MARAIS DES CYGNES RIVER BASIN TOTAL MAXIMUM DAILY LOAD

Waterbody: Hillsdale Lake
Water Quality Impairment: Eutrophication
Revision to Eutrophication TMDL originally approved August 28, 2001

1. INTRODUCTION AND PROBLEM IDENTIFICATION

Subbasin: Lower Marais des Cygnes

Counties: Douglas, Franklin, Johnson, Miami

HUC 8: 10290102

HUC 10 (12): 01 (01, 02, 03)

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

Drainage Area: 144 square miles

Conservation Pool: Surface Area = 4,355 acres
Watershed/Lake Ratio: 21:1
Maximum Depth = 14 meters
Mean Depth = 5.7 meters
Storage Volume = 77,665 acre-feet
Estimated Retention Time = 1.15 years
Mean Annual Inflow (2007-2012) = 90,509 acre-feet
Mean Annual Discharge (2007-2012) = 76,598 acre-feet
Constructed: 1981

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

303(d) Listings: 2002, 2004, 2008, 2010 & 2012 Marais Des Cygnes River Basin Lakes

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

Water Quality Criteria:

General – Narrative: Taste-producing and odor-producing substances of artificial origin shall not occur in surface waters at concentrations that interfere with the production of potable water by conventional water treatment processes, that impart an unpalatable flavor to edible aquatic or semiaquatic life or terrestrial wildlife, or that result in noticeable odors in the vicinity of surface waters (KAR 28-16-28e(b)(7)).

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

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

The introduction of plant nutrients into surface waters designated for primary or secondary contact recreational use shall be controlled to prevent the development of objectionable concentrations of algae or algal by-products or nuisance growths of submersed, floating, or emergent aquatic vegetation (KAR 28-16-28e(c)(7)(A)).

2. CURRENT WATER QUALITY CONDITION AND DESIRED ENDPOINT

Level of Support for Designated Uses under 2012 303(d): Excessive nutrients are not being controlled and are thus contributing to eutrophication which could interfere with domestic water supply use. The excessive nutrients are also impairing the special aquatic life use by supporting objectionable types and quantities of algae which also leads to impairment of contact recreation within Hillsdale Lake. A chlorophyll *a* endpoint of 10 µg/L is assigned to address the domestic water supply use; however, all other uses will be met when the chlorophyll *a* endpoint of 10 µg/L is met.

Level of Eutrophication (2007-2012): Very Eutrophic, Trophic State Index = 60.2

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

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

Lake Monitoring Sites:

KDHE Lake Sampling Stations:

LM035001: Near dam in Hillsdale Lake
Period of Record: 7/30/1985 through 6/28/2011

LM035002: Bull Creek arm in Hillsdale Lake
Period of Record: 7/30/1985 through 7/28/2005

LM035003: Little Bull arm in Hillsdale Lake
Period of Record: 7/30/1985 through 7/28/2005

United States Army Corps of Engineers (USACE) Lake Sampling Stations:

HD 3: Near dam in Hillsdale Lake
Period of Record: 4/20/1999 through 9/4/2012

HD 6: Bull Creek arm in Hillsdale Lake
Period of Record: 4/20/1999 through 9/4/2012

HD 11: Little Bull Creek arm in Hillsdale Lake
Period of Record: 4/20/1999 through 9/4/2012

Stream Chemistry Monitoring Sites:

KDHE Stream Probability Station SPA359: Bull Creek
Period of Record: 3/24/2008 through 10/13/2008

KDHE Stream Probability Station SPB088: Little Bull Creek
Period of Record: 3/15/2010 through 10/5/2000

KDHE Stream Probability Station SPA 103: Spring Creek
Period of Record: 3/14/2007 through 11/15/2007

USACE Station HD 2: Below the dam on Bull Creek
Period of Record: 4/20/1999 through 9/4/2012

USACE Station HD 10: Bull Creek above confluence with Martin Creek
Period of Record: 4/17/2007 through 7/19/2010

USACE Station HD 4: Little Bull Creek
Period of Record: 4/17/2007 through 9/9/2010

USACE Station HD 19: Rock Creek above Hillsdale Lake
Period of Record: 4/17/2007 through 9/9/2010

Flow Record:

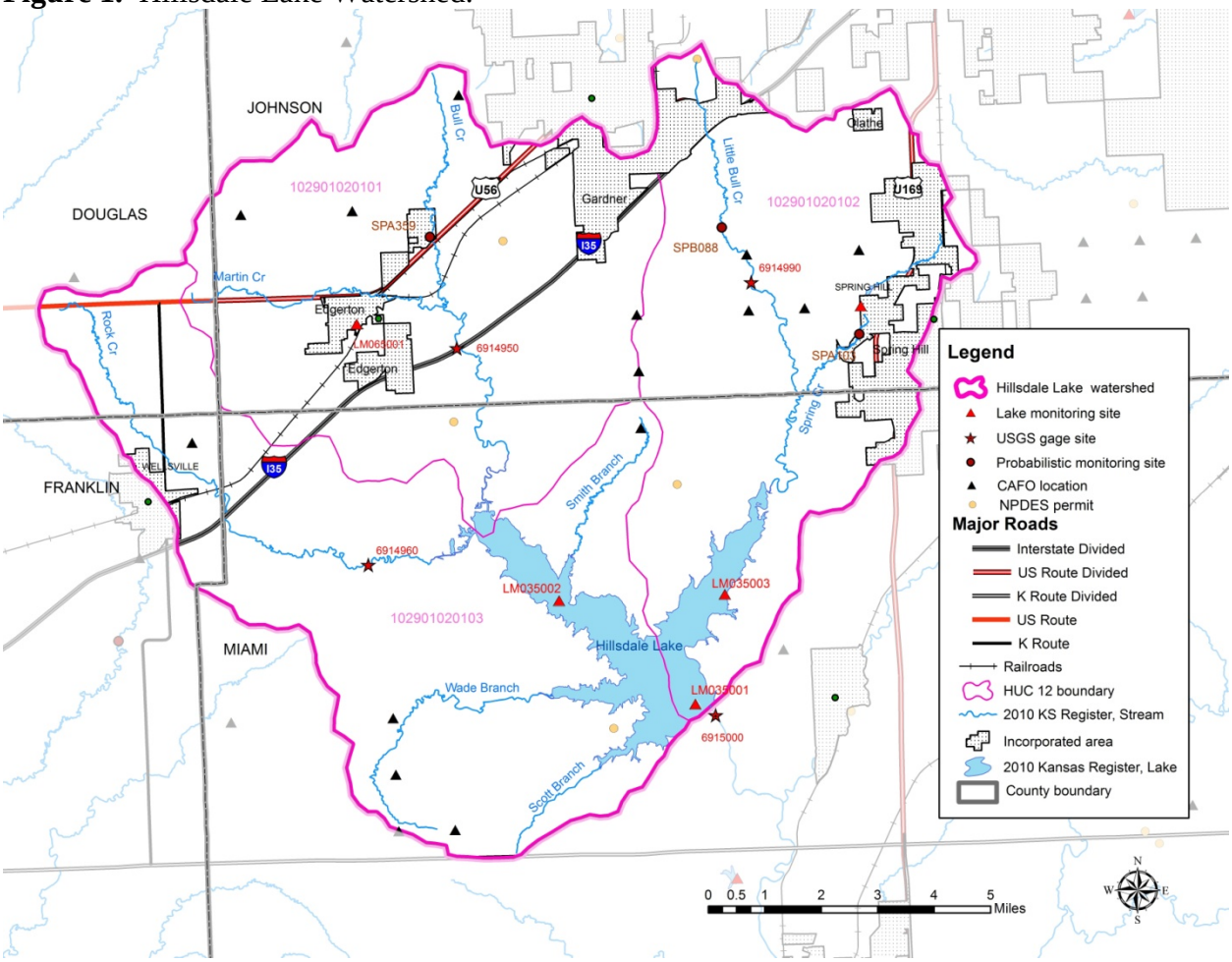
USGS Gage 06914950 Bull Creek near Edgerton, KS
Period of Record: 10/1/1993 through 12/31/2012

USGS Gage 06914990 Little Bull Creek near Spring Hill, KS
Period of Record: 1/1/1994 through 12/31/2012

USGS Gage 06914960 Rock Creek near Wellsville, KS
Period of Record: 10/1/1993 through 9/30/1996

USACE, Kansas City District – Hillsdale Lake
Period of Record: 1/1/1990 through 12/31/2012

Figure 1. Hillsdale Lake Watershed.



Hydrological Conditions: Hillsdale Lake receives most of its inflow via Rock Creek, Bull Creek and Little Bull Creek. It also receives inflow from Smith Branch and the unregistered streams Wade Branch and Scott Branch. The lake provides flood protection along Bull Creek downstream from the dam and, as part of the Osage River basin system of lakes, also contributes to flood protection on the Marais des Cygnes, Osage and Missouri rivers. Tributary flows for the entire period of record and for the period of record used for nutrient load modeling were calculated using the ratio of the drainage area of the tributary to the drainage area of the appropriate USGS gage. Drainage areas for Rock Creek, Bull Creek, Little Bull Creek and Scott Branch were assigned the USGS values determined by Perry et al. (2004) for the segment ending at Hillsdale Lake. Drainage areas for Wade Branch and Scott Branch were determined using GIS coverage. A linear regression was developed between the available flow data from USGS gage 06914960 on Rock Creek (10/1/1993 through 9/30/1996) and the flow data from USGS Gage 06914950 on Bull Creek from the same time period. The regression equation was then used to calculate flows for Rock Creek for the 10/1/1996 through 12/31/2012 period of record using the ratio of the drainage area of USGS Gage 06914960 to the drainage area of Rock Creek. Table 2 displays the estimated flow-duration values for the individual segments in the watershed (Perry, 2004). Reservoir accounting records kept by the U.S. Army Corps of Engineers (USACE) show the lake had an average inflow and outflow of 87,818 acre-feet and 49,787 acre-

feet, respectively, for the 1990 through 2012 time period (Figure 2). For the 2007 through 2012 period of record, the average annual inflow and outflow were 90,509 acre-feet and 76,598 acre-feet, respectively. Annual average precipitation calculated from the National Climatic Data Center's Hillsdale Lake station (GHCND: USC00143686) is also displayed in Figure 2 with 1990 through 2012 averaging 35.6 inches per year and the years 2007 through 2012 averaging 31.3 inches per year. The mean runoff in the watershed is 9.9 inches per year and the mean loss due to evaporation for the lake is 58.2 inches per year, according to Lake Hydro data.

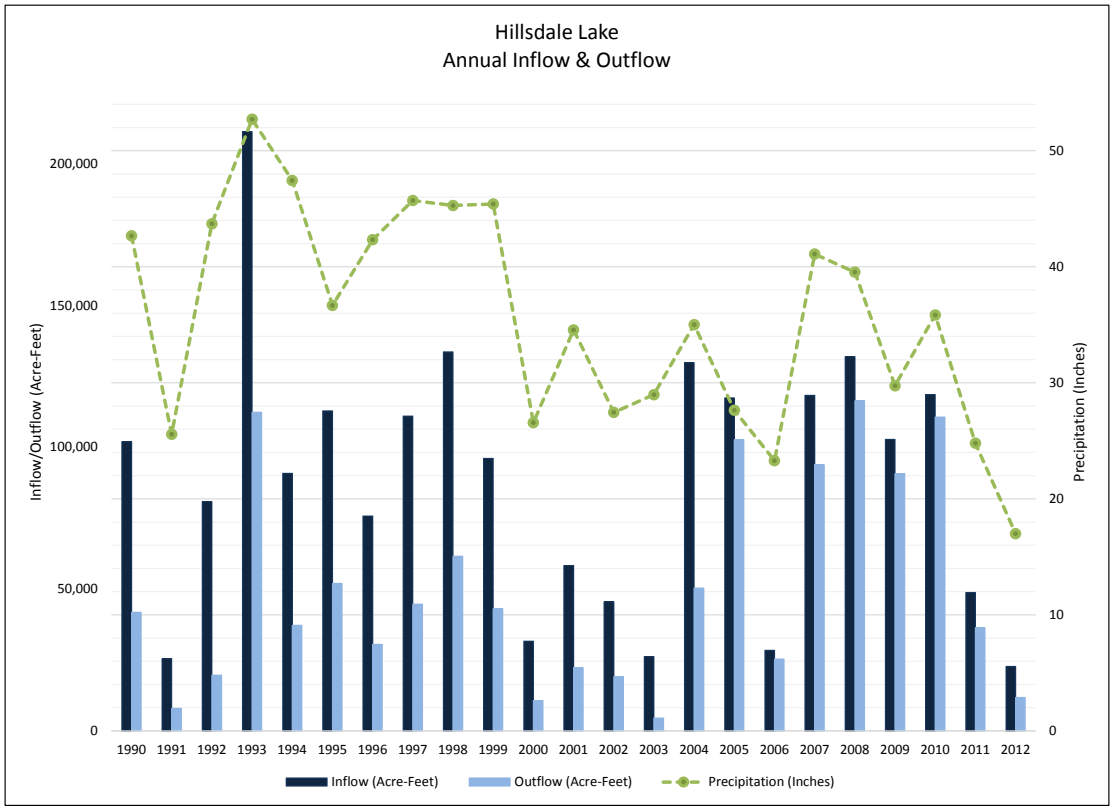
Table 1. Estimated flow-duration values (cfs) for indicated percentage of time flow equaled or exceeded for tributaries to Hillsdale Lake. Flows for Rock Creek, Bull Creek, Smith Branch, Wade Branch and Scott Branch were all determined using USGS 06914950 on Bull Creek. Flow for Little Bull Creek were determined using the USGS 06914990 on Little Bull Creek.

Stream	Period of Record	Drainage Area mi^2	Avg.	10%	25%	50%	75%	90%
USGS 06914950 Big Bull Cr near Edgerton	1994-2012	28.7	21	25	7.1	2.5	0.86	0.33
	2007-2012		23	35	9.5	2.6	0.46	0.081
Scott Branch	1994-2012	6.4	4.1	4.8	1.4	0.48	0.16	0.063
	2007-2012		4.4	6.7	1.8	0.50	0.088	0.015
Wade Branch	1994-2012	15.4	11	13	3.8	1.3	0.46	0.18
	2007-2012		12	19	5.1	1.4	0.25	0.043
Rock Creek	1994-2012	21.4	16	18	4.8	1.4	0.12	0
	2007-2012		17	26	6.7	1.5	0	0
Bull Creek	1994-2012	33.0	24	29	8.2	2.9	0.99	0.38
	2007-2012		26	40	11	3.0	0.53	0.093
Smith Branch	1994-2012	10.1	7.5	8.8	2.5	0.88	0.30	0.12
	2007-2012		8.0	12	3.3	0.91	0.16	0.029
USGS 06914990 Little Bull Cr near Spring Hill	1994-2012	7.86	8.6	11	3.6	1.5	0.69	0.37
	2007-2012		9.8	14	4.2	1.9	.89	0.53
Little Bull Creek	1994-2012	27.7	30	39	13	5.3	2.4	1.3
	2007-2012		34	49	15	6.7	3.1	1.9

Table 2. Estimated flow-duration values (cfs) for indicated percentage of time flow equaled or exceeded for streams entering Hillsdale Lake (Perry, 2004). DG: Douglas County; FR: Franklin County; MI: Miami County; JO: Johnson County.

Stream	County	USGS Site ID	Drainage Area mi^2	Avg	10%	25%	50%	75%	90%	2-year Peak
Rock Cr	DG/FR/MI	2493	21.4	18.0	23.2	7.89	2.16	0.01	0	2,290
Martin Cr	DG/JO	2364	16.0	13.2	16.4	5.59	1.56	0	0	1,940
Bull Cr	JO	2362	9.70	8.35	10.1	3.42	0.98	0	0	1,460
Bull Cr	JO	2408	33.0	26.6	35.3	12.2	3.48	0.42	0	4,280
Little Bull Cr	JO	2412	16.6	14.4	18.3	6.33	1.78	0	0	2,030
Little Bull Cr	JO	2437	27.7	24.1	32.2	11.2	3.18	0.31	0	2,750
Smith Br	MI	2483	10.1	10.1	13.3	4.79	1.41	0	0	1,540

Figure 2. 1990 through 2012 annual inflow, outflow and precipitation records for Hillsdale Lake.



Current Condition: Chlorophyll *a* averages 13.8 µg/L for the period of record (1985-2012) in Hillsdale Lake. The first near dam sample with a chlorophyll *a* concentration greater than 10 µg/L was collected in June of 1987 (Figure 3) and recent (2007-2012) samplings performed by KDHE and USACE have an average chlorophyll *a* concentration of 21.2 µg/L (Table 3). The highest annual concentration of chlorophyll *a* occurred in 2007 at 25.3 µg/L and average annual chlorophyll *a* concentrations have been consistently greater than 10 µg/L since 2003 (Figure 4).

Figure 3. KDHE and USACE near dam chlorophyll *a* concentrations in Hillsdale Lake, by sampling day, for the period of record.

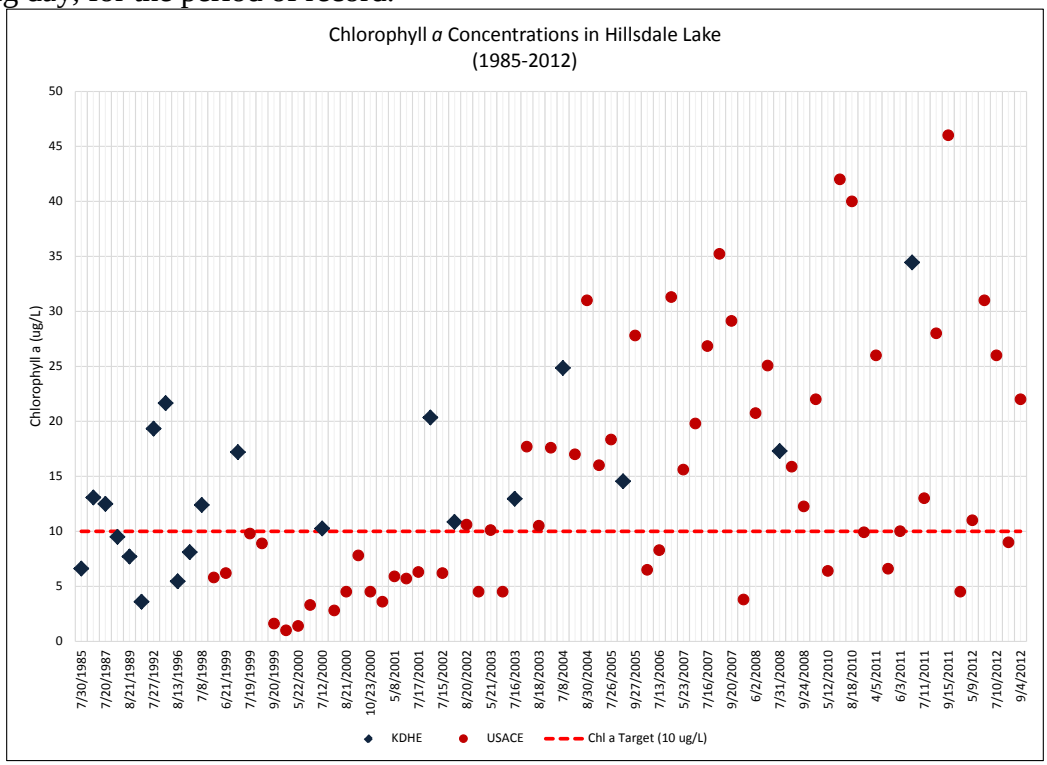
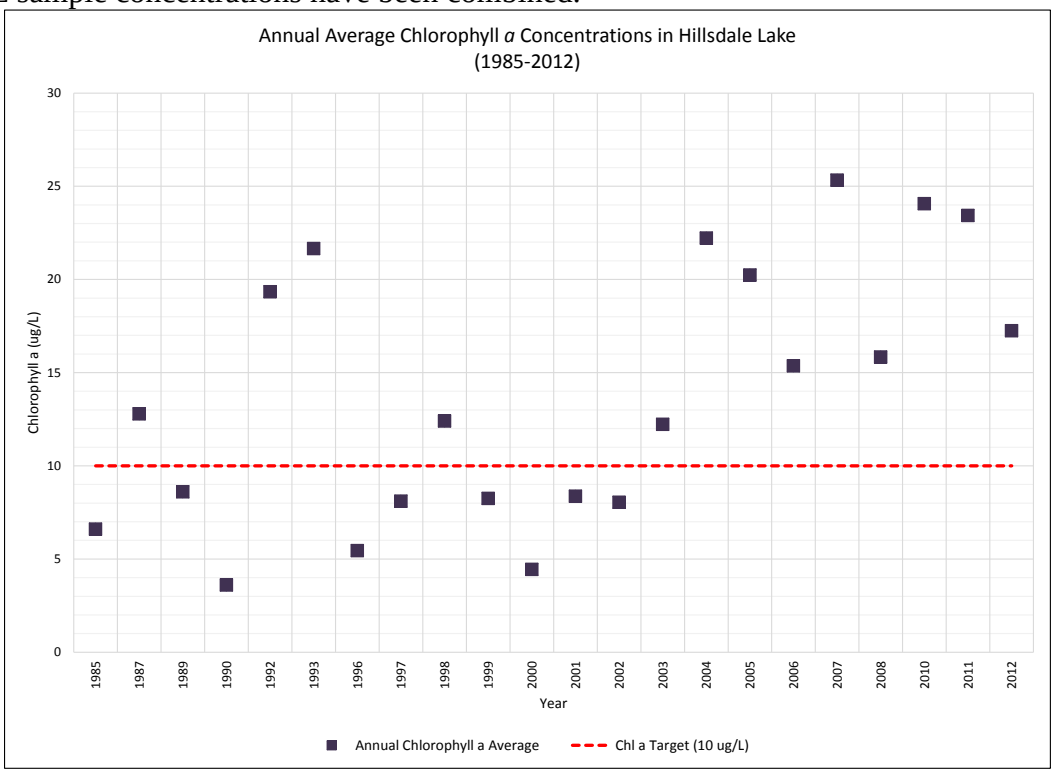
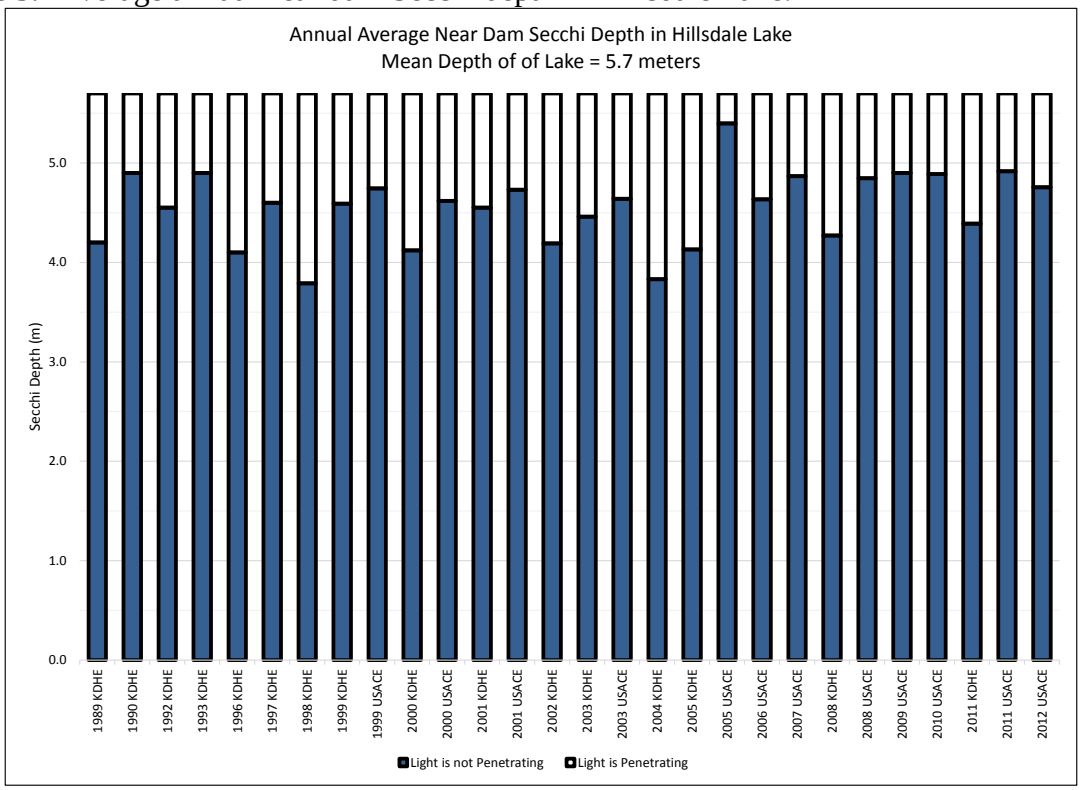


Figure 4. Average annual near dam chlorophyll *a* concentrations in Hillsdale Lake. KDHE and USACE sample concentrations have been combined.



Secchi depth readings were available beginning in 1989. A 1.9 meter reading taken in 1998 is the highest reading for the period of record (Figure 5). The 1990-2012 average Secchi depth comes in at 1.1 meters with the 2007 through 2012 average of 1.0 meter revealing slightly diminished clarity.

Figure 5. Average annual near dam Secchi depth in Hillsdale Lake.



The highest annual average total phosphorus (TP) concentration occurred in 1990 (Figure 7) while the sample with the highest total phosphorus concentration was collected on July 15, 2002 measuring 170 μg/L total phosphorus (Figure 6). The period of record (1985-2012) average total phosphorus concentration is 33 μg/L while the more recent (2007-2012) average is slightly lower at 31 μg/L (Table 3).

Total nitrogen (TN) concentration reached a single sample high of 2.24 mg/L in May of 1999 in a sample collected by USACE (Figure 8) boosting 1999 to the highest annual average at 1.22 mg/L (Figure 9). Total nitrogen period of record average (1992-2012) is 0.804 mg/L while the 2007-2012 average is slightly lower at 0.799 mg/L (Table 3).

Figure 6. Near dam total phosphorus concentrations in Hillsdale Lake, by sampling date, for the period of record.

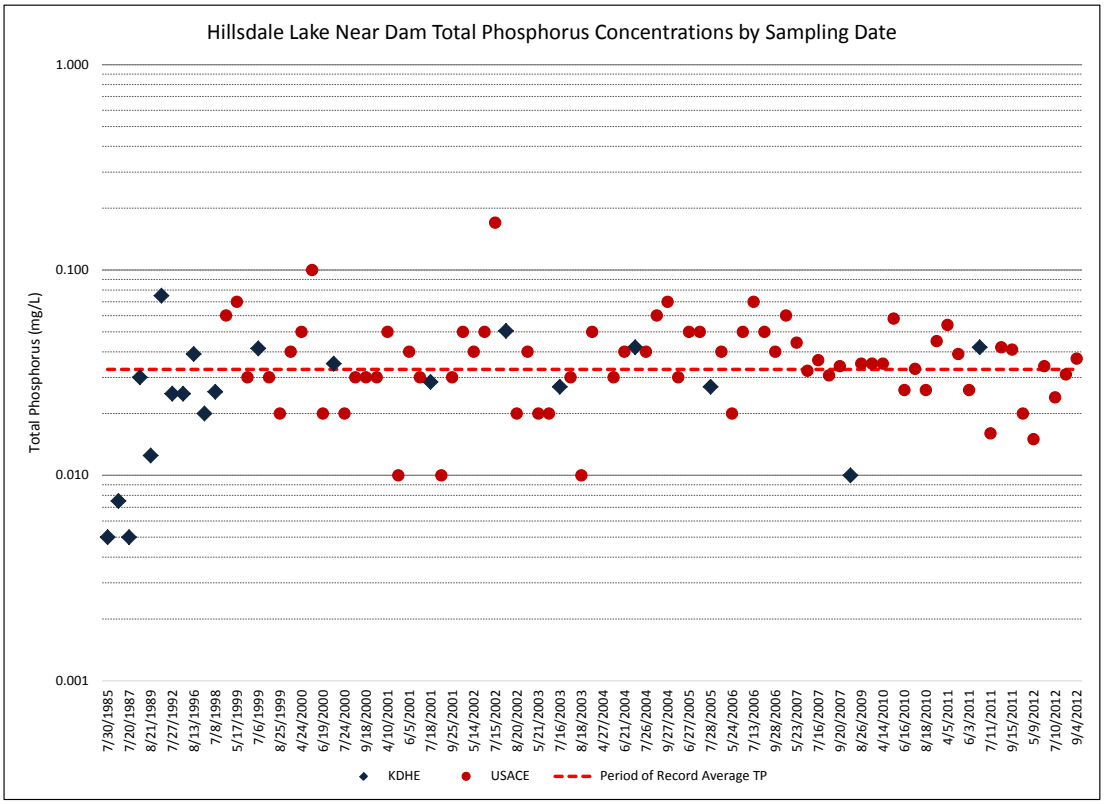


Figure 7. KDHE & USACE combined annual averages for total phosphorus in Hillsdale Lake.

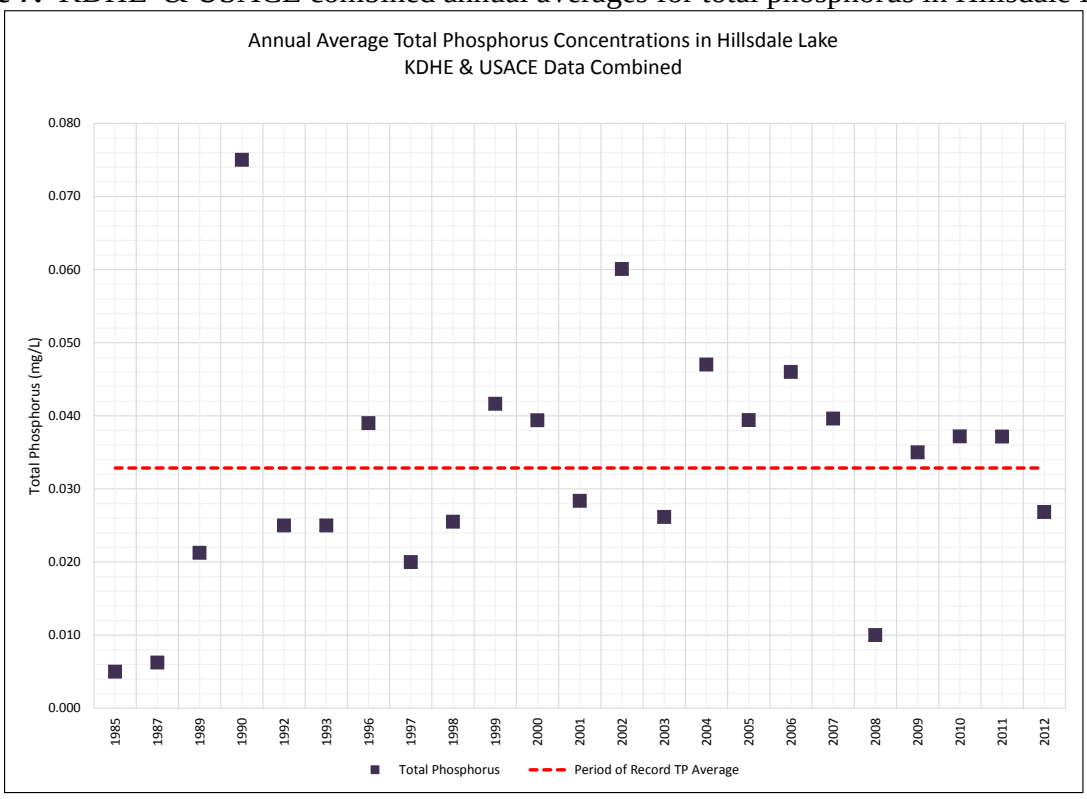


Figure 8. Total nitrogen concentrations in Hillsdale Lake, by sampling date, for the period of record.

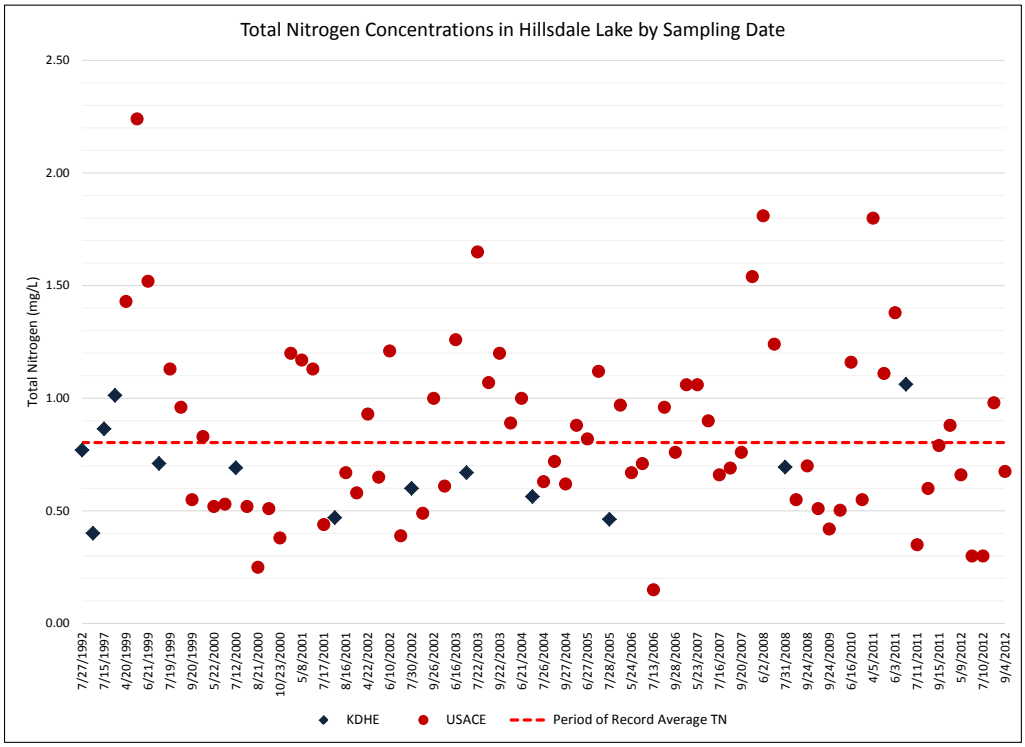
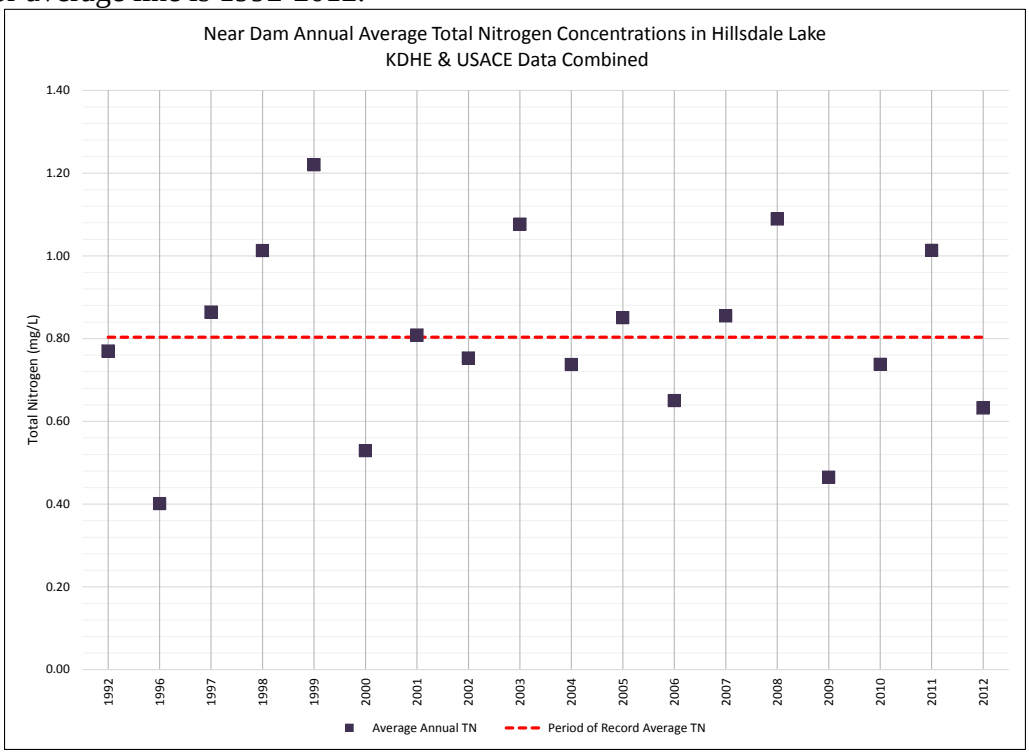
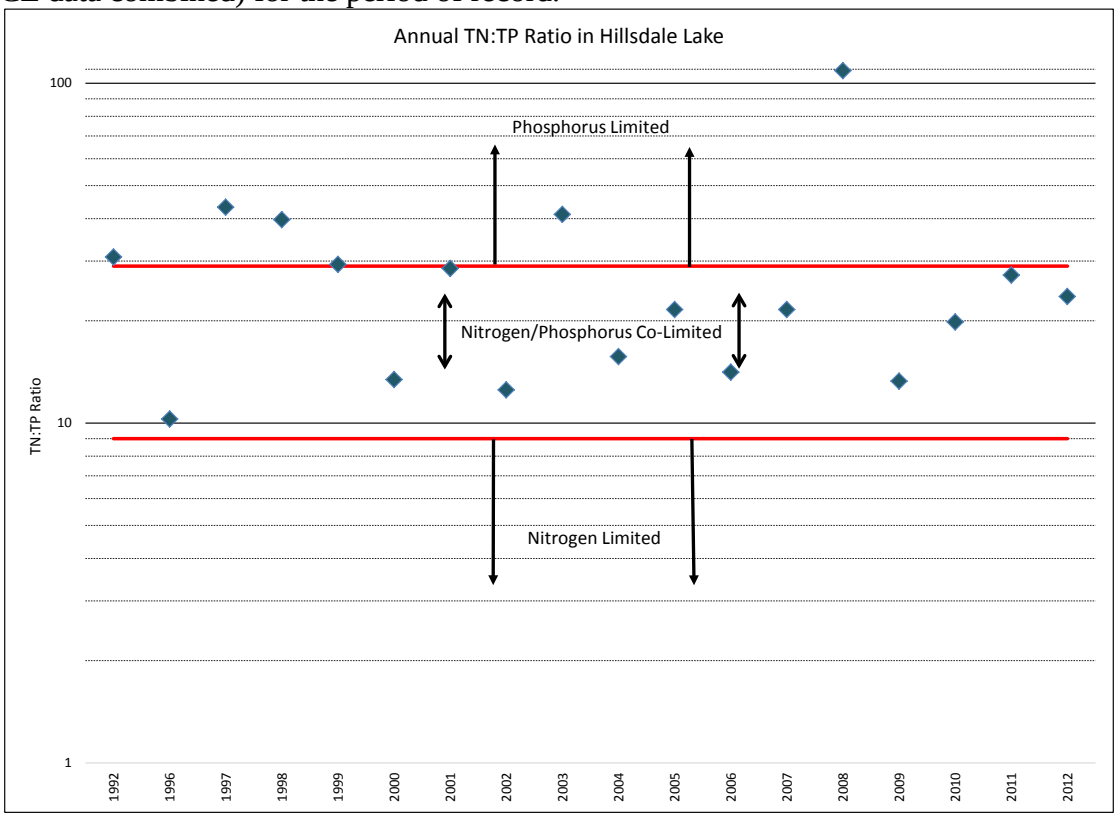


Figure 9. Average annual near dam total nitrogen concentrations in Hillsdale Lake. KDHE & USACE combined annual averages for total nitrogen concentration in Hillsdale Lake. Period of record for average line is 1992-2012.



The ratio of total nitrogen and total phosphorus has been used to determine which of these nutrients is most likely limiting plant growth in Kansas aquatic ecosystems. Generally, lakes that are nitrogen limited have water column TN:TP ratios < 8 (mass); lakes that are co-limited by nitrogen and phosphorus have water column TN:TP ratios between 8 and 29; and lakes that are phosphorus limited have water column TN:TP ratios > 29 (Dzialowski et al., 2005). The TN:TP ratio in Hillsdale Lake indicates the lake has been either phosphorus limited or co-limited by phosphorus and nitrogen for the period of record. For the most recent period of record (2007-2012) the lake has been co-limited with the exception of 2008 when the lake was limited by phosphorus only (Figure 10).

Figure 10. TN:TP ratio for annual average total phosphorus and total nitrogen (KDHE & USACE data combined) for the period of record.



Turbidity in Hillsdale Lake averages 7.8 NTU for the period of record (1985-2012) with a single sample high of 25 NTU taken by USACE on April 5, 2011 (Figure 11). The highest annual average turbidity occurred in 2010 with a value of 18 NTU (Figure 12). The average turbidity for the recent (2007-2012) period of record is 11 NTU (Table 3).

Figure 11. Turbidity values of daily samples in Hillsdale Lake for the period of record.

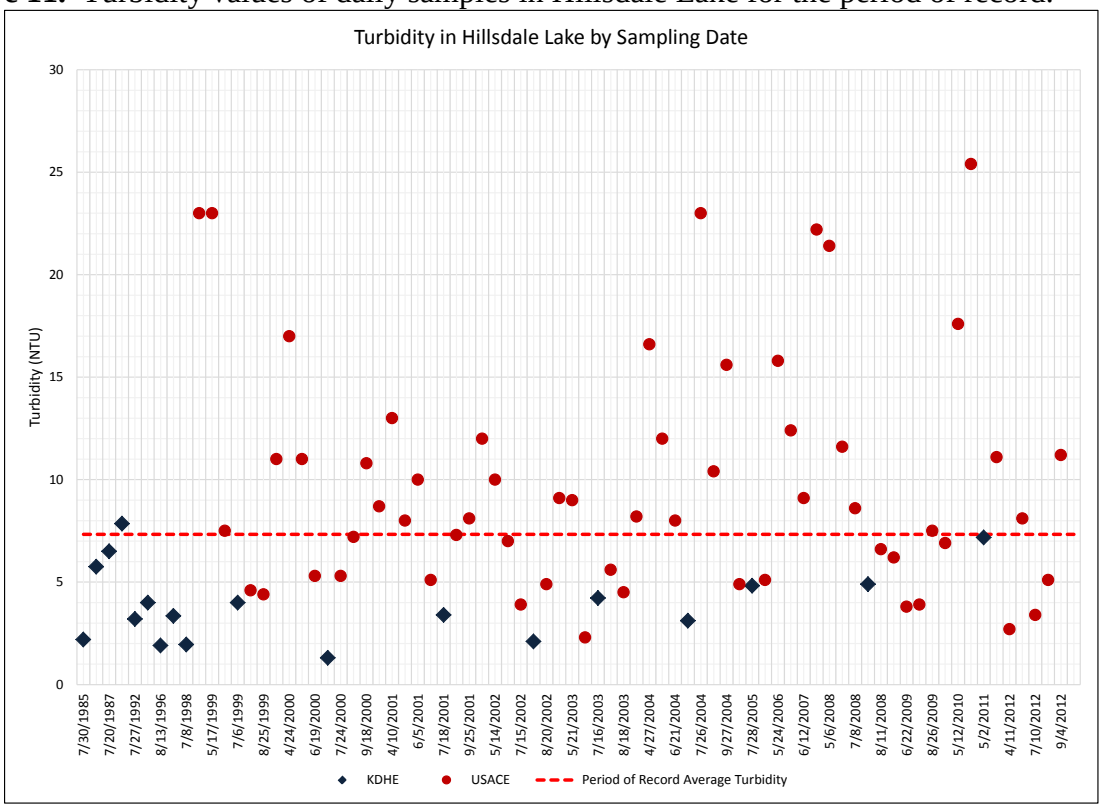


Figure 12. Annual average turbidity in Hillsdale Lake for the period of record.

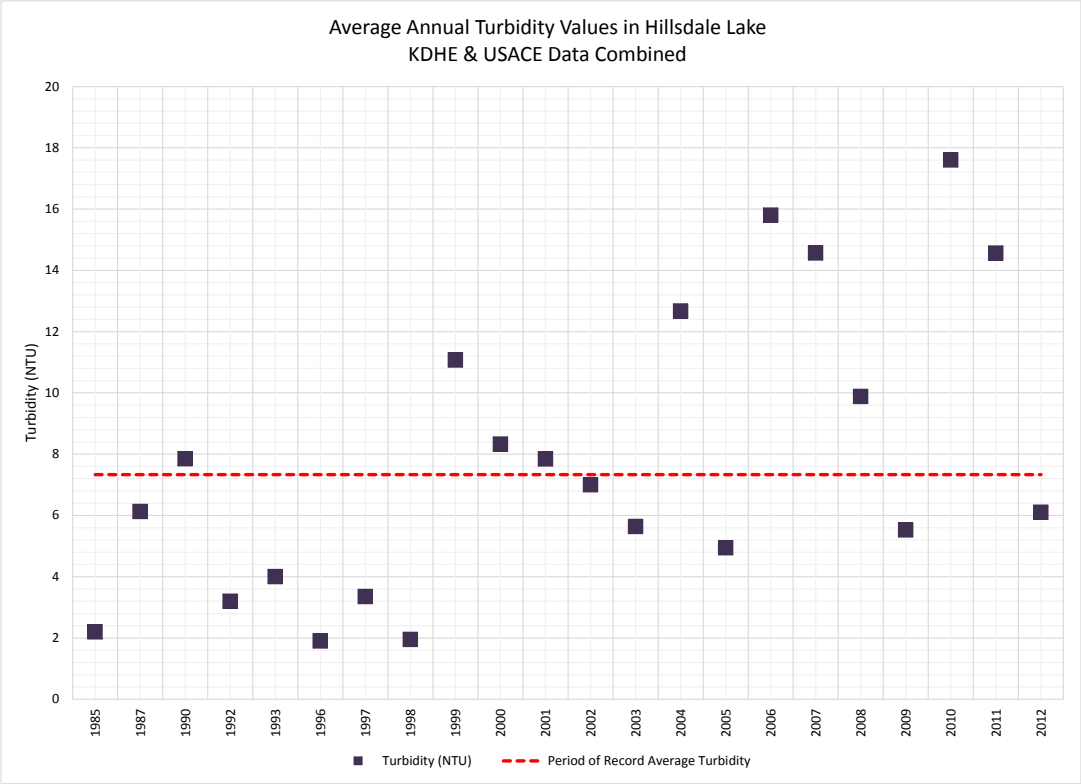


Table 3. Water quality data summary for Hillsdale Lake. Annual averages were calculated from daily sampling data with the exception of the TN:TP ratio which was calculated from the annual averages in Table 3. The KDHE & USACE annual averages were calculated from daily sampling data available from each source. The combined KDHE & USACE period of record data summarized at the bottom of the Table 3 were calculated by first calculating annual averages using daily sampling data from both sources and then averaging the annual averages for the applicable period of record. Empty cells indicate no data were available for year/source/parameter.

Sample Year	Source	Chl a (µg/L)	TN (mg/L)	TP (mg/L)	TN:TP Ratio	Secchi Depth (m)	Turbidity (NTU)
1985	KDHE	6.61		0.005			2.2
1987	KDHE	12.8		0.006			5.8
1989	KDHE	8.60		0.021		1.5	
1990	KDHE	3.60		0.075		0.80	6.5
1992	KDHE	19.3	0.770	0.025	30.8	1.2	7.9
1993	KDHE	21.7		0.025		0.80	3.2
1996	KDHE	5.45	0.401	0.039	10.3	1.6	4.0
1997	KDHE	8.10	0.864	0.020	43.2	1.1	1.9
1998	KDHE	12.4	1.01	0.026	38.8	1.9	3.4
1999	KDHE	17.2	0.710	0.042	16.9	1.1	4.0
1999	USACE	6.46	1.31	0.042	31.2	0.96	12
2000	KDHE	10.3	0.692	0.035	19.8	1.6	1.3
2000	USACE	3.61	0.506	0.040	12.7	1.1	9.3
2001	KDHE	5.38	0.470	0.029	16.2	1.2	3.4
2001	USACE	5.38	0.865	0.028	30.9	0.97	8.6
2002	KDHE	20.3	0.600	0.051	11.8	1.5	2.1
2002	USACE	7.10	0.778	0.062	12.5	0.90	7.8
2003	KDHE	13.0	0.670	0.027	24.8	1.2	4.2
2003	USACE	12.1	1.16	0.026	44.6	1.1	5.9
2004	KDHE	24.9	0.564	0.042	13.4	1.9	3.1
2004	USACE	21.3	0.772	0.048	16.1		14
2005	KDHE	14.6	0.463	0.027	17.1	1.6	4.8
2005	USACE	23.1	0.948	0.043	22.0	0.30	5.0
2006	USACE	15.4	0.650	0.046	14.1	1.1	16
2007	USACE	25.3	0.855	0.040	21.4	0.83	15
2008	KDHE	17.3	0.695	0.010	69.5	1.4	4.9
2008	USACE	15.5	1.17			0.85	11
2009	USACE		0.465	0.035	13.3	0.80	5.5
2010	USACE	24.1	0.738	0.037	19.9	0.81	18
2011	KDHE	34.4	1.06	0.042	25.2	1.3	7.2
2011	USACE	21.6	1.01	0.036	28.1	0.78	18
2012	USACE	17.3	0.633	0.027	23.4	0.95	6.1
1985-2011	***KDHE***	***14.5***	***0.690***	***0.030***	***23.0***	***1.4***	***4.1***
1999-2012	***USACE***	***15.2***	***0.846***	***0.039***	***21.7***	***0.87***	***11***
1985-2012	***KDHE & USACE***	***13.8***	***0.723***	***0.033***	***21.9***	***1.1***	***7.8***
2007-2012	***KDHE***	***25.9***	***0.878***	***0.026***	***33.8***	***1.4***	***6.0***
2007-2012	***USACE***	***20.8***	***0.811***	***0.035***	***23.2***	***0.84***	***12***
2007-2012	***KDHE & USACE***	***21.2***	***0.799***	***0.031***	***25.8***	***1.0***	***11***

As can be seen in Figure 13, Hillsdale Lake periodically stratifies increasing the likelihood of internal nutrient cycling in the lake.

Figure 13. Dissolved oxygen and temperature profile in main basin for Hillsdale Lake 2000-2011.

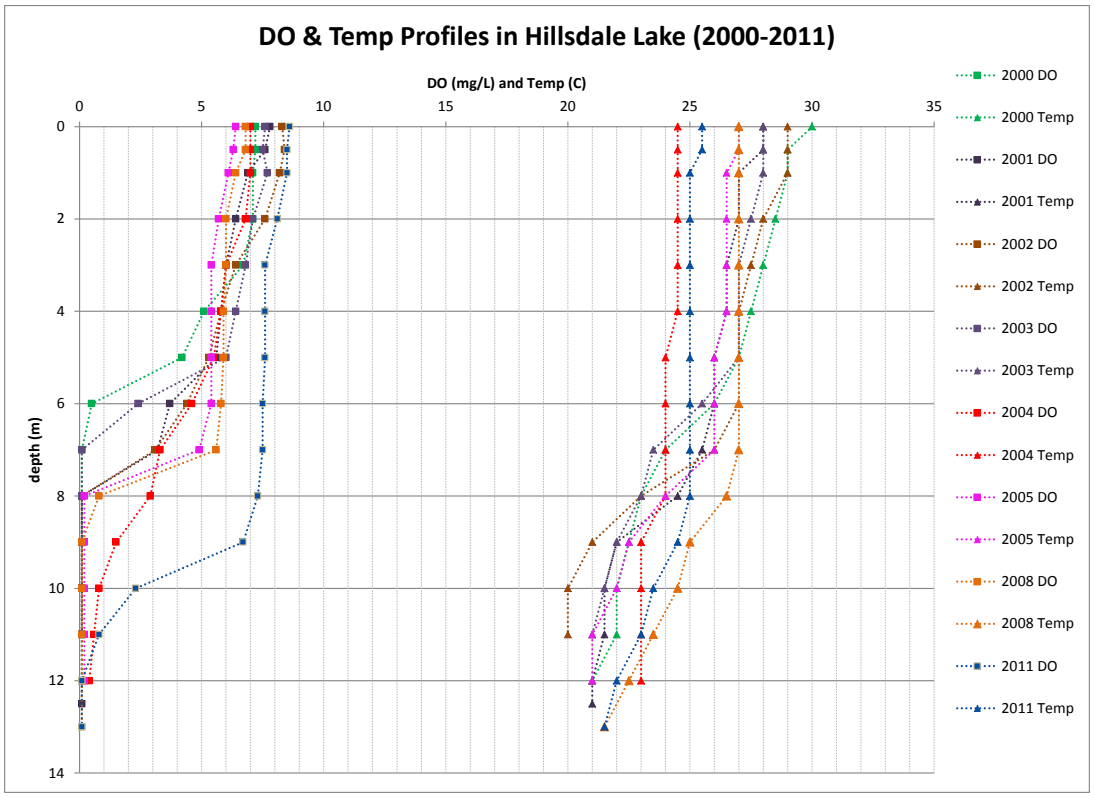


Table 4 lists the six metrics measuring the roles of light and nutrients in Hillsdale Lake. Non-algal turbidity (NAT) values <0.4m^{-1} indicates there are very low levels of suspended silt and/or clay. The values between 0.4 and 1.0m^{-1} indicate turbidity assumes greater influence on water clarity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

Table 4. Light limiting metrics in Hillsdale Lake. An empty cell indicates no data are available from the source for the noted period of record.

Sampling Year	Non-algal Turbidity	Light Availability in the Mixed Layer	Partitioning of Light Extinction between Algae & Non-algal Turbidity	Algal use of Phosphorus Supply	Light Availability in the Mixed Layer for a Given Surface Light	Shading in Water Column due to Algae and Inorganic Turbidity	Chl-*a* (μg/L)
	NAT	Zmix*NAT	Chl-a*SD	Chl-a/TP	Zmix/SD	Shading	
1989	0.41	2.0	12.0	0.47	3.59	6.77	8.60
1990	1.05	5.2	2.88	0.05	6.25	7.65	3.60
1992	0.37	1.8	22.2	0.77	4.35	8.05	19.3
1993	0.71	3.5	17.3	0.87	6.25	9.18	21.7
1996	0.38	1.9	8.72	0.14	3.13	6.28	5.45
1997	0.61	3.0	8.91	0.41	4.55	7.20	8.10
1998	0.14	0.71	23.7	0.49	2.62	6.62	12.4
1999	0.43	2.2	19.1	0.41	4.50	7.95	17.2
2000	0.29	1.5	16.2	0.29	3.16	6.71	10.3
2001	0.35	1.7	23.4	0.71	4.35	8.14	20.3
2002	0.31	1.5	16.4	0.21	3.31	6.83	10.9
2003	0.41	2.1	16.1	0.48	4.03	7.36	13.0
2004			46.5	0.59	2.67	7.70	24.9
2005	0.22	1.1	22.8	0.54	3.18	7.08	14.6
2008	0.23	1.2	24.7	1.73	3.50	7.46	17.3
2011	0.02	0.10	45.1	0.82	3.82	9.07	34.4

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

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

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

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

Shading values less than 16 indicate that self-shading of algae does not significantly impede productivity. This metric is most applicable to lakes with maximum depths of less than 5 meters (Carney, 2004).

The levels of non-algal turbidity in the lake are less than 1.0 for the period of record with the exception of 1990 when the Secchi depth in the lake was at 0.8 meters. The degree of NAT in the lake indicates that the levels of suspended silt and/or clay in the lake are not high enough to diminish light availability in Hillsdale Lake as demonstrated by consistent Zmix*NAT values less than three and Chl *a* * SD values greater than 16. The abundant light availability in the lake indicates there is a high probability of strong algal responses to the nutrient inputs in the lake.

Another method for evaluating limiting factors is the trophic state index (TSI) deviation metrics. Figure 14 (Multivariate Deviation Graph) summarizes the current trophic conditions in Hillsdale Lake using a multivariate TSI comparison chart for the period of record. Where TSI(Chl-a) is greater than TSI(TP), the situation indicates phosphorus is limiting chlorophyll *a*, whereas negative values indicate turbidity limits chlorophyll *a*. Where TSI(Chl-a)-TSI(SD) is plotted on the horizontal axis, if the Secchi depth (SD) trophic index is less than the chlorophyll *a* trophic index, then there is dominant zooplankton grazing. Transparency would be dominated by non-algal factors such as color or inorganic turbidity if the Secchi depth index were more than the chlorophyll *a* index. Points near the diagonal line occur in turbid situations where phosphorus is bound to clay particles and therefore turbidity values are closely associated with phosphorus concentrations.

The multivariate TSI comparison chart in Figure 14 displays that for the most recent period of record (2007-2012) turbidity in Hillsdale Lake is not limiting chlorophyll *a* production and the lake is in a phosphorus limited state. In 1998, 2000, and 2006 turbidity values were closely associated with the phosphorus concentration indicating the lake was turbid with phosphorus bound to clay particles. Zooplankton grazing does not appear to be occurring in Hillsdale Lake.

Comparing the trophic state indices for total phosphorus, chlorophyll *a* and Secchi depth in Hillsdale Lake reveals the lake reached a fully eutrophic state with respect to chlorophyll *a* in 2003 and has been either fullyor very eutrophic for the remaining period of record. The total phosphorus TSI value has bounced between slightly eutrophic and fully eutrophic since 1998 with the exception of 2002 when it reach a very eutrophic state and 2008 when a low average concentration resulted in a total phosphorus TSI value in the oligotrophic range. Secchi depth TSI values have been at or above the slightly eutrophic range for the period of record with one excursion into the hypereutrophic range in 2005 (Figure 15).

Figure 14. Multivariate TSI comparison chart for Hillsdale Lake.

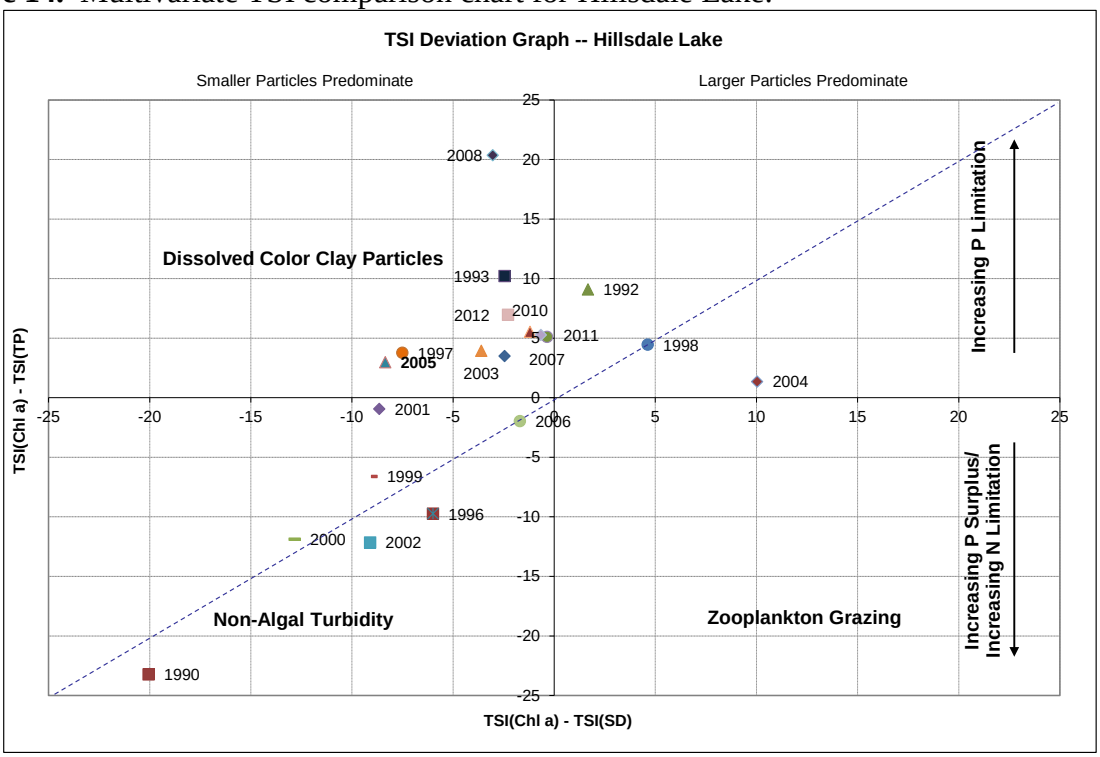
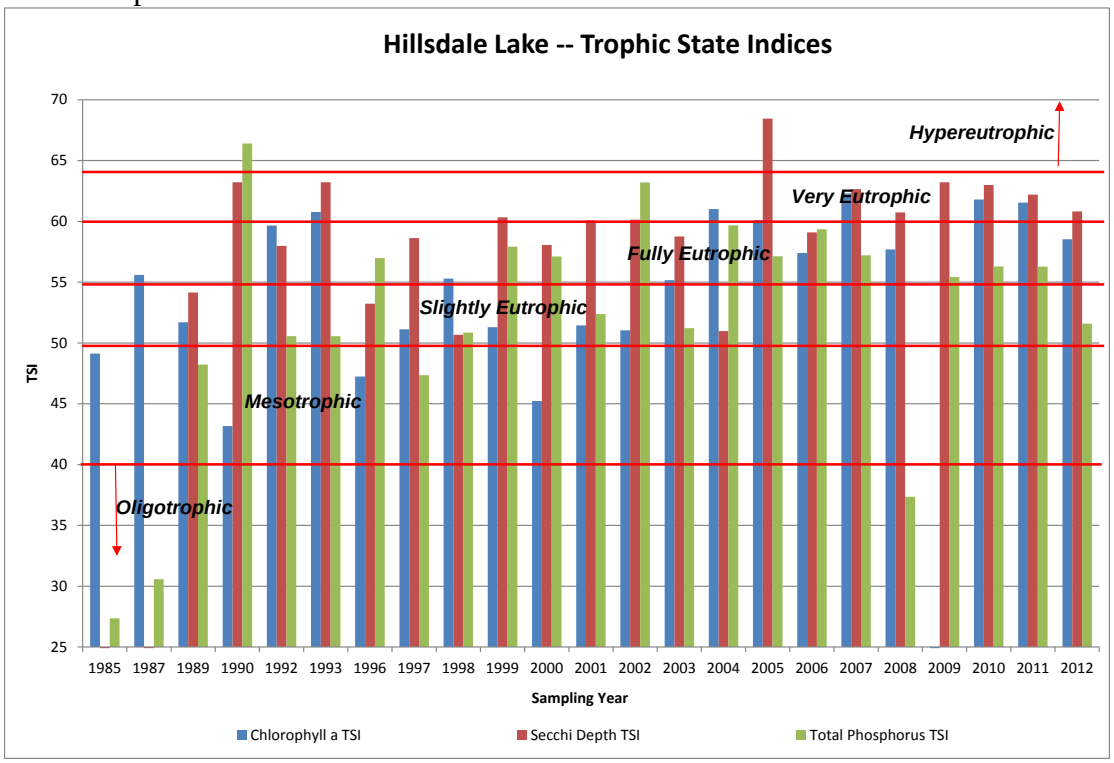


Figure 15. Trophic state indices for Hillsdale Lake.



A comparison of the median trophic conditions in Hillsdale Lake for the 2007 to 2012 time period to the benchmarks established for lakes in Kansas reveals that although both total nitrogen and total phosphorus concentrations in Hillsdale Lake meet the benchmarks established for federal lakes in Kansas, the median Secchi depth and chlorophyll *a* concentration do not. The Secchi depth benchmark was narrowly missed at 93 cm (Table 5). The median total phosphorus concentration narrowly meets the benchmark for the RTAG lakes. However, when measured against the benchmarks established for the Kansas lakes and lakes in the central irregular plains ecoregion the median total phosphorus values for Hillsdale Lake during the 2007 to 2012 time period fall short. The statewide benchmarks and benchmarks for Kansas lakes in the central irregular plains region were derived from analysis of trophic conditions in the lakes and reservoirs in Kansas (Dodds et al., 2006). RTAG benchmarks were established by the USEPA Region 7 Regional Technical Assistance Group (RTAG) and are for lakes and reservoirs in Kansas, Iowa, Missouri and Nebraska excluding the Sand Hills ecoregion (USEPA, 2011).

Table 5. Median trophic indicator values for Hillsdale Lake in comparison with federal lakes in Kansas, lakes located in the central irregular plains ecoregion, draft nutrient benchmarks in Kansas and nutrient reference conditions for lakes in USEPA Region 7. Median values are based on data from KDHE and USACE from 2007-2012.

Trophic Indicator	Hillsdale Lake	Federal Lakes	Central Irregular Plains Lakes	Statewide Benchmark	RTAG
Secchi Depth (cm)	93	95	130	129	N/A
TN (µg/l)	730	903	362	625	700
TP (µg/l)	35	76	20	23	35
Chlorophyll *a* (µg/l)	21	12	8	8	8

Algal Communities: As seen in Table 6, algal communities in Hillsdale Lake have been dominated by blue-green algae, or cyanobacteria, since 1999. An increasing supply of nutrients, especially phosphorus and possibly nitrogen, will often result in higher growth of blue-green algae because they possess certain adaptations that enable them to out compete true algae (Soil and Water Conservation Society of Metro Halifax, 2007). Several of the cyanobacteria species possess gas vacuoles that allow them to move within the water column vertically. This selective advantage allows for some species to move within the water column to avoid predation and reach optimal primary productivity. Their movement within the water column may influence chlorophyll *a* levels within the lake at various depths during the diel cycle.

Table 6. Cell count and percent composition of the algal communities in near dam samples with corresponding chlorophyll *a* concentrations observed in Hillsdale Lake by KDHE on the sampling date detailed.

Sampling Date	Total Cell Count cells/mL	Percent Composition				Chl-*a* μg/L
		Green	Blue Green	Diatom	Other	
7/27/1992	11,466	59	11	29	1	19.3
7/12/1993	1,260	50	0	20	30	21.7
8/13/1996	5,670	14	50	34	2	5.45
7/15/1997	3,717	26	40	32	3	8.10
7/8/1998	4,284	46	0	25	30	12.4
7/6/1999	10,364	12	73	13	3	17.2
7/12/2000	13,545	28	62	9	2	10.3
7/18/2001	111,132	0	96	4	0	20.3
7/30/2002	7,623	16	56	24	4	10.9
7/16/2003	24,759	2	95	3	0	13.0
7/8/2004	12,915	7	67	18	9	24.9
7/28/2005	43,155	7	83	7	3	14.6
7/31/2008	37,863	2	94	4	0	17.3
6/28/2011	20,381	26	54	14	6	34.4

Other Lake Sampling Data: KDHE and USACE have sampling sites in both the Bull Creek and Little Bull Creek pools of Hillsdale Lake. KDHE sites LM035002 (Bull Creek) and LM035003 (Little Bull Creek) are seen in Figure 1 while USACE sites HD 6 (Bull Creek) and HD 11 (Little Bull Creek) are displayed in Figure 16. Average annual concentrations for total phosphorus, total nitrogen and chlorophyll *a* are detailed in Figures 17, 18 and 19, respectively, for both segments. Segment water quality data mirrors main basin data with the recent period of record (2007-2012) averages for the both segments showing an uptick in chlorophyll *a* concentrations while the nutrient concentrations have remained steady or slightly decreased (Table 7).

Figure 16. USACE sampling sites in the Hillsdale Lake watershed.

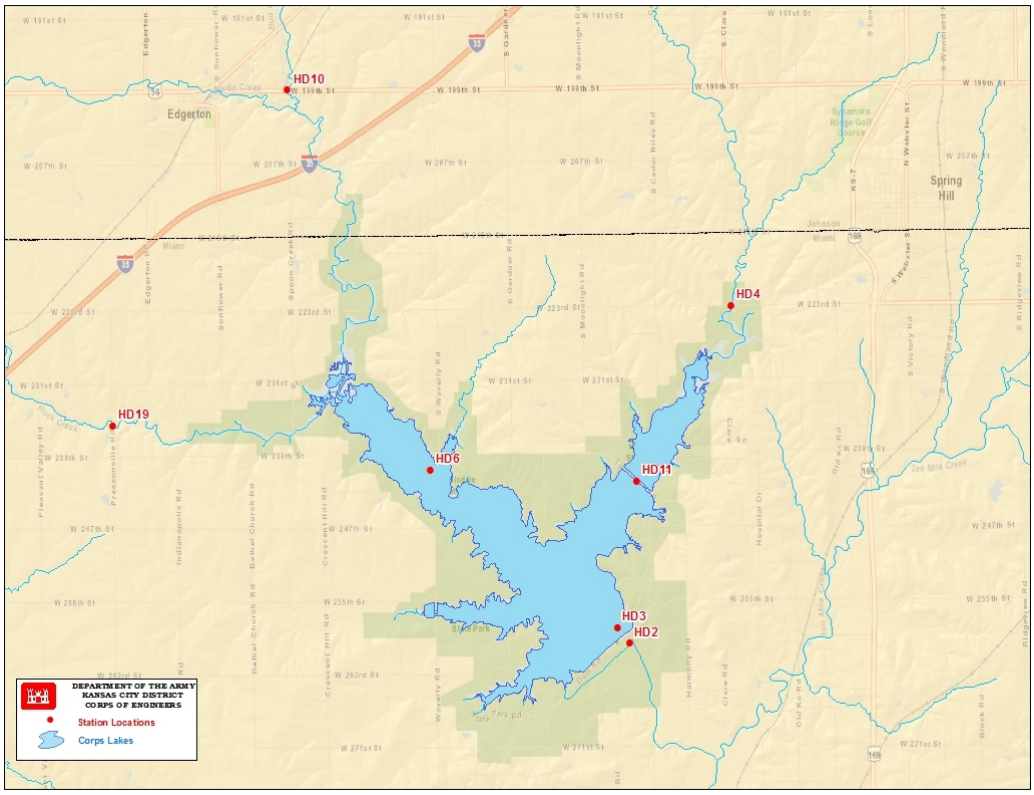


Figure 17. Average annual total phosphorus concentrations in Hillsdale Lake segments. USACE and KDHE data were combined, if both were available, for the annual average.

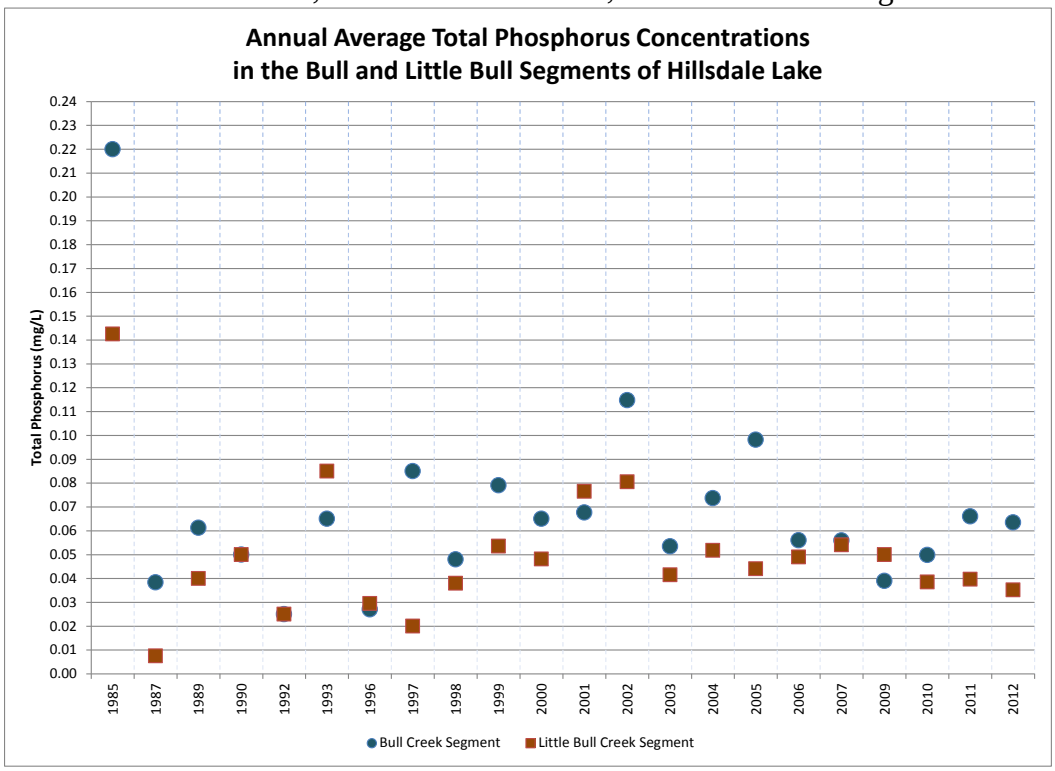


Figure 18. Average annual total nitrogen concentrations in Hillsdale Lake segments. USACE and KDHE data were combined, if both were available, for the annual average.

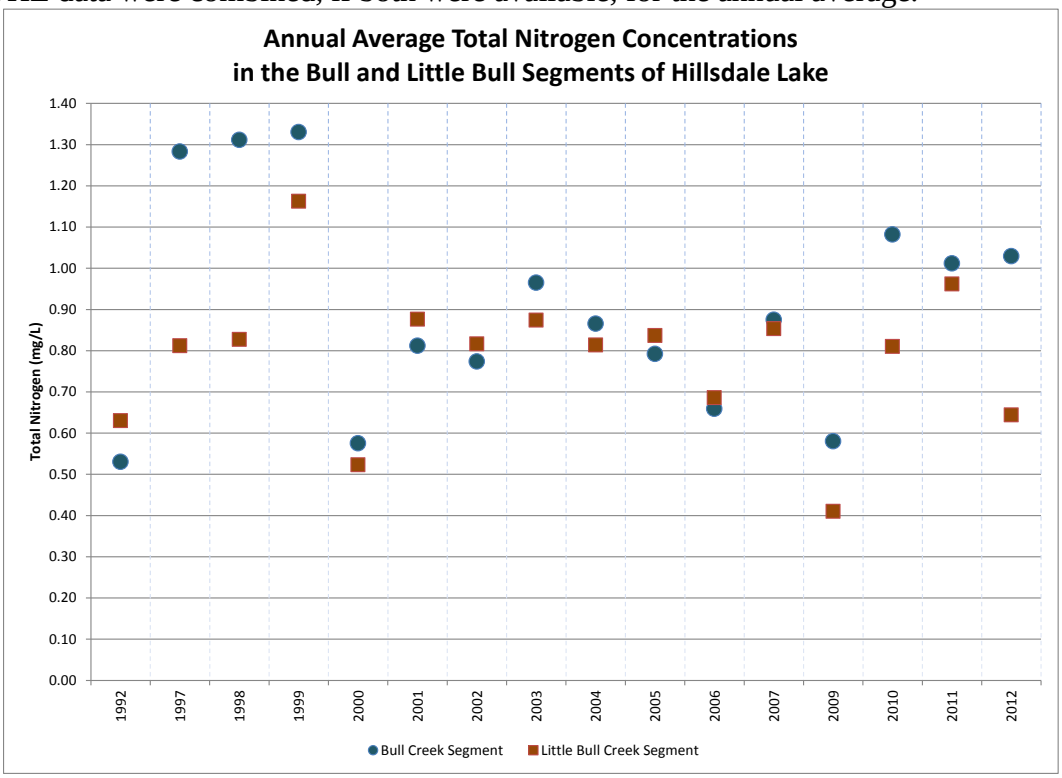


Figure 19. Average annual chlorophyll *a* concentrations in Hillsdale Lake segments. USACE and KDHE data were combined, if both were available, for the annual average.

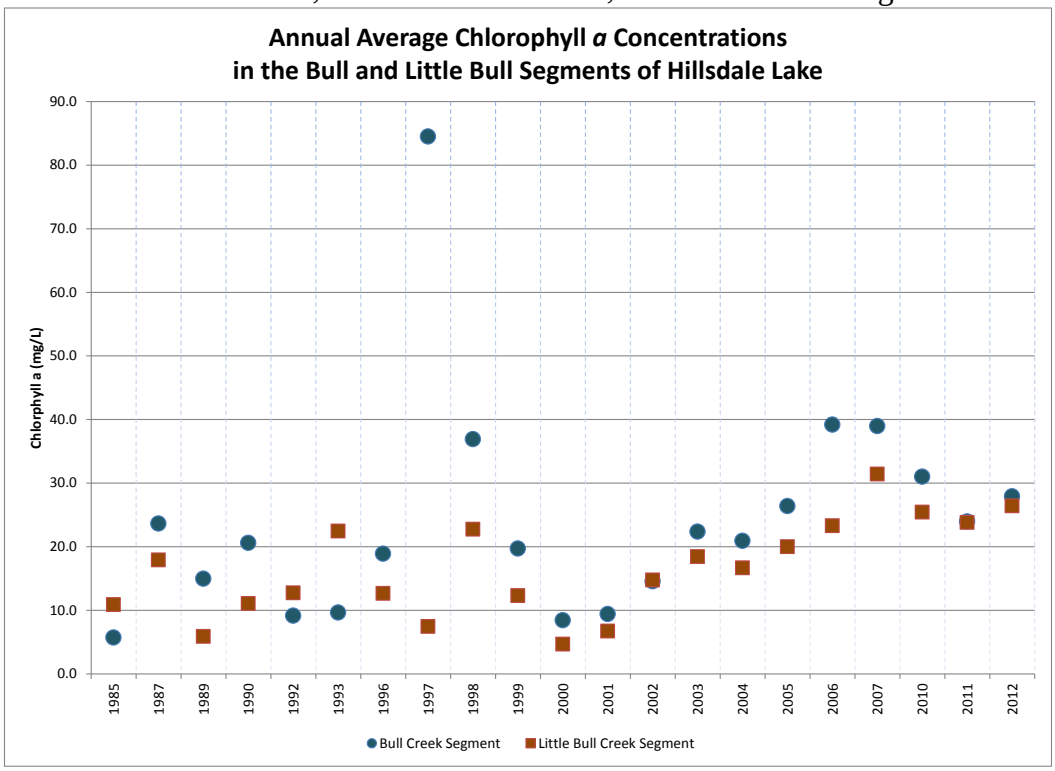
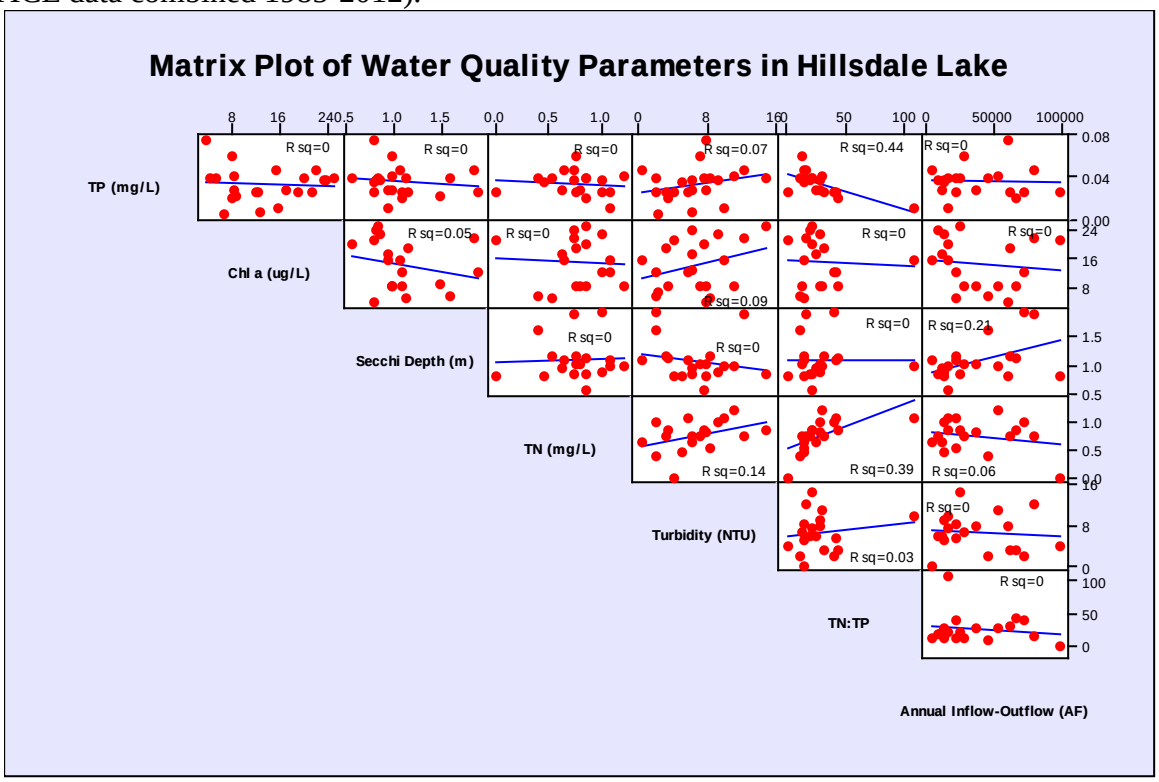


Table 7. Water quality data for the Bull Creek and Little Bull Creek segments of Hillsdale Lake.

USACE Sampling Point	Period of Record	Chl a (µg/L)	TN (mg/L)	TP (mg/L)	Secchi Depth (m)
HD 6: Bull Cr Arm	1999-2012	23.9	0.929	0.072	0.54
	2007-2012	30.1	0.966	0.055	0.60
LM035002: Bull Cr Arm	1985-2005	22.5	0.965	0.054	0.68
HD 11: Little Bull Cr Arm	1999-2012	18.2	1.46	0.053	0.71
	2007-2012	25.8	1.07	0.043	0.72
LM035003: Little Bull Cr Arm	1985-2005	16.4	0.590	0.039	1.1

Relationships: Relationships between water quality parameters in Hillsdale Lake are weak at best with a minor relationship between turbidity and total nitrogen; turbidity and chlorophyll *a;* turbidity and total phosphorus; turbidity and the TN:TP ratio and between chlorophyll *a* and Secchi depth (Figure 20). Annual average water quality parameters were also compared to the difference between the annual inflow and outflow in Hillsdale Lake revealing a small correlation between Secchi depth and total nitrogen with the difference between annual inflow and outflow.

Figure 20. Matrix plot of annual average water quality parameters in Hillsdale Lake (KDHE & USACE data combined 1985-2012).



Comparing the average total phosphorus concentration of samples collected in April and May in Hillsdale Lake's main basin versus the average chlorophyll *a* concentration of samples collected in June through September reveals that samples collected after 2004 have chlorophyll *a* concentrations greater than 19 μg/L and trend upward as total phosphorus concentrations increase while samples collected in 2004 and before have chlorophyll *a* concentrations below 13 μg/L and trend downwards as total phosphorus increases (Figure 21). A comparison of the same chlorophyll *a* concentrations to the difference between annual inflow and outflow in Hillsdale Lake shows that when the difference between inflow and outflow is less than 15,000 acre-feet chlorophyll *a* concentrations are greater than 19 μg/L (Figure 22). 2007 is the exception with a difference between inflow and outflow of about 24,000 acre-feet. With average evaporation in Hillsdale Lake (2000-2012) at 9,331 acre-feet, Figure 22 suggests that during the years the lake discharge is nearly equal to the inflow algae positively respond and summer chlorophyll *a* concentrations increase. The average difference between inflow and outflow for chlorophyll *a* samples greater than 19 μg/L is 12,729 while the average difference for samples below19 μg/L is 39,607 acre-feet (Table 8).

Figure 21. Annual average total phosphorus for samples collected in April and May versus annual average chlorophyll *a* concentrations for samples collected June through September in Hillsdale Lake.

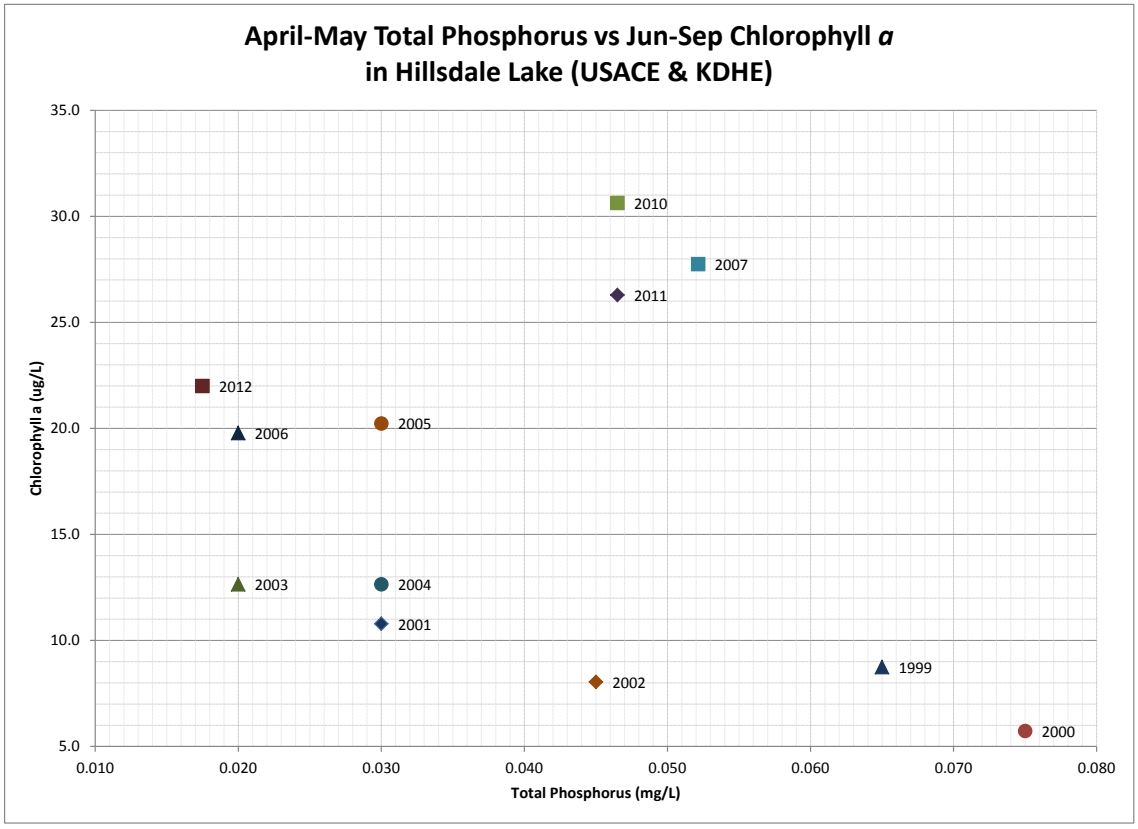


Figure 22. Annual inflow minus annual (calendar year) discharge in Hillsdale Lake versus chlorophyll *a* concentrations.

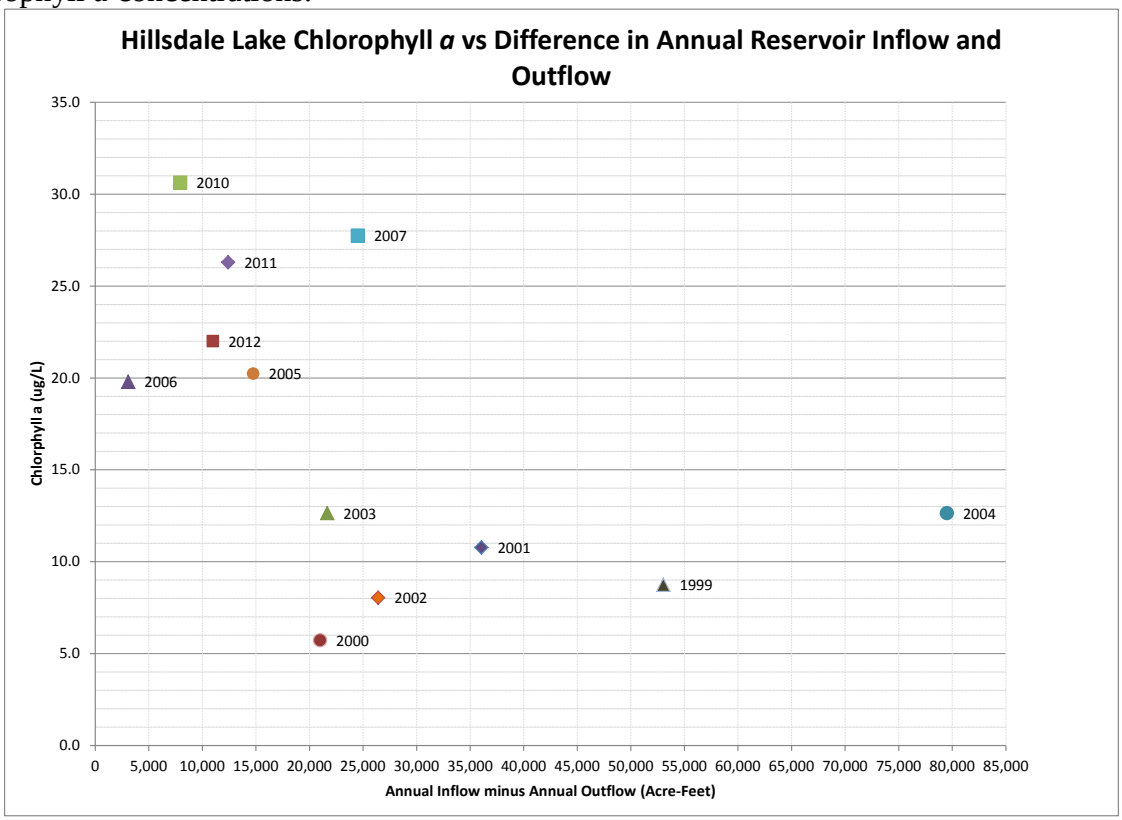


Table 8. Seasonal total phosphorus and chlorophyll *a* concentrations with corresponding annual difference in inflow and discharge to Hillsdale Lake.

Year	April thru May Avg. Total Phosphorus (mg/L)	June thru September Avg. Chlorophyll *a* (mg/L)	Inflow – Discharge (acre-feet)
Chlorophyll *a* < 19 mg/L			
1999	0.065	8.74	53,040
2000	0.075	5.73	20,982
2001	0.030	10.8	36,051
2002	0.045	8.04	26,421
2003	0.020	12.7	21,665
2004	0.030	12.7	79,485
Average	***0.044***	***9.76***	***39,607***
Chlorophyll *a* > 19 mg/L			
2005	0.030	20.2	14,757
2006	0.020	19.8	3,090
2007	0.052	27.8	24,506
2010	0.047	30.6	7,928
2011	0.047	26.3	12,407
2012	0.018	22.0	10,984
Average	***0.035***	***24.4***	***12,279***

Stream Data: USACE sampling stations in the watershed are located on Rock Creek (HD 19), on Bull Creek above its confluence with Martin Creek (HD 10), on Little Bull Creek below its confluence with Spring Creek (HD 4) and on Bull Creek below the dam (HD 2) (Figure 18). Data was available for the summers of 2007 and 2010 for Rock, Bull and Little Bull Creeks while the data for Bull Creek below the dam was available every summer from 1999 through 2012. Concentrations of total nitrogen, total phosphorus, turbidity and total suspended solids (TSS) were highest at the Bull Creek station, second highest at the Little Bull Creek station and lowest at the Rock Creek station for the streams feeding Hillsdale Lake (Table 9). Outflow concentrations of total nitrogen, total phosphorus, turbidity and TSS were markedly lower in Bull Creek below the dam highlighting the reservoir's role in trapping sediment and nutrients.

Probabilistic sampling occurred in the watershed in 2008 on Bull Creek at a site located above the USACE station HD 10; in 2010 on Little Bull Creek above USGS gage 06914990 and on Spring Creek above its confluence with Little Bull Creek (Figure 1). Average total phosphorus and total nitrogen concentrations in the samples taken on Little Bull Creek were high at 0.427 mg/L and 5.57 mg/L, respectively, indicating influence from the discharging point source located on Little Bull Creek (Table 10).

Table 9. USACE water quality data for sampling sites in the Hillsdale Lake watershed.

Source	Station/Stream	Period of Record	TN (mg/L)	TP (mg/L)	Turbidity (NTU)	TSS (mg/L)
USACE	**HD 19 Rock Creek**	2007 & 2010	0.955	0.101	41.3	31.0
USACE	**HD 10 Bull Creek**	2007 & 2010	2.80	0.497	80.6	22.1
USACE	**HD 4 Little Bull Creek**	2007 & 2010	1.81	0.193	62.9	55.5
USACE	**HD 2 Bull Creek below Hillsdale Dam**	1999-2012	0.904	0.050	19.5	15.1
		2007-2012	0.932	0.042	21.2	17.7

Table 10. KDHE probabilistic stream sampling station summary within the Hillsdale Lake watershed.

Station	Stream (Segment)	Year Sampled (# of samples)	TP Avg. (mg/L)	TN Avg. (mg/L)	TSS Avg. (mg/L)
SP359	Bull Creek (24)	2008 (4)	0.094	1.31	15.5
SP088	Little Bull Creek (51)	2010 (6)	0.427	5.57	15.1
SP103	Spring Creek (50)	2007 (5)	0.179	1.32	22.9

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

The ultimate endpoint for this TMDL will be to achieve the Kansas Water Quality Standards fully supporting the designated uses in Hillsdale Lake by eliminating impacts associated with excessive eutrophication. In order to improve the trophic condition of Hillsdale Lake from its current Very Eutrophic status, the desired endpoint will be to maintain summer chlorophyll *a* average concentrations below 10 μg/L, corresponding to a Carlson Trophic State Index of 53.2, with the reductions focused on nutrients (TN and TP) entering the lake. Reduction in nutrient loading will address the accelerated succession of aquatic biota and the development of objectionable concentrations of algae and algae by-products as determined by the chlorophyll *a* concentration in the lake. A chlorophyll *a* endpoint of 10 μg/L will also ensure long-term protection to fully support Primary Contact Recreation within the lake.

The 2001 Hillsdale Lake Eutrophication TMDL utilized the CNET Eutrophication Model to establish an annual total phosphorus loading capacity of 82,657.69 pounds. Of that, 10,147.84 lbs/year were allocated as wasteload, 64,244.07 lbs/year were designated as nonpoint source load, and 8,265.77 lbs/year were designated as the margin of safety. No total nitrogen loads were established by the 2001 TMDL.

For this TMDL, the BATHTUB reservoir eutrophication model (Appendix B) was utilized to develop total phosphorus and total nitrogen current condition loading and loading capacity for Hillsdale Reservoir. Using current conditions (2007-2012), the BATHTUB reservoir eutrophication model determined the current total phosphorus and total nitrogen entering Hillsdale Lake was 36,177 and 370,993 lbs/year, respectively. In order to achieve the endpoint of an area weighted mean of 10 μg/L chlorophyll *a* for this TMDL, total phosphorus inputs must be reduced by 67% and total nitrogen inputs must be reduced by 57%. These reductions at the inflow to Hillsdale Lake will result in a 49% reduction of total phosphorus, a 41% reduction of total nitrogen and a 62% reduction of Chlorophyll *a* within the lake (Table 11).

Achievement of the endpoint indicates loads are within the loading capacity of the lake, the water quality standards are attained and full support of the designated uses of the lake has been achieved. Seasonal variation has been incorporated in this TMDL since the peaks of algal growth occur in the summer months. The current average condition for Hillsdale Lake utilized in the model input was based on data from 2007-2012 from both the USACE and KDHE with calibration and reductions focused on area weighted means generated by the BATHTUB model.

Table 11. Hillsdale Lake current average condition (2007-2012) and TMDL. Current condition and TMDL nutrient concentrations reflect BATHTUB area weighted means. 2001 TMDL total phosphorus and chlorophyll *a* values are the whole lake KDHE values displayed in the table on page 3 of the TMDL.

	2001 TMDL	**Current Avg. Condition**	**TMDL**	**Percent Reduction**
Total Phosphorus – Annual Load (lbs/year)	82,65.77	36,177	11,910.90	67%
Total Phosphorus – Daily Load* (lbs/day)	608	266	87.57	67%
Total Phosphorus – Lake Concentration (μg/L)	48.6	42.8	21.8	49%
Total Nitrogen – Annual Load (lbs/year)	N/A	370,993	158,862.49	57%
Total Nitrogen – Daily Load* (lbs/day)	N/A	2,728	1,168.04	57%
Total Nitrogen – Lake Concentration (mg/L)	N/A	826	489	41%
Chlorophyll *a* Concentration (μg/L)	17.9	26.0	10	62%

*See Appendix A for daily load calculations.

3. SOURCE INVENTORY AND ASSESSMENT

Point Sources: There are currently eight NPDES permitted facilities in the Hillsdale Lake watershed (Table 12). Two permits are for facilities operating non-overflowing lagoon systems that are prohibited from discharging and one permit is for a portable central mix concrete plant also prohibited from discharging. These three facilities would only contribute a waste load under extreme precipitation or flooding events.

One permit is for a drinking water treatment plant owned by the City of Gardner that is permitted to discharge from settling basins that collect the settleable solids from the carbon contact basin and clarifiers and from filter backwashes. This facility is not expected to discharge a nutrient load and the permit does not require monitoring of nutrients; hence, no discharge data are available.

Two permits are tied to municipal mechanical plants operated by the Johnson County Unified Wastewater District and the City of Edgerton. The Johnson County New Century wastewater treatment facility is an activated sludge plant with UV disinfection that is currently permitted to discharge to Little Bull Creek at a rate of 1.1 million gallons per day (MGD). Current (July 2012-May 2013) average discharge for the New Century facility is 0.56 MGD with a total phosphorus concentration of 1.14 mg/L and a total nitrogen concentration of 30.7 mg/L. The Big Bull Creek wastewater treatment facility operated by the City of Edgerton is an upgraded mechanical plant with chemical phosphorus removal, biological nitrogen removal and UV disinfection that is permitted to discharge at a rate of 1.0 MGD (average) and 3.0 MGD (peak).

The Big Bull Creek facility became operational in August 2013, hence, there are no discharge monitoring data available.

Two permits are municipal separate storm sewer system (MS4) discharge permits assigned to Johnson County and the City of Olathe. These stormwater discharge permits require the implementation of best management practices in order to attenuate the discharge of nutrients into the stormwater discharge systems' receiving streams and lakes.

The 2001 Hillsdale Lake Eutrophication TMDL detailed six discharging facilities assigned total phosphorus wasteload allocations totaling 49.91 lbs/day. Average flow and average total phosphorus concentration of the discharge was used to calculate the wasteload allocations resulting in a daily wasteload allocation for the City of Edgerton's old plant (M-MC08-OO01) of 2.69 lbs/day and 1.43 lbs/day for the Johnson County New Century Air Center Plant (I-MC51-PO01). The remaining 45.79 lbs/day was assigned to four facilities that are no longer permitted to discharge to the Hillsdale Lake watershed. Gardner WTF South (M-MC51- IO01) and Gardner WTF (M-MC51-OO05) began discharging to Kill Creek in the Kansas-Lower Republican river basin in 2007 and were assigned total phosphorus wasteload allocations of 41.0 lbs/day and 3.61 lbs/day, respectively. The Lone Elm Estates Mobile Home Park (M-MC45-OO02) permit with a total phosphorus wasteload allocation of 0.49 lbs/day was inactivated in June 2002 when it's collection system connected to the Johnson County New Century Air Plant and the Conestoga Mobile Home Park (M-MC51-OO03) permit, with a total phosphorus wasteload allocation of 0.69 lbs/day, became inactive in December 2005 when the City of Gardner's wastewater treatment facility connected to the park's collection system.

Table 12. NPDES permitted facilities in the Hillsdale Lake watershed with design flows and average nutrient concentrations, where available.

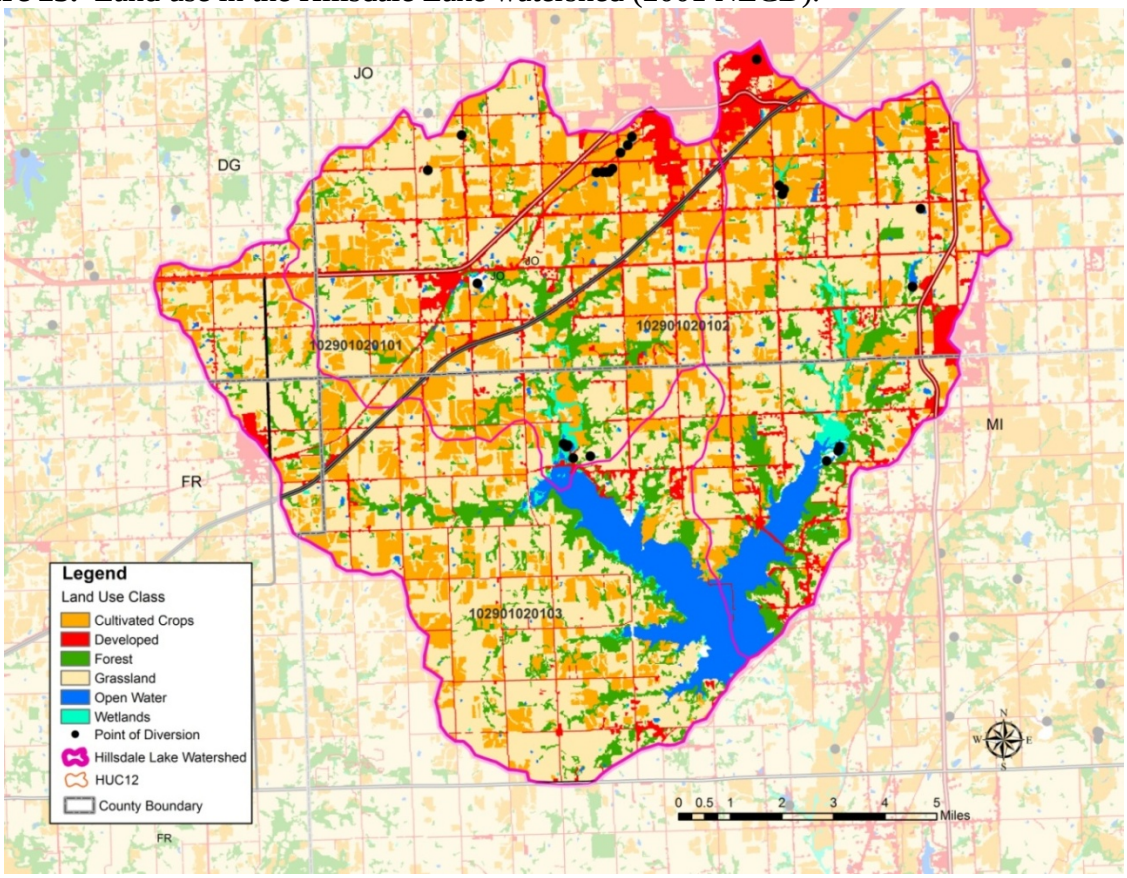
Name	NPDES Permit #	State Permit #	Type	Expiration Date	Current Design Capacity (MGD)	Avg. TP (mg/L)	Avg. TN (mg/L)
Hillsdale State Park (KDPWT)	KSJ000357	M-MC60-NO02	Non-Overflowing	5/31/15	N/A	N/A	N/A
Youth Front Camp West	KSJ000186	C-MC08-NO01	Non-Overflowing	5/31/15	N/A	N/A	N/A
Big Bull Cr WWTF	KS0100374	M-MC08-O002	Aerobic Sludge CNR/BNR/UV	12/31/16	1.0 Avg. 3.0 Peak	N/A	N/A
Fordyce Concrete	KSG110205	I-MC08-PR01	Non-Discharging Catch Basin	9/30/17	N/A	N/A	N/A
JoCo New Century WWTF	KS0119296	M-MC51-OO01	Activated Sludge/UV	10/31/17	1.1	1.13	30.7
Gardner WTP	KS0099295	I-MC60-PO02	Settling Basin	12/31/14	0.050	N/A	N/A
Johnson County	G-UA-0604-SO01	M-KS52-SU02	Stormwater Discharge	9/30/2009*	N/A	N/A	N/A
City of Olathe	G-UA-0604-SO01	M-KS52-SU01	Stormwater Discharge	9/30/2009*	N/A	N/A	N/A

*Permit pending

Land Use: The predominant land uses in the Hillsdale Lake watershed are grassland (46%), cultivated crops (26%) and developed land (11%) according to the 2001 National Land Cover Data. Together they account for 83% of the total land area in the watershed with the remaining land area composed of forest (10%), open water (6%) and wetlands (1%) (Figure 23). During precipitation runoff events, the cultivated cropland in the watershed may contribute to the nutrient loading to the lake. Grasslands could also contribute to the nutrient load during high flow events, particularly on livestock grazing lands located in the riparian areas of the watershed. The watershed is also 11% (16 mi^2) developed land of which 10.3 mi^2, or 7% of the total watershed area, is located in Johnson County. Southwest Johnson County, which includes the communities of Gardner, Edgerton, and Spring Hill is expected to experience significant growth resulting from the development of the BNSF intermodal facility and Kansas City Logistics Hub located in the Gardner-Edgerton area. A wasteload allocation was developed for the Johnson County MS4 permit by assuming that 10% of the unincorporated portion of Johnson County lying within the Hillsdale Lake drainage area is developed and mimics typical urban runoff. Figures provided by Johnson County estimate that an additional 10.2 mi^2 of land will be developed in the buildout of the intermodal facility, including industrial and residential developments, by 2040. Hence, a future MS4 allocation was developed for the City of Gardner and a reserve MS4 allocation was developed for future urban buildout in the watershed (Table 15).

Developed areas in the watershed may generate substantial nutrient loading from lawn fertilizers, domestic pet waste and other toxics found in the urban environment particularly during storm runoff events. Nutrient loading from the developed areas of the watershed, including golf courses since they appear as developed land in the 2001 NLCD data set, are addressed in the municipal separate storm sewer system (MS4) permit wasteload allocations in Table 15.

Figure 23. Land use in the Hillsdale Lake watershed (2001 NLCD).



Livestock Waste Management Systems: According to the United States Department of Agriculture's (USDA) National Agricultural Statistics Service (NASS), on January 1, 2013 there were 17,200, 32,500, 11,000 and 34,500 head of cattle (including calves) in Douglas, Franklin, Johnson and Miami Counties, respectively. The December 1, 2012 inventory of hogs in Franklin, Johnson and Miami Counties, according to the USDA NASS, was 14,400, 2,200 and 1,400 head, respectively. There are nineteen certified or permitted confined animal feeding operations (CAFOs) within the Hillsdale Lake watershed; however, none of them have enough animals to warrant a federal discharge (NPDES) permit (Table 13). These permitted or certified livestock facilities have waste management systems designed to minimize runoff entering their operation or detaining runoff emanating from their facilities. In addition, they are designed to retain a 25-year, 24-hr rainfall/runoff event as well as an anticipated two weeks of normal wastewater from their operations. Typically, this rainfall event coincides with stream flow occurring less than 1-5% of the time. It is likely that there are some smaller, unregistered livestock operations in the area and, depending on their proximity to the streams in the watershed, runoff from feedlots and grazing lands may be contributing to the nutrient and

siltation impairment in Hillsdale Lake. There are three sets of permit numbers that share latitude and longitude designations; hence, they appear as one marker on the Hillsdale Lake watershed map (Figure 1). The facilities with matching locations are highlighted in the same color in Table 13.

Table 13. Registered, certified or permitted confined animal feeding operations (CAFOs) in the Hillsdale Lake watershed. There are no federally permitted CAFOs in the watershed.

Kansas Permit Number	Animal Type	County	Animal Total
A-MCMI-BA04	Beef	Miami	500
A-MCMI-S005	Swine	Miami	560
A-MCMI-BA09	Beef, Horses	Miami	444
A-MCMI-B002	Beef	Miami	400
A-MCMI-M016	Dairy	Miami	299
1114*	Beef, Horses, Sheep, Goats	Franklin	155
A-MCJO-B003	Beef	Johnson	460
A-MCJO-BA05	Beef	Johnson	100
A-MCJO-BA07	Beef	Johnson	15
A-MCJO-BA09	Beef	Johnson	460
A-MCJO-BA01	Beef	Johnson	40
A-MCJO-BA06	Beef	Johnson	12
A-MCJO-BA08	Beef	Johnson	20
A-MCJO-BA03	Beef	Johnson	150
A-MCJO-BA11	Beef	Johnson	400
A-MCJO-M004	Dairy, Swine	Johnson	410
A-MCJO-BA02	Beef	Johnson	50
A-MCJO-S007	Beef, Swine	Johnson	1093
A-MCJO-M002	Dairy	Johnson	120

*Placeholder while registration is in progress

On-Site Waste Systems: The Hillsdale Lake watershed is a mixture of rural agricultural areas and developed land that lies primarily in Johnson and Miami Counties. It can be assumed that all of the rural residences in the watershed are not connected to public sewer systems and according to the Spreadsheet Tool for Estimating Pollutant Load (STEPL), there are a total of 2,252 septic systems in the watershed with a 0.93% failure rate. Failing on-site septic systems have the potential to contribute to nutrient loading in the watershed.

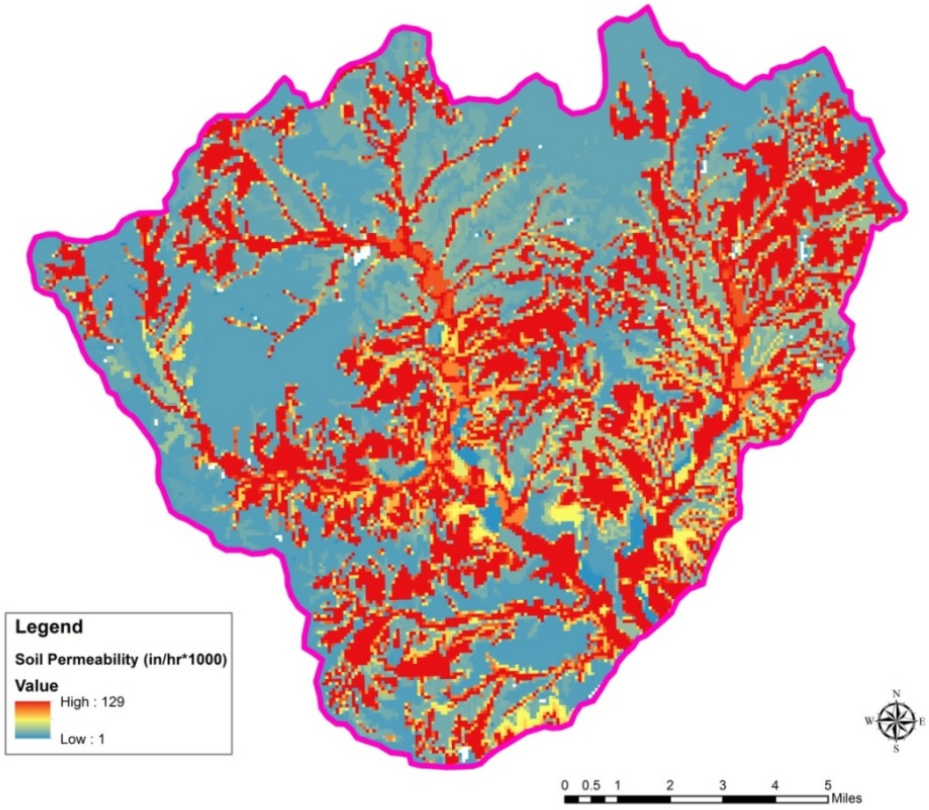
Population: According to the 2010 U.S. Census, the population of the Hillsdale Lake watershed was 19,001 people giving a population density of about 132 people per square mile. Population figures tallied by the 2000 and 2010 U.S. Census are detailed in Table 14 for Johnson and Miami Counties along with figures for the cities that lie within the lake's watershed. Population in the watershed increased 14% and 17% in Miami and Johnson Counties, respectively, between 2000 and 2010 with the City of Gardner increasing its population by over 50%. Population projections estimate the population of Gardner and Edgerton will rise to 37,867 and 2,601, respectively, by the year 2040 (Johnson County, 2013).

Table 14. U.S. Census results for populations in the Hillsdale Lake watershed.

County/City	Year of Census		% Difference
	2000	2010	
Miami County	28,351	32,787	+14%
Wellsville	1,606	1,857	+14%
Johnson County	451,086	544,179	+17%
Edgerton	1,440	1,671	+14%
Gardner	9,396	19,123	+51%
Spring Hill	2,727	5,437	+50%

Contributing Runoff: The watershed of Hillsdale Lake has a mean soil permeability value of 0.59 inches/hour. Permeability ranges from 0.01 inches/hour to 1.29 inches/hour according to NRCS STATSGO database with nearly 60% of the watershed having a permeability value of 1.29 inches/hour, which contributes to runoff during low to very low rainfall intensity events (Figure 24). According to a USGS open-file report (Juracek, 2000), the threshold soil-permeability values are set at 3.43 inches/hour for very high, 2.86 inches/hour for high, 2.29 inches/hour for moderate, 1.71 inches/hour for low, 1.14 inches/hour for very low, and 0.57 inches/hour for extremely low soil-permeability. Runoff is primarily generated as infiltration excess when soil profiles become saturated and produce excess overland flow due to rainfall intensities that are greater than soil permeability.

Figure 24. Soil permeability in the Hillsdale Lake watershed.



Background and Natural Sources: Undissolved nutrients bound to suspended solids in the inflow to Hillsdale Lake are potentially significant sources of nutrients that may endure in the sediment layer until they are removed by dredging. These internal nutrient loads can undergo remineralization and resuspension and may be a continuing source of nutrients in Hillsdale Lake. In addition, geological formations (i.e. soil and bedrock) may also contribute to nutrient loads and, with deciduous forest making up about 10% of the land cover in the watershed, leaf litter and wastes derived from natural wildlife in the area are also likely to add to the nutrient and Hillsdale Lake. Further nutrient loading is also occurring through the atmospheric deposition of nitrogen and phosphorus compounds to Hillsdale Lake and its watershed.

Unique Points of Diversion: The Hillsdale Lake watershed contains twenty seven unique points of diversion that are composed of a water right and point of diversion combination (Figure 24). Nineteen of the points are located in Johnson County with two designated for municipal use, three designated for industrial use and the remaining fourteen designated for use in irrigating. Eight of the points are located in Miami County and all eight are designated for use in recreation.

Internal Loading: It is likely that internal mechanisms in Hillsdale Lake are contributing to the eutrophic trophic state of the lake. Nutrients can accumulate in reservoir sediments and then be released back into the water column. Mechanisms affecting the rate of release of nutrients from the sediment are complicated but are associated with anoxic conditions at the sediment-water interface. As the water above the sediments becomes anoxic the redox-potential is lowered and iron (Fe) (III) is reduced to Fe (II) resulting in a release of soluble reactive phosphorus back into the water column (Dzialowski, 2012). Dzialowski and Carter (2012) studied sediment phosphorous release rates in Central Plains reservoirs including Melvern and Pomona Lakes in the Marais des Cygnes river basin and Marion Lake in the Neosho river basin. Marion Lake has a similar watershed/lake area ratio to Hillsdale Lake and Dzialowski's study determined a phosphorus release rate of nearly 33 $mg/m^2/day$ while sediment cores from Melvern and Pomona Lakes gave phosphorus release rates of 9.8 and 11 $mg/m^2/day$, respectively. Dzialowski and Carter (2012) determined the relationship between percent cropland in the watershed to the sediment phosphorus release rate (RR) at $Log_{10}RR = -0.341 + 0.997 \log_{10}\%Crop$ ($r^2 = 0.53$, $P<0.001$). Land use figures for the Hillsdale Lake watershed reveals 26% of the watershed is cropland and utilizing the cropland/release rate relationship estimates a phosphorus release rate of 12 $mg/m^2/day$ for Hillsdale Lake under anoxic conditions.

4. ALLOCATION OF POLLUTANT REDUCTION RESPONSIBILITY

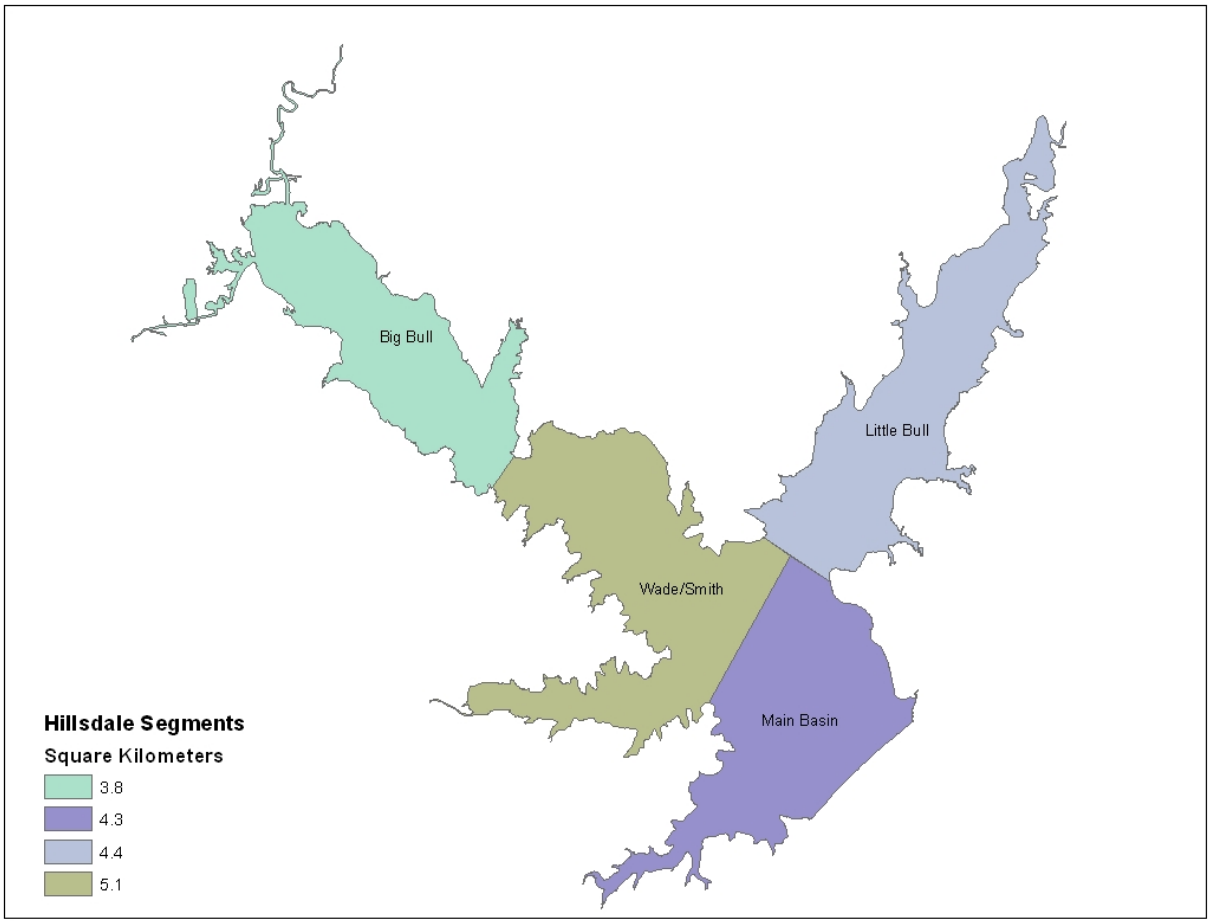
Hillsdale Lake is co-limited by nitrogen and phosphorus; therefore, both are allocated under this TMDL. The general inventory of sources within the drainage area of the lake indicates load reductions should be focused on nonpoint source runoff contributions attributed to fertilizer applicators and smaller livestock operations and on stormwater runoff contributions in the industrial and urban areas of the watershed.

Nutrients: The lake model utilized for the development of the eutrophication TMDL was BATHTUB (Appendix B). BATHTUB is an empirical receiving water quality model, that was developed by the U.S. Army Corps of Engineers (Walker, 1996), and has been commonly applied in the nation to address many TMDLs relating to issues associated with morphometrically complex lakes and reservoirs (Mankin et al., 2003; Wang et al., 2005).

Atmospheric total nitrogen was obtained from the Clean Air Status and Trends Network (CASTNET), which is available at http://www.epa.gov/castnet. The CASTNET station from the Konza Prairie (KS) was used to estimate the atmospheric TN concentration for the model. Total phosphorus atmospheric loading was estimated using the 1983 study of Rast and Lee.

For modeling purposes, Hillsdale Lake was considered as four segments (Figure 25). 2007-2012 data from both USACE and KDHE was used to populate the Main Basin, Big Bull and Little Bull segment water quality inputs. The Wade/Smith segment was populated by averaging the water quality concentrations in the Big Bull and Main Basin segments. Segment depths were estimated using the KBS 2010 bathymetric study on Hillsdale Lake. Tributary inputs for Rock Creek, Bull Creek and Little Bull Creek were developed by using the water quality data collected in 2007 and 2010 at USACE sampling stations HD 19, HD 10 and HD 4 along with their respective flow records in the Flux32 model to generate flow weighted concentrations for the BATHTUB model tributary inputs. Concentrations developed for Rock Creek were used to populate the Wade Branch and Scott Branch tributary inputs. 2007-2012 flow values for Rock Creek were based on a regression between the USGS gage on Rock Creek (06914960) and the USGS gage on Bull Creek (06914950) for the 10/1/1993-9/30/96 time frame and taking into account the drainage area ratio between the Rock Creek gage and of Rock Creek at the Hillsdale inlet. Bull Creek and Little Bull Creek tributary flow inputs for model calibration were based on flow measured at USGS gage 06914950 and USGS gage 06914990, respectively, minus average flow (1/1/2008 through 6/30/13) from the Edgerton and Johnson County treatment facilities and using the drainage area ratio of the creek to the drainage area of its respective gage. For the reduction model, design flows for the Johnson County and Edgerton treatment facilities were subtracted from the flows at USGS gages 06914990 and 06914950, respectively. Flow for Scott Branch, Wade Branch and Smith Branch were all based on the Bull Creek gage (06914950) using the drainage area ratio of the creek to the gage. The flow for Hillsdale Outflow was calculated from USACE gaged outflow records for 2007 through 2012. Three point source dischargers were included in the model as tributaries in order to account for their contribution to the nutrient loading in the lake. For calibration purposes, historical flow values and nutrient concentrations as determined from discharge monitoring reports (1/1/2008 through 6/30/13) were used as inputs for the City of Edgerton and Johnson County discharge permits. The Gardner water plant was assigned 50% of their design flow and nominal nutrient concentrations as they are an unlikely source of nutrient loading to the lake. In the reduced model, point source flows were increased to 100% of design flow and the City of Edgerton permit and the Johnson County permit were assigned total phosphorus concentrations of 0.5 mg/L and a total nitrogen concentrations of 8 mg/L while the Gardner water plant inputs remained at 0.1 mg/L total phosphorus and 1 mg/L total nitrogen in the reduced model.

Figure 25. Segmentation of Hillsdale Lake for the lake eutrophication model.



The BATHTUB model was calibrated for and reduced from the area-weighted mean concentrations. The model results estimate that Hillsdale Lake currently retains 81% of the total phosphorus and 59% of the total nitrogen load annually. Because Hillsdale Lake is co-limited by total phosphorus and total nitrogen, a 75% reduction in the total phosphorus and total nitrogen concentrations in the tributaries feeding the lake is necessary to meet the TMDL endpoint of an area weighted mean of 10 μg/L chlorophyll *a* within Hillsdale Lake (Appendix B).

Point Sources: Wasteload allocations are established for the three NPDES permits discharging to the Hillsdale watershed, for the Johnson County MS4 permit and, in anticipation of future development in the watershed, reserve wasteload allocations have been developed for wastewater treatment and for stormwater runoff (Table 15). Within the BATHTUB model, wasteload allocations for the NPDES dischargers were generated using design flows and assigned nutrient concentrations resulting in wasteload allocations totaling 4,456.60 lbs/year of total phosphorus and 71,072.80 lbs/year total nitrogen for the facilities currently discharging in the watershed. The Gardner water treatment facility (WTF) is not expected to contribute significant nutrient loads to the watershed; hence, nominal nutrient concentrations of 0.1 mg/L TP and 1 mg/L TN were used to generate the wasteload allocation for this facility. The Johnson County New Century wastewater treatment facility is scheduled for capital improvements early in 2014 that will expand the capacity of the treatment facility from 1.1 MGD to 1.65 MGD during phase one

of the project. Phase two will increase design capacity of the Johnson County plant to 1.91 MGD, hence, wasteload allocations of 2,920.00 lbs/year total phosphorus and 46,574.00 lbs/year total nitrogen were developed using a TP concentration of 0.5 mg/L, TN concentration of 8 mg/L and a flow of 1.91 MGD. The City of Edgerton's wasteload allocations were also developed using a total phosphorus concentration of 0.5 mg/L and a total nitrogen concentration of 8 mg/L, however the permitted design flow of 1 MGD was used to develop the annual loads of 1,522.00 lbs TP and 24,345.50 lbs TN. In addition, a wasteload allocation of 2,259.00 lbs/year of total phosphorus has been reserved in anticipation of further development in Southwest Johnson County.

The stormwater wasteload allocation for the Johnson County MS4 permit was determined by assuming 10% of the unincorporated portion of Johnson County that lies within the Hillsdale Lake watershed (~5.5 mi^2) mimics typical urban runoff resulting in a wasteload allocation of 810.30 lbs/year total phosphorus and 9,234.50 lbs/year total nitrogen (Table 15). The City of Olathe has approximately 122 acres of incorporated land in the Hillsdale Lake watershed, hence, stormwater wasteload allocations of 25.60 lbs/year and 310.30 lbs/year for total phosphorus and total nitrogen respectively, have been developed and applied to the Olathe's MS4 permit. A total phosphorus stormwater wasteload allocation of 580.40 lbs/year and a total nitrogen stormwater wasteload allocation of 6,606.50 lbs/year for the City of Gardner were determined using the current footprint of the city (~0.9 mi^2) in anticipation of a future MS4 permit for the city. In addition, a reserve stormwater wasteload allocation equal to that assigned to the Johnson County MS4 permit was developed in to account for the future buildout in the watershed. The resulting total municipal separate storm sewer system (MS4) wasteload allocation is 2,226.00 lbs/year total phosphorus and 25,385.80 lbs/year total nitrogen (Table 15).

Table 15. Wasteload allocations for the Hillsdale Lake watershed.

Facility	Federal Permit #	Receiving Stream	Design Flow (MGD)	Total Phosphorus			Total Nitrogen		
				mg/L	lbs/day	lbs/year	mg/L	lbs/day	lbs/year
Johnson County New Century WWTF	KS0119296	Little Bull Creek	1.91	0.5	8.00	2,920.00	8	127.60	46,574.00
City of Edgerton WWTF	KS0100374	Bull Creek	1	0.5	4.17	1,522.00	8	66.70	24,345.50
Gardner WTP	KS0099295	Unnamed Trib to Little Bull Creek	0.050	0.1	0.04	14.60	1	0.42	153.30
Reserve Wasteload Allocation for Future NPDES Permitted Dischargers				N/A	6.19	2,259.00	N/A	N/A	N/A
Total WWTF Wasteload Allocations				***N/A***	***18.40***	***6,715.60***	***N/A***	***194.72***	***71,072.80***
Johnson County MS4	KSR041007	N/A	N/A	N/A	2.22	810.30	N/A	25.30	9,234.50
City of Olathe MS4	KSR041025	N/A	N/A	N/A	0.07	25.60	N/A	0.85	310.30
City of Gardner (future) MS4	N/A	N/A	N/A	N/A	1.59	580.40	N/A	18.10	6,606.50
Future Buildout Reserve MS4	N/A	N/A	N/A	N/A	2.22	810.30	N/A	25.30	9,234.50
Total Municipal Separate Storm Sewer (MS4) Wasteload Allocations				***N/A***	***6.10***	***2,226.60***	***N/A***	***69.55***	***25,385.80***
Total Wasteload Allocations				***N/A***	***24.50***	***8942.20***	***N/A***	***264.27***	***96,458.60***

Nonpoint Sources: Nonpoint sources are significant contributors for the nutrient input and impairment in Hillsdale Lake. Background levels may be attributed to nutrient recycling and leaf litter. The assessment suggests that runoff transporting nutrient associated with animal wastes and fertilized cultivated cropland and pastureland is contributing to siltation and eutrophication in the lake. Nutrient load allocations were calculated using the BATHTUB model (Appendix B) and are detailed in Table 16.

Table 16. Hillsdale Lake Total Phosphorus and Total Nitrogen TMDL.

Description	Allocations (lbs/year)	Allocations (lbs/day)
Total Phosphorus Atmospheric Load*	388.01	2.85
Total Phosphorus Nonpoint Source Load Allocation	1,389.60	51.46
Total Phosphorus Wastewater Wasteload Allocation (Including Future Allocations)	6,715.60	18.40
Total Phosphorus Stormwater Wasteload Allocation (Including Future Allocations)	2,226.60	6.10
Total Phosphorus Margin of Safety*	1,191.09	8.76
Total Phosphorus TMDL*	11,910.90	87.57
Total Nitrogen Atmospheric Load*	27,510.13	202.27
Total Nitrogen Nonpoint Source Load Allocation	19,007.51	584.70
Total Nitrogen Wastewater Wasteload Allocation (Including Future Allocations)	71,072.80	194.72
Total Nitrogen Stormwater Wasteload Allocation (Including Future Allocations)	25,385.80	69.55
Total Nitrogen Margin of Safety*	15,886.25	116.80
Total Nitrogen TMDL*	158,862.49	1,168.04

*****See appendix A for daily load calculation.

Defined Margin of Safety: The margin of safety provides some hedge against the uncertainty of variable annual total phosphorus and total nitrogen loads and the chlorophyll *a* endpoint. Therefore, the margin of safety is explicitly set at 10% of the total allocations for total phosphorus and total nitrogen, which compensates for the lack of knowledge about the relationship between the allocated loadings and the resulting water quality. The margin of safety for TP and TN is 8.76 lbs/day and 116.80 lbs/day, respectively, as detailed in Table 16.

State Water Plan Implementation Priority: Because Hillsdale Lake has a regional benefit for recreation and because it serves as a drinking water supply the City of Gardner and several rural water districts in Johnson and Miami Counties, this TMDL will be a **High** Priority for implementation.

Unified Watershed Assessment Priority Ranking: This watershed lies within the Lower Marais des Cygnes Basin (HUC 8: 10290102) with a priority ranking of 12 (High Priority for restoration work).

5. IMPLEMENTATION

Desired Implementation Activities: There is a very good potential that agricultural best management practices will improve the condition of Hillsdale Lake. Table 17 details the reduction in nonpoint source loading required to meet this TMDL. 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.

Table 17. Nonpoint source load reduction needed to meet this TMDL.

	Current Average Condition (lbs/year)	**TMDL (lbs/year)**	**Nonpoint Source Reduction Needed (lbs/year)**	**Nonpoint Source Reduction Needed (%)**
Total Phosphorus	36,177	11,910.90	25,457.19	70%
Total Nitrogen	370,993	158,862.49	228,016.76	61%

There is also potential that the implementation of urban best management practices in the watershed will improve the condition of Hillsdale Lake. Some of the recommended urban practices are as follows:

1. Educate watershed residents on proper lawn fertilizer application.
2. Install grass buffer strips along drainage channels in the watershed.
3. Promote proper management of construction sites to minimize sediment and nutrient runoff.

4. Investigate feasibility of installing a stormwater wetland in the watershed to aid in the removal of nutrients.
5. Promote installation of porous and concrete grid pavement in the watershed.

Implementation Program Guidance:

NPDES – MS4 – KDHE

a. Evaluate nutrient loading from all permitted dischargers in the watershed and establish applicable permit limits.
b. Work with dischargers to reduce individual loadings.
c. Work with the larger municipalities to ensure statewide nutrient reduction goals are met.
d. Inspect permitted livestock facilities to ensure compliance.
e. New livestock permitted facilities will be inspected for integrity of applied pollution prevention technologies.
f. New livestock registered facilities with less than 300 animal units will apply pollution prevention technologies.
g. Manure management plans will be implemented, to include proper land application rates and practices that will prevent runoff of applied manure.

Watershed Management Program – KDHE

a. Support selected Section 319 project activities including demonstration projects and outreach efforts dealing with sediment control and nutrient management.
b. Provide technical assistance on practices geared to the establishment of vegetative buffer strips.
c. Provide technical assistance on nutrient management in the vicinity of streams.
d. Incorporate the provisions of this TMDL into WRAPS documents relating to Hillsdale Lake (Appendix C).

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

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

Riparian Protection Program – KDA Division of Conservation

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

Buffer Initiative Program – KDA Division of Conservation

a. Install grass buffer strips near streams.
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 fields to hold nutrients.

Time Frame for Implementation: Initial implementation will proceed over the years from 2014-2021. Additional implementation may be required over 2022-2030 to achieve the endpoints of this TMDL.

Targeted Participants: Primary participants for implementation will be agricultural producers within the Hillsdale Lake watershed, the Johnson County Department of Public Works and Infrastructure, and the Hillsdale Area Water Cooperative (HAWC). A detailed assessment of sources conducted over 2014-2015 should include local assessments by conservation district personnel and city and county public works to survey, locate, and assess the following within the lake drainage area:

1. Total row crop acreage and fertilizer application rates.
2. Cultivation alongside lake.
3. Livestock use of riparian areas.
4. Fields with manure applications.
5. Impervious surfaces in developed areas

Milestone for 2022: In accordance with the TMDL strategy for the State of Kansas, the year 2022 marks a review and evaluation of period of 303(d) activities in the Marais des Cygnes River Basin. At that point in time, data from site LM035001 at Hillsdale Lake will be examined to assess improved conditions in the lake.

Delivery Agents: The primary delivery agents for program participation will be the Kansas Department of Health and Environment, the Kansas Department of Agriculture Division of Conservation, the Natural Resources Conservation Service, the Kansas State University Extension Service and the Johnson County Department of Public Works and Infrastructure. Producer outreach and awareness will be delivered by Kansas State Extension.

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 Kansas Department of Agriculture – Division of Conservation 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 Kansas Department of Agriculture – Division of Conservation 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 Marais Des Cygnes 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 along with addressing stormwater runoff in urban areas 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 Hillsdale Lake. Based on the sampling results, the 303(d) listing will be evaluated in 2022. Should impairment status continue, the desired endpoints under this TMDL may be refined and sampling conducted over the period 2022-2026 to assess progress in this implementation.

7. FEEDBACK

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

Public Hearing: A Public Hearing on the Marais des Cygnes TMDLs was held on December 10, 2013 in Ottawa to receive comments on this TMDL. Comments were received from the Johnson County Stormwater Management Program which correctly pointed out that the land use numbers used to determine the stormwater wasteload allocation for their MS4 permit included incorporated portions of Edgerton and Gardner over which Johnson County has no jurisdiction. Stormwater wasteload allocations were recalculated by assuming 10% of the unincorporated portion of Johnson County that lies within the Hillsdale Lake drainage area mimics urban runoff conditions. Comments were also received from Johnson County Wastewater informing us of capital improvements to the New Century plant that will increase the design flow of the facility to 1.91 MGD that are scheduled to begin early in 2014. The upgraded design flow of 1.91 MGD was used to determine the wasteload allocations for the Johnson County New Century wastewater treatment plant.

Basin Advisory Committee: The Marais des Cygnes Basin Advisory Committee met to discuss TMDLs in the basin on October 15, 2013 in Paola.

Milestone Evaluation: In accordance with the TMDL development schedule for the State of Kansas, the year 2022 marks an evaluation period of 303(d) activities in the Marais des Cygnes Basin. At that point in time, sample data from Hillsdale 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.

Consideration for 303d Delisting: Hillsdale Lake will be evaluated for delisting under Section 303(d), based on the monitoring data over 2013-2021. Therefore, the decision for delisting will come about in the preparation of the 2022 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 may 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 2014, 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 2014-2022.

Developed 03/06/14

References

Carney, E., 1993, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2004, 2008, 2011. Lake and Wetland Monitoring Program Annual Report/ Summary. Kansas Department of Health and Environment.

Dodds W.K., E. Carney, and R.T. Angelo, 2006. Determining ecoregional reference conditions for nutrient, Secchi depth and chlorophyll *a* in Kansas lakes and reservoirs. Lake and Reservoir Management 22(2): 151-159.

Dzialowski, A.R., Carter, L.D., 2012. Predicting internal nutrient release rates from Central Plains reservoirs for use in TMDL development. Project Number: X7 97703801 submitted to EPA Region 7.

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.

Juracek, K.E., 2000. Soils – Potential Runoff. U.S. Geological Survey Open-File Report 00-253.

Johnson County Kansas, 2013. Southwest Johnson County Area Plan – Draft Report.

Johnson County Wastewater, 2013. Nutrient Removal Study, New Century Air Center WWTP. JCW Authorization 11012, B&V Project 180191.

Kansas Biological Survey. 2010. Bathymetric and Sediment Survey of Hillsdale Lake, Miami County, Kansas.

Kansas Water Office. 2011. Hillsdale Lake Reservoir Information Sheet. http://www.kwo.org/reservoirs/ReservoirFactSheets/Rpt_Hillsdale_2011.pdf

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 Locations, USGS Scientific Investigations Report 2004-5033.

Regional Technical Advisory Group. 2011. Nutrient Reference Condition Identification and Ambient Water Quality Benchmark Development Process, Freshwater Lakes and Reservoirs within USEPA Region 7.

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

U.S. Army Corps of Engineers, Kansas City District. Hillsdale Lake Water Quality Data Reports (1999-2012) and Hillsdale Lake Flow Records (1990-2012).

U.S. Army Corps of Engineers. FLUX32 Load Estimation Software, version 3.26.

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

Appendix A. Calculation of Daily Loads

Conversion to Daily Loads as Regulated by EPA Region VII*

The TMDL has estimated annual average loads for total phosphorus and total nitrogen 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
ATM = Atmospheric Load
MOS= Margin of Safety

Parameter	LTA	CV	$e^{[Z\sigma - 0.5\sigma^2]}$	MDL lbs/day	ATM lbs/day	MOS lbs/day
TP	11,910.90 lbs/year	0.5	2.7	87.57	2.85	8.76
TN	158,862.49 lbs/year	0.5	2.7	1,168.04	202.27	116.80

Appendix A. Calculation of Daily Loads

Maximum Daily Load Calculation

Annual TP Load = 11,910.90 lbs/yr

Maximum Daily TP Load = [(11,910.90 lbs/yr)/(365 days/yr)]*$e^{[2.326*(0.47)-0.5*(0.47)^2]}$
= 87.57 lbs/day

Annual TN Load = 158,862.49 lbs/yr

Maximum Daily TN Load = [(158,862.49 lbs/yr)/(365 days/yr)]*$e^{[2.326*(0.47)-0.5*(0.47)^2]}$
= 1,168.04 lbs/day

Margin of Safety (MOS) for Daily Load

Annual TP MOS = 1,191.09 lbs/yr

Daily TP MOS = [(1,191.09 lbs/yr)/(365 days/yr)]*$e^{[2.326*(0.47)-0.5*(0.47)^2]}$
= 8.76 lbs/day

Annual TN MOS = 15,886.25 lbs/yr

Daily TN MOS = [(15,886.25 lbs/yr)/(365 days/yr)]*$e^{[2.326*(0.47)-0.5*(0.47)^2]}$
= 116.80 lbs/day

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

Appendix B. Case Data -- Current Condition

Global Variables	Mean	CV
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.91	0.5
Evaporation (m)	1.21	0.5
Storage Increase (m)	-0.0026	0.5

Atmos. Loads (kg/km^2-yr)	Mean	CV
Conserv. Substance	0	0.00
Total P	10	0.50
Total N	709	0.50
Ortho P	10	0.50
Inorganic N	709	0.50

Model Options	Code	Description
Conservative Substance	0	NOT COMPUTED
Phosphorus Balance	2	2ND ORDER, DECAY
Nitrogen Balance	1	2ND ORDER, AVAIL N
Chlorophyll-a	5	P, JONES & BACHMAN
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	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	Big Bull Pool	2	1	3.8	3.8	3.24	3.7	0.12	0	0	0.93	0.32	0	0	0	0	0	0
2	Wade/Smith Pool	4	1	5.1	5.1	3.1	4.6	0.12	0	0	1.05	0.28	0	0	0	0	0	0
3	Little Bull Pool	4	1	4.4	4.9	5.36	4.5	0.12	0	0	0.76	0.24	0	0	0	0	0	0
4	Main Basin	0	1	4.3	8.1	1.78	6.1	0.12	0	0	0.62	0.76	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	54.9	0.2	916	0.22	30.5	0.21	0.59	0.15	594	0.31	42.3	0.2	0	0	0	0
2	0	0	43	0.4	858	0.33	25.9	0.21	0.73	0.15	564	0.3	32.8	0.4	0	0	0	0
3	0	0	43.5	0.19	736	0.54	26.8	0.12	0.7	0.16	498	0.3	31.9	0.4	0	0	0	0
4	0	0	31	0.36	799	0.26	21.2	0.87	0.87	0.08	533	0.27	27.6	0.36	0	0	0	0

Segment Calibration Factors

	Dispersion Rate		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0
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
4	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	Wade Branch	2	1	39.8	10.6	0.1	0	0	89.6	0.36	696	1.2	5.6	0.5	78.7	0.5
2	Scott Branch	4	1	5.48	3.8	0.1	0	0	89.6	0.36	696	1.2	5.6	0.5	78.7	0.5
3	Rock Cr	1	1	66.1	14.6	0.1	0	0	89.6	0.36	696	1.2	5.6	0.5	78.7	0.5
4	Big Bull	1	1	120.8	22.8	0.1	0	0	307	0.26	2420	0.37	154	0.44	731	1.8
5	Smith Br	2	1	16.6	7	0.1	0	0	89.6	0.36	696	1.2	5.6	3.7	78.7	0.5
6	Little Bull	3	1	114.6	28.2	0.1	0	0	169	0.57	1740	0.17	44.7	0.05	794	0.07
7	JOCO New Century WW Point	3	3	0	0.768	0.1	0	0	1130	0.5	30700	0.5	0	0	0	0
8	Edgerton WW Point Source	1	3	0	0.151	0.1	0	0	2460	0.5	19130	0.5	0	0	0	0
9	Gardner Water Plant Point Sou	3	3	0	0.035	0	0	0	100	0.5	1000	0.5	0	0	0	0
10	Hillsdale Outflow	4	4	0	94.5	0.1	0	0	47	0.12	1100	0.17	13	0.12	579	0.69

Model Coefficients	Mean	CV
Dispersion Rate	1.000	0.70
Total Phosphorus	0.772	0.45
Total Nitrogen	1.037	0.55
Chl-a Model	1.352	0.26
Secchi Model	1.000	0.10
Organic N Model	1.000	0.12
TP-OP Model	1.000	0.15
HODv Model	1.000	0.15
MODv Model	1.000	0.22
Secchi/Chla Slope (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

Appendix B. Current Condition
Predicted & Observed Values Ranked Against CE Model Development Dataset

Segment: 5 Area-Wtd Mean

	Predicted Values--->			Observed Values--->		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	42.2	0.50	44.4%	42.8	0.28	45.0%
TOTAL N MG/M3	826.9	0.57	38.2%	825.6	0.33	38.1%
C.NUTRIENT MG/M3	33.7	0.40	47.1%	33.7	0.31	47.2%
CHL-A MG/M3	25.9	0.78	90.6%	26.0	0.32	90.7%
SECCHI M	0.7	0.38	27.3%	0.7	0.13	30.1%
ORGANIC N MG/M3	810.9	0.58	85.4%	546.4	0.30	61.0%
TP-ORTHO-P MG/M3	62.0	0.60	77.8%	33.4	0.34	54.4%
ANTILOG PC-1	635.3	1.00	76.6%	538.8	0.15	72.6%
ANTILOG PC-2	10.4	0.35	81.8%	10.2	0.17	80.8%
(N - 150) / P	16.0	0.84	46.6%	16.3	0.27	47.4%
INORGANIC N / P	37.3	10.26	59.1%	38.1	2.46	59.9%
TURBIDITY 1/M	0.8	0.19	64.6%	0.8	0.19	64.6%
ZMIX * TURBIDITY	3.9	0.23	61.1%	3.9	0.23	61.1%
ZMIX / SECCHI	6.9	0.38	74.0%	6.5	0.09	70.3%
CHL-A * SECCHI	17.5	0.45	77.7%	18.6	0.24	80.1%
CHL-A / TOTAL P	0.6	0.35	96.3%	0.6	0.29	96.4%
FREQ(CHL-a>10) %	88.3	0.26	90.6%	88.3	0.10	90.7%
FREQ(CHL-a>20) %	53.7	0.89	90.6%	53.9	0.26	90.7%
FREQ(CHL-a>30) %	29.1	1.44	90.6%	29.3	0.36	90.7%
FREQ(CHL-a>40) %	15.8	1.90	90.6%	15.9	0.42	90.7%
FREQ(CHL-a>50) %	8.7	2.28	90.6%	8.8	0.47	90.7%
FREQ(CHL-a>60) %	5.0	2.61	90.6%	5.0	0.50	90.7%
CARLSON TSI-P	58.1	0.12	44.4%	58.0	0.04	45.0%
CARLSON TSI-CHLA	62.4	0.12	90.6%	62.5	0.04	90.7%
CARLSON TSI-SEC	65.6	0.08	72.7%	64.7	0.02	69.9%

Appendix B. Current Condition
Overall Water & Nutrient Balances

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	2	Wade Branch	39.8	10.6	1.12E+00	0.10	0.27
2	1	4	Scott Branch	5.5	3.8	1.44E-01	0.10	0.69
3	1	1	Rock Cr	66.1	14.6	2.13E+00	0.10	0.22
4	1	1	Big Bull	120.8	22.8	5.20E+00	0.10	0.19
5	1	2	Smith Br	16.6	7.0	4.90E-01	0.10	0.42
6	1	3	Little Bull	114.6	28.2	7.95E+00	0.10	0.25
7	3	3	JOCO New Century WW Point Source		0.8	5.90E-03	0.10	
8	3	1	Edgerton WW Point Source		0.2	2.28E-04	0.10	
9	3	3	Gardner Water Plant Point Source		0.0	0.00E+00	0.00	
10	4	4	HIllsdale Outflow		94.5	8.93E+01	0.10	
PRECIPITATION				17.6	16.0	6.41E+01	0.50	0.91
TRIBUTARY INFLOW				363.4	87.0	1.70E+01	0.05	0.24
POINT-SOURCE INFLOW					1.0	6.13E-03	0.08	
***TOTAL INFLOW				381.0	104.0	8.12E+01	0.09	0.27
GAUGED OUTFLOW					94.5	8.93E+01	0.10	
ADVECTIVE OUTFLOW				381.0	-11.8	2.84E+02	1.43	
***TOTAL OUTFLOW				381.0	82.7	1.95E+02	0.17	0.22
***EVAPORATION					21.3	1.13E+02	0.50	
***STORAGE INCREASE					0.0	0.00E+00	0.00	

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

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	2	Wade Branch	949.8	5.8%	1.26E+05	1.0%	0.37	89.6	23.9
2	1	4	Scott Branch	340.5	2.1%	1.62E+04	0.1%	0.37	89.6	62.1
3	1	1	Rock Cr	1308.2	8.0%	2.39E+05	2.0%	0.37	89.6	19.8
4	1	1	Big Bull	6999.6	42.7%	3.80E+06	31.5%	0.28	307.0	57.9
5	1	2	Smith Br	627.2	3.8%	5.49E+04	0.5%	0.37	89.6	37.8
6	1	3	Little Bull	4765.8	29.0%	7.61E+06	62.9%	0.58	169.0	41.6
7	3	3	JOCO New Century WW Poi	867.8	5.3%	1.96E+05	1.6%	0.51	1130.0	
8	3	1	Edgerton WW Point Source	371.5	2.3%	3.59E+04	0.3%	0.51	2460.0	
9	3	3	Gardner Water Plant Point S	3.5	0.0%	3.06E+00	0.0%	0.50	100.0	
10	4	4	HIllsdale Outflow	3596.0		3.37E+06		0.51	38.1	
PRECIPITATION				176.0	1.1%	7.74E+03	0.1%	0.50	11.0	10.0
TRIBUTARY INFLOW				14991.0	91.4%	1.18E+07	98.0%	0.23	172.3	41.3
POINT-SOURCE INFLOW				1242.8	7.6%	2.32E+05	1.9%	0.39	1302.7	
***TOTAL INFLOW				16409.8	100.0%	1.21E+07	100.0%	0.21	157.8	43.1
GAUGED OUTFLOW				3596.0	21.9%	3.37E+06		0.51	38.1	
ADVECTIVE OUTFLOW				-448.3		4.94E+05		1.57	38.1	
***TOTAL OUTFLOW				3147.7	19.2%	2.54E+06		0.51	38.1	8.3
***STORAGE INCREASE				-2.0		8.83E-02		0.15	42.8	
***RETENTION				13264.0	80.8%	1.23E+07		0.26		

Overflow Rate (m/yr)	4.7	Nutrient Resid. Time (yrs)	0.2489
Hydraulic Resid. Time (yrs)	1.1713	Turnover Ratio	4.0
Reservoir Conc (mg/m3)	42	Retention Coef.	0.808

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

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	2	Wade Branch	7377.6	4.4%	7.89E+07	7.9%	1.20	696.0	185.4
2	1	4	Scott Branch	2644.8	1.6%	1.01E+07	1.0%	1.20	696.0	482.6
3	1	1	Rock Cr	10161.6	6.0%	1.50E+08	15.0%	1.20	696.0	153.7
4	1	1	Big Bull	55176.0	32.8%	4.47E+08	44.7%	0.38	2420.0	456.8
5	1	2	Smith Br	4872.0	2.9%	3.44E+07	3.4%	1.20	696.0	293.5
6	1	3	Little Bull	49068.0	29.2%	9.37E+07	9.4%	0.20	1740.0	428.2
7	3	3	JOCO New Century WW Poi	23577.6	14.0%	1.45E+08	14.5%	0.51	30700.0	
8	3	1	Edgerton WW Point Source	2888.6	1.7%	2.17E+06	0.2%	0.51	19130.0	
9	3	3	Gardner Water Plant Point S	35.0	0.0%	3.06E+02	0.0%	0.50	1000.0	
10	4	4	HIllsdale Outflow	71622.0		1.70E+09		0.58	757.9	
PRECIPITATION				12478.4	7.4%	3.89E+07	3.9%	0.50	779.1	709.0
TRIBUTARY INFLOW				129300.0	76.8%	8.14E+08	81.4%	0.22	1486.2	355.8
POINT-SOURCE INFLOW				26501.2	15.7%	1.47E+08	14.7%	0.46	27779.1	
***TOTAL INFLOW				168279.6	100.0%	1.00E+09	100.0%	0.19	1618.5	441.7
GAUGED OUTFLOW				71622.0	42.6%	1.70E+09		0.58	757.9	
ADVECTIVE OUTFLOW				-8928.3		2.02E+08		1.59	757.9	
***TOTAL OUTFLOW				62693.7	37.3%	1.29E+09		0.57	757.9	164.6
***STORAGE INCREASE				-37.8		4.41E+01		0.18	825.6	
***RETENTION				105623.7	62.8%	1.80E+09		0.40		

Overflow Rate (m/yr)	4.7	Nutrient Resid. Time (yrs)	0.4759
Hydraulic Resid. Time (yrs)	1.1713	Turnover Ratio	2.1
Reservoir Conc (mg/m3)	827	Retention Coef.	0.628

Appendix B. Case Data -- Reduced

Global Variables	Mean	CV
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.91	0.5
Evaporation (m)	1.21	0.5
Storage Increase (m)	-0.0026	0.5

Atmos. Loads (kg/km^2-yr)	Mean	CV
Conserv. Substance	0	0.00
Total P	10	0.50
Total N	709	0.50
Ortho P	10	0.50
Inorganic N	709	0.50

Model Options	Code	Description
Conservative Substance	0	NOT COMPUTED
Phosphorus Balance	2	2ND ORDER, DECAY
Nitrogen Balance	1	2ND ORDER, AVAIL N
Chlorophyll-a	5	P, JONES & BACHMAN
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	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	Big Bull Pool	2	1	3.8	3.8	3.24	3.7	0.12	0	0	0.93	0.32	0	0	0	0	0	0
2	Wade/Smith Pool	4	1	5.1	5.1	3.1	4.6	0.12	0	0	1.05	0.28	0	0	0	0	0	0
3	Little Bull Pool	4	1	4.4	4.9	5.36	4.5	0.12	0	0	0.76	0.24	0	0	0	0	0	0
4	Main Basin	0	1	4.3	8.1	1.78	6.1	0.12	0	0	0.62	0.76	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	54.9	0.2	916	0.22	30.5	0.21	0.59	0.15	594	0.31	42.3	0.2	0	0	0	0
2	0	0	43	0.4	858	0.33	25.9	0.21	0.73	0.15	564	0.3	32.8	0.4	0	0	0	0
3	0	0	43.5	0.19	736	0.54	26.8	0.12	0.7	0.16	498	0.3	31.9	0.4	0	0	0	0
4	0	0	31	0.36	799	0.26	21.2	0.87	0.87	0.08	533	0.27	27.6	0.36	0	0	0	0

Segment Calibration Factors

	Dispersion Rate		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0
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
4	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	Wade Branch	2	1	39.8	10	0.1	0	0	21	0.36	160	1.2	1	0.5	18	0.5
2	Scott Branch	4	1	5.48	3.6	0.1	0	0	21	0.36	160	1.2	1	0.5	18	0.5
3	Rock Cr	1	1	66.1	13.9	0.1	0	0	21	0.36	160	1.2	1	0.5	18	0.5
4	Big Bull	1	1	120.8	21.5	0.1	0	0	71	0.26	557	0.37	35	0.44	168	1.8
5	Smith Br	2	1	16.6	6.6	0.1	0	0	21	0.36	160	1.2	1	3.7	18	0.5
6	Little Bull	3	1	114.6	24.8	0.1	0	0	39	0.57	400	0.17	10	0.05	183	0.07
7	JOCO New Century WW Point	3	3	0	2.64	0.1	0	0	500	0.5	8000	0.5	0	0	0	0
8	Edgerton WW Point Source	1	3	0	1.38	0.1	0	0	500	0.5	8000	0.5	0	0	0	0
9	Gardner Water Plant Point Sou	3	3	0	0.069	0	0	0	100	0.5	1000	0.5	0	0	0	0
10	Hillsdale Outflow	4	4	0	94.5	0.1	0	0	47	0.12	1100	0.17	13	0.12	579	0.69

Model Coefficients	Mean	CV
Dispersion Rate	1.000	0.70
Total Phosphorus	0.772	0.45
Total Nitrogen	1.037	0.55
Chl-a Model	1.352	0.26
Secchi Model	1.000	0.10
Organic N Model	1.000	0.12
TP-OP Model	1.000	0.15
HODv Model	1.000	0.15
MODv Model	1.000	0.22
Secchi/Chla Slope (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

Appendix B. Reduced
Predicted & Observed Values Ranked Against CE Model Development Dataset

Segment: 5 Area-Wtd Mean

	Predicted Values--->			Observed Values--->		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	21.8	0.50	19.1%	42.8	0.28	45.0%
TOTAL N MG/M3	489	0.57	13.1%	826	0.33	38.1%
C.NUTRIENT MG/M3	17.3	0.43	18.2%	33.7	0.31	47.2%
CHL-A MG/M3	10	0.77	52.7%	26.0	0.32	90.7%
SECCHI M	0.9	0.28	42.6%	0.7	0.13	30.1%
ORGANIC N MG/M3	446.4	0.41	45.3%	546.4	0.30	61.0%
TP-ORTHO-P MG/M3	33.6	0.45	54.7%	33.4	0.34	54.4%
ANTILOG PC-1	175.0	0.86	39.9%	538.8	0.15	72.6%
ANTILOG PC-2	6.9	0.43	55.5%	10.2	0.17	80.8%
(N - 150) / P	15.5	0.95	44.6%	16.3	0.27	47.4%
INORGANIC N / P	43.1	7.70	64.6%	38.1	2.46	59.9%
TURBIDITY 1/M	0.8	0.19	64.6%	0.8	0.19	64.6%
ZMIX * TURBIDITY	3.9	0.23	61.1%	3.9	0.23	61.1%
ZMIX / SECCHI	5.1	0.27	54.4%	6.5	0.09	70.3%
CHL-A * SECCHI	9.2	0.62	44.5%	18.6	0.24	80.1%
CHL-A / TOTAL P	0.5	0.34	90.5%	0.6	0.29	96.4%
FREQ(CHL-a>10) %	36.9	1.23	52.7%	88.3	0.10	90.7%
FREQ(CHL-a>20) %	7.7	2.34	52.7%	53.9	0.26	90.7%
FREQ(CHL-a>30) %	2.0	3.09	52.7%	29.3	0.36	90.7%
FREQ(CHL-a>40) %	0.6	3.66	52.7%	15.9	0.42	90.7%
FREQ(CHL-a>50) %	0.2	4.12	52.7%	8.8	0.47	90.7%
FREQ(CHL-a>60) %	0.1	4.51	52.7%	5.0	0.50	90.7%
CARLSON TSI-P	48.5	0.15	19.1%	58.0	0.04	45.0%
CARLSON TSI-CHLA	53.0	0.14	52.7%	62.5	0.04	90.7%
CARLSON TSI-SEC	61.1	0.06	57.4%	64.7	0.02	69.9%

Appendix B. Reduced
Overall Water & Nutrient Balances

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	2	Wade Branch	39.8	10.0	1.00E+00	0.10	0.25
2	1	4	Scott Branch	5.5	3.6	1.30E-01	0.10	0.66
3	1	1	Rock Cr	66.1	13.9	1.93E+00	0.10	0.21
4	1	1	Big Bull	120.8	21.5	4.62E+00	0.10	0.18
5	1	2	Smith Br	16.6	6.6	4.36E-01	0.10	0.40
6	1	3	Little Bull	114.6	24.8	6.15E+00	0.10	0.22
7	3	3	JOCO New Century WW Point Source		2.6	6.97E-02	0.10	
8	3	1	Edgerton WW Point Source		1.4	1.90E-02	0.10	
9	3	3	Gardner Water Plant Point Source		0.1	0.00E+00	0.00	
10	4	4	HIllsdale Outflow		94.5	8.93E+01	0.10	
PRECIPITATION				17.6	16.0	6.41E+01	0.50	0.91
TRIBUTARY INFLOW				363.4	80.4	1.43E+01	0.05	0.22
POINT-SOURCE INFLOW					4.1	8.87E-02	0.07	
***TOTAL INFLOW				381.0	100.5	7.85E+01	0.09	0.26
GAUGED OUTFLOW					94.5	8.93E+01	0.10	
ADVECTIVE OUTFLOW				381.0	-15.2	2.81E+02	1.10	
***TOTAL OUTFLOW				381.0	79.3	1.92E+02	0.17	0.21
***EVAPORATION					21.3	1.13E+02	0.50	
***STORAGE INCREASE					0.0	0.00E+00	0.00	

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

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	2	Wade Branch	210.0	3.9%	6.16E+03	0.6%	0.37	21.0	5.3
2	1	4	Scott Branch	75.6	1.4%	7.98E+02	0.1%	0.37	21.0	13.8
3	1	1	Rock Cr	291.9	5.4%	1.19E+04	1.1%	0.37	21.0	4.4
4	1	1	Big Bull	1526.5	28.3%	1.81E+05	16.4%	0.28	71.0	12.6
5	1	2	Smith Br	138.6	2.6%	2.68E+03	0.2%	0.37	21.0	8.3
6	1	3	Little Bull	967.2	17.9%	3.13E+05	28.5%	0.58	39.0	8.4
7	3	3	JOCO New Century WW Poi	1320.0	24.4%	4.53E+05	41.2%	0.51	500.0	
8	3	1	Edgerton WW Point Source	690.0	12.8%	1.24E+05	11.3%	0.51	500.0	
9	3	3	Gardner Water Plant Point S	6.9	0.1%	1.19E+01	0.0%	0.50	100.0	
10	4	4	HIllsdale Outflow	1898.6		9.25E+05		0.51	20.1	
PRECIPITATION				176.0	3.3%	7.74E+03	0.7%	0.50	11.0	10.0
TRIBUTARY INFLOW				3209.8	59.4%	5.16E+05	46.9%	0.22	39.9	8.8
POINT-SOURCE INFLOW				2016.9	37.3%	5.77E+05	52.4%	0.38	493.3	
***TOTAL INFLOW				5402.7	100.0%	1.10E+06	100.0%	0.19	53.8	14.2
GAUGED OUTFLOW				1898.6	35.1%	9.25E+05		0.51	20.1	
ADVECTIVE OUTFLOW				-306.3		1.51E+05		1.27	20.1	
***TOTAL OUTFLOW				1592.3	29.5%	6.28E+05		0.50	20.1	4.2
***STORAGE INCREASE				-2.0		8.83E-02		0.15	42.8	
***RETENTION				3812.4	70.6%	1.36E+06		0.31		

Overflow Rate (m/yr)	4.5	Nutrient Resid. Time (yrs)	0.3911
Hydraulic Resid. Time (yrs)	1.2226	Turnover Ratio	2.6
Reservoir Conc (mg/m3)	22	Retention Coef.	0.706

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

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	2	Wade Branch	1600.0	2.2%	3.71E+06	1.7%	1.20	160.0	40.2
2	1	4	Scott Branch	576.0	0.8%	4.81E+05	0.2%	1.20	160.0	105.1
3	1	1	Rock Cr	2224.0	3.1%	7.17E+06	3.2%	1.20	160.0	33.6
4	1	1	Big Bull	11975.5	16.6%	2.11E+07	9.4%	0.38	557.0	99.1
5	1	2	Smith Br	1056.0	1.5%	1.62E+06	0.7%	1.20	160.0	63.6
6	1	3	Little Bull	9920.0	13.8%	3.83E+06	1.7%	0.20	400.0	86.6
7	3	3	JOCO New Century WW Poi	21120.0	29.3%	1.16E+08	51.7%	0.51	8000.0	
8	3	1	Edgerton WW Point Source	11040.0	15.3%	3.17E+07	14.1%	0.51	8000.0	
9	3	3	Gardner Water Plant Point S	69.0	0.1%	1.19E+03	0.0%	0.50	1000.0	
10	4	4	HIllsdale Outflow	43293.1		6.34E+08		0.58	458.1	
PRECIPITATION				12478.4	17.3%	3.89E+07	17.3%	0.50	779.1	709.0
TRIBUTARY INFLOW				27351.5	38.0%	3.79E+07	16.9%	0.23	340.2	75.3
POINT-SOURCE INFLOW				32229.0	44.7%	1.48E+08	65.8%	0.38	7881.9	
***TOTAL INFLOW				72058.9	100.0%	2.24E+08	100.0%	0.21	717.0	189.1
GAUGED OUTFLOW				43293.1	60.1%	6.34E+08		0.58	458.1	
ADVECTIVE OUTFLOW				-6984.3		8.30E+07		1.30	458.1	
***TOTAL OUTFLOW				36308.8	50.4%	4.32E+08		0.57	458.1	95.3
***STORAGE INCREASE				-37.8		4.41E+01		0.18	825.6	
***RETENTION				35787.9	49.7%	5.12E+08		0.63		

Overflow Rate (m/yr)	4.5	Nutrient Resid. Time (yrs)	0.6578
Hydraulic Resid. Time (yrs)	1.2226	Turnover Ratio	1.5
Reservoir Conc (mg/m3)	489	Retention Coef.	0.497

Appendix C. Cropland Scenario

Hillsdale WRAPS

Acres of Cropland		20,897
BMP Implementation (treated acres)	**Increased Adoption (%)**	**Acres**
No-Till	10%	2,090
Grassed Waterways	25%	5,224
Vegetative Buffers	10%	2,090
Nutrient Mgmt Plans	10%	2,090
Terraces	25%	5,224
Permanent Vegetation	5%	1,045
Subsurface Fert Application	5%	1,045
Total	**90%**	**18,807**
Estimated Cost		
Total Investment Cost		$1,973,861
Available Cost-Share		$1,010,692
Net Cost		**$963,169**
Estimated Annual Runoff Reduction		
Soil Erosion (tons)		15,568
Phosphorus (pounds)		18,180
Nitrogen (pounds)		109,393
Estimated Average Annual Runoff		
Soil Erosion (tons/acre)		2.00
Phosphorus (pounds/acre)		2.40
Nitrogen (pounds/acre)		15.74

Total Load Reduction by Category

	Crop	Livestock	Total	TMDL	% of TMDL
Sediment (tons)	15,568		**15,568**		
Phosphorous (pounds)	18,180	73,933	**92,113**	**26,095**	*353%*
Nitrogen (pounds)	109,393	139,253	**248,646**	**249,173**	*100%*

Hillsdale WRAPS, 12/6/13

Josh Roe, roe@ksu.edu 785-532-3035

Appendix C. Hillsdale Livestock BMPs, Costs, and Estimated Phosphorous and Nitrogen Reduction.

BMP	Approximate P Reduction Efficiency	Unit Cost	After Cost Share*	Estimated P Reduction (Pounds)	Annual Installations	Total Installations	Total Estimated P Reduction	Total Estimated N Reduction
Vegetative Filter Strip	50%	$714	$357	638	1	20	12,758	24,029
Relocate Feedlot	95%	$6,621	$3,311	797	1	20	15,947	30,036
Relocated Pasture Feeding Site	50-90%	$2,203	$1,102	63	2	40	2,522	4,751
Off-Stream Watering System	85%	$3,795	$1,898	63	5	100	6,306	11,877
Rotational Grazing	25%	$7,000	$3,500	140	3	60	8,400	15,821
Grazing Mgmt Plan	25%	$1,600	$800	280	5	100	28,000	52,738

Total Cost After Cost Share	$597,160
Year 1 Cost	$14,929
Year 20 Cost	$26,963
Total Estimate of P Reduction	73,933
Total Estimate of N Reduction	139,253

Cost of P Reduction over Project Life (25 Years)	
Dollars per pound of P	$0.57

**50% Cost-Share from EQIP*

Hillsdale WRAPS, 12/6/13
Josh Roe, roe@ksu.edu (785) 532-3035