VERDIGRIS BASIN TOTAL MAXIMUM DAILY LOAD

Waterbody / Assessment Unit (AU): Toronto Lake

Water Quality Impairment: Eutrophication bundled with Siltation and Dissolved Oxygen

1. INTRODUCTIONS AND PROBLEM IDENTIFICATION

Subbasin:	Upper Verdigris
Counties:	Greenwood, Woodson
HUC 8 (HUC 11):	11070101 (010, 020, 030)
Ecoregion:	Central Irregular Plains, Osage Cuestas (40b); Flint Hills (28)
Drainage Area:	Approximately 690 square miles
Conservation Pool:	Surface Area = 2800 acres (4.375 square miles) Watershed/Lake Ratio = 158:1 Maximum Depth = 5.5 meters Mean Depth = 2.1 meters Storage Volume = 24,787 acre-feet Estimated Retention Time = ~0.06 years Mean Annual Inflow = 378,664 acre-feet (1992-2007) Mean Annual Discharge = 365,153 acre-feet (1992-2007) Year Constructed: 1960
Designated Uses:	Primary Contact Recreation (A); Expected Aquatic Life Support; Domestic Water Supply; Food Procurement; Ground Water Recharge; Industrial Water Supply; Irrigation Use; Livestock Watering Use
303(d) Listings:	2002, 2004 & 2008 Verdigris River Basin Lakes
Impaired Use:	All uses are impaired to a degree by eutrophication
Water Quality Standard:	Nutrients – Narratives: The introduction of plant nutrients into streams, lakes, or wetlands from artificial sources shall be controlled to prevent the accelerated succession or replacement of aquatic biota or the production of undesirable quantities or kinds of aquatic life (K.A.R. 28-16-28e(c)(2)(A)).

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

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

Dissolved Oxygen: The concentration of Dissolved Oxygen in surface waters shall not be lowered by the influence of artificial sources of pollution. Dissolved Oxygen (DO): 5mg/L (K.A.R. 28-16-28e(d) Table 1g).

2. CURRENT WATER QUALITY CONDITION AND DESIRED ENDPOINT

Level of Eutrophication:

Recent Average (1995-2007): Trophic State Index = 56.81, Fully Eutrophic
Chlorophyll *a* = 14.9

Current Condition (2007): Trophic State Index = 57.74, Fully Eutrophic
Chlorophyll *a* = 15.9

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

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

Level of Dissolved Oxygen Deficiency: Low dissolved oxygen (DO) concentrations are frequently encountered when the lake is turbid and/or when water temperatures are extremely warm. Water quality violations (DO < 5 mg/L) began at the 2 - 3 meter range in 1989, 1995, 2001, 2004 and in 2007 and continued to the lake bottom. Violations were not encountered in the top 3 meters prior to 1989.

Level of Siltation Impairment: Toronto Lake has high inorganic turbidity and high levels of siltation. The lake is shallow and sediment is re-suspended easily due to wind, motorboat traffic, and moderate to high inflow events. In addition, siltation is aggravated during large runoff events, when releases from Toronto Lake are minimized to accommodate flood control along the Verdigris River, which causes large silt deposits within the lake and the inflowing river channels. Subsequent runoff events of moderate duration then facilitate the transport of that deposited sediment into the lake where it may settle out.

Lake Chemistry Monitoring Sites: KDHE Station LM024001 in Toronto Lake.
Period of Record Used: Eleven surveys conducted by KDHE in calendar years; 1975, 1978, 1981, 1986, 1989, 1992, 1995, 1998, 2001, 2004, and 2007.

Lake Inflow and Outflow Data: U.S. Army Corps of Engineers, Tulsa District Office
Period of Record Used: 1992-2007

Stream Chemistry Monitoring Sites (Period of Record Used):
Station 289 on Verdigris River, near Virgil (1985-2007);
Station 290 on West Creek near Quincy (1985-2007);
Station 576 on Walnut Creek near Neal (1990-2007).

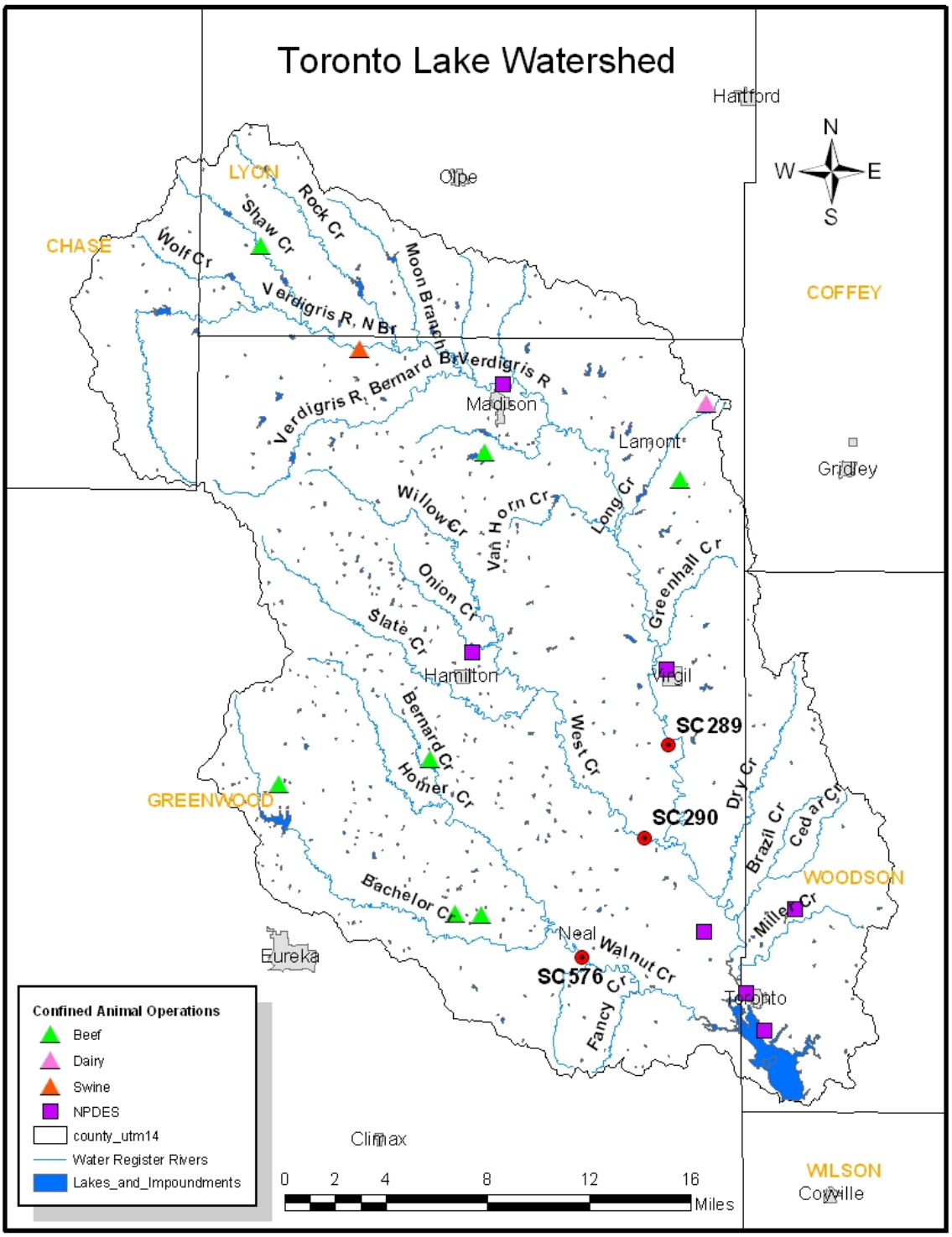
Hydrologic Conditions: The Verdigris River and Walnut Creek flow into Toronto Lake. The estimated flow durations and mean flows of these streams are illustrated in Table 1a (Perry, 2004).

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

Inflow	USGS Site ID #	90%	75%	50%	25%	10%	Mean Q	Mean Q hm^3/yr	Drainage Area $miles^2$
Verdigris R	3974	2.87	11.3	55.8	173	541	304	272	504
Walnut Cr	4049	0.04	2.87	13.7	49	155	109	97	193
Total		2.91	14.17	69.5	222	696	413	369	697

According to the USGS Lake Hydro data, the mean runoff in the watershed is 8.9 inches/year; the mean precipitation in the watershed is 38.6 inches/year and the mean loss due to evaporation for the Lake is 51.5 inches/year. Based on the U.S. Army Corps of Engineers (USACE) daily outflow and inflow data for Toronto Lake, the calculated mean annual outflow for the lake is 365,153 acre-feet per year. The average annual total inflow for Toronto Lake is 378,664 acre-feet over the period from 1992-2007 (USACE). As seen in Figure 2, the years of 1996, 2000, 2002, 2003, and 2006 are considered dry years, while the years of 1992, 1995, 1998, 1999, 2004, 2005, and 2007 are generally considered wet years.

Figure 1. Toronto Lake Watershed Base Map**.**



Stream Chemistry Data: The KDHE stream chemistry data for the Toronto Lake Watershed is summarized in Table 1b.

Table 1b. Stream Chemistry Data averages within the Toronto Watershed for the period of record used.

Stream Station	Total P (mg/L)	Total N (mg/L)	Ortho P (mg/L)	TKN (mg/L)	TSS (mg/L)	Turbidity (NTU)	DO (mg/L)
SC289, Verdigris R	0.086	0.85	0.01*	0.541	62.9	29.9	8.41
SC290, West Cr	0.082	0.753	0.01*	0.565	57.0	26.9	8.08
SC576, Walnut Cr	0.092	0.773	0.01*	0.600	62.0	27.63	7.62

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

Current Condition: The chlorophyll *a* (chl-a) concentration average over the period of record is 10.04 µg/L. Annual concentration averages exceeded 10 µg/L in the sampling years of: 1992, 1995, 1998, 2001 and 2007, with the maximum yearly average of 20.55 µg/L occurring in 1998. The more recent chlorophyll *a* concentration average for KDHE samples obtained from 1992-2007 is 14.09 µg/L.

The average secchi depth is 0.35 meters, with the lowest reading of 0.1 meters occurring in 1989 and a maximum depth reading of 0.47 meters occurring in 2007. The average turbidity value in Toronto Lake is 38.9 NTU, ranging from a low of 14.5 NTU in 1995 to a high of 83 NTU in 1989. The turbidity average has decreased to 29.2 NTU for samples obtained since 1992. As seen in Figure 7, high chlorophyll *a* detections appeared when turbidity values were below 30 NTU. With the exception of the 2004 data, turbidity values have a negative relationship with Secchi depth readings, where the higher turbidity values yield a lower secchi depth reading. The average Total Suspended Solids concentration within Toronto Lake is 30 mg/L over the entire period of record and a more recent average of 27.1 mg/L for samples obtained since 1992.

The average total nitrogen (TN) and total phosphorus (TP) concentrations are 0.64 mg/L and 0.081 mg/L, respectively. The maximum TP concentration of 0.13mg/L was detected in 1989. The TP concentration average from 1992-2007 is 0.073 mg/L. Data for calculating TN is not available prior to the 1992 sampling event and a maximum TN detection of 1.11 mg/L occurred in 1998.

Figure 2. Summary of Toronto Lake annual inflow and outflow (USACE).

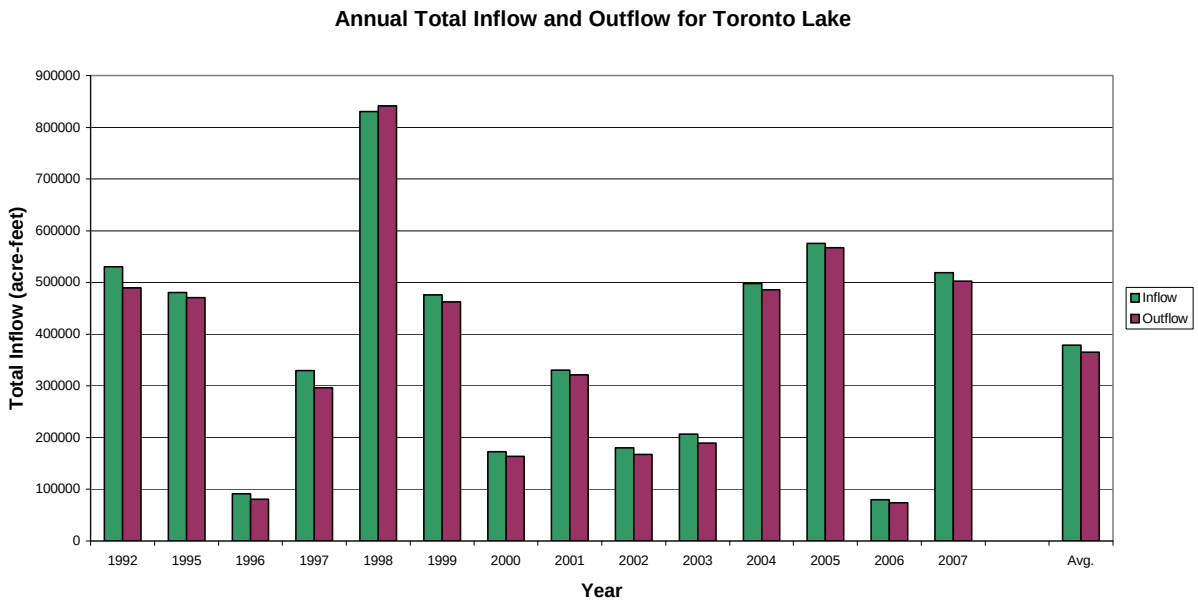


Figure 3. Chlorophyll *a* concentrations at Toronto Lake for years sampled by KDHE.

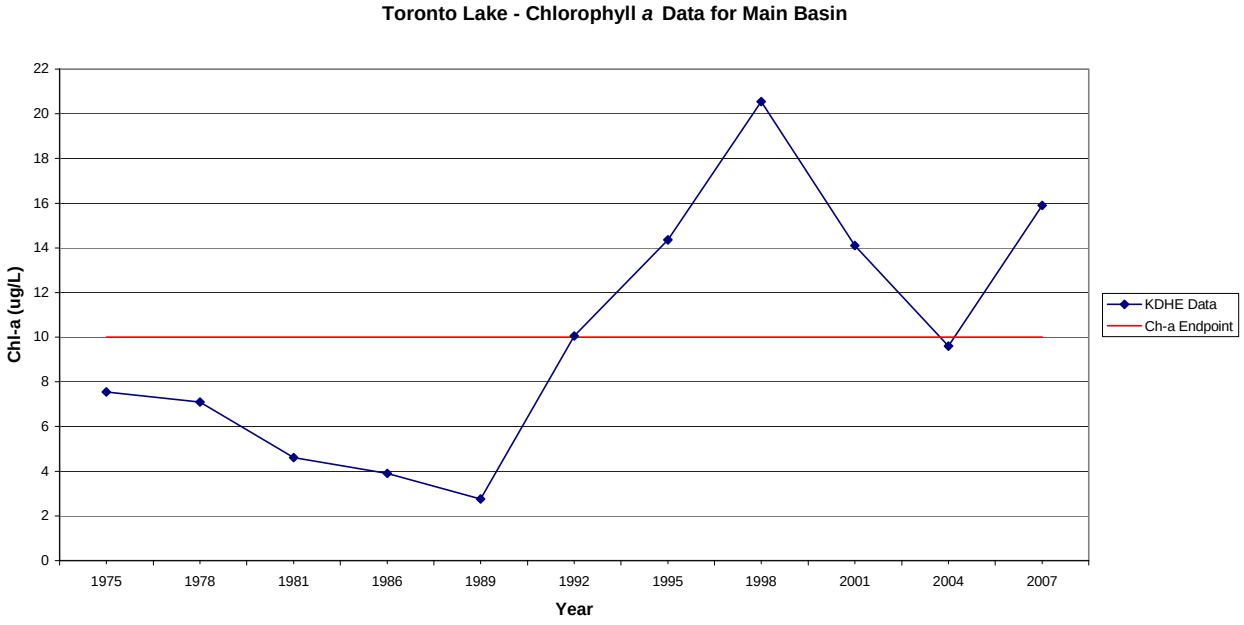


Figure 4. Total Phosphorus Concentrations in Toronto Lake.

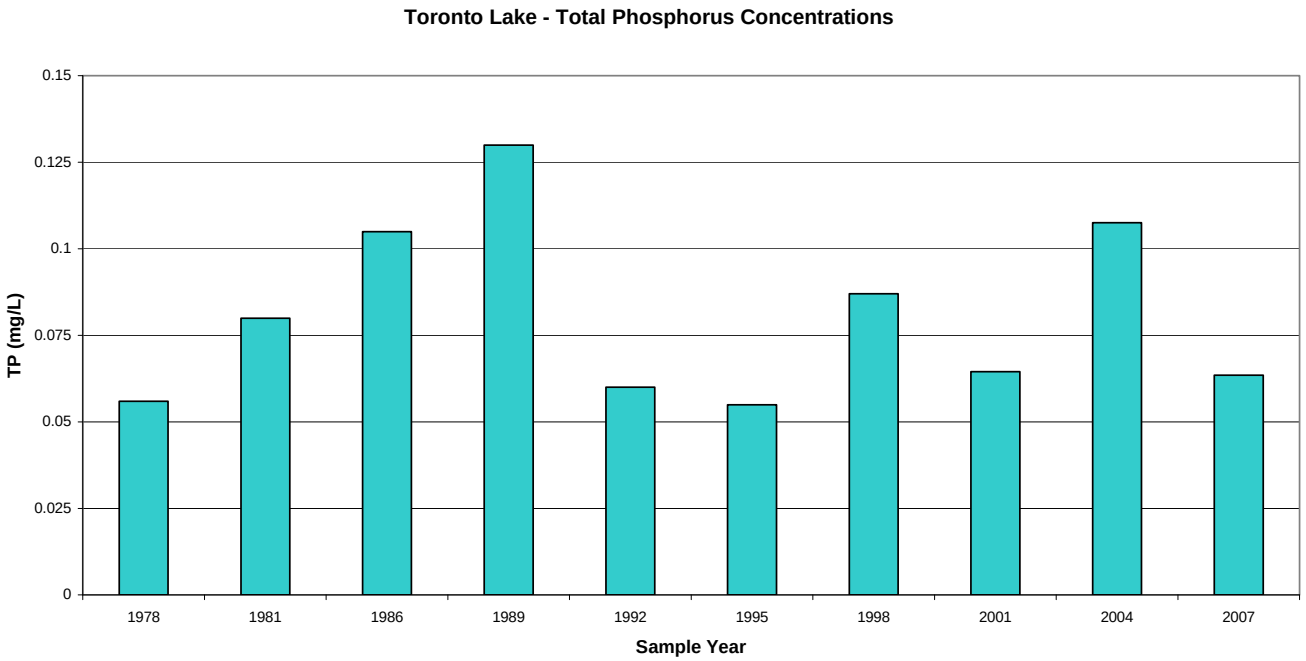


Figure 5. Total Suspended Solids and Turbidity in Toronto Lake.

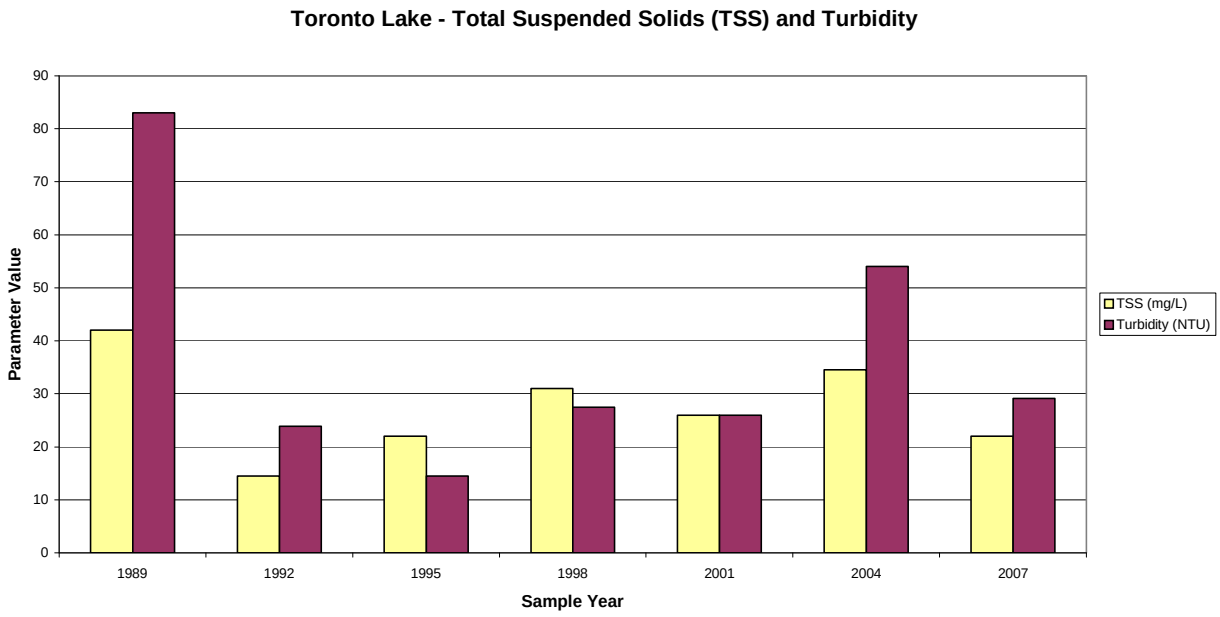


Figure 6. Total Nitrogen and Secchi-Depth Values in Toronto Lake.

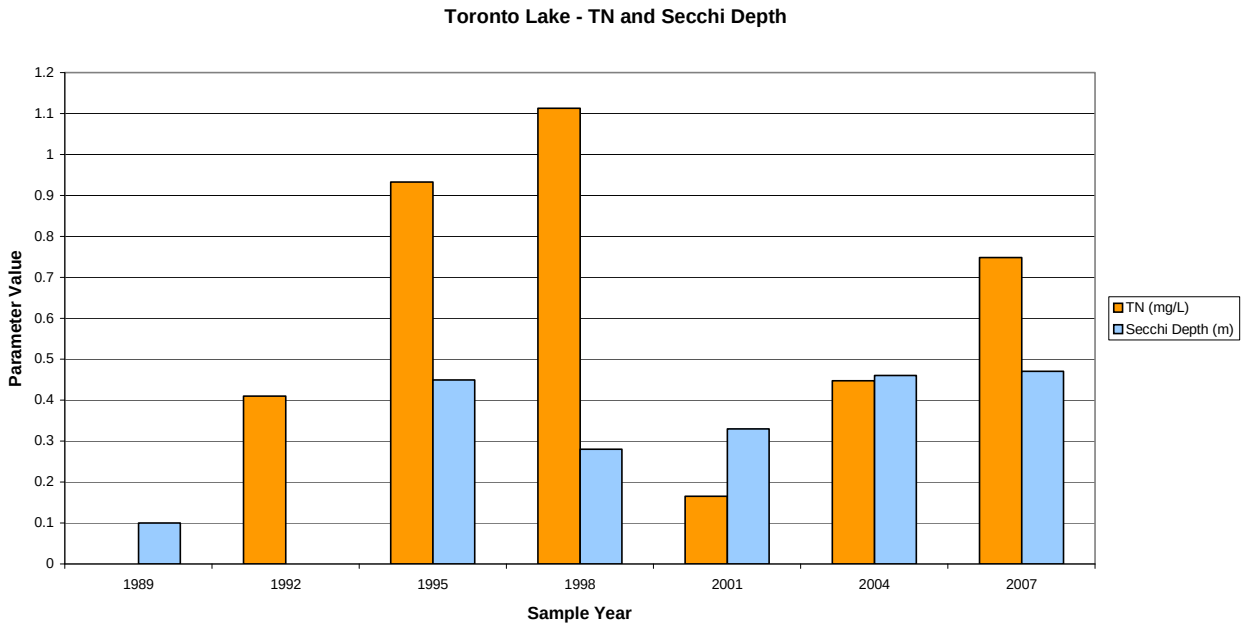


Figure 7. Relationship between turbidity values and Chlorophyll *a* in Toronto Lake.

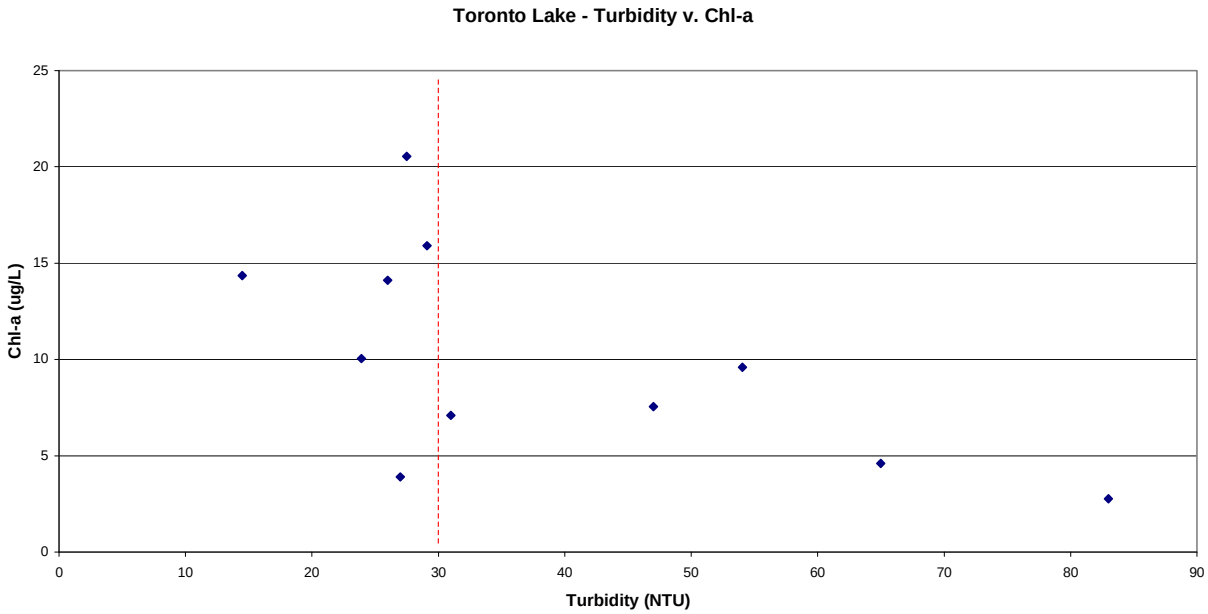
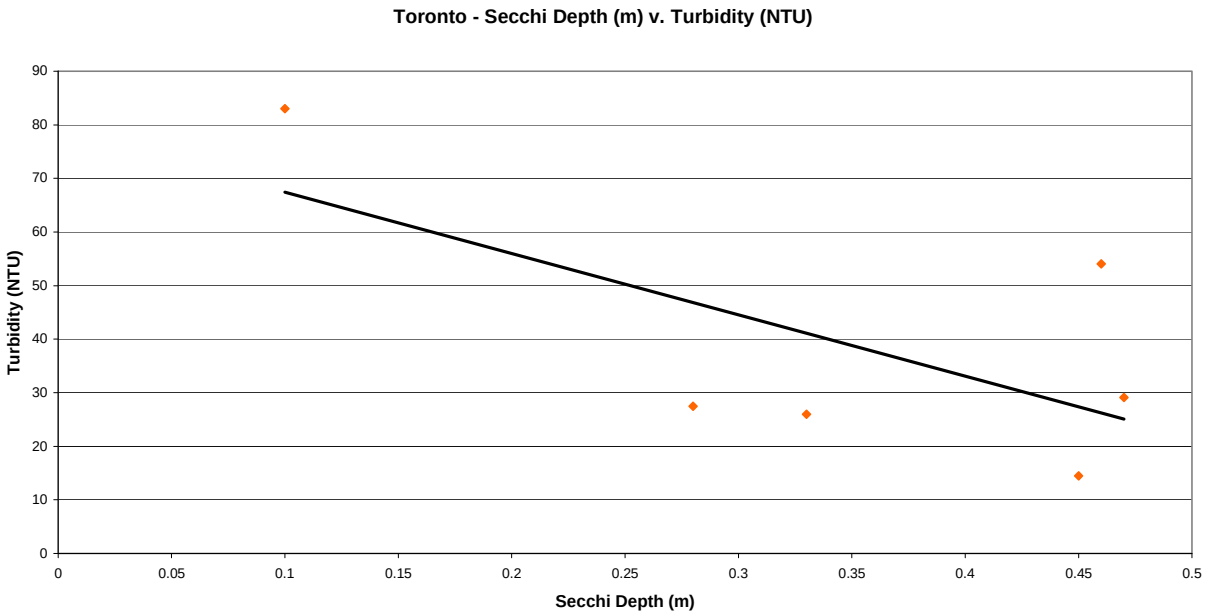


Figure 8. Relationship between turbidity and Secchi depth at Toronto Lake.
The ratio of total nitrogen and total phosphorus is a common ratio utilized to determine



which of these nutrients is likely limiting plant growth in Kansas aquatic ecosystems. Typically, lakes that are nitrogen limited have a water column TN:TP ratio < 8 (mass); lakes that are co-limited by nitrogen and phosphorus have a TN:TP ratio between 9 and 21; and lakes that are P limited have a water column TN:TP ratio > 29 (Dzialowski et al., 2005). Toronto Lake has varied between being nitrogen limited in 1992, 2001, and 2004; and co-limited by nitrogen and phosphorus in 1995, 1998, and 2007. Since 1992, Chlorophyll *a* concentrations averaged 16.93 µg/L when the lake displayed co-limiting characteristics and 11.25 µg/L when the lake was found to be nitrogen limited.

Table 3 lists six metrics measuring the roles of light and nutrients in Toronto Lake. Non-algal turbidity (NAT) values < 0.4 m^{-1} indicates there are very low levels of suspended silt and/or clay. The values between 0.4 and 1.0 m^{-1} indicate inorganic turbidity assumes greater influence on water clarity but would not assume a significant limiting role until values exceed 1.0 m^{-1}.

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

Table 2. KDHE sampling results from Toronto Lake.

Sample Date	Sample Time	Chl-a (µg/L)	TN (mg/L)	TP (mg/L)	TN:TP ratio	Secchi Depth (m)	Turbidity (NTU)
6/9/1975	NA	7.55	NA	NA	NA	NA	47
6/5/1978	NA	7.1	NA	0.056	NA	NA	31
6/1/1981	NA	4.61	NA	0.08	NA	NA	65
8/19/1986	1145	3.9	NA	0.105	NA	NA	27
6/6/1989	1150	2.76	NA	0.13	NA	0.1	83
8/10/1992	1450	10.05	0.41	0.06	6.83	NA	23.9
7/31/1995	1035	14.35	0.94	0.055	16.96	0.45	14.5
6/22/1998	1105	20.55	1.11	0.087	12.79	0.28	27.5
7/23/2001	1105	14.1	0.17	0.0645	2.56	0.33	26
8/9/2004	1050	9.6	0.45	0.108	4.16	0.46	54.05
2007	0950	15.9	0.75	0.0635	11.80	0.47	29.1
Average	All Data	10.04	0.636	0.081	9.18	0.35	38.9
Average-1992-2007	Recent Data	14.09	0.636	0.0729	9.18	0.40	29.2

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

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

Table 3. Limiting factor determinations for Toronto Lake

Year	TN/TP	Non-algal Turbidity	Light Availability in the Mixed Layer	Partioning of Light Extinction between Algae & Non-algal Turbidity	Algal Use of Phosphorus Supply	Light Availability in the Mixed Layer for a Given Surface Light	Shading in Water Column due to Algae and Inorganic Turbidity
		NAT	Zmix*NAT	Chl-a*SD	Chl-a/TP	Zmix/SD	Shading
1989		9.9	21.98	0.276	.021	22	
1992	6.83				0.17		
1995	16.96	2.22	4.88	6.45	0.26	4.89	
1998	12.7	3.06	6.68	5.75	0.24	7.80	5.97
2001	3.7	2.68	5.24	4.65	0.22	5.93	4.71
2004	4.3	1.93	4.22	4.42	0.091	4.75	4.21
2007	11.8	2.13	4.60	7.47	0.25	4.68	

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

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

The above metrics conclude that Toronto Lake generally has high levels of inorganic turbidity (suspended silt/clay particles), there is a lack of light availability in the mixed layer, inorganic turbidity limits light in the water column, there is a low to moderate algal response to changes in phosphorus levels and self-shading of algae does not significantly impede productivity. According to these metrics, Toronto Lake is limited by light and nitrogen in 1989, 2001, and 2004 and the lake is most likely limited by light, nitrogen, and phosphorus (co-limited) in 1995, 1998 and 2007.

Another method for evaluating limiting factors is the TSI deviation metrics. Figure 9 (Multivariate Deviation Graph) summarizes the current trophic conditions at Toronto Lake using a multivariate TSI comparison chart for data obtained by KDHE throughout the period of record. Where TSI(Chl-a) is greater than TSI(TP), the situation indicates phosphorus is limiting chlorophyll *a*, whereas negative values indicate turbidity limits chlorophyll *a*. Where TSI(Chl-a)-TSI(SD) is plotted on the horizontal axis, if the Secchi depth (SD) trophic index is less than the chlorophyll *a* trophic index, than there is dominant zooplankton grazing. Transparency would be dominated by non-algal factors such as color or inorganic turbidity if the Secchi depth index were more than the chlorophyll *a* index. Points near the diagonal line occur in turbid situations where phosphorus is bound to clay particles and therefore turbidity values are closely associated with phosphorus concentrations. For the years plotted in Figure 9, Toronto Lake is generally limited by non-algal turbidity, light and nitrogen.

Figure 9. Multivariate TSI comparison chart for Toronto Lake.

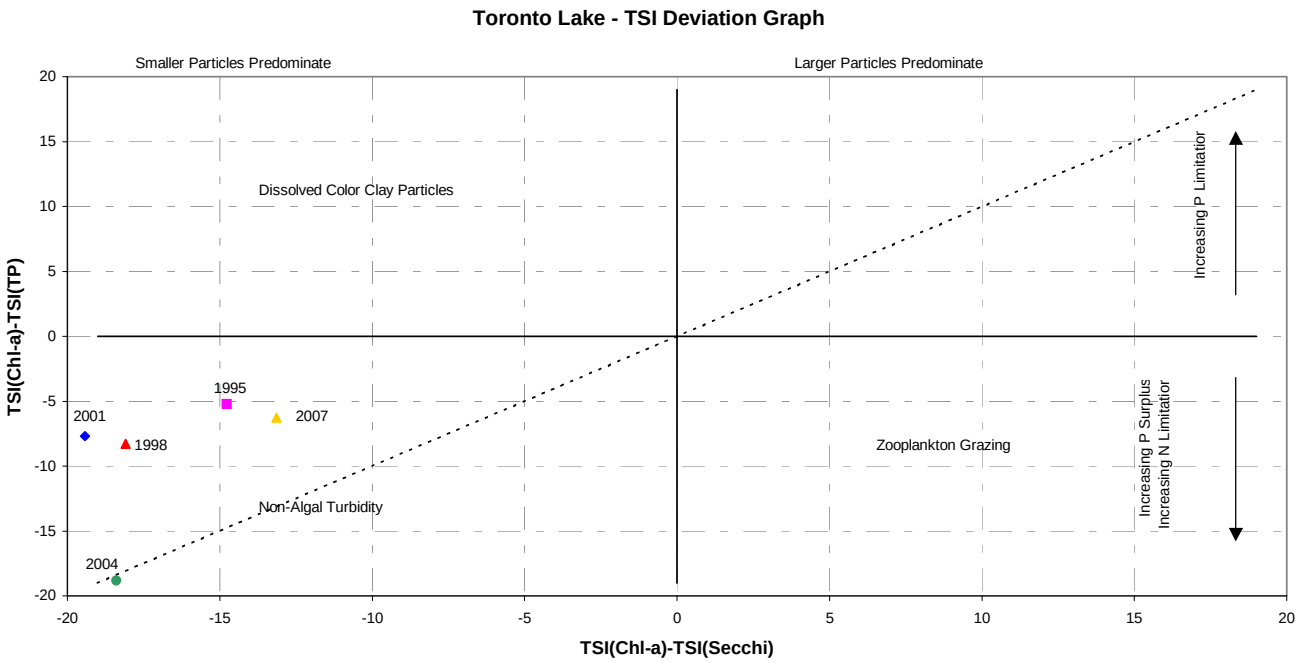


Figure 10. Trophic State Indices in Toronto Lake for year's lake sampled by KDHE.

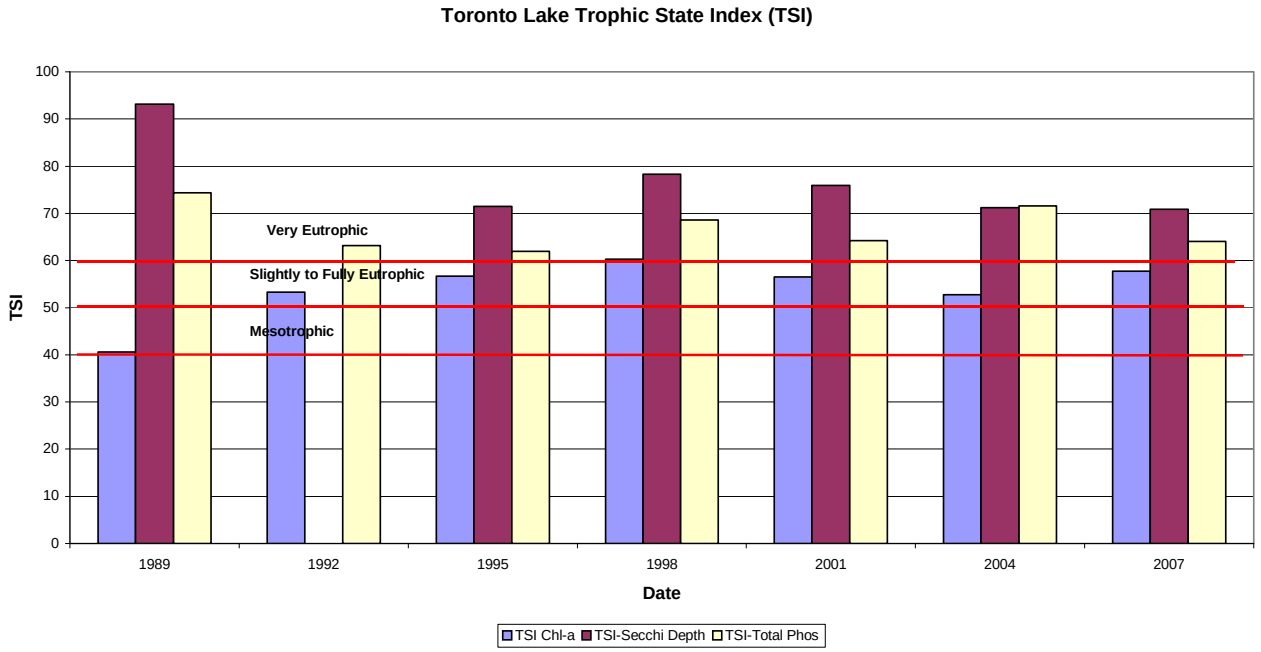


Table 4 summarizes median trophic conditions within Toronto Lake in relation to other federal lakes in the state. The trophic indicator values within Toronto Lake meets the statewide benchmark for TN, however it is more than 99% higher than the trophic benchmark for lakes within the Flint Hills. The median TP concentrations within Toronto Lake is considerably higher than the statewide benchmark and other Flint Hills lakes, however it is better than the median value for Federal Lakes. The median chlorophyll *a* concentration for Toronto Lake is higher than all of the other benchmarks. The median secchi depth reading for the lake is very poor in contrast to the other benchmarks as well. Since the majority of the watershed lies within the Flint Hills ecoregion, the median trophic conditions for Toronto Lake ranks well below the median values for reference lakes within the Flint Hills.

Table 4. Median trophic indictor values of Toronto Lake (KDHE data 1992-2004) in comparison with other federal lakes and draft nutrient benchmarks in Kansas. The nutrient benchmarks were derived from 47-58 lakes and reservoirs, based on the data collected between 1985 and 2002 (Dodds et al., 2006)

Trophic Indicator	Toronto Lake	Federal Lakes	Central Great Plains	Flint Hills	Statewide Benchmark
Secchi Depth (cm)	45	95	117	149	129
TN (µg/L)	598	903	695	301	625
TP (µg/L)	64.0	76	44	19	23
Chlorophyll a (µg/L)	14.2	12	11	5	8

Figure 11. Relationship between TN:TP ratio and average daily lake inflow for the 30-day period prior to the KDHE sampling date (1992-2007).

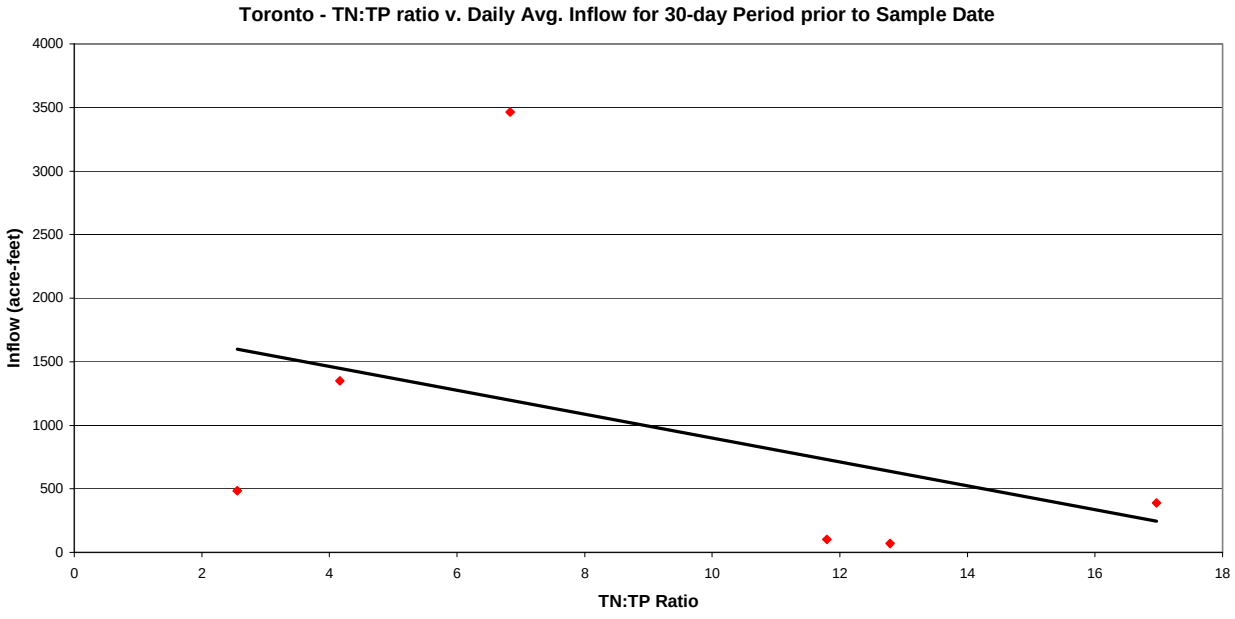


Figure 12. Relationship between TN:TP ratio and Chl-a concentrations in Toronto Lake.

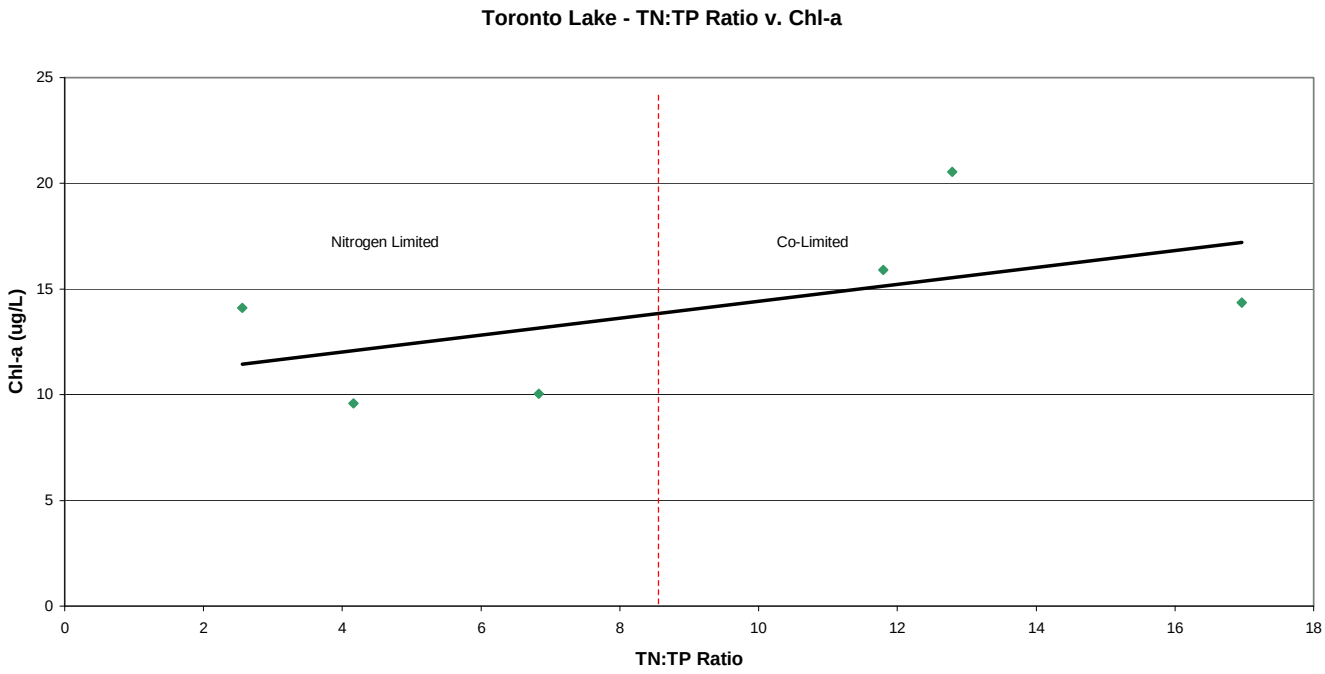


Figure 13. Relationship between Chl-a and daily average inflow for 30-day period prior to KDHE sampling date (1992-2007).

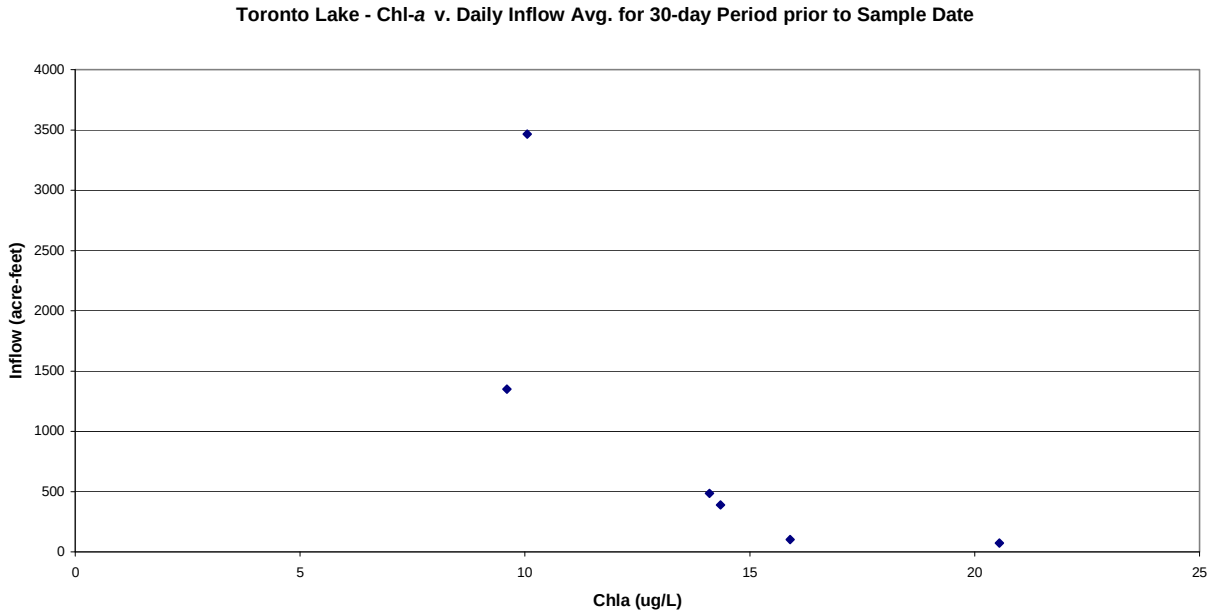


Figure 14. Relationship between TN concentrations and daily average inflow for the 30-day period prior to KDHE sampling date (1992-2007).

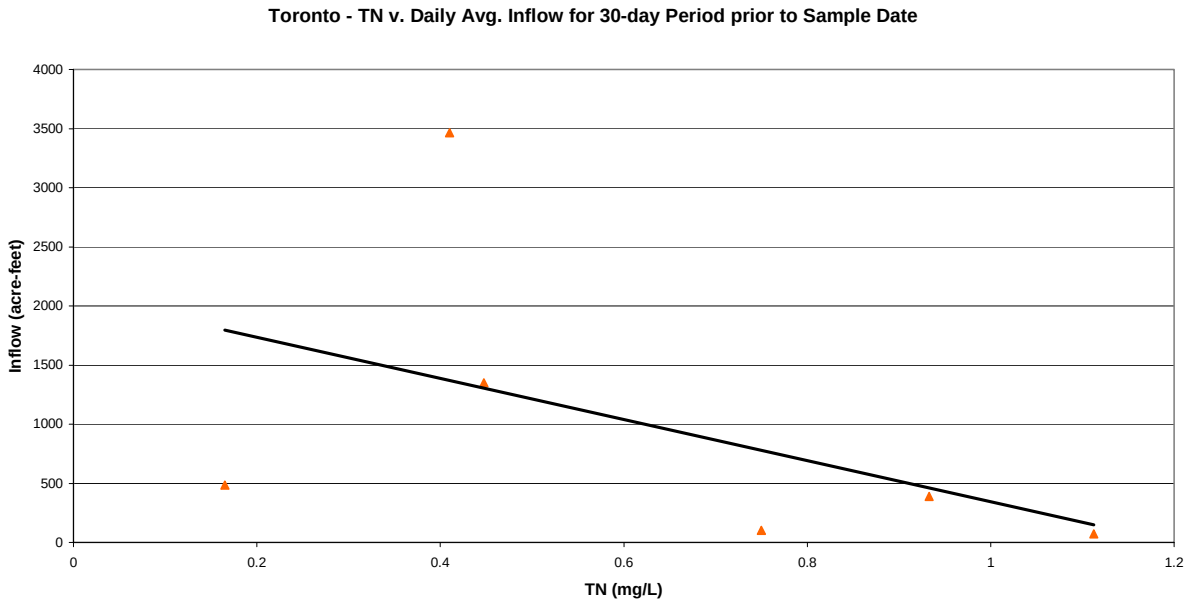


Figure 15. Relationship between Turbidity and Daily average inflow for the 30-day period prior to KDHE sampling date (1992-2007).

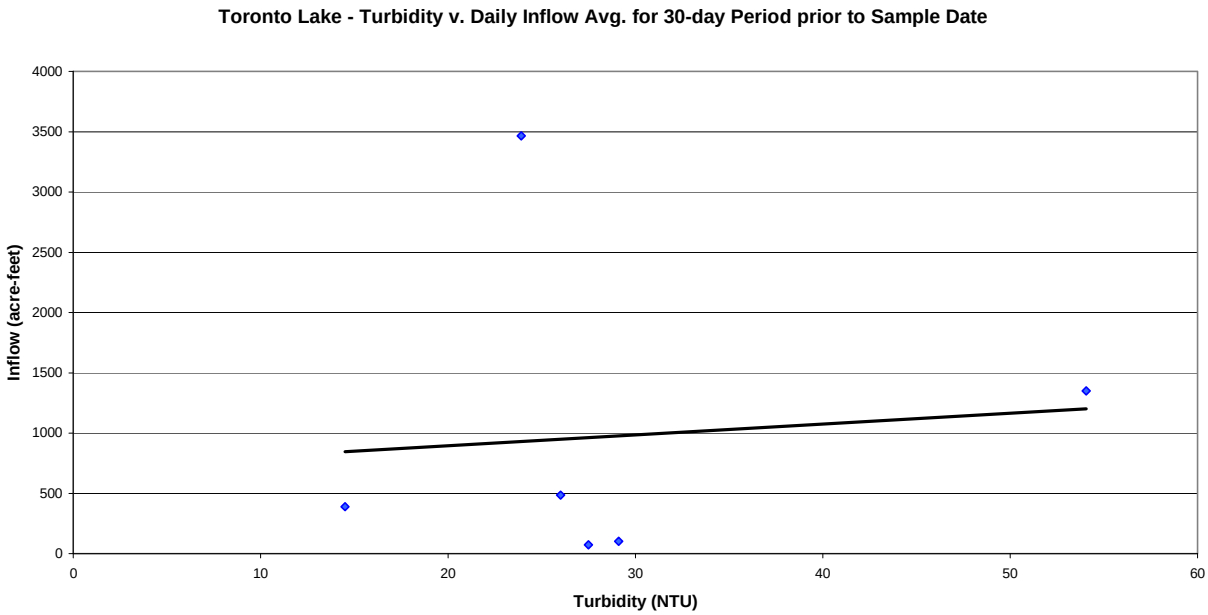


Figure 16. Daily average inflow and outflow amounts for 30-day period prior to KDHE sampling date (1992-2007).

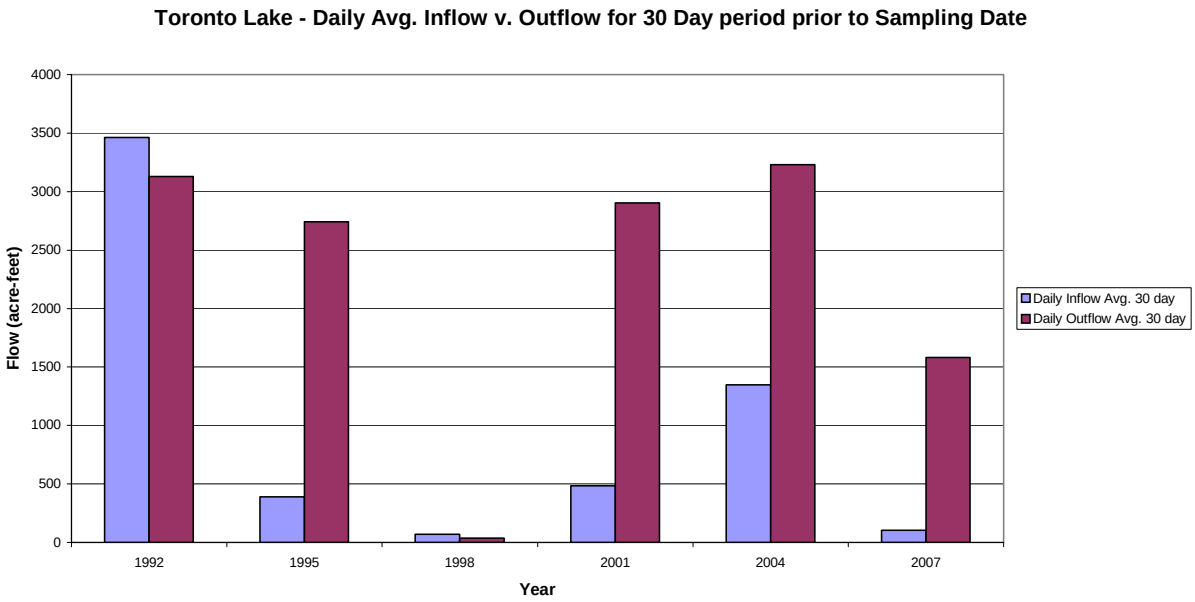
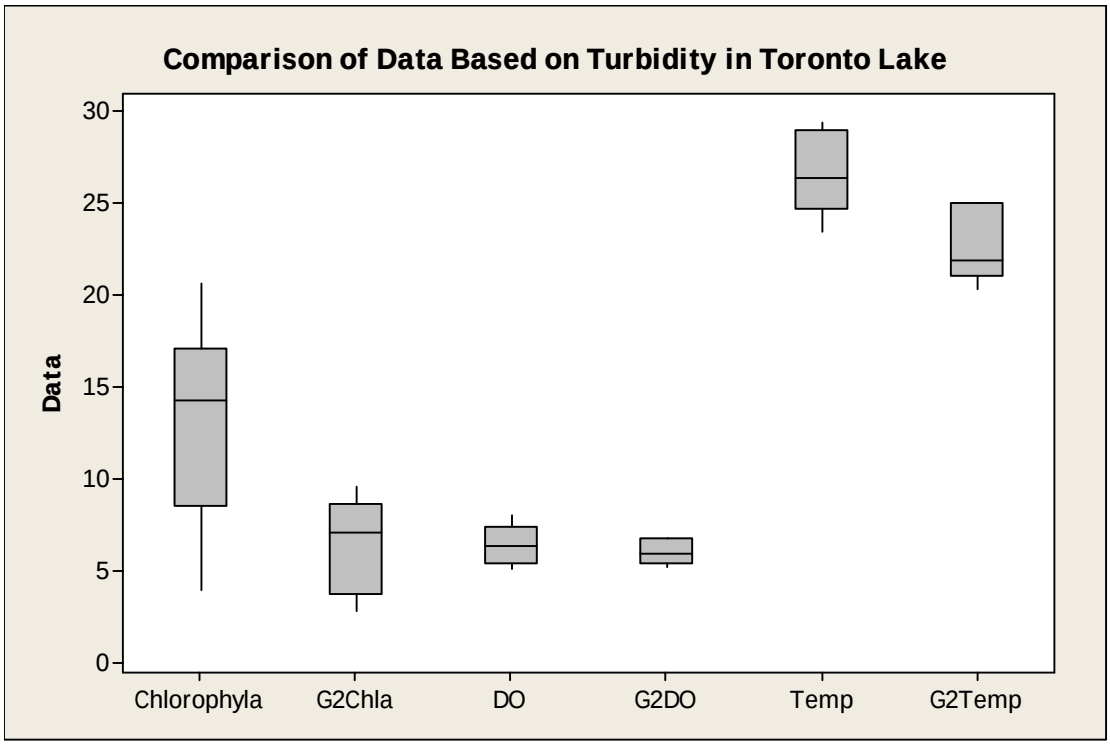


Figure 17. Comparison of grouped KDHE data, data with Turbidity values of < 30 NTU v. data ≥ 30 NTU (G2).



Common water quality patterns observed in Toronto Lake are shown in Figures 11, 12, 13, 14 and 15. In general, negative relationships are found between: the TN:TP ratio and average daily lake inflow, TN concentrations and average daily lake inflow, and between the chlorophyll *a* concentration and the average daily lake inflow for the 30-day period prior to the KDHE sampling date. There are positive relationships between the TN:TP ratio and chlorophyll *a* concentrations and between turbidity values and average daily lake inflow.

Figure 16 illustrates the inflow and outflow volumes for Toronto Lake within the 30-day period prior to the sampling date. The lake has regularly been releasing more water during this time frame prior to the sampling date, which generally concludes that larger runoff and inflow events preceded this time frame. Therefore when these conditions occurred the lake was presumably discharging water that has been captured for some time.

Figure 17 compares KDHE data that has been grouped based on the turbidity value of the sample. Group 1 contains KDHE data for sampling years that had turbidity values less than 30 NTU, whereas Group 2 contains data for samples with turbidity values greater than 30 NTU. Chlorophyll *a* concentrations are significantly higher when turbidity values are less than 30 NTU. The years of data that encompass Group 1 also experienced higher lake temperatures and slightly higher dissolved oxygen concentrations. Higher chlorophyll *a* concentrations in Toronto Lake would be more likely during dry conditions, or when lake conditions are calm, which would allow for the sediment to settle out of the water column and allow for sunlight to readily penetrate. The increase in light within the water column provides conditions for maximum algal production, which would tend to increase dissolved oxygen concentrations. When runoff or wet conditions persist, turbid conditions would likely exist causing microbial processes to govern Toronto Lake's water quality, leading to lower dissolved oxygen levels. Therefore in Figure 17, Group 1 is reflective of primary production activities (algal) and Group 2 is associated with microbial activities.

Algal Communities: As seen in Table 5, algal communities in Toronto Lake, based on total cell count, are dominated by diatoms. Though diatom communities could contribute to taste and odor problems, in Kansas they are typically dominant in lakes that have less nutrient enrichment, where lakes that are primarily composed of dominant green or blue-green algae are nutrient enriched (Carney, 2004).

Table 5. Algal Communities Observed in Toronto Lake.

Sampling Date	Total Cell Count cells/mL	Percent Composition				Chl-*a*
		Green	Blue Green	Diatom	Other	
6/6/1989	1100	47	29	0	24	2.76
8/10/1992	7900	56	5	34	5	10.05
7/31/1995	3650	41	9	45	5	14.35
6/22/1998	5040	20	0	43	37	20.55
7/23/2001	7781	8	13	78	1	14.1
8/9/2004	7403	3	0	96	1	9.6

Fish Population: Toronto Lake offers sport-fishing opportunities throughout the year and is known for having "an abundance of some of the largest white bass in the world" (USACE). According to the Kansas Department of Wildlife and Parks fish survey, the number of adult fish Captured Per Unit Time Effort (CPUE) shows that White Bass have been increasing, Largemouth Bass fluctuate from year to year and White Crappie have remained somewhat stable. Bottom feeding fish are dominated by variable Gizzard Shad populations and Channel Catfish have been stable.

Figure 18. Toronto Lake Sight-Feeding Fish Stock CPUE.

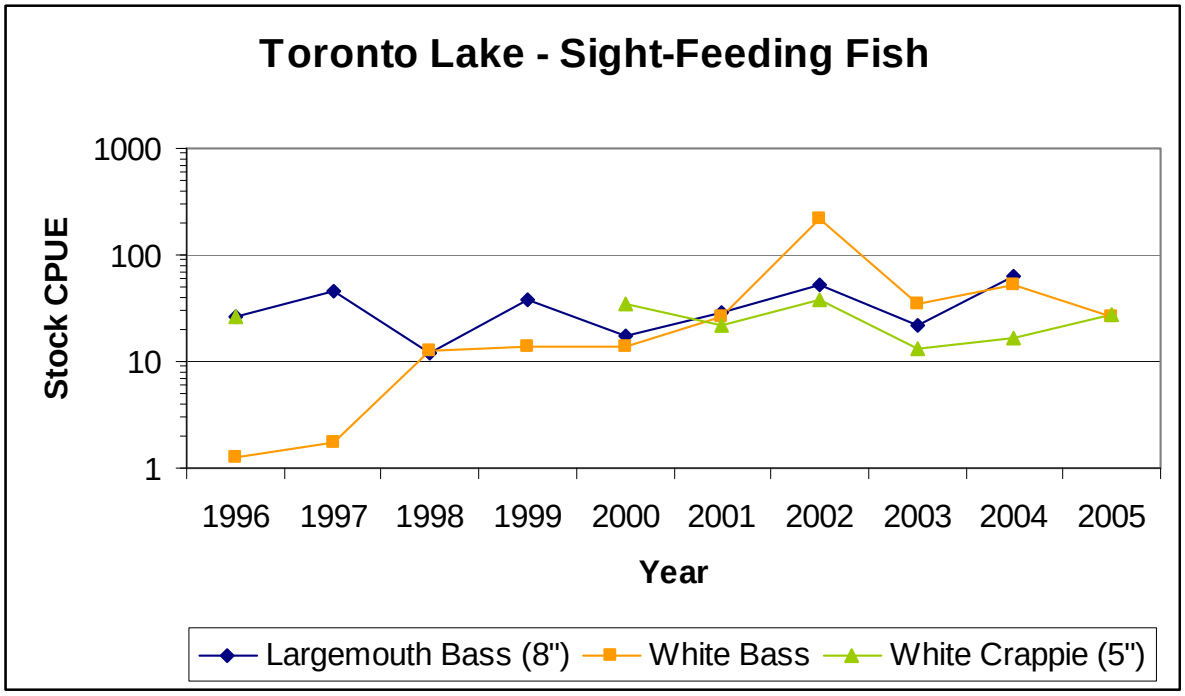


Figure 19. Toronto Lake Bottom-Feeding Fish Stock CPUE.

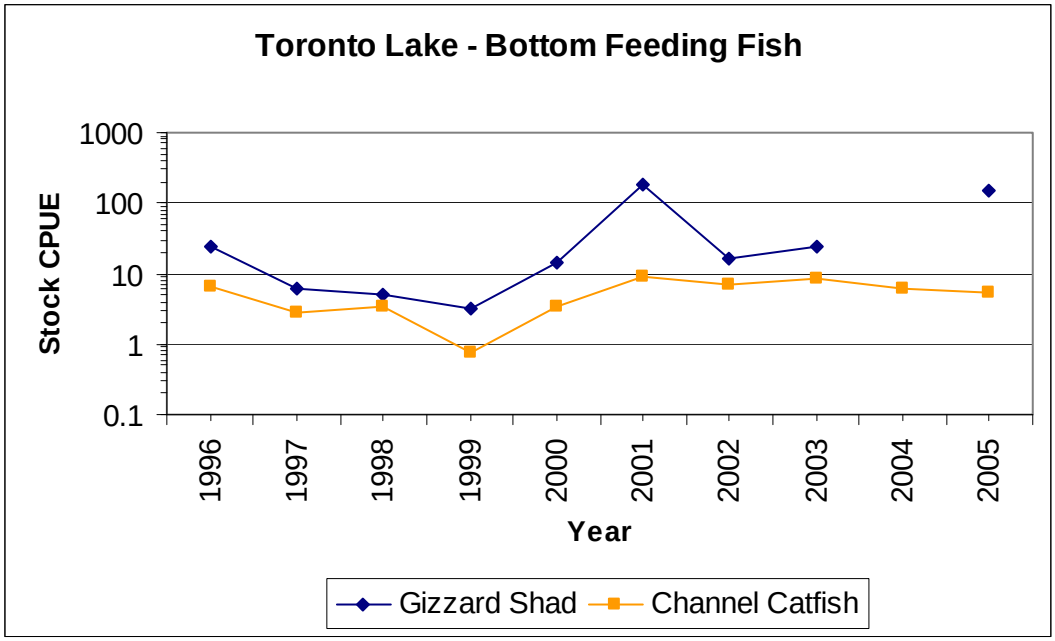
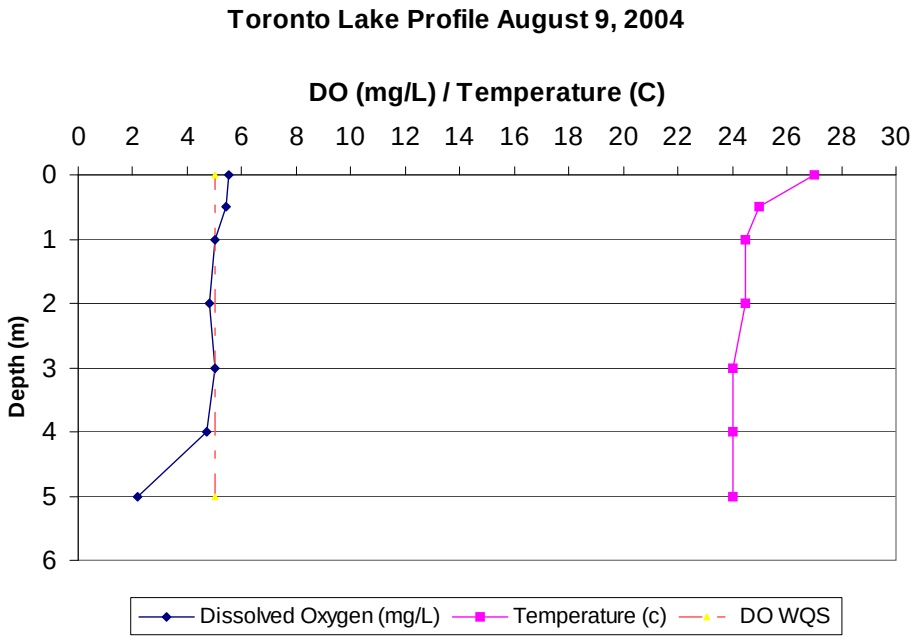


Figure 20. Toronto Lake Dissolved Oxygen and Temperature profile during the August 9, 2004 sampling event.



Dissolved Oxygen: The temperature and dissolved oxygen profile from the 2004 sampling event is illustrated in Figure 20, which indicates Toronto Lake did not stratify. Dissolved Oxygen concentrations significantly drop around the 4-meter range. Temperature readings are generally stable throughout the water column, with the exception of the surface water being slightly warmer from solar radiation. The decomposition of plant material has lowered the dissolved oxygen concentrations toward the lake bottom.

Tables 6 and 7 details the dissolved oxygen (DO) concentrations at various depths throughout the water column in Toronto Lake for each KDHE sampling event. Water quality standard violations for dissolved oxygen were observed in five of the eleven sampling years at 3.0 meters or less. Violations were observed at the 2.0 meter sampling point in 1995, 2004, and 2007 and at the 3.0 meter sampling point in 1989, 1995, 2001, and 2007. The average DO concentration for Toronto Lake ranges from 5.2 at 3.0 meters to 6.83 at the surface. Other than the violations detected in 1989, the DO violations occurred when the water temperature was above the average for the period of record, indicating DO violations may be attributed to warm weather, which supported high microbial respiratory activities in either the water column or sediment.

Table 6. Shallow Dissolved Oxygen Samples (mg/L) by Depth in Toronto Lake.

Date/ Depth	**0.0 m**	**~ 0.5 m**	**~ 1.0 m**	**~ 2.0 m**	**~ 3.0 m**	**All 0-3.0 m**	**Avg. Temp**
6/9/1975	6.0	5.8 (0.3m)	5.9 (0.9m)	5.9 (1.8m)	5.9 (2.7m)	5.9	25
6/5/1978	7.2		6.9 (0.9m)	6.7 (1.8m)	6.4 (2.7m)	6.8	20.25
6/1/1981	7	7 (0.3m)	6.6 (0.9m)	6.6 (1.8m)	6.5 (2.7m)	6.74	21.7
8/19/1986	7.4	6.9	6.8	6.8	6.4	6.86	23.4
6/6/1989	6.7	6.2	6	5.6	*4*	5.7	21.8
8/10/1992	8						
7/31/1995	6.1	6.1	5.8	*4.7*	*2.8*	5.1	28.8
6/22/1998	7.2	7.2	7.2	7.1	7	7.14	26.3
7/23/2001	6.5	6.4	6.5	5.7	*4.8*	5.98	29.3
8/9/2004	5.5	5.4	5	*4.8*	5	5.14	25
9/4/2007	7.5	6.8	5.9	*3.8*	*3.2*	5.44	26.4
Average	**6.83**	**6.42**	**6.26**	**5.77**	**5.2**	**6.08**	**24.6**

Table 7. Deeper Dissolved Oxygen Samples (mg/L) by depth in Toronto Lake.

Date / Depth	~4.0 m	~5.0m	≥6.0m	All > 3.0m
6/9/1975	5.8	5.8	1.26	4.3
6/5/1978	5.8	5	3.54	4.78
6/1/1981	4.9	4.05	2.3	3.74
8/19/1986	6.2	NA	NA	6.2
6/6/1989	4	3.7	1.7	3.13
8/10/1992	NA	NA	NA	NA
7/31/1995	1.8	0.4	NA	1.1
6/22/1998	6.8	2.5	NA	4.65
7/23/2001	2.3	1	NA	1.65
8/9/2004	4.7	2.2	NA	3.45
9/4/2007	2.1	0.7	NA	1.4
Average	**4.4**	**2.8**	**2.2**	**3.4**

Figure 21. Average DO concentrations within the 0-3 meter range and the 2-3 meter range within Toronto Lake.

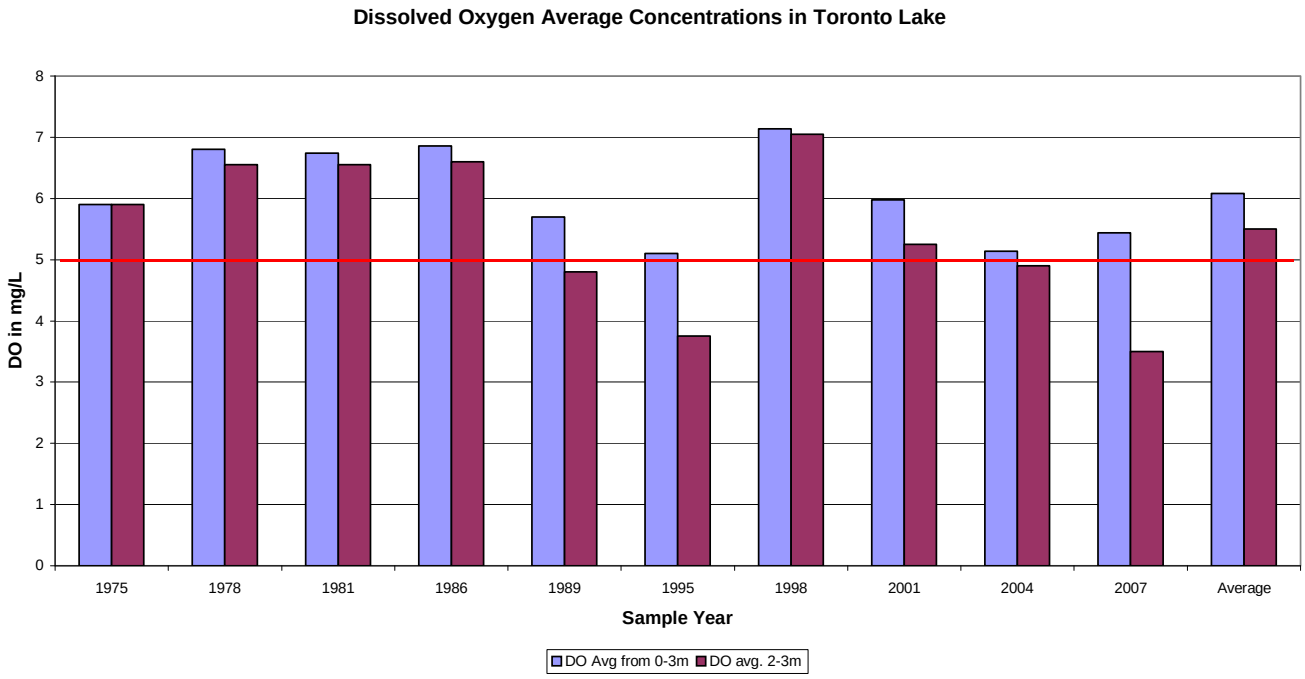
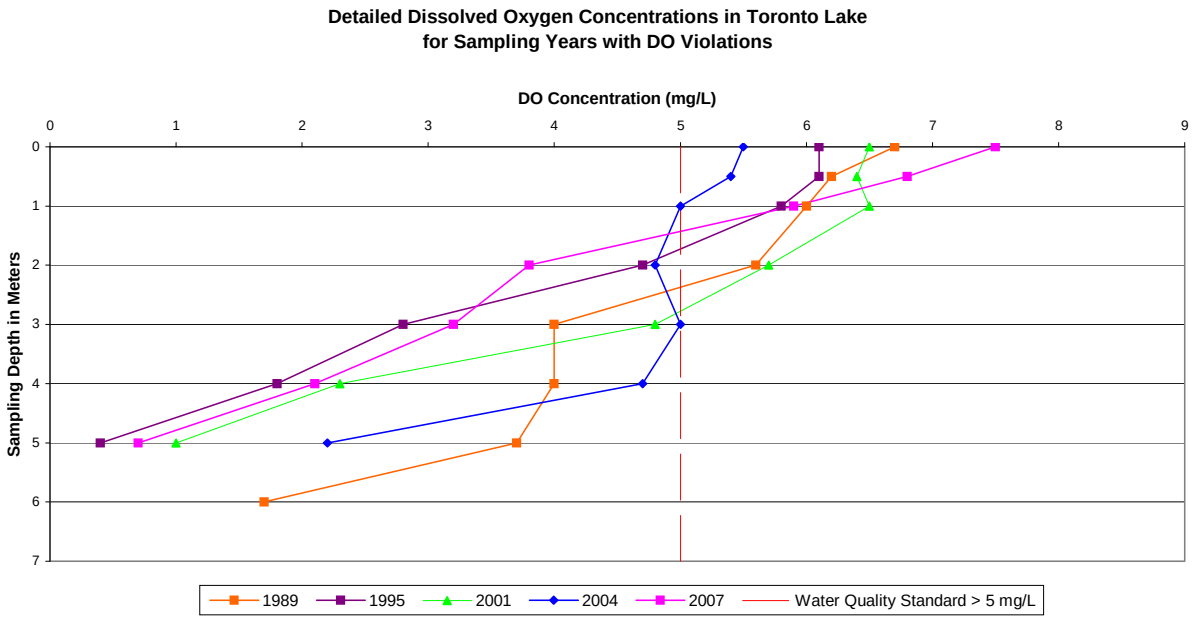


Figure 22. Dissolved Oxygen Concentration profiles for KDHE sampling events that encountered a DO deficiency at <3.0m.



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

In order to improve the trophic condition of Toronto Lake from its Fully Eutrophic status, the desired endpoint will be to maintain summer chlorophyll *a* concentrations below 10 µg/L, with the reductions focused on nutrients (TN and TP) entering the lake. The chlorophyll *a* endpoint of 10 µg/L is the statewide goal for Federal Lakes and lakes serving as Public Water Supplies, which will also ensure long-term protection to fully support Primary Contact Recreation within the lake. In order to improve the quality of the water column and the siltation impairment, the endpoint should also result in an increase in the average transparency of the lake to 0.70 meters, as measured by the secchi disk depth within the main basin of the lake. Finally, DO should exceed 5 mg/L for the entire water column of the lake.

Based on the BATHTUB reservoir eutrophication model (see Appendix A), nutrient concentrations entering the lake via the Verdigris River and Walnut Creek must be reduced by 30%, to achieve a ~29% load reduction for total phosphorus and total nitrogen. The City of Toronto's outfall accounts for the difference between these reduction percentages. The translating concentrations within the main basin of the lake will be reduced by 28% and 23% for total phosphorus and total nitrogen respectively. Achievement of the endpoints indicates loads are within the loading capacity of the lake, the water quality standards are attained, and full support of the designated uses of the lake has been achieved. Seasonal variation has been incorporated in this TMDL since the peaks of algal growth occur in the summer months. The current average condition for Toronto Lake calculated in the model was based on lake data from 1992 through 2007. Tributary data for the water flowing into the lake was averaged from the available data

for KDHE monitoring stations SC289 on the Verdigris River and SC576 on Walnut Creek.

Table 8. Desired water quality endpoint for Toronto Lake.

Parameter	Current Avg. Condition	TMDL	Percent Reduction
TP Annual Load (lbs/year)	71,686	50,585	29.4%
TP Daily Load (lbs/day)*	373.2	263.3	29.4%
TN Annual Load (lbs/year)	691,437	490,450	29.1%
TN Daily Load (lbs/day)*	5077	3601	29.1%
TP Main Basin (µg/L)	73.0	52.4	28%
TN Main Basin (µg/L)	636.0	492.3	23%
Secchi Depth (m)	0.4	> 0.70	75% Increase

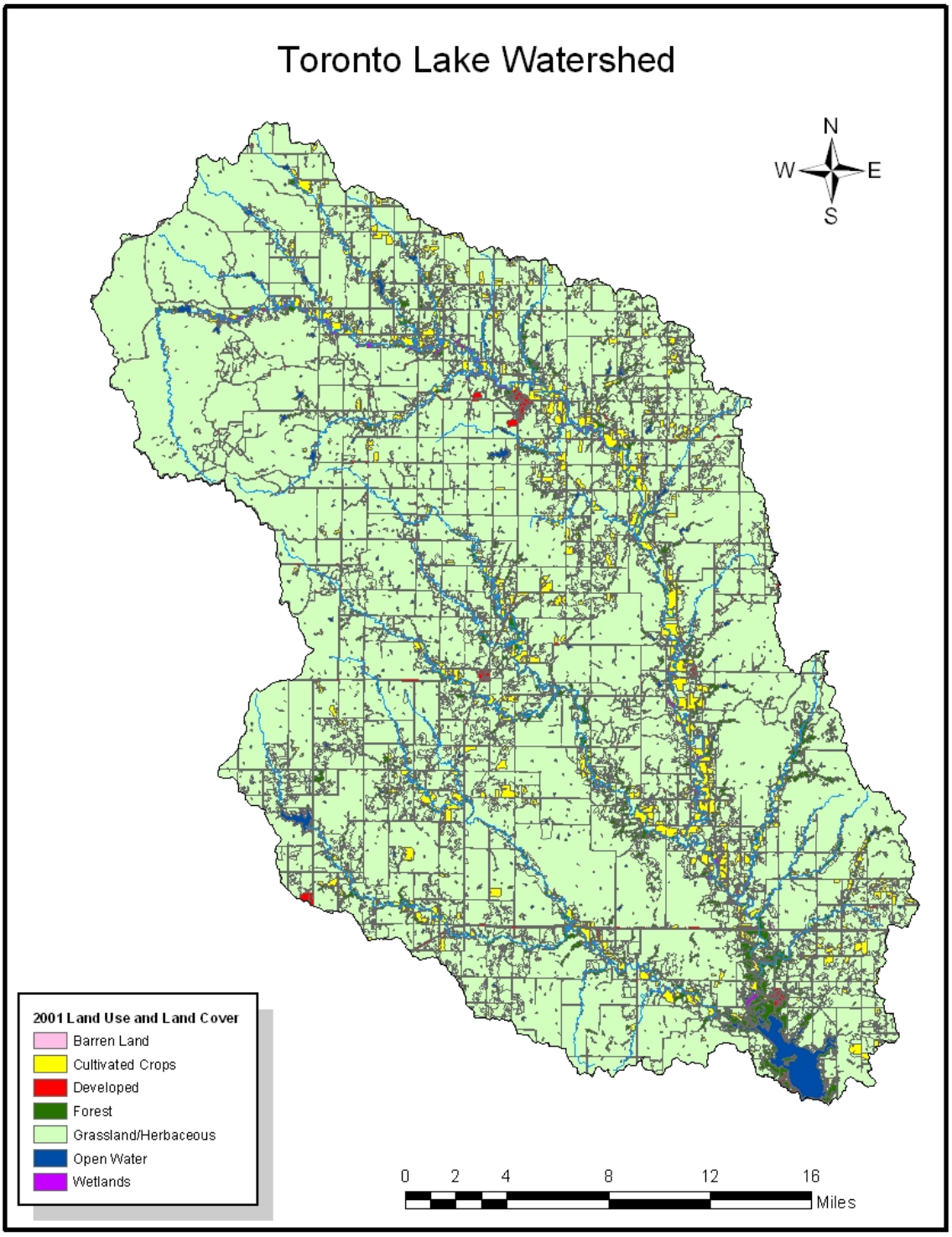
* - See Appendix B for Daily Load Calculations

3. SOURCE INVENTORY AND ASSESSMENT

Land Use: The predominant land cover in the watershed around Toronto Lake includes 70% grassland, 15% pasture, 5% forest, and 4% croplands. The remaining land uses within the watershed contain: 1.3% open water, 4% developed, and less than one percent of wetlands and barren land. The grasslands are the predominant land cover lying within the scenic Flint Hills. As seen in Figure 23, the majority of the pasture and croplands lie within the flood plain of the streams within the watershed.

Livestock Waste Management Systems: There are nine certified confined animal feedlot operations located throughout the watershed, which are all located adjacent to stream corridors. All of these permitted livestock facilities (7 beef, 1 swine, 1 dairy) have waste management systems designed to minimize runoff entering their facility and detain runoff emanating from their operations. In addition, they are designed to retain a 25-year, 24-hour rainfall/runoff event as well as an anticipated two weeks of normal wastewater from their operations. Typically, this rainfall event coincides with streamflow that is less than 1-5% of the time. Though the potential number of animals associated with the certified confined animal feedlot operations is 3,325 head in the watershed, the actual number of animals at the feedlot operations is typically less than the allowable permitted number. However, since the watershed is dominated by grassland and pasture the number of smaller animal feeding operations that are not registered is presumably high, particularly during seasonal feeding months in the winter.

Figure 23. Toronto Lake Watershed land use and land cover map (2001 NLCD).



According to the 2006-2007 Kansas Agricultural Farm Facts, there are 77,000 and 31,600 head of cattle in Greenwood and Woodson Counties respectively. In addition, Greenwood County ranks second in the state for pasture acreage. Grazing densities within the watershed are estimated at approximately 68 head of cattle per square mile. The high percentage of grassland and pasture in the watershed may serve as ideal seasonal grazing lands for livestock during the winter months, which may account for highly variable livestock populations within the watershed from one year to the next.

Table 9. Animal Feeding Operations in the Toronto Lake Watershed.

Permit	*County*	*Type*	*Head*
A-VEGW-BA04	Greenwood	Beef	180
A-VEGW-BA03	Greenwood	Beef	100
A-VEGW-B002	Greenwood	Beef	120
A-VEGWBA02	Greenwood	Beef	900
A-VEGW-BA08	Greenwood	Beef	200
A-VEGW-BA10	Greenwood	Beef	475
A-NEGW-M002	Greenwood	Dairy	400
A-VEGW-SA03	Greenwood	Swine	350
A-VELY-BA01	Lyon	Beef	600

Nutrients within the Toronto Lake watershed may be attributed to fertilizer or manure application to the agricultural lands being utilized for pasture, hay, or cropland production. Of particular concern are lands near the riparian areas that are subject to livestock grazing or watering and fertilizer applications. The animal wastes from both confined and unconfined feeding sites are considered a major potential source of nutrient loading going into Toronto Lake.

NPDES: There are seven permitted waste treatment facilities located within the Toronto Lake watershed. Four of these are non-overflowing facilities that are prohibited from discharging and three are discharging municipal wastewater treatment plants.

The non-overflowing lagoons may contribute to the load under extreme precipitation events, however these events would not occur at a frequency or for a sufficient duration to cause impairment in the watershed. All non-discharging lagoon systems are prohibited by the state from discharging to the surface waters. Under standard conditions of these non-discharging facility permits, when the water level of the lagoon raises to within two feet of the top of the lagoon dikes the permit holder must notify KDHE. Steps may be taken to lower the water level of the lagoon and diminish the probability of a discharge of treated effluent during an extreme wet weather period. A discharge may be allowed if there are no other alternatives and 1) it would be necessary to prevent loss of life, personal injury or severe property damage; 2) excessive stormwater inflow or infiltration would damage the facility; or 3) the permittee has notified KDHE at least seven days before the anticipated discharge. The four non-discharging permits in Table 10 all expire in 2012 and the three discharging permits expire in 2011.

The population within the watershed is approximately 3,687 people according to the 2000 U.S. Census. There are several small towns located within the watershed, which all have either stable or slightly declining populations. The towns and their population estimates are illustrated in Table 11. The population density within the watershed is approximately 5.3 people / square mile. Projections of future water use and resulting wastewater appear to be within design flows for these current system's treatment capacities. However, the City of Hamilton is within 10% of it's operating design flow capacity based on the standard usage of 100 gallons per day (gpd) for each person, and contingencies should be considered and put in place to increase capacity if there is unexpected growth or demand in the near future.

Table 10. NPDES facilities within the Toronto Lake watershed.

Kansas Permit Number	**Facility**	**Type**	**Design Flow (mgd)**
M-VE36-NO02	KDWP- Toronto Point Wastewater Treatment Facility	Two-Cell Lagoon	Non-Discharging
M-VE16-NO02	KDOT- Greenwood County Safety Rest Area	Septic with Filter	Non-Discharging
C-VE36-NO02	Camp Ascension Wastewater Treatment Lagoon	One-Cell Lagoon	Non-Discharging
M-VE38-NO01	City of Virgil Wastewater Treatment Facility	Three-Cell Lagoon	Non-Discharging
M-VE36OO01	City of Toronto Wastewater Treatment Facility	Trickling Filter, UV	0.058
M-VE20-OO01	City of Hamilton Wastewater Treatment Plant	Three-Cell Lagoon	0.035
M-VE26-OO02	City of Madison Wastewater Treatment Facility	Three-Cell Lagoon	0.112

The cities of Madison and Hamilton are required to sample for Biological Oxygen Demand (BOD), Total Suspended Solids (TSS), pH, ammonia, and fecal coliform once quarterly. The BOD limitations for these two permits are to maintain a weekly average of 45 mg/L and a monthly average of 30 mg/L. There are also TSS limitations for both permits, where both permits have a weekly average of 120 mg/L and a monthly average of 80 mg/L within the permit. The City of Madison discharges into the Verdigris River in the upper portion of the watershed, whereas the City of Hamilton discharges into Onion Creek via an unnamed tributary in the central portion of the watershed.

Table 11. Population Estimates for cities within the Toronto Lake watershed (Kansas Water Office, 2002).

City	Population Estimate
Toronto	271
Neal	NA
Quincy	NA
Virgil	78
Hamilton	322
Madison	872
Lamont	NA

The municipal permit for the City of Toronto requires monthly BOD, TSS, pH, ammonia, fecal coliform, e. coli, total phosphorus, nitrate, nitrite, total Kjeldahl nitrogen, total nitrogen and dissolved oxygen monitoring. BOD and TSS limitations are in place and the Toronto facility is not to exceed a weekly average of 45 mg/L and a monthly average of 30 mg/L for both parameters. Ammonia limits for the Toronto permit specify a daily maximum of 9.2 mg/L for all months and monthly averages not to exceed: 7.8 mg/L for January, February, and December; 4.7 mg/L for March and April; 3.7 mg/L for May; 3.0 mg/L for June; 2.3 mg/L for July; 2.4 mg/L for August; 2.8 mg/L for September; 4.5 mg/L for October; and 6.4 mg/L for November. Fecal coliform bacteria limitations for the City of Toronto state the monthly geometric average will not exceed: 200 colonies per 100 ml for the months of April through October and 2000 colonies per 100 ml for the months of November through March. The limitations for e.coli bacteria are also based on the monthly geometric average, which should not exceed: 160 colonies per 100 ml from April through October and 2,358 colonies per 100 ml for the months of November through March. The City of Toronto's effluent is discharged directly to the lake.

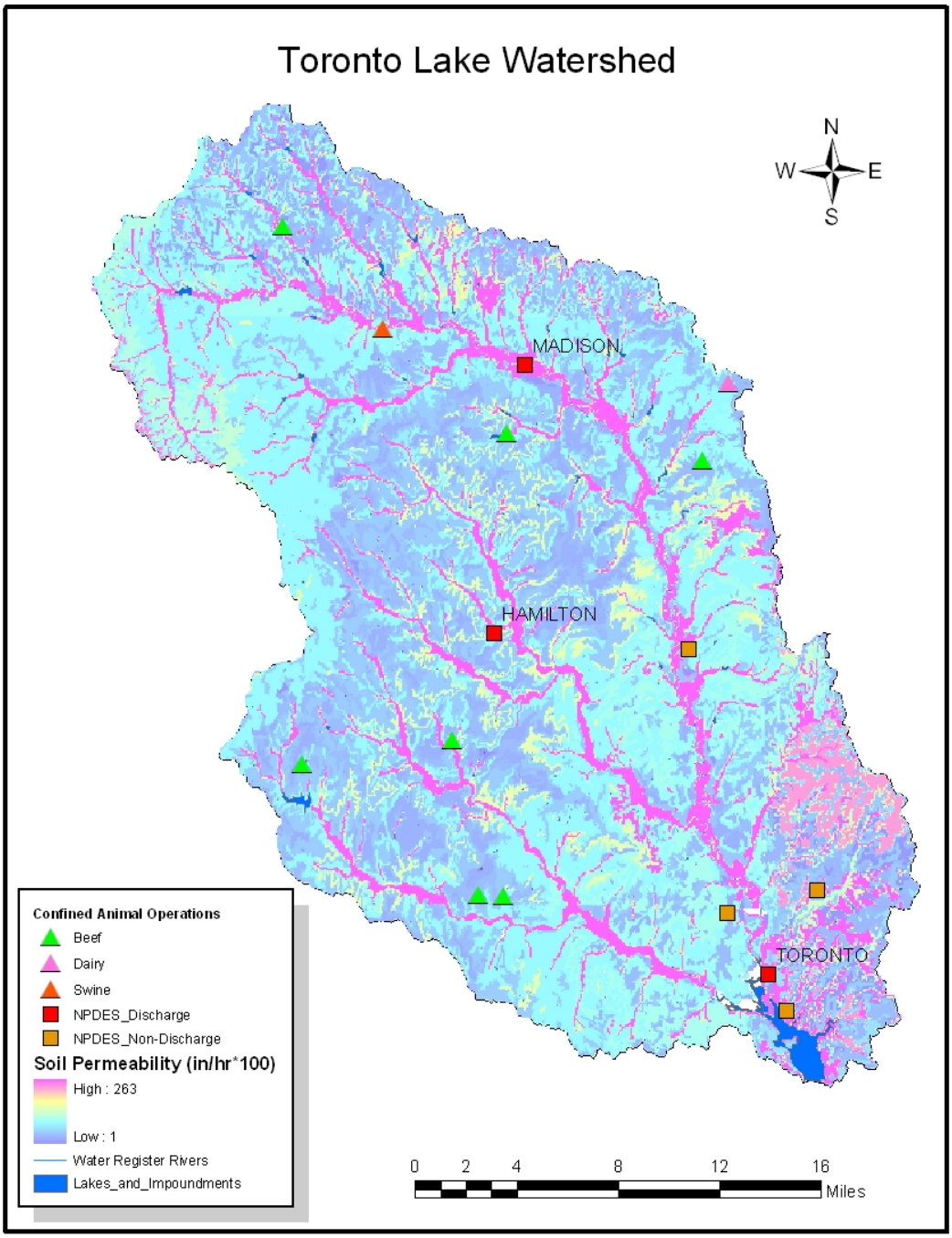
Table 12. City of Toronto Wastewater Treatment Facility's effluent water quality from June 2004 through October 2007.

Parameter	BOD mg/L	DO (mg/L)	FCB (#/100ml)	NH3 (mg/L)	NO2 (mg/L)	NO3 (mg/L)	TN (mg/L)	TKN mg/L	TP (mg/L)	TSS (mg/L)	Flow (mgd)
Average	5.3	8.3	167	1.8	0.74	11.9	15.1	2.5	2.6	5.0	0.026
Median	4.5	8.2	90	0.5	0.15	11.0	14.7	1.2	2.5	3.7	0.020
Maximum	20.6	10.9	2000	12.2	9.52	21.5	27.9	18.2	4.9	20.2	0.111

On-site Waste Systems: One-third of the households in Greenwood County are on septic systems (U.S. Census, 1990). Several of the households within the cities of this watershed and the majority of the rural households within the Toronto Lake watershed are presumably on septic systems. The main concern for failing septic systems is associated with communities surrounding the lake, to include the City of Toronto. Failing septic systems throughout the watershed may account for minor nutrient contributions to the lake, however failing systems in and around the City of Toronto and other residences that surround the lake could contribute moderate amounts of nutrients to the lake and are a concern.

Contributing Runoff: The watershed of Toronto Lake has a mean soil permeability value of 0.43 inches/hour, ranging from 0.01 to 2.63 inches/hour according to the NRCS STATSGO database. About 81% of the watershed has a permeability value less than 0.57 inches/hour, which contributes to runoff during extremely low rainfall intensity events (Juracek, 2000). Runoff is primarily generated as infiltration excess with rainfall intensities greater than soil permeability. As the watersheds' soil profiles become saturated, excess overland flow is produced. As seen in Figure 24, the majority of the nonpoint source nutrient runoff will be contributed to the central portion of the watershed.

Figure 24. Soil permeability with NPDES and CAFO facilities for Toronto watershed.



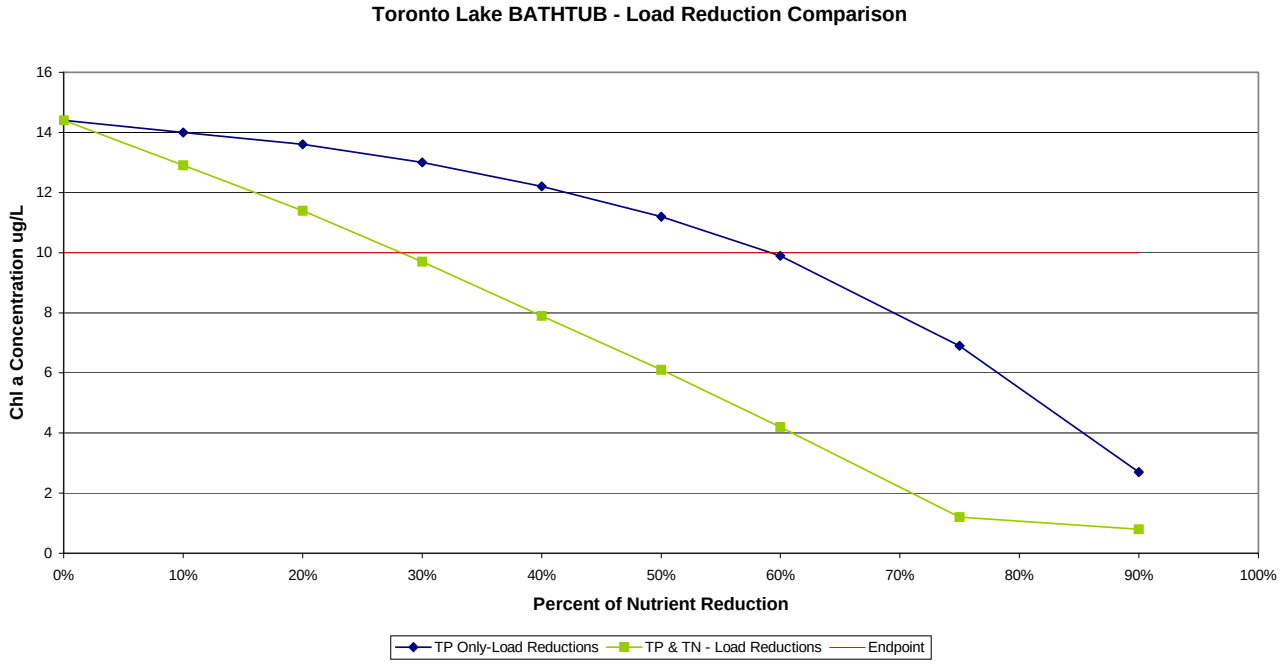
Background: Approximately 5% of the land in the watershed is forest, which is predominantly within the riparian areas of the watershed in accordance with the land cover map (Figure 23). Nutrients released from leaf decomposition and wastes derived from natural wildlife may be contributing to the nutrient load. Atmospheric deposition and seepage from geological formations (i.e., soil and bedrock) may also contribute to the nutrient load. The suspension of sediment and nutrients within the lake may be influenced by the wind. Internal loading is not a factor within Toronto Lake since the lake is so shallow and does not typically stratify as indicated by the temperature profile within the lake. In addition, the dissolved oxygen concentrations at the deeper depths suggest that internal loading is unlikely to occur.

4. ALLOCATION OF POLLUTANT REDUCTION RESPONSIBILITY

Toronto Lake is primarily limited by nitrogen and light availability, with the exception of a few sampling years with co-limiting conditions. Since the years that were co-limited have higher chlorophyll *a* concentrations, both phosphorus and nitrogen allocations will be made under this TMDL. To address the siltation component of this TMDL, load allocations will be made for sediment loading by establishing loads for Total Suspended Solids (TSS) within the watershed.

BATHTUB is an empirical receiving water quality model that was developed by the U.S. Corps of Engineers (Walker, 1996), and has been widely used in the nation to address many TMDLs relating to issues associated with morphometrically complex lakes and reservoirs (Wang et al., 2005). The BATHTUB model was utilized for the eutrophication assessment of Toronto Lake. Toronto Lake was segmented into three sections for the BATHTUB model, which included the upper lake (riverine area), middle lake (transitional area), and the main basin (near dam). Atmospheric total nitrogen was obtained from the Clean Air Status and Trends Network (CASTNET), which is available at www.epa.gov/casnet/site.html. The CASTNET stations from the Konza Prairie (KS) and Cherokee Nation (OK) were averaged to estimate the atmospheric TN concentration for the model. Total phosphorus atmospheric loading was estimated using the 1983 study of Rast and Lee. Water quality data from the main basin segment was averaged using the 1992-2007 data from KDHE. Model input data for the lake inflow tributary was estimated using averages from the KDHE stream chemistry monitoring stations along the Verdigris River (SC289) and West Creek (SC290). Inflow data for the lake was obtained from the USGS mean flow data as indicated in Table 1a along with the City of Toronto's design flow for their discharge since this flows directly into the lake. The BATHTUB model was calibrated for the main basin and results (see Appendix A) estimate that the lake currently retains 21% of the TP and 24% of the TN load annually. Based on modeling results, a 30% reduction of both TP and TN within the inflow of Walnut Creek and the Verdigris River is necessary to achieve the TMDL endpoint of 10 µg/L of Chlorophyll *a* within the main basin of Toronto Lake. As Figure 25 illustrates, if reductions were only applied to TP, a 60% TP reduction would be necessary to meet the TMDL endpoint.

Figure 25. Changes in Chlorophyll *a* levels relation to watershed nutrient reduction.



Point Sources: Wasteload allocations are established for the discharging wastewater treatment facilities permitted within the watershed. These allocations apply to the cities of Toronto, Hamilton, and Madison. The total wasteload allocation for the watershed is set at 1381 pounds per year of total phosphorus and 6289 pounds per year of total nitrogen. The wasteload allocation is based on discharging at design flows with a concentration of 2 mg/L TP and 8 mg/L TN for the cities of Hamilton and Madison. The wasteload allocation (WLA) for the city of Toronto is based on the approximate current average concentrations (TN =15.25 mg/L; TP = 2.75 mg/L) at the design flow. These wastewater treatment plants will comply with any future permit limits for nitrogen and phosphorus.

Table 13. Wasteload Allocations for discharging facilities in the Toronto watershed.

NPDES	**Design Flow (mgd)**	**WLA TP lbs/year**	**WLA TN lbs/year**	**WLA TSS lbs/year**
City of Toronto (trickling filter)	0.058	486	2696	5304
City of Hamilton (lagoon)	0.035	215	855	8546
City of Madison (lagoon)	0.112	682	2738	27,278
Total WLA		**1383**	**6289**	**41,128**

The City of Toronto currently utilizes a trickling filter wastewater treatment system. When this system reaches its mechanical lifespan, the wastewater treatment processes utilized by the City of Toronto will need to be upgraded to accommodate more effective nutrient removal. When the plant is upgraded, the nutrient concentrations of the effluent should be consistent with the goals of the statewide Nutrient Reduction Plan. As table 14 illustrates, the City of Toronto's current and future wasteload allocations do not comprise significant load contributions in comparison to the watershed. Future wasteload allocations for the City of Toronto were based on the assumption that the discharging flow is equal to their current system's design flow and the concentrations for TN and TP are limited to annual averages of 8.0 mg/L and 2.0 mg/L respectively. Since the City of Toronto's wasteload allocation is less than 1% of the total load for both TP and TN, KDHE has determined the economic impact of requiring plant upgrades while the trickling filter system is meeting its designed performance warrants deferral until such time as the system needs an upgrade.

Within the BATHTUB model, the WLA for the Cities of Hamilton and Madison is included within the total load inflowing from the Verdigris River since these facilities discharge further up in the watershed. The calculated WLA for the Cities of Hamilton and Madison is then subtracted out of the BATHTUB output to differentiate between the inflowing load allocation and waste load allocation. The City of Toronto discharges directly to the lake and was therefore setup as a separate tributary within the BATHTUB model.

Table 14. Current and future wasteload allocations for the City of Toronto.

	Toronto WLA	**Other WLA**	**TMDL**	**Toronto's WLA % of Total Load Capacity**
TMDL WLA with current Toronto WWTP				
TN (lbs/year)	2696	3593	490,450	0.55
TP (lbs/year)	486	897	50,585	0.96
Future WLA with new Toronto WWTP				
TN (lbs/year)	1410	3593	489,170	0.29
TP (lbs/year)	352	897	50,450	0.70

To further determine the impact of delaying upgrades to the Toronto facility, the BATHTUB model was utilized to assess the lake response to the two loading scenarios associated with the City of Toronto's allocations within Table 14. The model predicts the chlorophyll *a* concentration within the main basin of the lake will be 9.8 µg/L with the current wasteload allocations (existing Toronto WWTP), whereas the chlorophyll *a* concentration is slightly reduced to 9.7 µg/L when the model is adjusted to reflect a facility upgrade by the City of Toronto (see Appendix A).

The wasteload allocation for total suspended solids (TSS) is 41,128 pounds/year, based on the current monthly average TSS permit limit concentrations that are in place for these facilities.

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

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

Table 15. Toronto Lake TMDL summary for TP and TN.

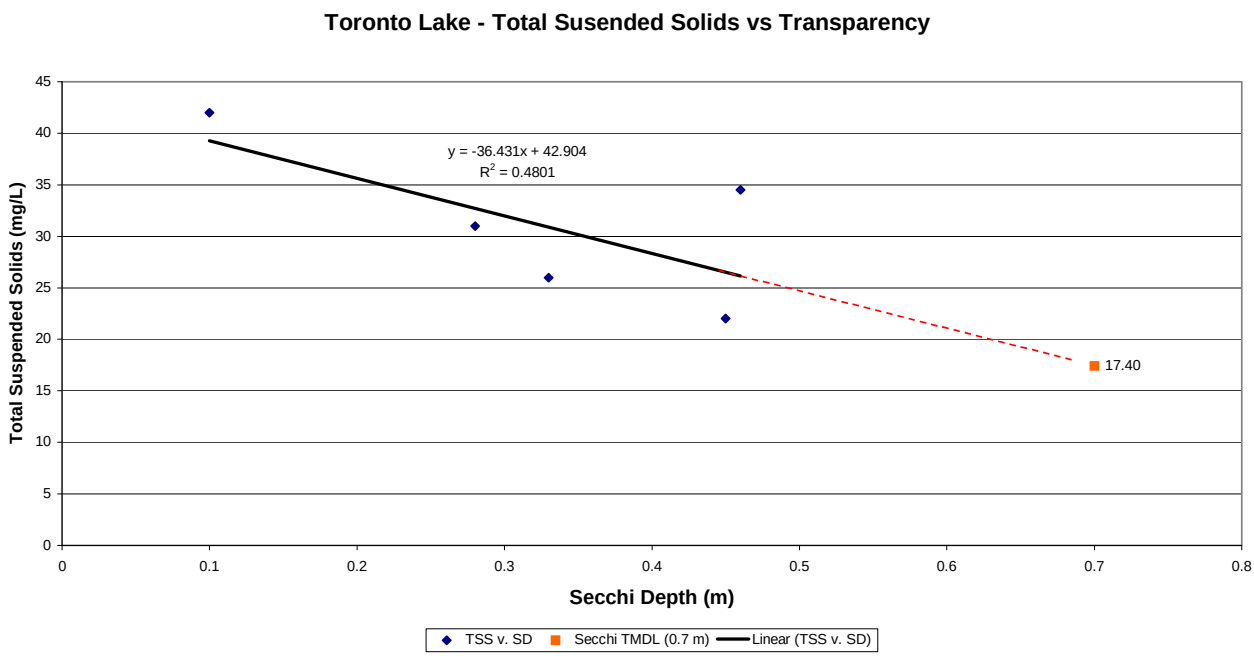
Description	**Allocations (lbs/year)**	**Allocations (lbs/day)***
TP Atmospheric Deposition Load Allocation	230	1.2
TP Nonpoint Source Load Allocation	43,913	228.6
TP Wasteload Allocation	1383	7.2
TP Margin of Safety	5059	26.3
TP TMDL	***50,585***	**263.3**
TN Atmospheric Deposition Load Allocation	15,247	112
TN Nonpoint Source Load Allocation	419,869	3083
TN Wasteload Allocation	6289	46
TN Margin of Safety	49,045	360
TN TMDL	***490,450***	**3601**

*-See Appendix B for Daily Load Calculations

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

As indicated in Figure 26, total suspended solids (TSS) showed a strong relationship with secchi depth. Over the entire period of record, the average TSS and Secchi depth are 30 mg/L and 0.35 m respectively, suggesting that a 42 % TSS reduction is necessary to reach the endpoint, a Secchi depth of 0.70 m.

Figure 26. Relationship between TSS and Secchi depth in Toronto Lake.



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

[Lake Volume (15,734 ac-ft)]*[TSS (30 mg/L)]*[Lake Retention Time (365 days / 21.9 days)]*[Unit Conversion Factors (1,233,482 L/ac-ft)*(2.204 lbs/ 10^6 mg)*(1 ton / 2000 lbs)]

=10,700 tons of TSS (or sediment)

Total amount of sediment exported from the watershed
= 10,700 tons / 0.1 (assumes 90% trapping efficiency)
= 107,000 tons of TSS
= 107,000 tons / 441,598 acres = 0.24 tons / acre

Assuming a 90% trapping efficiency of the lake, the amount of sediment accumulated on the lake bottom annually is 107,000 – 10,700 = 96,300 (tons).

Based on the regression equation developed in Figure 26, the targeted TSS concentration associated with meeting the secchi depth endpoint of 0.7m is 17.4 mg/L of TSS. Therefore the targeted TSS TMDL is calculated as:

0.58 * 107,000 tons/yr = 62,060 tons/yr of TSS following a 42% reduction in TSS

The amount of sediment accumulated on the lake bottom annually is
62,060-6,206= 55,854 tons/yr

Defined Margin of Safety: The margin of safety provides some hedge against the uncertainty of variable annual total phosphorus, total nitrogen, and TSS loads and the chlorophyll *a* endpoint. Therefore, the margin of safety is explicitly set at 10% of the total allocations for total phosphorus, total nitrogen, and TSS, which compensates for the lack of knowledge about the relationship between the allocated loadings and the resulting water quality. The margin of safety for TP and TN is expressed in Table 15, and the margin of safety for TSS is illustrated in Table 16.

Table 16. Toronto Lake TMDL Summary for TSS.

TSS Load	**TSS tons/year**	**TSS tons/day***
Wasteload Allocation	21	0.1
Load Allocation	50248	261.5
Margin of Safety	5585	29.1
TSS TMDL	***55854***	***290.7***

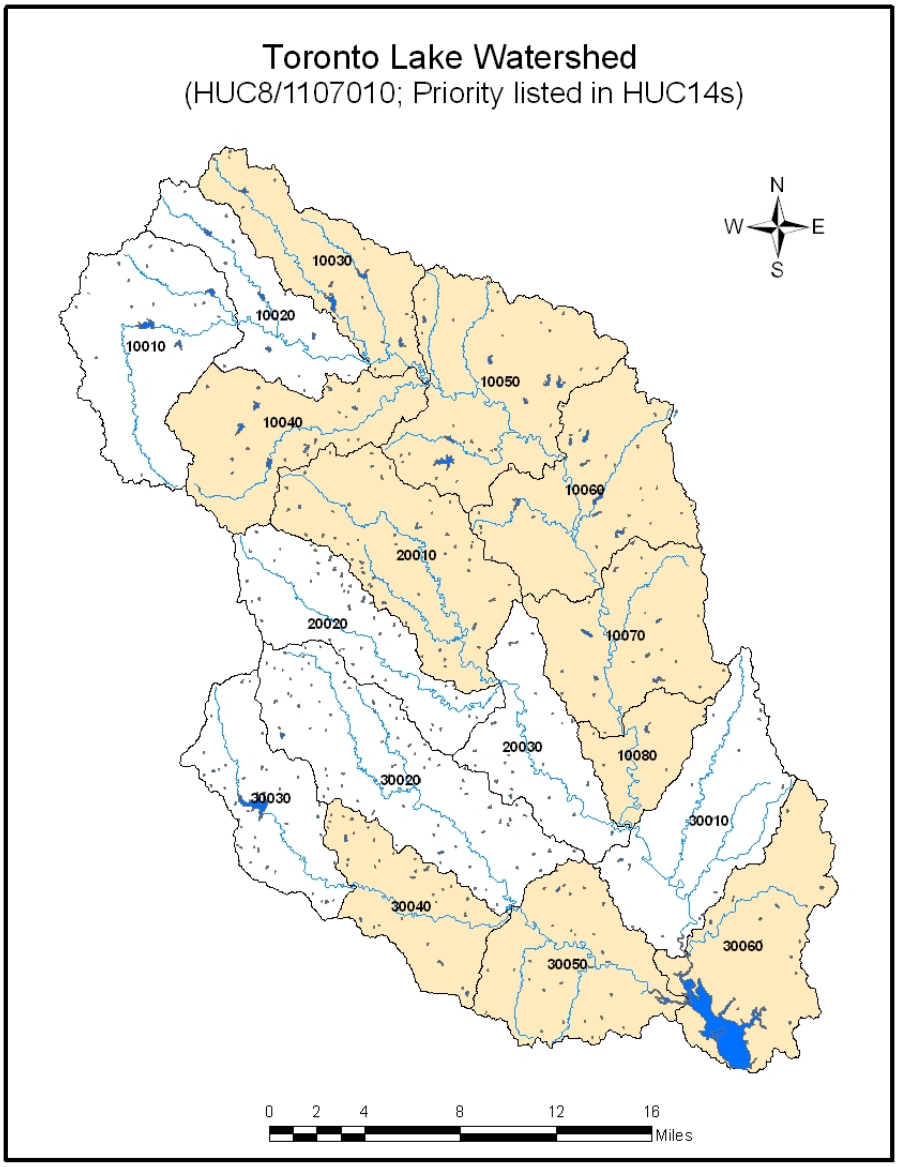
*-See Appendix B for Daily Load Calculations

State Water Plan Implementation Priority: Since Toronto Lake is a federal reservoir with siltation and eutrophication problems accompanied by dissolved oxygen deficiencies, which may contribute to short-term and immediate consequences for aquatic life, this TMDL will be a High Priority for implementation.

Unified Watershed Assessment Priority Ranking: The Toronto Lake watershed lies within the Upper Verdigris Subbasin (HUC 8: 11070101) with a priority ranking of 58 (Low Priority for restoration work).

Priority HUC 11s and 14s: The watershed lies within three HUC 11s: 11070101(010), (020), and (030). The HUC 8 has been modeled using the Spreadsheet Tool For Estimating Pollution Loads (STEPL). Though the modeling results were not utilized for TMDL development, they provide a reasonable estimate for establishing priority areas for implementation within the watershed. The modeling results indicate priority areas for implementation should be focused on areas within HUC 14s: 11070101(010030), (010040), (010050), (010060), (010070), (010080), (020010), (020030), (030040), (030050), and (030060).

Figure 27. High priority HUC 14s in the Toronto Lake Watershed.



5. IMPLEMENTATION

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

1. Implement soil sampling to recommend appropriate fertilizer applications on cultivated croplands.
2. Maintain conservation tillage and contour farming to minimize cropland erosion.

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

Implementation Program Guidance:

NPDES-KDHE

a. Evaluate nutrient loading from all permitted dischargers in the watershed.
b. Work with dischargers to reduce individual loadings.
c. Work with the City of Toronto to ensure statewide nutrient reduction goals are met in the future when the current WWTP is upgraded.

Watershed Management Program – KDHE

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

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

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

Riparian Protection Program – SCC

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

Buffer Initiative Program – SCC

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

Extension Outreach and Technical Assistance – Kansas State University

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

Time Frame for Implementation: Initial implementation will proceed over the years from 2008-2015. Additional implementation may be required over 2016-2018 to achieve the endpoints of this TMDL.

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

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

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

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

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

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

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

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

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

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

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

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

8. The *Kansas Water Plan* and the Verdigris Basin Plan provide the guidance to state agencies to coordinate programs intent on protecting water quality and to

target those programs to geographic areas of the state for high priority in implementation.

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

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

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

6. MONITORING

KDHE will continue its 3-year sampling schedule in order to assess the trophic state of Toronto Lake. Based on the sampling results, the improved state of the lake will be evaluated in 2016. Should impairment status continue, the desired endpoints under this TMDL will be refined and more intensive sampling will be conducted over the period 2016-2018 to assess progress in this implementation.

7. FEEDBACK

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

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

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

Milestone Evaluation: In 2013, evaluation will be made as to implementation of management practices to minimize the nonpoint source runoff contributing to this impairment. Subsequent decisions will be made regarding the implementation approach, priority of allotting resources for implementation and the need for additional or follow up implementation in this watershed at the next TMDL cycle for this basin in 2013 with consultation from the Verdigris Basin WRAPS teams.

Consideration for 303(d) Delisting: Toronto Lake will be evaluated for delisting under Section 303(d), based on the monitoring data over 2008-2015. Therefore, the decision for delisting will come about in the preparation of the 2016-303(d) list. Should modifications be made to the applicable water quality criteria during the implementation period, consideration for delisting, desired endpoints of this TMDL and implementation activities might be adjusted accordingly.

Incorporation into Continuing Planning Process, Water Quality Management Plan and the Kansas Water Planning Process: Under the current version of the Continuing Planning Process, the next anticipated revision would come in 2008, which will emphasize implementation of WRAPS activities. At that time, incorporation of this TMDL will be made into the WRAPS. Recommendations of this TMDL will be considered in the *Kansas Water Plan* implementation decisions under the State Water Planning Process for Fiscal Years 2008-2015.

Developed April 15, 2009

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Appendix A – BATHTUB Model Summary

Input Files – Current Condition

Global Variables	Mean	CV
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.98	0.2
Evaporation (m)	1.3081	0.3
Storage Increase (m)	0	0.0

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

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

Segment Morphometry

		Outflow		Area	Depth	Length	Mixed Depth (m)		Hypol Depth		Non-Algal Turb (m^{-1})		Internal Loads (mg/m2-day) Conserv.		Total P		Total N	
Seg	Name	Segment	Group	km^2	m	km	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Upper Pool	2	1	2.74	1.5	2	1.5	0.12	0	0	2.9	0.2	0	0	0	0	0	0
2	Mid Pool	3	1	4.22	1.75	1.733	1.75	0.12	0	0	2.6	0.2	0	0	0	0	0	0
3	Near Dam	0	1	3.44	2.1	1.96	2.1	0.12	0	0	2.29	0.2	0	0	0	0	0	0

Segment Observed Water Quality

	Conserv		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	73	0.3	636	0.5	14.1	0.3	0.4	0.25	489	0.7	37.3	0.5	0	0	0	0

Segment Calibration Factors

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

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	Verdigris River	1	1	1305	272	0.1	0	0	86	0.5	850	0.5	10	0.5	340	0.5
2	Walnut Cr	1	1	500	97	0.1	0	0	92	0.2	773	0	20	0	170	0
3	Toronto WWTP	1	3	0	0.035	0	0	0	2750	0	15250	0	250	0	14450	0

Model Coefficients	Mean	CV
Dispersion Rate	1.000	0.70
Total Phosphorus	0.600	0.45
Total Nitrogen	2.500	0.55
Chl-a Model	1.411	0.26
Secchi Model	1.050	0.10
Organic N Model	0.800	0.12
TP-OP Model	0.600	0.15
HODv Model	1.000	0.15
MODv Model	1.000	0.22
Secchi/Chla Slope (m^2/mg)	0.025	0.00
Minimum Qs (m/yr)	0.100	0.00
Chl-a Flushing Term	1.000	0.00
Chl-a Temporal CV	0.620	0
Avail. Factor - Total P	0.330	0
Avail. Factor - Ortho P	1.930	0
Avail. Factor - Total N	0.590	0
Avail. Factor - Inorganic N	0.790	0

Model Output – Current Condition
Predicted vs. Observed

Toronto Lake Main Basin

Segment:	**3**	**Near Dam**				
	Predicted Values--->			**Observed Values--->**		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	70.2	0.31	66.5%	73.0	0.30	68.0%
TOTAL N MG/M3	653.3	0.31	25.2%	636.0	0.50	23.9%
C.NUTRIENT MG/M3	36.0	0.31	50.4%	35.4	0.43	49.6%
CHL-A MG/M3	14.4	0.43	71.1%	14.1	0.30	70.1%
SECCHI M	0.4	0.19	9.4%	0.4	0.25	9.6%
ORGANIC N MG/M3	526.2	0.24	58.1%	469.0	0.70	49.2%
TP-ORTHO-P MG/M3	45.5	0.23	66.9%	37.3	0.50	59.1%
ANTILOG PC-1	520.7	0.49	71.8%	486.9	0.41	70.0%
ANTILOG PC-2	4.4	0.30	24.2%	4.3	0.30	22.8%
(N - 150) / P	7.2	0.51	10.2%	6.7	0.72	8.4%
INORGANIC N / P	5.1	1.69	3.9%	4.7	2.85	3.1%
TURBIDITY 1/M	2.3	0.20	93.4%	2.3	0.20	93.4%
ZMIX * TURBIDITY	4.8	0.23	70.7%	4.8	0.23	70.7%
ZMIX / SECCHI	5.3	0.22	57.2%	5.2	0.27	56.5%
CHL-A * SECCHI	5.7	0.45	20.6%	5.6	0.39	20.1%
CHL-A / TOTAL P	0.2	0.48	52.8%	0.2	0.42	49.1%
FREQ(CHL-a>10) %	61.0	0.43	71.1%	59.7	0.31	70.1%
FREQ(CHL-a>20) %	20.0	0.97	71.1%	19.1	0.69	70.1%
FREQ(CHL-a>30) %	6.8	1.35	71.1%	6.3	0.97	70.1%
FREQ(CHL-a>40) %	2.5	1.64	71.1%	2.3	1.18	70.1%
FREQ(CHL-a>50) %	1.0	1.88	71.1%	0.9	1.35	70.1%
FREQ(CHL-a>60) %	0.5	2.08	71.1%	0.4	1.50	70.1%
CARLSON TSI-P	65.5	0.07	66.5%	66.0	0.06	68.0%
CARLSON TSI-CHLA	56.8	0.07	71.1%	56.6	0.05	70.1%
CARLSON TSI-SEC	73.3	0.04	90.6%	73.2	0.05	90.4%

Model Output – Current Condition
Overall Water and Nutrient Balances

Overall Water & Nutrient Balances

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

Trb	Type	Seq	Name	Area km^2	Flow hm^3/yr	Variance (hm3/yr)^2	CV -	Runoff m/yr
1	1	1	Verdigris River	1305.0	272.0	7.40E+02	0.10	0.21
2	1	1	Walnut Cr	500.0	97.0	9.41E+01	0.10	0.19
3	3	1	Toronto WWTP		0.0	0.00E+00	0.00	
PRECIPITATION				10.4	10.2	4.16E+00	0.20	0.98
TRIBUTARY INFLOW				1805.0	369.0	8.34E+02	0.08	0.20
POINT-SOURCE INFLOW					0.0	0.00E+00	0.00	
***TOTAL INFLOW				1815.4	379.2	8.38E+02	0.08	0.21
ADVECTIVE OUTFLOW				1815.4	365.6	8.55E+02	0.08	0.20
***TOTAL OUTFLOW				1815.4	365.6	8.55E+02	0.08	0.20
***EVAPORATION					13.6	1.67E+01	0.30	

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

Trb	Type	Seq	Name	Load kg/yr	%Total	Load Variance (kg/yr)^2	%Total	CV	Conc mg/m^3	Export kg/km^2/yr
1	1	1	Verdigris River	23392.0	71.9%	1.42E+08	97.3%	0.51	86.0	17.9
2	1	1	Walnut Cr	8924.0	27.4%	3.98E+06	2.7%	0.22	92.0	17.8
3	3	1	Toronto WWTP	96.3	0.3%	0.00E+00		0.00	2750.0	
PRECIPITATION				104.0	0.3%	1.08E+02	0.0%	0.10	10.2	10.0
TRIBUTARY INFLOW				32316.0	99.4%	1.46E+08	100.0%	0.37	87.6	17.9
POINT-SOURCE INFLOW				96.3	0.3%	0.00E+00		0.00	2750.0	
***TOTAL INFLOW				32516.3	100.0%	1.46E+08	100.0%	0.37	85.7	17.9
ADVECTIVE OUTFLOW				25673.4	79.0%	6.82E+07		0.32	70.2	14.1
***TOTAL OUTFLOW				25673.4	79.0%	6.82E+07		0.32	70.2	14.1
***RETENTION				6842.9	21.0%	2.12E+07		0.67		

Overflow Rate (m/yr)	35.2	Nutrient Resid. Time (yrs)	0.0405
Hydraulic Resid. Time (yrs)	0.0512	Turnover Ratio	24.7
Reservoir Conc (mg/m3)	70	Retention Coef.	0.210

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

Trb	Type	Seq	Name	Load kg/yr	%Total	Load Variance (kg/yr)^2	%Total	CV	Conc mg/m^3	Export kg/km^2/yr
1	1	1	Verdigris River	231200.0	73.7%	1.39E+10	99.6%	0.51	850.0	177.2
2	1	1	Walnut Cr	74981.0	23.9%	5.62E+07	0.4%	0.10	773.0	150.0
3	3	1	Toronto WWTP	533.8	0.2%	0.00E+00		0.00	15250.0	
PRECIPITATION				6916.0	2.2%	9.37E+05	0.0%	0.14	678.6	665.0
TRIBUTARY INFLOW				306181.0	97.6%	1.40E+10	100.0%	0.39	829.8	169.6
POINT-SOURCE INFLOW				533.8	0.2%	0.00E+00		0.00	15250.0	
***TOTAL INFLOW				313630.8	100.0%	1.40E+10	100.0%	0.38	827.0	172.8
ADVECTIVE OUTFLOW				238871.3	76.2%	6.12E+09		0.33	653.3	131.6
***TOTAL OUTFLOW				238871.3	76.2%	6.12E+09		0.33	653.3	131.6
***RETENTION				74759.5	23.8%	2.63E+09		0.69		

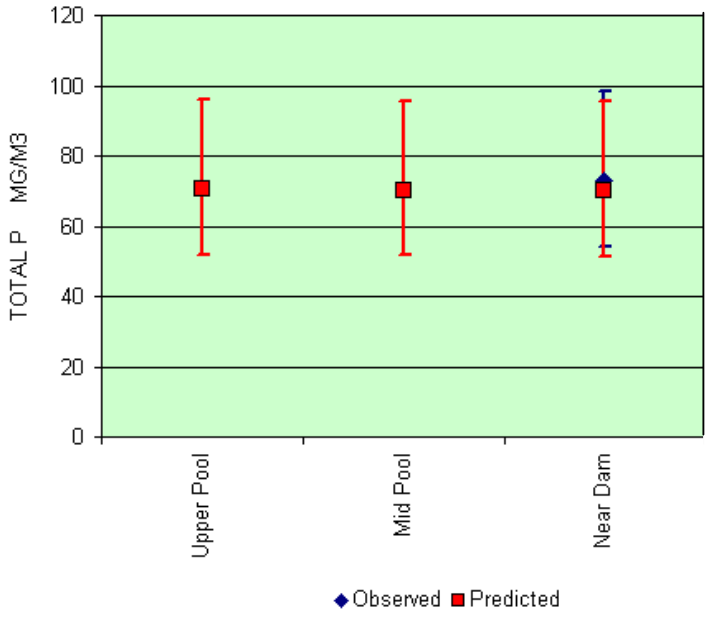
Overflow Rate (m/yr)	35.2	Nutrient Resid. Time (yrs)	0.0390
Hydraulic Resid. Time (yrs)	0.0512	Turnover Ratio	25.6
Reservoir Conc (mg/m3)	654	Retention Coef.	0.238

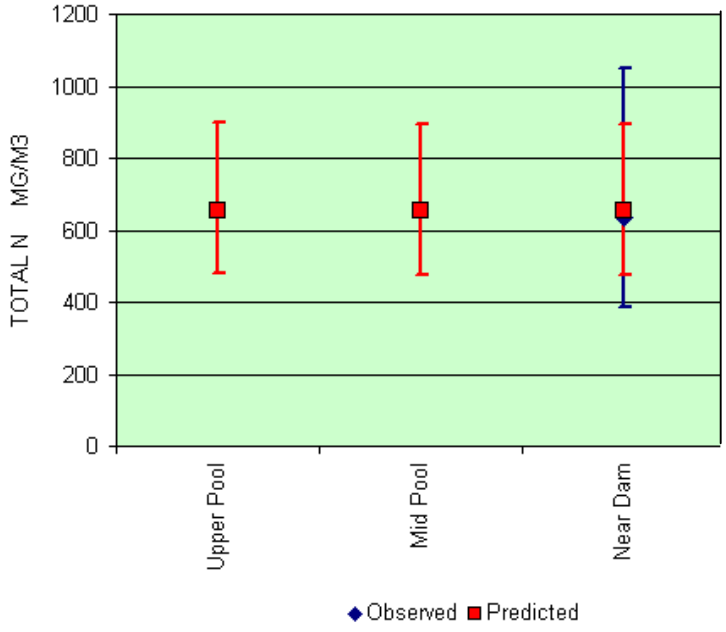
Goodness of Fit (Calibration/Validation)

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

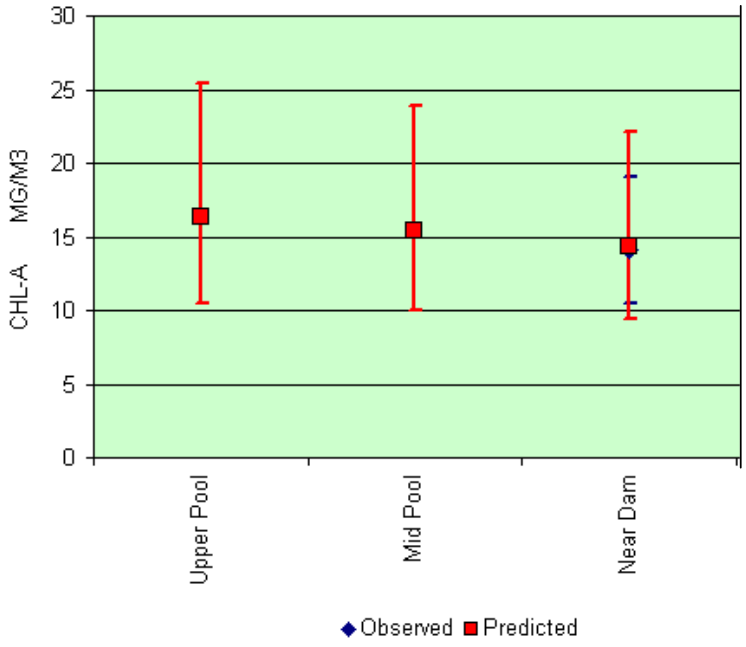
The BATHTUB model was calibrated for the main basin (Toronto Lake) and calibrated for TP, TN, Chlorophyll *a*, and Secchi Depth. The appropriate model options within BATHTUB were selected and the calibration factors were adjusted to calibrate the simulated values closer to the observed values (for the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

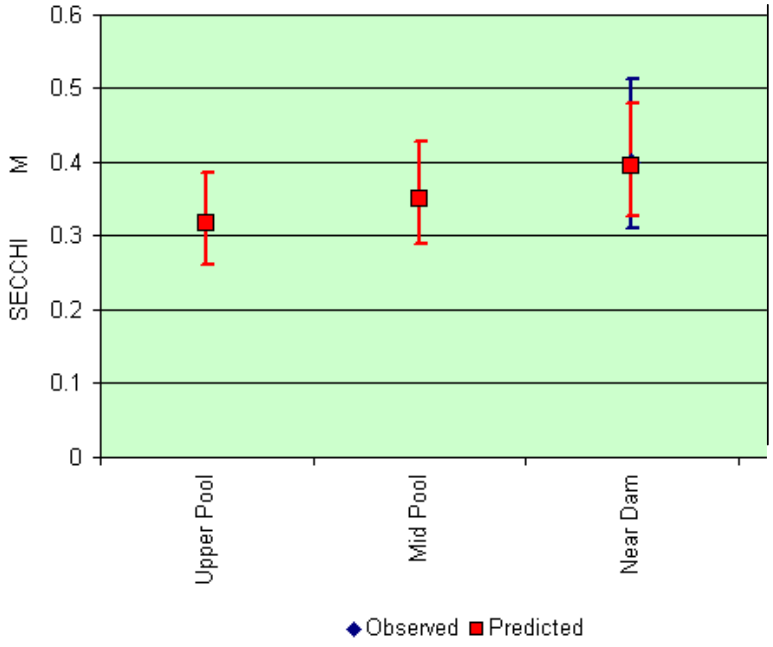
Toronto Lake BATHTUB Modeling Results: Error bar plots (mean ± standard deviation of TN < TP, Chla, Secchi depth parameters estimated by BATHTUB model.





Toronto Lake





Input File - TMDL with 30% TP and TN Concentration Reductions at Inflow with Toronto WWTP at design flow

Global Variables	Mean	CV
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.98	0.2
Evaporation (m)	1.3081	0.3
Storage Increase (m)	0	0.0

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

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

Segment Morphometry

		Outflow		Area	Depth	Length	Mixed Depth (m)		Hypol Depth		Non-Algal Turb (m^{-1})		Internal Loads (mg/m2-day) Conserv.		Total P		Total N	
Seg	Name	Segment	Group	km^2	m	km	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Upper Pool	2	1	2.74	1.5	2	1.5	0.12	0	0	2.9	0.2	0	0	0	0	0	0
2	Mid Pool	3	1	4.22	1.75	1.733	1.75	0.12	0	0	2.6	0.2	0	0	0	0	0	0
3	Near Dam	0	1	3.44	2.1	1.96	2.1	0.12	0	0	2.29	0.2	0	0	0	0	0	0

Segment Observed Water Quality

	Conserv		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	73	0.3	636	0.5	14.1	0.3	0.4	0.25	469	0.7	37.3	0.5	0	0	0	0

Segment Calibration Factors

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

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	Verdigris River	1	1	1305	272	0.1	0	0	60.2	0.5	595	0.5	7	0.5	238	0.5
2	Walnut Cr	1	1	500	97	0.1	0	0	64.4	0.2	541.1	0	14	0	119	0
3	Toronto WWTP	1	3	0	0.0801	0	0	0	2750	0	15250	0	250	0	14450	0

Model Coefficients	Mean	CV
Dispersion Rate	1.000	0.70
Total Phosphorus	0.600	0.45
Total Nitrogen	2.500	0.55
Chl-a Model	1.411	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

Output File - TMDL with 30% TP and TN Concentration Reductions at Inflow with Toronto WWTP at design flow (Predicted)

Predicted vs. Observed for Main Basin

Segment:	**3**	**Near Dam**				
	Predicted Values--->			**Observed Values--->**		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	52.4	0.32	53.9%	73.0	0.30	68.0%
TOTAL N MG/M3	492.3	0.32	13.3%	636.0	0.50	23.9%
C.NUTRIENT MG/M3	25.1	0.36	32.9%	35.4	0.43	49.6%
CHL-A MG/M3	9.8	0.49	52.1%	14.1	0.30	70.1%
SECCHI M	0.4	0.20	9.3%	0.4	0.25	9.6%
ORGANIC N MG/M3	552.2	0.23	61.8%	469.0	0.70	49.2%
TP-ORTHO-P MG/M3	67.6	0.24	80.4%	37.3	0.50	59.1%
ANTILOG PC-1	346.6	0.55	60.4%	486.9	0.41	70.0%
ANTILOG PC-2	3.7	0.33	14.5%	4.3	0.30	22.8%
(N - 150) / P	6.5	0.55	8.0%	6.7	0.72	8.4%
INORGANIC N / P	1.0		0.0%	4.7	2.85	3.1%
TURBIDITY 1/M	2.3	0.20	93.4%	2.3	0.20	93.4%
ZMIX * TURBIDITY	4.8	0.23	70.7%	4.8	0.23	70.7%
ZMIX / SECCHI	5.3	0.23	57.5%	5.2	0.27	56.5%
CHL-A * SECCHI	3.9	0.52	8.5%	5.6	0.39	20.1%
CHL-A / TOTAL P	0.2	0.54	46.9%	0.2	0.42	49.1%
FREQ(CHL-a>10) %	36.4	0.81	52.1%	59.7	0.31	70.1%
FREQ(CHL-a>20) %	7.1	1.53	52.1%	19.1	0.69	70.1%
FREQ(CHL-a>30) %	1.7	2.01	52.1%	6.3	0.97	70.1%
FREQ(CHL-a>40) %	0.5	2.37	52.1%	2.3	1.18	70.1%
FREQ(CHL-a>50) %	0.2	2.66	52.1%	0.9	1.35	70.1%
FREQ(CHL-a>60) %	0.1	2.90	52.1%	0.4	1.50	70.1%
CARLSON TSI-P	61.2	0.07	53.9%	66.0	0.06	68.0%
CARLSON TSI-CHLA	53.0	0.09	52.1%	56.6	0.05	70.1%
CARLSON TSI-SEC	73.4	0.04	90.7%	73.2	0.05	90.4%

Output File - TMDL with 30% TP and TN Concentration Reductions at Inflow with Toronto WWTP at design flow
Overall Water and Nutrient Balances

Overall Water & Nutrient Balances

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

Trb	Type	Seq	Name	Area km^2	Flow hm^3/yr	Variance (hm3/yr)^2	CV -	Runoff m/yr
1	1	1	Verdigris River	1305.0	272.0	7.40E+02	0.10	0.21
2	1	1	Walnut Cr	500.0	97.0	9.41E+01	0.10	0.19
3	3	1	Toronto WWTP		0.1	0.00E+00	0.00	
PRECIPITATION				10.4	10.2	4.16E+00	0.20	0.98
TRIBUTARY INFLOW				1805.0	369.0	8.34E+02	0.08	0.20
POINT-SOURCE INFLOW					0.1	0.00E+00	0.00	
***TOTAL INFLOW				1815.4	379.3	8.38E+02	0.08	0.21
ADVECTIVE OUTFLOW				1815.4	365.7	8.55E+02	0.08	0.20
***TOTAL OUTFLOW				1815.4	365.7	8.55E+02	0.08	0.20
***EVAPORATION					13.6	1.67E+01	0.30	

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

Trb	Type	Seq	Name	Predicted Load kg/yr	%Total	Load Variance (kg/yr)^2	%Total	CV	Conc mg/m^3	Export kg/km^2/yr
1	1	1	Verdigris River	16374.4	71.4%	6.97E+07	97.3%	0.51	60.2	12.5
2	1	1	Walnut Cr	6246.8	27.2%	1.95E+06	2.7%	0.22	64.4	12.5
3	3	1	Toronto WWTP	220.3	1.0%	0.00E+00		0.00	2750.0	
PRECIPITATION				104.0	0.5%	1.08E+02	0.0%	0.10	10.2	10.0
TRIBUTARY INFLOW				22621.2	98.6%	7.17E+07	100.0%	0.37	61.3	12.5
POINT-SOURCE INFLOW				220.3	1.0%	0.00E+00		0.00	2750.0	
***TOTAL INFLOW				22945.5	100.0%	7.17E+07	100.0%	0.37	60.5	12.6
ADVECTIVE OUTFLOW				19143.7	83.4%	3.91E+07		0.33	52.4	10.5
***TOTAL OUTFLOW				19143.7	83.4%	3.91E+07		0.33	52.4	10.5
***RETENTION				3801.8	16.6%	7.11E+06		0.70		

Overflow Rate (m/yr)	35.2	Nutrient Resid. Time (yrs)	0.0427
Hydraulic Resid. Time (yrs)	0.0512	Turnover Ratio	23.4
Reservoir Conc (mg/m3)	52	Retention Coef.	0.166

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

Trb	Type	Seq	Name	Predicted Load kg/yr	%Total	Load Variance (kg/yr)^2	%Total	CV	Conc mg/m^3	Export kg/km^2/yr
1	1	1	Verdigris River	161840.0	72.7%	6.81E+09	99.6%	0.51	595.0	124.0
2	1	1	Walnut Cr	52486.7	23.6%	2.75E+07	0.4%	0.10	541.1	105.0
3	3	1	Toronto WWTP	1221.5	0.5%	0.00E+00		0.00	15250.0	
PRECIPITATION				6916.0	3.1%	9.37E+05	0.0%	0.14	678.6	665.0
TRIBUTARY INFLOW				214326.7	96.3%	6.84E+09	100.0%	0.39	580.8	118.7
POINT-SOURCE INFLOW				1221.5	0.5%	0.00E+00		0.00	15250.0	
***TOTAL INFLOW				222464.2	100.0%	6.84E+09	100.0%	0.37	586.6	122.5
ADVECTIVE OUTFLOW				180036.3	80.9%	3.50E+09		0.33	492.3	99.2
***TOTAL OUTFLOW				180036.3	80.9%	3.50E+09		0.33	492.3	99.2
***RETENTION				42428.0	19.1%	9.29E+08		0.72		

Overflow Rate (m/yr)	35.2	Nutrient Resid. Time (yrs)	0.0415
Hydraulic Resid. Time (yrs)	0.0512	Turnover Ratio	24.1
Reservoir Conc (mg/m3)	493	Retention Coef.	0.191

Input File – **Future TMDL** with 30% TP and TN Concentration Reductions at Inflow; with Upgraded Toronto WWTP at current design flow; with nutrient reduction.

Global Variables	Mean	CV
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.98	0.2
Evaporation (m)	1.3081	0.3
Storage Increase (m)	0	0.0

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

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

Segment Morphometry

		Outflow		Area	Depth	Length	Mixed Depth (m)		Hypol Depth		Non-Algal Turb (m^{-1})		Internal Loads (mg/m2-day) Conserv.		Total P		Total N	
Seg	Name	Segment	Group	km^2	m	km	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Upper Pool	2	1	2.74	1.5	2	1.5	0.12	0	0	2.9	0.2	0	0	0	0	0	0
2	Mid Pool	3	1	4.22	1.75	1.733	1.75	0.12	0	0	2.6	0.2	0	0	0	0	0	0
3	Near Dam	0	1	3.44	2.1	1.96	2.1	0.12	0	0	2.29	0.2	0	0	0	0	0	0

Segment Observed Water Quality

	Conserv		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	73	0.3	636	0.5	14.1	0.3	0.4	0.25	469	0.7	37.3	0.5	0	0	0	0

Segment Calibration Factors

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

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	Verdigris River	1	1	1305	272	0.1	0	0	60.2	0.5	595	0.5	7	0.5	238	0.5
2	Walnut Cr	1	1	500	97	0.1	0	0	64.4	0.2	541.1	0	14	0	119	0
3	Toronto WWTP	1	3	0	0.0801	0	0	0	2000	0	8000	0	250	0	7000	0

Model Coefficients	Mean	CV
Dispersion Rate	1.000	0.70
Total Phosphorus	0.600	0.45
Total Nitrogen	2.500	0.55
Chl-a Model	1.411	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

Output File – **Future TMDL** with 30% TP and TN Concentration Reductions at Inflow; with Upgraded Toronto WWTP at current design flow; with nutrient reduction (Predicted).

Predicted vs. Observed at Main Basin

Segment:	**3**	**Near Dam**				
	Predicted Values--->			**Observed Values--->**		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	52.2	0.32	53.8%	73.0	0.30	68.0%
TOTAL N MG/M3	491.3	0.32	13.3%	636.0	0.50	23.9%
C.NUTRIENT MG/M3	25.0	0.36	32.8%	35.4	0.43	49.6%
CHL-A MG/M3	9.7	0.49	51.9%	14.1	0.30	70.1%
SECCHI M	0.4	0.20	9.3%	0.4	0.25	9.6%
ORGANIC N MG/M3	551.5	0.23	61.7%	469.0	0.70	49.2%
TP-ORTHO-P MG/M3	67.5	0.24	80.3%	37.3	0.50	59.1%
ANTILOG PC-1	345.1	0.55	60.3%	486.9	0.41	70.0%
ANTILOG PC-2	3.7	0.33	14.4%	4.3	0.30	22.8%
(N - 150) / P	6.5	0.55	8.0%	6.7	0.72	8.4%
INORGANIC N / P	1.0		0.0%	4.7	2.85	3.1%
TURBIDITY 1/M	2.3	0.20	93.4%	2.3	0.20	93.4%
ZMIX * TURBIDITY	4.8	0.23	70.7%	4.8	0.23	70.7%
ZMIX / SECCHI	5.3	0.23	57.4%	5.2	0.27	56.5%
CHL-A * SECCHI	3.8	0.52	8.4%	5.6	0.39	20.1%
CHL-A / TOTAL P	0.2	0.54	46.9%	0.2	0.42	49.1%
FREQ(CHL-a>10) %	36.2	0.82	51.9%	59.7	0.31	70.1%
FREQ(CHL-a>20) %	7.1	1.54	51.9%	19.1	0.69	70.1%
FREQ(CHL-a>30) %	1.7	2.02	51.9%	6.3	0.97	70.1%
FREQ(CHL-a>40) %	0.5	2.38	51.9%	2.3	1.18	70.1%
FREQ(CHL-a>50) %	0.2	2.67	51.9%	0.9	1.35	70.1%
FREQ(CHL-a>60) %	0.1	2.91	51.9%	0.4	1.50	70.1%
CARLSON TSI-P	61.2	0.07	53.8%	66.0	0.06	68.0%
CARLSON TSI-CHLA	52.9	0.09	51.9%	56.6	0.05	70.1%
CARLSON TSI-SEC	73.4	0.04	90.7%	73.2	0.05	90.4%

Output File – **Future TMDL** with 30% TP and TN Concentration Reductions at Inflow; with Upgraded Toronto WWTP at current design flow; with nutrient reduction.

Overall Water & Nutrient Balances

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

Trb	Type	Seq	Name	Area km^2	Flow hm^3/yr	Variance (hm3/yr)^2	CV -	Runoff m/yr
1	1	1	Verdigris River	1305.0	272.0	7.40E+02	0.10	0.21
2	1	1	Walnut Cr	500.0	97.0	9.41E+01	0.10	0.19
3	3	1	Toronto WWTP		0.1	0.00E+00	0.00	
PRECIPITATION				10.4	10.2	4.16E+00	0.20	0.98
TRIBUTARY INFLOW				1805.0	369.0	8.34E+02	0.08	0.20
POINT-SOURCE INFLOW					0.1	0.00E+00	0.00	
***TOTAL INFLOW				1815.4	379.3	8.38E+02	0.08	0.21
ADVECTIVE OUTFLOW				1815.4	365.7	8.55E+02	0.08	0.20
***TOTAL OUTFLOW				1815.4	365.7	8.55E+02	0.08	0.20
***EVAPORATION					13.6	1.67E+01	0.30	

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

Trb	Type	Seq	Name	Load kg/yr	%Total	Load Variance (kg/yr)^2	%Total	CV	Conc mg/m^3	Export kg/km^2/yr
1	1	1	Verdigris River	16374.4	71.5%	6.97E+07	97.3%	0.51	60.2	12.5
2	1	1	Walnut Cr	6246.8	27.3%	1.95E+06	2.7%	0.22	64.4	12.5
3	3	1	Toronto WWTP	160.2	0.7%	0.00E+00		0.00	2000.0	
PRECIPITATION				104.0	0.5%	1.08E+02	0.0%	0.10	10.2	10.0
TRIBUTARY INFLOW				22621.2	98.8%	7.17E+07	100.0%	0.37	61.3	12.5
POINT-SOURCE INFLOW				160.2	0.7%	0.00E+00		0.00	2000.0	
***TOTAL INFLOW				22885.4	100.0%	7.17E+07	100.0%	0.37	60.3	12.6
ADVECTIVE OUTFLOW				19100.4	83.5%	3.91E+07		0.33	52.2	10.5
***TOTAL OUTFLOW				19100.4	83.5%	3.91E+07		0.33	52.2	10.5
***RETENTION				3785.0	16.5%	7.09E+06		0.70		

Overflow Rate (m/yr)	35.2	Nutrient Resid. Time (yrs)	0.0428
Hydraulic Resid. Time (yrs)	0.0512	Turnover Ratio	23.4
Reservoir Conc (mg/m3)	52	Retention Coef.	0.165

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

Trb	Type	Seq	Name	Load kg/yr	%Total	Load Variance (kg/yr)^2	%Total	CV	Conc mg/m^3	Export kg/km^2/yr
1	1	1	Verdigris River	161840.0	72.9%	6.81E+09	99.6%	0.51	595.0	124.0
2	1	1	Walnut Cr	52486.7	23.7%	2.75E+07	0.4%	0.10	541.1	105.0
3	3	1	Toronto WWTP	640.8	0.3%	0.00E+00		0.00	8000.0	
PRECIPITATION				6916.0	3.1%	9.37E+05	0.0%	0.14	678.6	665.0
TRIBUTARY INFLOW				214326.7	96.6%	6.84E+09	100.0%	0.39	580.8	118.7
POINT-SOURCE INFLOW				640.8	0.3%	0.00E+00		0.00	8000.0	
***TOTAL INFLOW				221883.5	100.0%	6.84E+09	100.0%	0.37	585.0	122.2
ADVECTIVE OUTFLOW				179641.7	81.0%	3.50E+09		0.33	491.3	99.0
***TOTAL OUTFLOW				179641.7	81.0%	3.50E+09		0.33	491.3	99.0
***RETENTION				42241.8	19.0%	9.25E+08		0.72		

Overflow Rate (m/yr)	35.2	Nutrient Resid. Time (yrs)	0.0415
Hydraulic Resid. Time (yrs)	0.0512	Turnover Ratio	24.1
Reservoir Conc (mg/m3)	492	Retention Coef.	0.190

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

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

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

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

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

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

CV = Coefficient of variation = Standard Deviation / Mean

Z = 2.326 for 99th percentile probability basis

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

Parameter	LTA lbs/year	CV	$e^{[Z\sigma - 0.5\sigma^2]}$	MDL lbs/day	Atm LA lbs/day	NonPoint LA lbs/day	WLA lbs/day	MOS (10%) lbs/day
TP	50,585	0.3	1.9	263.3	1.2	228.6	7.2	26.3
TN	490,450	0.5	2.68	3601	112	3083	46	360
TSS*	55,854*	0.3	1.9	290.7		261.5	0.1	29.1

* - TSS in tons/year and tons/day.

Maximum Daily Load Calculation

Annual TP Load = 50,585 lbs/yr

Maximum Daily TP Load = [(50,585 lbs/yr)/(365 days/yr)]*$e^{[2.326*(0.294)-0.5*(0.294)^2]}$
= 263.3 lbs/day

Annual TN Load = 490,450 lbs/yr

Maximum Daily TN Load = [(490,450 lbs/yr)/(365 days/yr)]*$e^{[2.326*(0.472)-0.5*(0.472)^2]}$
= 3601 lbs/day

Annual TSS Load = 55,854 tons/yr

Maximum Daily TSS Load = [(55,854 tons/yr)/(365 days/yr)]*$e^{[2.326*(0.294)-0.5*(0.294)^2]}$
= 290.7 tons/day

Margin of Safety (MOS) for Daily Load

Annual TP MOS = 5059 lbs/yr

Daily TP MOS = [(5059 lbs/yr)/(365 days/yr)]*$e^{[2.326*(0.294)-0.5*(0.294)^2]}$
= 26.3 lbs/day

Annual TN MOS = 49,045 lbs/yr

Daily TN MOS = [(49,045 lbs/yr)/(365 days/yr)]*$e^{[2.326*(0.472)-0.5*(0.472)^2]}$
= 360 lbs/day

Annual TSS MOS = 5585 tons/yr

Daily TSS MOS = [(5585 tons/yr)/(365 days/yr)]*$e^{[2.326*(0.294)-0.5*(0.294)^2]}$
= 29.1 tons/day

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