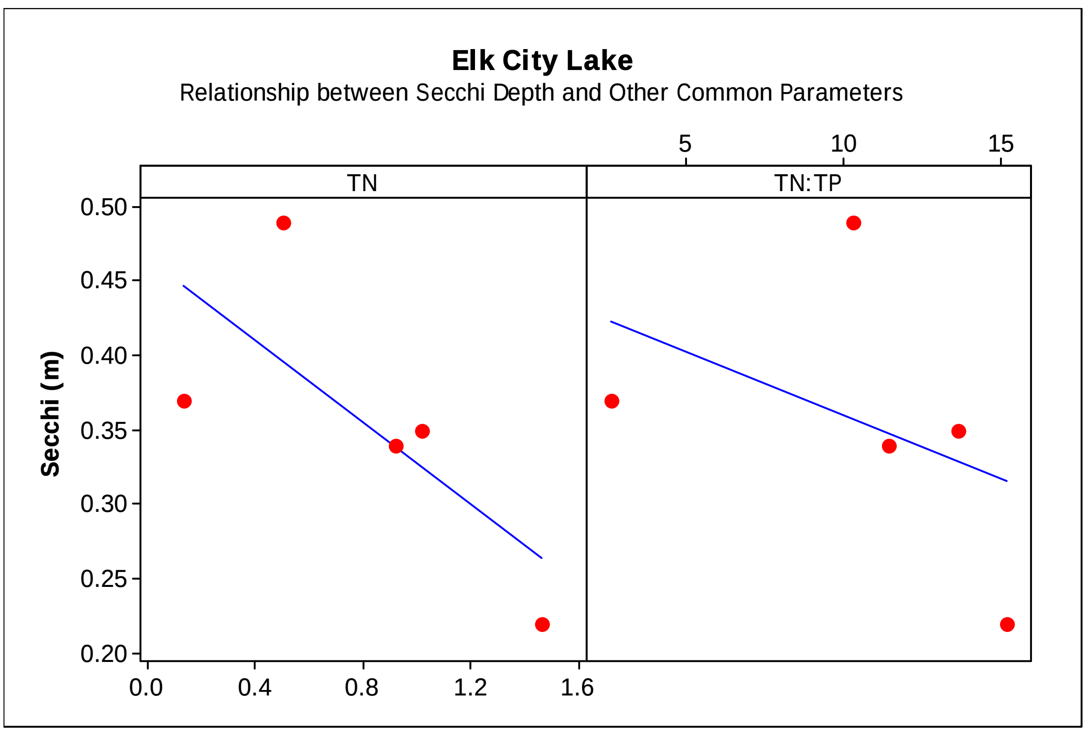
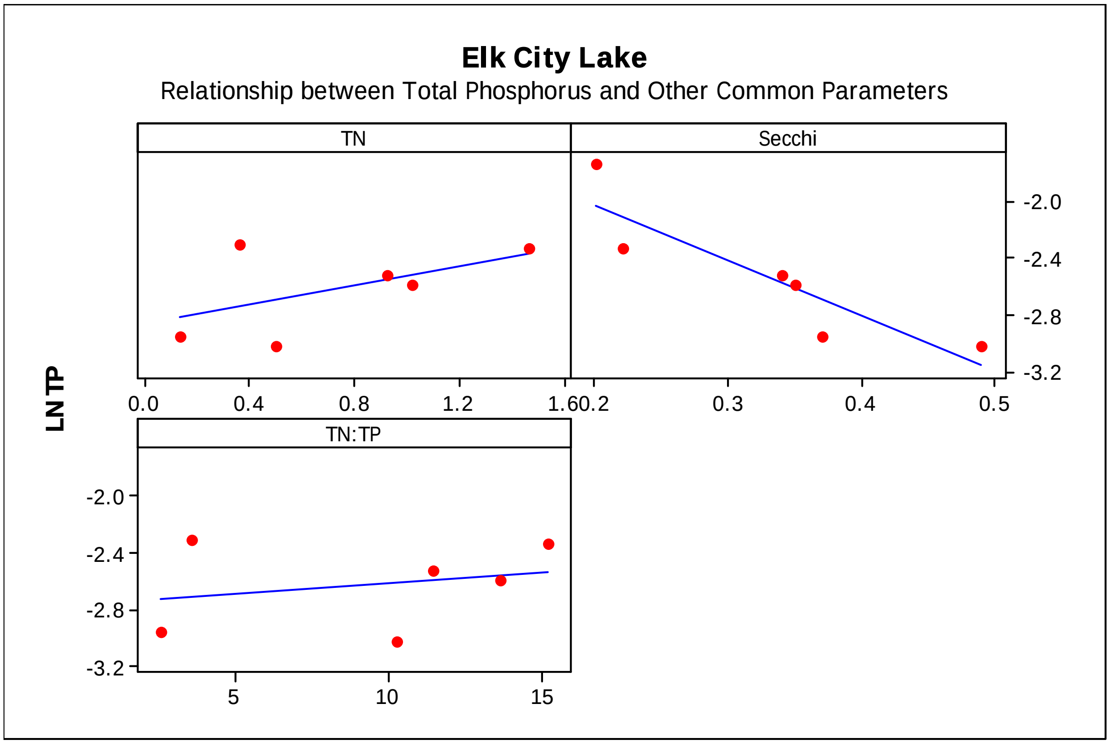


Figure 9. Common Water Quality relationships between Total Phosphorus and other common parameters (1989-2007). LN indicates data was natural log transformed.

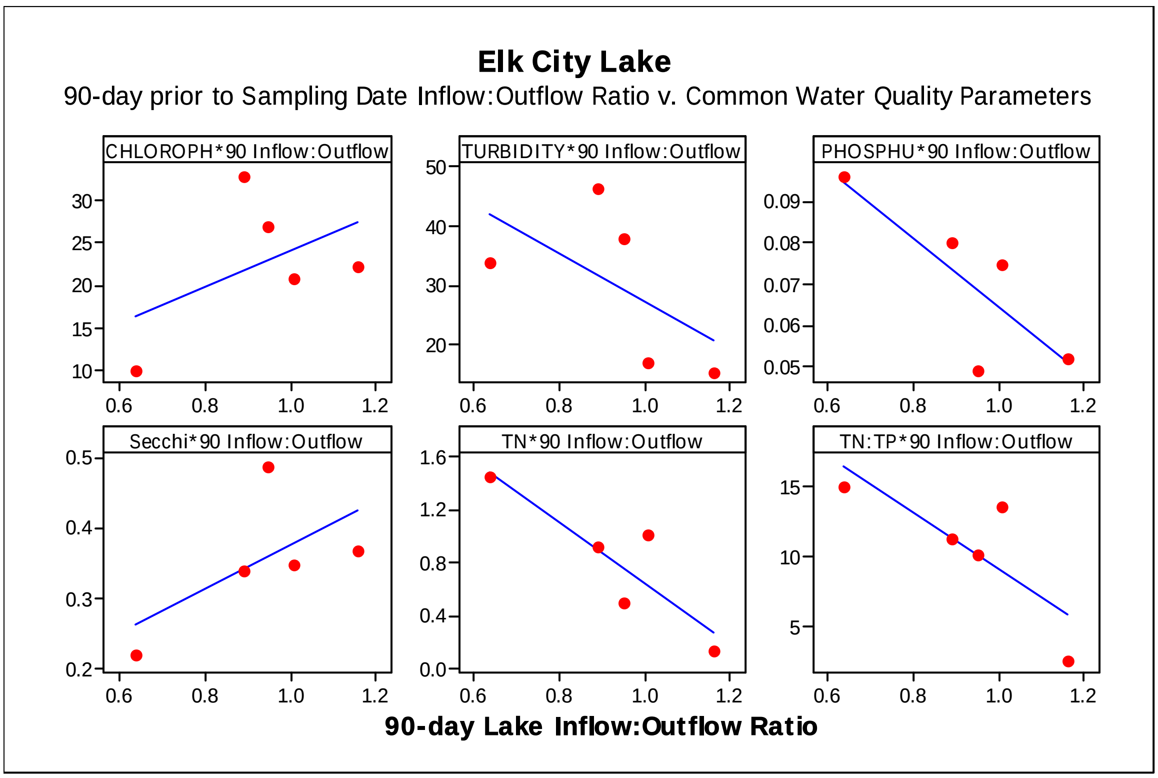


As seen in Figure 10, the ratio between the lake inflow and outflow for the 90-day period prior to the sampling date for the years from 1995-2007 was compared with several common water quality parameters. When the ratio is greater than 1.0, there was more water coming into the lake than was being released. Turbidity, total phosphorus, and total nitrogen are all higher during the times when the lake was releasing more water within this 90-day period. This concludes that large runoff events preceded and or occurred during this period and the lake levels may have been higher than normal. Chlorophyll *a* concentrations and secchi depth measurements were higher when the lake had more water entering the lake than what was being released. This indicates that conditions could have been dictated by a variety of factors such as: drier conditions, rainfall events with less intensity, or reservoir management decisions relating to flood control. The lake displayed better water clarity, which contributes to, increased sunlight penetration and primary algal production when the amount of water entering the lake exceeded the amount of water that was being released.

Table 5. Elk City Lake, comparative data for years with inflow and outflow data.

Sampling Year	90-day Inflow acre-feet	90-day Outflow acre-feet	90-day Inflow:Outflow Ratio	90-day Rainfall (inches)	Chl-a (µg/L)	Turbidity (NTU)
1995	337,973	335,771	1.01	17.59	20.9	17
1998	87,768	138,647	0.63	7.94	10	34
2001	31,391	27,003	1.16	5.91	22.3	15.5
2004	122,740	129,339	0.95	10.98	27.1	37.9
2007	527,062	593,417	0.89	17.45	33.0	46.55

Figure 10. Common water quality patterns in relation to the inflow and outflow ratio for the 90-day period prior to the KDHE sampling date (1995-2007).



Algal Communities: As seen in Table 6, algal communities in Elk City Lake, based on total cell count, have typically been dominated by green algal, with the exception of 1989 when diatoms dominated and in 2001 when blue-green algal dominated. The two most recent sampling dates have a considerably higher number of the total algal cell count within the lake. Lakes that are primarily composed of dominant green or blue-green algae are nutrient enriched (Carney, 2004).

Table 6. Algal Communities Observed in Elk City Lake

Sampling Date	Total Cell Count cell/mL	Percent Composition				Chl-*a*
		Green	Blue Green	Diatom	Other	
6/7/1989	1100	28	0	0	72	1.5
8/11/1992	1400	45	0	36	18	6.9
7/31/1995	6170	55	0	26	19	20.9
6/22/1998	2867	56	33	0	11	10.0
7/23/2001	24,633	11	79	9	1	22.3
8/9/2004	26,271	75	5	5	15	27.1

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

In order to improve the trophic condition of Elk City Lake from its Hypereutrophic status, the desired endpoint will be to maintain summer chlorophyll *a* 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 the statewide goal for Federal Lakes and lakes serving as Public Water Supplies, which will also ensure long-term protection to fully support Primary Contact Recreation within the lake. In order to improve the quality of the water column and the siltation impairment, the endpoint should also result in an increase in the average transparency of the lake to 0.70 meters, as measured by the secchi disk depth within the main basin of the lake.

Based on the BATHTUB reservoir eutrophication model (see Appendix A), nutrient concentrations entering the lake via the Elk River, Card Creek, and Chetopa Creek must be reduced by 45%, to achieve a ~45% load reduction for total phosphorus and ~44% load reduction for total nitrogen. 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 for Elk City Lake calculated in the model was based on lake data from 1995 through 2007. Tributary data for the water flowing into the lake was averaged from the available data for KDHE monitoring station SC573 along the Elk River near Elk City.

Table 7. Desired water quality endpoint for Elk City Lake.

Parameter	Current Avg. Condition	TMDL	Percent Reduction
TP Annual Load (lbs/year)	76,470	42,192	44.8%
TP Daily Load (lbs/day)*	398.1	219.6	44.8%
TN Annual Load (lbs/year)	712,031	400,524	43.7%
TN Daily Load (lbs/day)*	5228.1	2940.8	43.7%
TP Main Basin (µg/L)	71.0	39.2	44.8%
TN Main Basin (µg/L)	810.0	464.0	42.7%
Secchi Depth (m)	0.4	> 0.70	75% Increase

* - See Appendix B for Daily Load Calculations

3. SOURCE INVENTORY AND ASSESSMENT

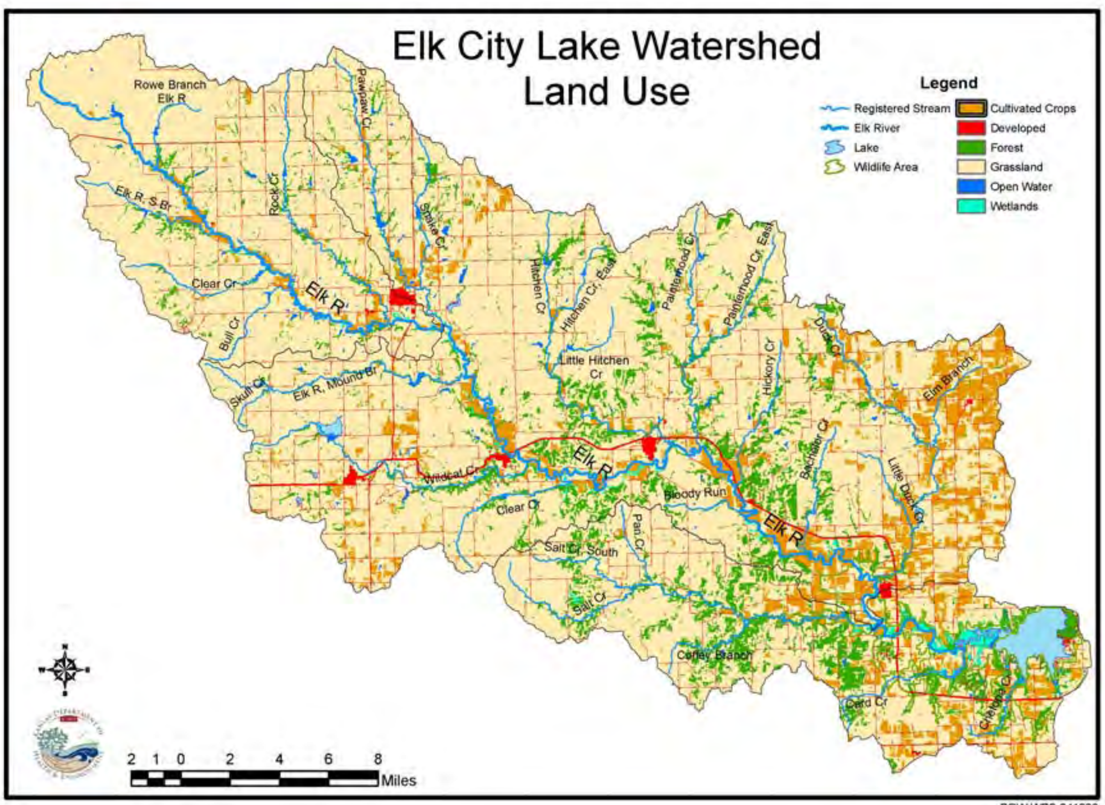
Land Use: The predominant land cover in the watershed around Elk City Lake includes 75% grassland/pasture, 10% forest, and 9% croplands. The remaining land uses within the watershed contain: 3.5% developed, 1.6 % open water, and less than one percent of wetlands. As seen in Figure 11a, the majority of the croplands lie within the flood plain of the Elk River and in the lower portion of the watershed.

Livestock Waste Management Systems: There are thirteen certified or permitted confined animal feedlot operations located throughout the watershed. The majority of these lie within the lower portion of the watershed near Duck Creek, Elm Branch and the lower portion of the Elk River within Wilson and Montgomery counties. All of the permitted livestock facilities have waste management systems designed to minimize runoff entering their facility and detain runoff emanating from their operations. In addition, they are designed to retain a 25-year, 24-hour rainfall/runoff event as well as an anticipated two weeks of normal wastewater from their operations. Typically, this rainfall event coincides with streamflow that is less than 1-5% of the time. Though the potential number of animals associated with the certified confined animal feedlot operations is 27,262 head in the watershed, the actual number of animals at the feedlot operations is typically less than the allowable permitted number. However, since the watershed is dominated by grassland and pasture the number of smaller animal feeding operations that are not registered is presumably high, particularly during seasonal feeding months in the winter.

Table 8. Animal Feeding Operations in the Elk City Lake Watershed.

Permit	County	Type	Record - Status	Head
A-VEEK-S004	Elk	Swine	Permit- Active	2400
A-VEEK-S010	Elk	Swine	Renewal-Active	1000
A-VEEK-S011	Elk	Swine	Renewal- Active	620
A-VEWL-H002	Wilson	Swine	Permit- Active	3900
N-VEWL-BA01	Wilson	Beef	Application-Active	299
A-VEWL-BA01	Wilson	Beef	Certification- Active	275
A-VEEK-E001	Elk	Exotic	Permit- Active	200
A-VEMG-H010	Montgomery	Swine	Permit- Active	8224
A-VEMG-S025	Montgomery	Swine	Permit- Active	3650
A-VEMG-S039	Montgomery	Swine	Permit- Active	1880
A-VEMG-MA05	Montgomery	Dairy	Certification- Active	40
A-VEMG-M009	Montgomery	Dairy	Permit- Active	40
A-VEMG-H011	Montgomery	Swine	Permit- Active	4734

Figure 11a. Elk City Lake Watershed land use and land cover map (2001 NLCD).



According to the 2006-2007 Kansas Agricultural Farm Facts, there are 29,500 and 33,900 head of cattle in Elk and Montgomery Counties respectively. In addition, Elk County ranks eleventh in the state for pasture acreage. Grazing densities within the watershed are estimated at approximately 54 head of cattle per square mile. The high percentage of grassland and pasture in the watershed may serve as ideal seasonal grazing lands for livestock during the winter months, which may account for highly variable livestock populations within the watershed from one year to the next.

Nutrients within the Elk City 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 livestock grazing or watering and fertilizer applications. The animal wastes from both confined and unconfined feeding sites are considered a major potential source of nutrient loading going into Elk City Lake.

NPDES: There are eight permitted waste treatment facilities located within the Elk City Lake watershed. Of these eight facilities, two are non-overflowing facilities that are prohibited from discharging and two are quarry operations that have minimal discharges. The remaining four facilities are discharging municipal wastewater treatment facilities.

The non-overflowing lagoons may contribute to the load under extreme precipitation events, however these events would not occur at a frequency or for a sufficient duration to cause impairment in the watershed. All non-discharging lagoon systems are prohibited by the state from discharging to the surface waters. Under standard conditions of these non-discharging facility permits, when the water level of the lagoon raises to within two feet of the top of the lagoon dikes the permit holder must notify KDHE. Steps may be taken to lower the water level of the lagoon and diminish the probability of a discharge of treated effluent during an extreme wet weather period. A discharge may be allowed if there are no other alternatives and 1) it would be necessary to prevent loss of life, personal injury or severe property damage; 2) excessive stormwater inflow or infiltration would damage the facility; or 3) the permittee has notified KDHE at least seven days before the anticipated discharge. The two quarry facilities limit discharges to pit de-watering and stormwater runoff, with the Harshman facility also having wash water and three settling ponds.

Table 9. NPDES facilities within the Elk City Lake watershed.

Permit	Facility	Type	Design Flow (mgd)	Permit Expires
I-VE27-PO02	Harshman Construction	Settling Ponds		2011
I-VE14-PO01	Midwest Minerals - #23 Elk City Qry	Stormwater Runoff/ pit de-watering		2011
I-VE27-NP02	C & M Car Wash	Single-cell Lagoon	Non-Discharging	2011
M-VE23-NO01	KDWP – Elk City State Park	Two-cell Lagoon	Non-Discharging	2012
M-VE27-OO01	City of Moline	Three-Cell Lagoon	0.105	2011
M-VE25-OO01	City of Longton	Three-Cell Lagoon	0.0566	2011
M-VE22-OO02	City of Howard	Three-Cell Lagoon	0.1325	2011
M-VE14-OO01	City of Elk City	Two-Cell Lagoon	0.0344	2011

The population within the watershed is approximately 4081 people according to the 2000 U.S. Census. There are several small towns located within the watershed, which all have either stable or insignificant declining or increasing populations. The towns and their population estimates are illustrated in Table 10. The population density within the watershed is approximately 6.4 people/square mile. Projections of future water use and resulting wastewater appear to be within design flows for these current system's treatment capacities.

Table 10. Population Estimates for cities within the Elk City watershed (Kansas Water Office, 2002).

City	Population Estimate
Howard	799
Moline	481
Elk Falls	121
Longton	390
Elk City	325
Oak Valley	NA

The cities of Howard, Moline, Longton, and Elk City are required to sample for Biological Oxygen Demand (BOD), Total Suspended Solids (TSS), pH, ammonia, and fecal coliform once quarterly. The BOD limitations for these permits are to maintain a weekly average of 45mg/L and a monthly average of 30 mg/L. There are also TSS limitations for these permits, with a weekly average of 120 mg/L and a monthly average of 80 mg/L. The City of Howard discharges into the Elk river via Paw Paw Creek; the

City of Moline into Elk River via Wildcat Creek; the City of Longton into Elk River via Hitchen Creek; and the City of Elk City discharges directly into the Elk River.

On-site Waste Systems: A little more than one-third of the households in Elk County are on septic systems (U.S. Census, 1990). Households that are not served by the public sewer system associated with four municipal NPDES facilities within this watershed are presumably on septic systems. Failing on-site systems may contribute nutrient loadings and aggravate eutrophication problems.

Contributing Runoff: The watershed of Elk City Lake has a mean soil permeability value of 0.72 inches/hour, ranging from 0.02 to 4.0 inches/hour according to the NRCS STATSGO database. About 64% of the watershed has a permeability value less than 0.57 inches/hour, which contributes to runoff during extremely low rainfall intensity events (Juracek, 2000). 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 areas in the upper and lower portions of the watershed.

Background: Approximately 10% of the land in the watershed is forest, which is predominantly within the middle and lower portions of the watershed. Nutrients released from leaf decomposition and wastes derived from natural wildlife may be contributing to the nutrient load. Atmospheric deposition and seepage from geological formations (i.e., soil and bedrock) may also contribute to the nutrient load. The suspension of sediment and nutrients within the lake may be influenced by the wind. Internal loading is not likely a significant factor within Elk City Lake since the dissolved oxygen and temperature concentrations suggest that the lake typically does not stratify (Figure 11b). In addition, the dissolved oxygen concentrations at the deeper depths suggest that internal loading is unfavorable.

Figure 11b. Dissolved Oxygen and Temperature profile for the sampling years of 1995 and 2001 in Elk City Lake.

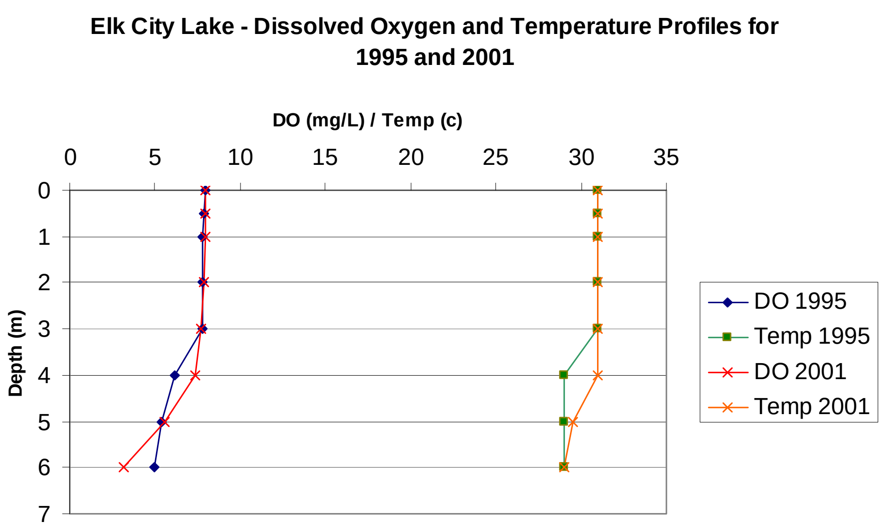
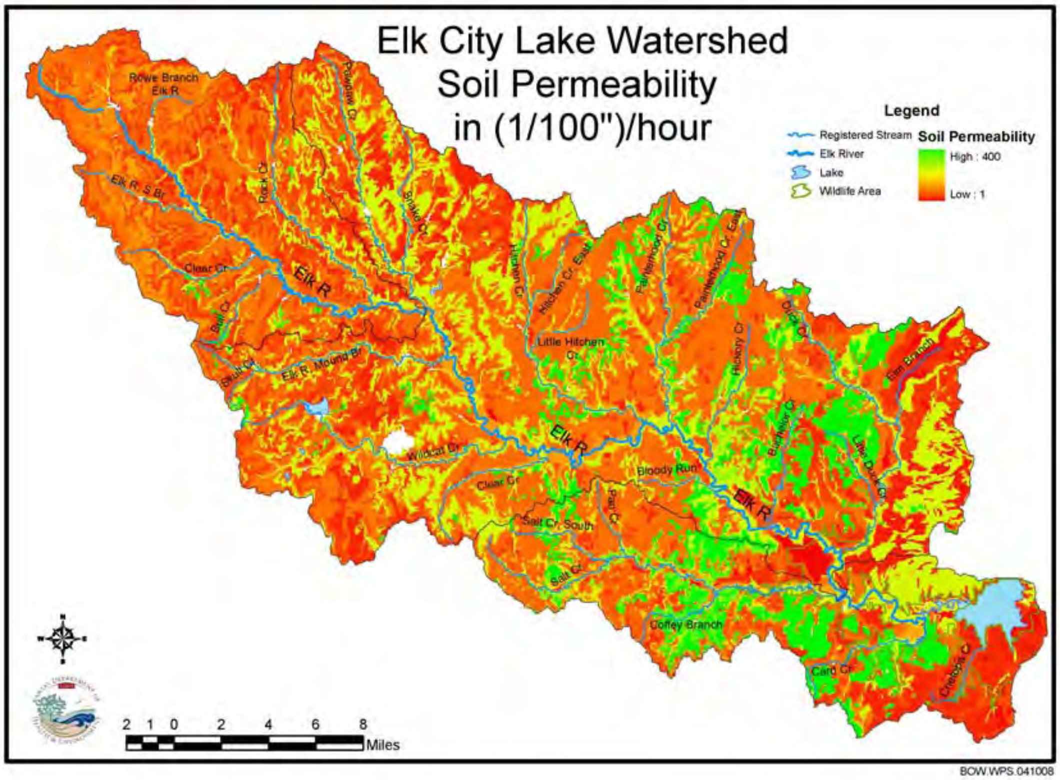


Figure 12. Soil Permeability Map for Elk City watershed.

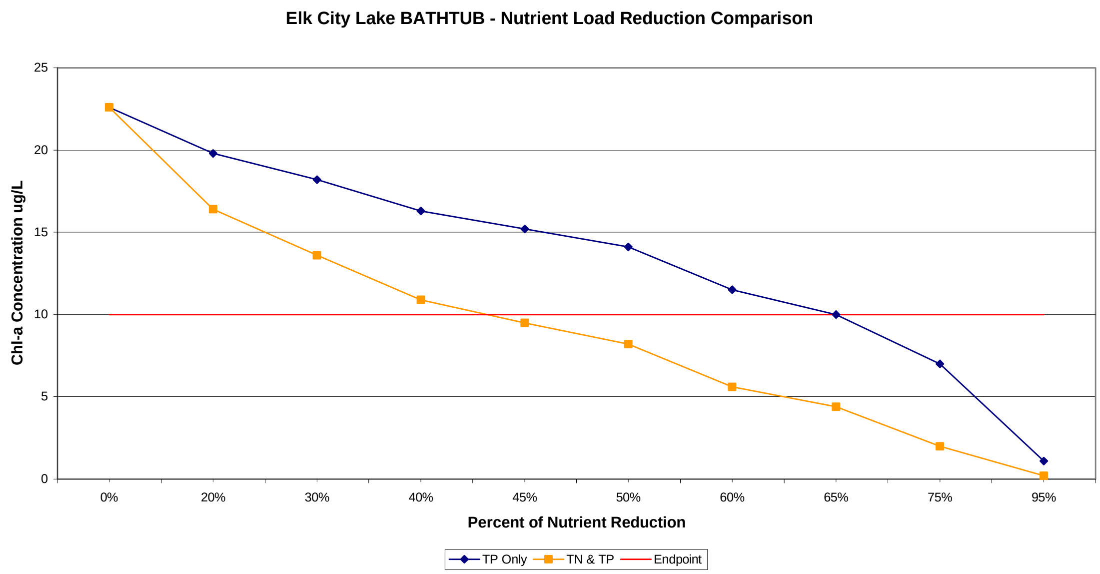


4. ALLOCATION OF POLLUTANT REDUCTION RESPONSIBILITY

Elk City Lake is primarily co-limited by nitrogen and phosphorus and light availability. Therefore, both phosphorus and nitrogen allocations will be made under this TMDL. To address the siltation component of this TMDL, load allocations will be made for sediment loading by establishing loads for Total Suspended Solids (TSS) within the watershed.

BATHTUB is an empirical receiving water quality model that was developed by the U.S. Corps of Engineers (Walker, 1996), and has been widely used in the nation to address many TMDLs relating to issues associated with morphometrically complex lakes and reservoirs (Wang et al., 2005). The BATHTUB model was utilized for the eutrophication assessment of Elk City Lake. Elk City Lake was segmented into three sections for the BATHTUB model, which included the upper lake (riverine area), middle lake (transitional area), and the main basin (near dam). Atmospheric total nitrogen was obtained from the Clean Air Status and Trends Network (CASTNET), which is available at 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 1995-2007 data from KDHE. Model input data for the lake inflow tributary was estimated using averages from the KDHE stream chemistry monitoring station (SC573) along the Elk River near Elk City. Inflow data for the tributaries entering the lake was obtained from the USGS mean flow data as indicated in Table 1a. The BATHTUB model was calibrated for the main basin and results (see Appendix A) estimate that the lake currently retains 23 % of the TP and 7.5% of the TN load annually. Based on the modeling results, a 45% reduction of both TP and TN within the inflow of the Elk River, Card Creek, and Chetopa Creek is necessary to achieve the TMDL endpoint of 10 µg/L of Chlorophyll *a* within the main basin of Elk City Lake. As Figure 13 illustrates, if reductions were only applied to TP, a 65% TP reduction would be necessary to meet the TMDL endpoint.

Figure 13. Changes in Chlorophyll *a* levels in relation to watershed nutrient reductions.



Point Sources: Wasteload allocations are established for the discharging wastewater treatment facilities permitted within the watershed. These allocations apply to the cities of Moline, Longton, Howard, and Elk City. The total wasteload allocation for the watershed is set at 2,004 pounds per year of total phosphorus and 8,014 pounds per year of total nitrogen. The wasteload allocation is based on discharging at design flows with a concentration of 2 mg/L TP and 8 mg/L TN for all four of these cities, which are typical concentrations associated with lagoon systems. These wastewater treatment plants will comply with any future permit limits for nitrogen and phosphorus. The wasteload allocation for total suspended solids (TSS) is 80,142 pounds per year, based on the current monthly average TSS permit limit of 80mg/L, which is currently in place for these facilities. The established wasteload allocations are conservative, as actual flows originating from these facilities is not reported and the current wasteload is most likely less.

Table 11. Wasteload Allocations for discharging facilities in the Elk City Lake watershed.

NPDES Facility	Design Flow	WLA TP lbs/year	WLA TN lbs/year	WLA TSS lbs/year
City of Moline	0.105	640.4	2561.7	25616.5
City of Longton	0.0566	345.3	1381.3	13812.8
City of Howard	0.1325	808.1	3232.4	32324.4
City of Elk City	0.0344	209.7	838.9	8388.6
Total		**2003.5**	**8014.3**	**80142.3**

The wasteload allocation for the non-discharging permitted facilities and the quarry operations is set at 0 lbs/year since they do not discharge or add to the impairment within Elk City Lake, except potentially under extreme wet conditions.

Nonpoint Sources: Nonpoint sources are the main contributor for the nutrient input and impairment in Elk City 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 eutrophic condition of the lake. Nutrient load allocations for Elk City Lake were calculated using the BATHTUB model (see Appendix A).

Table 12. Elk City Lake TMDL summary for TP and TN.

Description	***Allocations (lbs/year)***	***Allocations (lbs/day)****
TP Atmospheric Deposition – Load Allocation	298	1.6
TP-Nonpoint Source- Load Allocation	35,671	185.6
TP – Wasteload Allocation	2004	10.4
TP Margin of Safety	4219	22.0
TP TMDL	42,192	219.6
TN Atmospheric Deposition – Load Allocation	19,792	145.3
TN Nonpoint Source Load Allocation	332,666	2442.5
TN Wasteload Allocation	8,014	58.9
TN Margin of Safety	40,052	294.1
TN TMDL	400,524	2940.8

*- See Appendix B for Daily Load Calculations

Siltation: Siltation loading comes predominantly from nonpoint source pollution. Based on the soil characteristics of the watershed, overland runoff can easily carry sediment to the stream segments and eventually to the lake. Though Kansas does not have numeric water quality criteria from inorganic turbidity associated with soil/sediment particles (often referred to as non-algal turbidity), “Brown” scores, derived from 1998-2002 statewide lake monitoring (Carney, 2003), were utilized as a guideline due to the appearance of low water clarity as a result of non-algal turbidity. To achieve full support status, 0.70 m of Secchi depth is targeted as the TMDL and watershed management goals of restoring water quality in Elk City Lake.

Based on the estimated current lake capacity provided by the Kansas Water Office, lake retention time, recent TSS average concentration and dam trapping efficiency, the sediment exiting the lake under normal conditions annually is calculated to be:

[Lake Volume 38,043 ac-ft)]*[TSS (28.2 mg/L)]*[Lake Retention Time (365 days/70 days)]*[Unit Conversion Factors (1,233,482 L/ac-ft)*(2.204 lbs / 1,000,000 mg)*(1 ton / 2000 lbs)]

= 7,603 tons of TSS (or sediment)

Total amount of sediment exported from the watershed
= 7,603 tons / 0.1 (assumes 90% trapping efficiency)
= 76,030 tons of TSS
= 76,030 tons /405,758 acres = 0.19 tons/ acre

Assuming a 90% trapping efficiency of the lake, the amount of sediment accumulated on the lake bottom annually under normal conditions is 76,030-7,603 = 68,427 (tons)

Based on the Reservoir Fact Sheet for Elk City Lake, produced by the Kansas Water Office, the current sedimentation rate for Elk City Lake is 341 acre-ft/year. The fact sheet is based on a detailed lake survey conducted in 1992. This survey captures sediment delivery under all flow conditions, whereas the previous calculation utilizing the TSS concentration is based on available KDHE lake sampling data, which occurs during typical seasonal conditions and does not reflect conditions during significant runoff events. The current estimated sedimentation rate is transposed as follows:

[(341 acre-ft/year)*(43,600cft/ac-ft)*(60lbs/cft)*(1 ton / 2000 lbs)
= 446,028 tons of sediment exported from the watershed
= 446,028/ 405,758 acres = 1.1 tons/acre

A more detailed assessment of sources and confirmation of the silation impairment must be completed before detailed allocations could be made. Until this time, the siltation allocation is set at the 76,030 tons of TSS/year, which represents typical conditions as determined by the KDHE lake sampling data. This requires an 83% reduction in the total sediment delivery to the lake, which is primarily delivered in the form of high flow runoff events.

Table 13. Elk City Lake TMDL summary for TSS.

TSS Load	TSS tons/year	TSS tons/day*
Wasteload Allocation	40	0.25
Load Allocation	68,387	425.31
Margin of Safety	7,603	47.28
TSS TMDL	76,030	472.84

*-See Appendix B for Daily Load Calculations

Margin of Safety: The margin of safety provides some hedge against the uncertainty of variable annual total phosphorus, total nitrogen, and TSS loads and the chlorophyll *a* endpoint. Therefore, the margin of safety is explicitly set at 10% of the total allocations for total phosphorus, total nitrogen, and TSS, 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 expressed in Table 12, and the margin of safety for TSS is illustrated in Table 13.

State Water Plan Implementation Priority: Based on input from the Verdigris Basin Advisory Committee, local interest and efforts with Watershed Restoration and Protection Strategies (WRAPS) are lagging. Therefore, this TMDL will be Medium Priority for implementation until such time that the WRAPS is active.

Unified Watershed Assessment Priority Ranking: The Elk City Lake watershed lies with the Elk Subbasin (HUC 8: 11070104) with a priority ranking of 61 (Low Priority for restoration work).

Priority HUC 11s and 14s: The watershed lies within three HUC 11s: 11070104(010), (020) and (030). Based on the land use and soil permeability maps, a reasonable estimate for establishing priority areas for implementation within the watershed lie within the lower portion of the watershed to include HUC 14s: 11070104030(010), (020), (030), (040), (050), and (060).

5. IMPLEMENTATION

Desired Implementation Activities: There is good potential that agricultural best management practices will improve the condition of Elk City Lake. Some of the recommended agricultural practices are as follows:

1. Implement soil sampling to recommend appropriate fertilizer applications on cultivated croplands.
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 Elk City Lake WRAPS process to coordinate load reduction of nutrients to the lake.

Implementation Program Guidance:

NPDES-KDHE

a. Evaluate nutrient loading from all permitted dischargers in the watershed by establishing monitoring requirements.
b. Work with dischargers to reduce individual loadings.

Watershed Management Program – KDHE

a. Support new and ongoing Section 319 implementation and demonstration activities conducted under Verdigris Basin WRAPS projects focused on Elk City Lake, including demonstration projects and outreach efforts dealing with erosion and sediment control and nutrient management.
b. Provide technical assistance on practices geared to 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 Elk City Lake.
e. Incorporate the provisions of the TMDL into WRAPS documents relating to Elk City 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

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 – SCC

a. Install grass buffer strips near streams.

b. Leverage Conservation Reserve Enhancement Program to hold riparian land out of production.

Sediment Survey – Kansas Water Office

a. Contract Kansas Biological Survey to survey the bathymetry of Elk City Lake in 2010.
b. Estimate correct siltation rates.
c. Inform KDHE, WRAPS and BAC of latest siltation estimates.

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 Elk City Lake 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 participant for implementation will be agricultural producers and stakeholders within the Elk City 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 and fertilizer application rates,
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 Elk City 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 the 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 pollutants to point and nonpoint sources can be attained.

1. K.S.A. 65-164 and 165 empowers the Secretary of KDHE to regulate the discharge of sewage into the waters of the state.

2. 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.

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. 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.

5. 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.

6. 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.

7. 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.

8. 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.

9. 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 watershed 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 Medium priority consideration for funding.

Effectiveness: Nutrient and sediment control has been proven effective through conservation tillage, contour farming riparian restoration projects 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 Elk City 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 of 2016-2018 to assess progress in this implementation. In addition, a detailed bathymetric survey is scheduled to be conducted in 2010. Based on this survey, the siltation component of this TMDL will be subject to revision to more accurately reflect the current status of the lake as determined by the survey.

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 Hearings: 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 of 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 303(d) Delisting: Elk City Lake will be evaluated for delisting under Section 303(d), based on the monitoring data over 2008-2015. Therefore, the decision for delisting will come about in the preparation of the 2016-303(d) 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 September 24, 2008

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Appendix A – BATHTUB Model Summary

Input Files – Current Condition

Global Variables	Mean	CV
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.93	0.2
Evaporation (m)	1.36	0.3
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	666	0.50
Ortho P	10	0.10
Inorganic N	666	0.50

Model Options	Code	Description
Conservative Substance	0	NOT COMPUTED
Phosphorus Balance	5	VOLLENWEIDER
Nitrogen Balance	3	2ND ORDER, FIXED
Chlorophyll-a	3	P, N, LOW-TURBIDITY
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	km^2	m	km	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Upper Pool	2	1	4.28	1.9	1.326	1.9	0.12	0	0	3.02	0.2	0	0	0	0	0	0
2	Mid Pool	3	1	6.03	3	1.643	3	0.12	0	0	3.02	0.2	0	0	0	0	0	0
3	Near Dam	0	1	9.19	3.2	1.49	3.2	0.12	0	0	3.02	0.3	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	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	71	0.3	810	0.6	22.6	0.4	0.36	0.3	533	0.7	46	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	1.000003	0	1	0	1.040951	0	1	0	1	0	1	0	1	0	1	0
2	1	0	1.000003	0	1	0	1.040951	0	1	0	1	0	1	0	1	0	1	0
3	1	0	1.000003	0	1	0	1.040951	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	Elk River	1	1	1510	367	0.1	0	0	91	0.5	827	0.5	10	0.5	294	0.5
2	Card Creek	1	1	37.5	13.3	0.1	0	0	91	0.5	827	0.5	10	0.5	294	0.5
3	Chetopa Creek	1	1	34.2	9.38	0.1	0	0	91	0.5	827	0.5	10	0.5	294	0.5

Model Coefficients	Mean	CV
Dispersion Rate	1.000	0.70
Total Phosphorus	0.901	0.45
Total Nitrogen	0.330	0.55
Chl-a Model	0.972	0.26
Secchi Model	1.300	0.10
Organic N Model	0.600	0.12
TP-OP Model	0.400	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

Elk City Lake Main Basin

Segment:	**3**	**Near Dam**				
	Predicted Values--->			**Observed Values--->**		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	71.0	0.48	66.9%	71.0	0.30	66.9%
TOTAL N MG/M3	798.9	0.43	36.2%	810.0	0.60	37.0%
C.NUTRIENT MG/M3	43.0	0.37	59.2%	43.5	0.47	59.7%
CHL-A MG/M3	22.3	0.53	86.9%	22.6	0.40	87.3%
SECCHI M	0.4	0.28	7.6%	0.4	0.30	7.4%
ORGANIC N MG/M3	535.7	0.33	59.5%	533.0	0.70	59.1%
TP-ORTHO-P MG/M3	42.9	0.32	64.6%	46.0	0.50	67.4%
ANTILOG PC-1	771.7	0.66	80.9%	784.3	0.45	81.3%
ANTILOG PC-2	5.5	0.34	38.1%	5.5	0.37	38.1%
(N - 150) / P	9.1	0.70	18.1%	9.3	0.79	18.8%
INORGANIC N / P	9.4	1.70	12.3%	11.1	2.54	16.1%
TURBIDITY 1/M	3.0	0.30	96.6%	3.0	0.30	96.6%
ZMIX * TURBIDITY	9.7	0.32	92.6%	9.7	0.32	92.6%
ZMIX / SECCHI	8.8	0.31	85.4%	8.9	0.32	85.8%
CHL-A * SECCHI	8.1	0.52	37.3%	8.1	0.50	37.5%
CHL-A / TOTAL P	0.3	0.55	77.1%	0.3	0.49	77.7%
FREQ(CHL-a>10) %	83.7	0.24	86.9%	84.3	0.18	87.3%
FREQ(CHL-a>20) %	44.6	0.75	86.9%	45.5	0.56	87.3%
FREQ(CHL-a>30) %	21.5	1.17	86.9%	22.2	0.87	87.3%
FREQ(CHL-a>40) %	10.5	1.50	86.9%	10.9	1.12	87.3%
FREQ(CHL-a>50) %	5.3	1.77	86.9%	5.6	1.33	87.3%
FREQ(CHL-a>60) %	2.8	2.01	86.9%	3.0	1.51	87.3%
CARLSON TSI-P	65.6	0.10	66.9%	65.6	0.06	66.9%
CARLSON TSI-CHLA	61.1	0.08	86.9%	61.2	0.06	87.3%
CARLSON TSI-SEC	74.6	0.05	92.4%	74.7	0.06	92.6%

Model Output – Current Condition
Overall Water and Nutrient Balances

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	Elk River	1510.0	357.0	1.27E+03	0.10	0.24
2	1	1	Card Creek	37.5	13.3	1.77E+00	0.10	0.35
3	1	1	Chetopa Creek	34.2	9.4	8.80E-01	0.10	0.27
PRECIPITATION				13.5	12.6	6.31E+00	0.20	0.93
TRIBUTARY INFLOW				1581.7	379.7	1.28E+03	0.09	0.24
***TOTAL INFLOW				1595.2	392.2	1.28E+03	0.09	0.25
ADVECTIVE OUTFLOW				1595.2	374.0	1.31E+03	0.10	0.23
***TOTAL OUTFLOW				1595.2	374.0	1.31E+03	0.10	0.23
***EVAPORATION					18.2	2.99E+01	0.30	

Overall Mass Balance Based Upon Component: **Predicted TOTAL 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	Elk River	32487.0	93.7%	2.74E+08	99.8%	0.51	91.0	21.5
2	1	1	Card Creek	1210.3	3.5%	3.81E+05	0.1%	0.51	91.0	32.3
3	1	1	Chetopa Creek	853.6	2.5%	1.89E+05	0.1%	0.51	91.0	25.0
PRECIPITATION				135.0	0.4%	1.82E+02	0.0%	0.10	10.8	10.0
TRIBUTARY INFLOW				34550.9	99.6%	2.75E+08	100.0%	0.48	91.0	21.8
***TOTAL INFLOW				34685.9	100.0%	2.75E+08	100.0%	0.48	88.4	21.7
ADVECTIVE OUTFLOW				26554.9	76.6%	1.70E+08		0.49	71.0	16.6
***TOTAL OUTFLOW				26554.9	76.6%	1.70E+08		0.49	71.0	16.6
***RETENTION				8131.0	23.4%	2.26E+07		0.58		

Overflow Rate (m/yr)	27.7	Nutrient Resid. Time (yrs)	0.0746
Hydraulic Resid. Time (yrs)	0.0974	Turnover Ratio	13.4
Reservoir Conc (mg/m3)	71	Retention Coef.	0.234

Overall Mass Balance Based Upon Component: **Predicted TOTAL 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	Elk River	295239.0	91.4%	2.27E+10	99.7%	0.51	827.0	195.5
2	1	1	Card Creek	10999.1	3.4%	3.15E+07	0.1%	0.51	827.0	293.3
3	1	1	Chetopa Creek	7757.3	2.4%	1.56E+07	0.1%	0.51	827.0	226.8
PRECIPITATION				8977.5	2.8%	2.01E+07	0.1%	0.50	715.1	665.0
TRIBUTARY INFLOW				313995.3	97.2%	2.27E+10	99.9%	0.48	827.0	198.5
***TOTAL INFLOW				322972.8	100.0%	2.27E+10	100.0%	0.47	823.4	202.5
ADVECTIVE OUTFLOW				298798.6	92.5%	1.71E+10		0.44	798.9	187.3
***TOTAL OUTFLOW				298798.6	92.5%	1.71E+10		0.44	798.9	187.3
***RETENTION				24174.2	7.5%	5.79E+08		1.00		

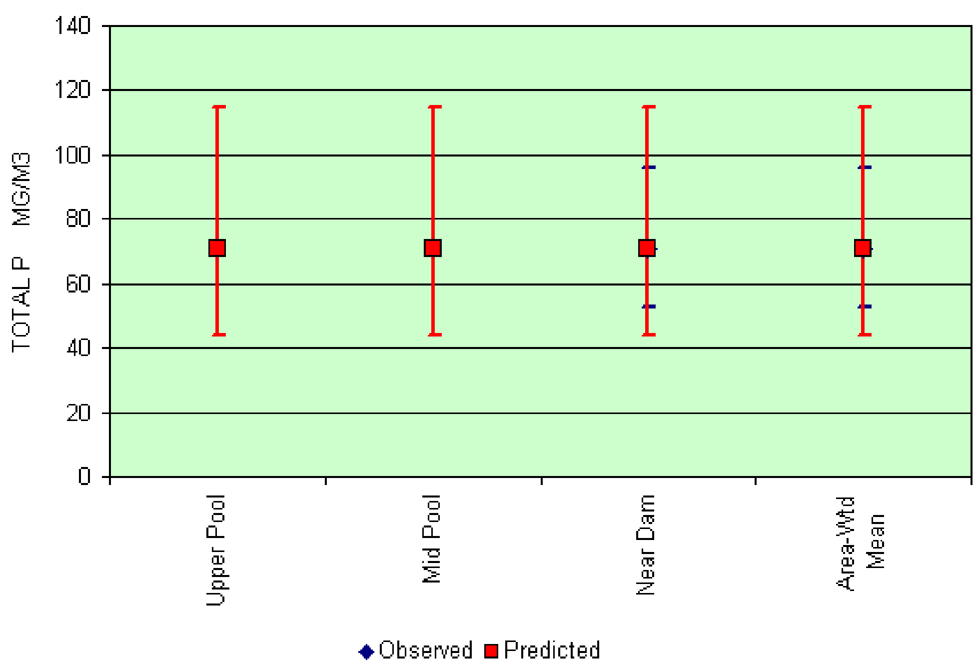
Overflow Rate (m/yr)	27.7	Nutrient Resid. Time (yrs)	0.0901
Hydraulic Resid. Time (yrs)	0.0974	Turnover Ratio	11.1
Reservoir Conc (mg/m3)	799	Retention Coef.	0.075

Goodness of Fit (Calibration/Validation)

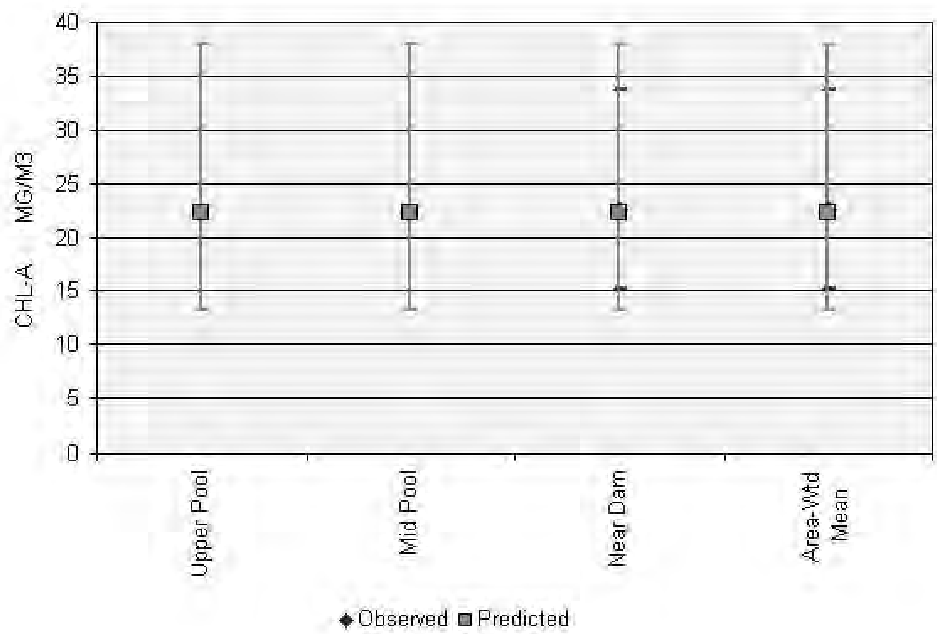
T= Student's t-statistic testing for significant difference between observed & predicted means using three alternative measures of error: observed error only, T(1); error typical of model development data set, T(2); and observed and predicted error, T(3). Tests of model applicability are normally based 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.

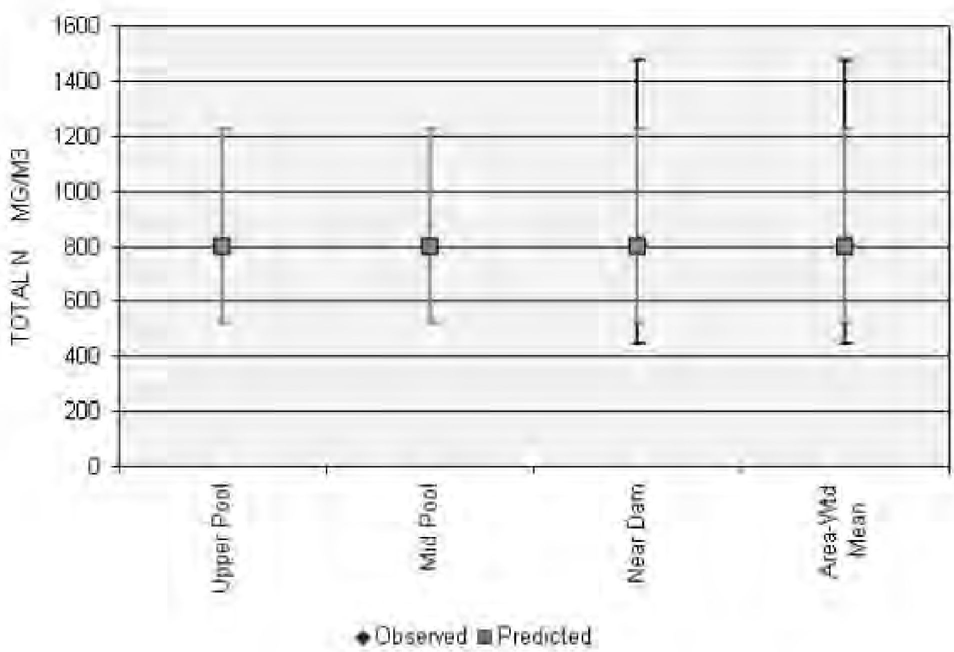
The BATHTUB model was calibrated for the main basin (Elk City Lake) and calibrated for TP, TN, Chlorophyll *a*, and Secchi Depth. The appropriate model options within BATHTUB were selected and the calibration factors were adjusted to calibrate the simulated values closer to the observed values (for the calibrated parameters) for the main basin. Model 3 was chosen for the chlorophyll model because it displayed the closest fit for the simulated chlorophyll *a* value to the observed value, and based on the shading index in table 3, turbidity does not impose an effect on algal productivity within Elk City Lake. In addition, a bioassay study of 18 lakes was conducted in eastern Kansas, which concluded strong turbidity effects were only found in three lakes that had turbidity values typically greater than 100 NTU (Wang et. al., 2004). Elk City Lake has an average turbidity of 30 NTU for the last decade. The lake, though is turbid, is not turbid enough to affect algal productivity. KDHE does not directly measure Organic N, however this is estimated by calculating the TKN-NH3 from the KDHE data. The Total P – Ortho P value was estimated as KDHE does have Ortho P data but it is all typically below the detection limit.

Elk City Lake BATHTUB Modeling Results: Error bar plots (mean + standard deviation of TN < TP, Chla, Secchi depth parameters estimated by BATHTUB model.

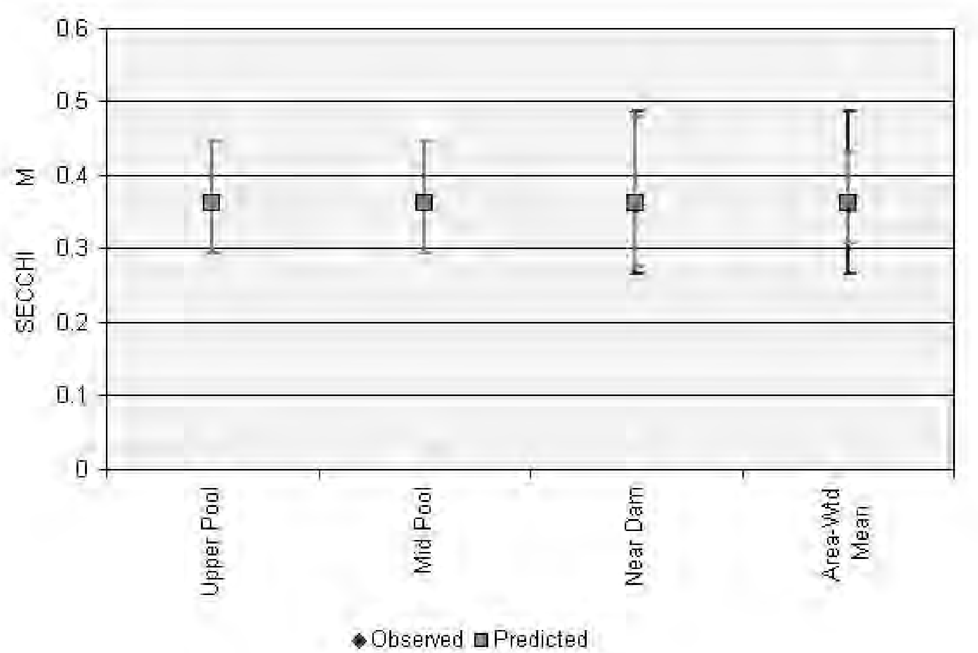


Elk City Lake





Elk City Lake



Input File – TMDL with 45% TP and TN Concentration Reductions for inflowing streams.

Global Variables	Mean	CV
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.93	0.2
Evaporation (m)	1.35	0.3
Storage Increase (m)	0	0.0

Atmos. Loads (kg/km²-yr	Mean	CV
Conserv. Substance	0	0.00
Total P	10	0.10
Total N	665	0.50
Ortho P	10	0.10
Inorganic N	665	0.50

Model Options	Code	Description
Conservative Substance	0	NOT COMPUTED
Phosphorus Balance	5	VOLLENWEIDER
Nitrogen Balance	3	2ND ORDER, FIXED
Chlorophyll-a	3	P, N, LOW-TURBIDITY
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	Upper Pool	2	1	4.28	1.9	1.326	1.9	0.12	0	0	3.02	0.2	0	0	0	0	0	0
2	Mid Pool	3	1	6.03	3	1.643	3	0.12	0	0	3.02	0.2	0	0	0	0	0	0
3	Near Dam	0	1	3.19	3.2	1.49	3.2	0.12	0	0	3.02	0.3	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	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	71	0.3	810	0.6	22.6	0.4	0.36	0.3	533	0.7	46	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	1.000003	0	1	0	1.040951	0	1	0	1	0	1	0	1	0	1	0
2	1	0	1.000003	0	1	0	1.040951	0	1	0	1	0	1	0	1	0	1	0
3	1	0	1.000003	0	1	0	1.040951	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	Elk River	1	1	1510	357	0.1	0	0	50.05	0.5	454.85	0.5	5.5	0.5	161.7	0.5
2	Card Creek	1	1	37.5	13.3	0.1	0	0	50.05	0.5	454.85	0.5	5.5	0.5	161.7	0.5
3	Chetopa Creek	1	1	34.2	9.38	0.1	0	0	50.05	0.5	454.85	0.5	5.5	0.5	161.7	0.5

Model Coefficients	Mean	CV
Dispersion Rate	1.000	0.70
Total Phosphorus	0.981	0.45
Total Nitrogen	0.330	0.55
Chl-a Model	0.972	0.26
Secchi Model	1.300	0.10
Organic N Model	0.600	0.12
TP-OP Model	0.400	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

Output File – TMDL for Elk City Lake with 45% TP and TN Concentration Reductions for inflowing streams.

Predicted vs. Observed for Main Basin

Segment:	3	Near Dam				
	Predicted Values--->			Observed Values--->		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	39.2	0.48	41.2%	71.0	0.30	66.9%
TOTAL N MG/M3	464.0	0.43	11.4%	810.0	0.60	37.0%
C.NUTRIENT MG/M3	21.8	0.45	26.8%	43.5	0.47	59.7%
CHL-A MG/M3	9.5	0.63	50.7%	22.6	0.40	87.3%
SECCHI M	0.4	0.29	9.5%	0.4	0.30	7.4%
ORGANIC N MG/M3	360.8	0.28	29.6%	533.0	0.70	59.1%
TP-ORTHO-P MG/M3	33.8	0.32	54.9%	46.0	0.50	67.4%
ANTILOG PC-1	268.5	0.73	52.8%	784.3	0.45	81.3%
ANTILOG PC-2	3.5	0.40	12.4%	5.5	0.37	38.1%
(N - 150) / P	8.0	0.79	13.5%	9.3	0.79	18.8%
INORGANIC N / P	19.1	4.03	32.8%	11.1	2.54	16.1%
TURBIDITY 1/M	3.0	0.30	96.6%	3.0	0.30	96.6%
ZMIX * TURBIDITY	9.7	0.32	92.6%	9.7	0.32	92.6%
ZMIX / SECCHI	8.0	0.32	81.4%	8.9	0.32	85.8%
CHL-A * SECCHI	3.8	0.65	8.1%	8.1	0.50	37.5%
CHL-A / TOTAL P	0.2	0.67	63.2%	0.3	0.49	77.7%
FREQ(CHL-a>10) %	34.8	1.07	50.7%	84.3	0.18	87.3%
FREQ(CHL-a>20) %	6.6	2.01	50.7%	45.5	0.56	87.3%
FREQ(CHL-a>30) %	1.5	2.64	50.7%	22.2	0.87	87.3%
FREQ(CHL-a>40) %	0.4	3.11	50.7%	10.9	1.12	87.3%
FREQ(CHL-a>50) %	0.1	3.49	50.7%	5.6	1.33	87.3%
FREQ(CHL-a>60) %	0.1	3.81	50.7%	3.0	1.51	87.3%
CARLSON TSI-P	57.0	0.12	41.2%	65.6	0.06	66.9%
CARLSON TSI-CHLA	52.7	0.11	50.7%	61.2	0.06	87.3%
CARLSON TSI-SEC	73.2	0.06	90.5%	74.7	0.06	92.6%

Output File – TMDL for Elk City Lake with 45% TP and TN Reductions for inflowing streams.

Overall Water and Nutrient Balances

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	Elk River	1510.0	357.0	1.27E+03	0.10	0.24
2	1	1	Card Creek	37.5	13.3	1.77E+00	0.10	0.35
3	1	1	Chetopa Creek	34.2	9.4	8.80E-01	0.10	0.27
PRECIPITATION				13.5	12.6	6.31E+00	0.20	0.93
TRIBUTARY INFLOW				1581.7	379.7	1.28E+03	0.09	0.24
***TOTAL INFLOW				1595.2	392.2	1.28E+03	0.09	0.25
ADVECTIVE OUTFLOW				1595.2	374.0	1.31E+03	0.10	0.23
***TOTAL OUTFLOW				1595.2	374.0	1.31E+03	0.10	0.23
***EVAPORATION					18.2	2.99E+01	0.30	

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

Trb	Type	Seg	Name	Load kg/yr	Load %Total	Load Variance (kg/yr)^2	Load Variance %Total	CV	Conc mg/m^3	Export kg/km^2/yr
1	1	1	Elk River	17867.8	93.4%	8.30E+07	99.8%	0.51	50.0	11.8
2	1	1	Card Creek	665.7	3.5%	1.15E+05	0.1%	0.51	50.0	17.8
3	1	1	Chetopa Creek	469.5	2.5%	5.73E+04	0.1%	0.51	50.0	13.7
PRECIPITATION				135.0	0.7%	1.82E+02	0.0%	0.10	10.8	10.0
TRIBUTARY INFLOW				19003.0	99.3%	8.32E+07	100.0%	0.48	50.0	12.0
***TOTAL INFLOW				19138.0	100.0%	8.32E+07	100.0%	0.48	48.8	12.0
ADVECTIVE OUTFLOW				14651.4	76.6%	5.17E+07		0.49	39.2	9.2
***TOTAL OUTFLOW				14651.4	76.6%	5.17E+07		0.49	39.2	9.2
***RETENTION				4486.6	23.4%	6.78E+06		0.58		

Overflow Rate (m/yr)	27.7	Nutrient Resid. Time (yrs)	0.0746
Hydraulic Resid. Time (yrs)	0.0974	Turnover Ratio	13.4
Reservoir Conc (mg/m3)	39	Retention Coef.	0.234

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

Trb	Type	Seg	Name	Load kg/yr	Load %Total	Load Variance (kg/yr)^2	Load Variance %Total	CV	Conc mg/m^3	Export kg/km^2/yr
1	1	1	Elk River	162381.5	89.4%	6.86E+09	99.5%	0.51	454.9	107.5
2	1	1	Card Creek	6049.5	3.3%	9.52E+06	0.1%	0.51	454.9	161.3
3	1	1	Chetopa Creek	4266.5	2.3%	4.73E+06	0.1%	0.51	454.9	124.8
PRECIPITATION				8977.5	4.9%	2.01E+07	0.3%	0.50	715.1	665.0
TRIBUTARY INFLOW				172697.5	95.1%	6.87E+09	99.7%	0.48	454.9	109.2
***TOTAL INFLOW				181675.0	100.0%	6.89E+09	100.0%	0.46	463.2	113.9
ADVECTIVE OUTFLOW				173528.5	95.5%	5.81E+09		0.44	464.0	108.8
***TOTAL OUTFLOW				173528.5	95.5%	5.81E+09		0.44	464.0	108.8
***RETENTION				8146.5	4.5%	6.62E+07		1.00		

Overflow Rate (m/yr)	27.7	Nutrient Resid. Time (yrs)	0.0930
Hydraulic Resid. Time (yrs)	0.0974	Turnover Ratio	10.7
Reservoir Conc (mg/m3)	464	Retention Coef.	0.045

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 described 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	NonPoint LA lbs/day	WLA lbs/day	MOS (10%) lbs/day
TP	42,192	0.3	1.9	**219.6**	1.6	185.6	10.4	22.0
TN	400,524	0.5	2.68	**2940.8**	145.3	2442.5	58.9	294.1
TSS – (tons)	76,030	0.4	2.27	**472.84**		425.31	0.25	47.28

*-TSS is calculated in Tons/day

Maximum Daily Load Calculation

Annual TP Load = 42,192 lbs/yr

Maximum Daily TP Load = [(42,192 lbs/yr)/(365 days/yr)]*e $^{[2.326*(0.294)-0.5*(0.294)^2]}$
= 219.6 lbs/day

Annual TN Load = 400,524 lbs/yr

Maximum Daily TN Load = [(400,524 lbs/yr)/(365 days/yr)]*e $^{[2.326*(0.472)-0.5*(0.472)^2]}$
= 2940.8 lbs/day

Annual TSS Load = 76,030 tons/yr

Maximum Daily TSS Load = [(76,030 lbs/yr)/(365 days/yr)]*e $^{[2.326*(0.385)-0.5*(0.385)^2]}$
= 472.84 tons/day

Margin of Safety (MOS) for Daily Load

Annual TP MOS = 4219 lbs/yr

Daily TP MOS = [(4219 lbs/yr)/(365 days/yr)]*e $^{[2.326*(0.294)-0.5*(0.294)^2]}$
= 21.96 lbs/day

Annual TN MOS = 40,052 lbs/yr

Daily TN MOS = [(40,052 lbs/yr)/(365 days/yr)]*e $^{[2.326*(0.472)-0.5*(0.472)^2]}$
= 294.1 lbs/day

Annual TSS MOS = 7,603 tons/yr

Daily TSS MOS = [(7603 lbs/yr)/(365 days/yr)]*e $^{[2.326*(0.385)-0.5*(0.385)^2]}$
= 47.3 tons/day

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