5. NTR Reservoirs

5.1. General Characteristics

There are only two large reservoirs, Wildwood and Fanshawe, which were described in Freshwater Research (2005). Three other reservoirs are shallow with maximum depths close to their dams of 4 m or less. Since they are all situated in populated urban areas of the towns, Mitchell, Stratford (Lake Victoria with the R.T. Orr Dam) and St. Mary's, they have important recreational functions besides flood control. Small Fullarton Pond located in the Fullarton Recreation Area on the Neil Drain, represents a small pond that is typical of several wetland areas in the NTR watershed. Even though its small size and outflow volume cannot be expected to severely affect the NTR, it was studied as an example how small ponds could be improved.

Morphometric and hydrological characteristics are described in Table 5-1. Volumetric variables and flows are based on the years 1968 to 2005. Field inspection in early summer 2005 revealed the visibly deteriorated water quality of these reservoirs: murky algal broth in the Mitchell Reservoir, scum in St. Mary's Reservoir and Fullarton Pond, and an apparently idyllic scene indicating possible water quality culprits of abundant water fowl and open turf at the waters edge in Lake Victoria (Figure 5-1).

Table 5-1. Morphometric and hydrological characteristics of the investigated reservoirs in the NTR watershed

Reservoir	Mitchell	Victoria	Wildwood	St. Mary's	Fullarton
River	NTR	Avon	Trout Creek	NTR	Neil Drain
Watershed area, A_d (km^2)	171	90.1	129	1080	3.2
Surface area, A_o (ha)	14.8	15.9	200	14.2	1.82
Area-Ratio, A_d/A_o	1,155	567	65	7,606	178
Maximum depth (m)	3	4	12	3	1.5
Mean depth, z (m)	1.5	1.6	4.2	2.2	1.1
Volume[1] (10^6 m³)	0.23	0.26	8.48	0.32	0.02
Outflow volume[2,3] (10^6 m³ per yr)	150	44.16	65.6	273.6	1.4
Water residence time[2], τ (year)	0.002	0.006	0.129	0.001	0.014
(volume/outflow) (days)	0.55	2.15	47.18	0.43	5.21
Annual flushing rate[2], $\rho = 1/\tau$ (per yr)	658	170	7.7	858	70
Annual water load[2], $q_s = z/\tau$ (m/yr)	1,014	278	33	1,927	77

[1] Based on Dam Safety reports completed for various dams in UTRCA watershed by Acres Int. 2004
[2] Longterm average 1968 - 2005
[3] For Victoria or Mitchell: Factor 0.69 or 0.6 of next downstream flow site

Mitchell Reservoir

St. Mary's Reservoir

Fullarton Pond

Lake Victoria, Stratford

Figure 5-1. Investigated reservoirs in the North Thames watershed of June 29, 2005.

Photos by G. Nürnberg

The watershed/lake area ratios are large, as is typical for run-of-the-river reservoirs. The morphometric characteristics are typical of polymictic reservoirs, i.e. the water mixes from time to time; these reservoirs are probably always mixed at the shallower upstream part, but may occasionally stratify in the summer at the deeper sections close to the dam. On such occasions, dissolved oxygen (DO) concentration may decrease to hypoxic (defined here as below 5.5 mg/L) and even anoxic (defined here as below 2 mg/L, when measured by immersed probes). All reservoirs have experienced water quality problems in the past, ranging from occasional oxygen deficits in the deeper water to severe algal blooms.

5.2. Wildwood Reservoir

Since Wildwood Reservoir is the largest of the reservoirs in the NRT watershed upstream of Fanshawe Lake (Table 5-1) it is described here separately based on the more detailed evaluation of Freshwater Research (2005) and new data for 2005. Its algal blooms as determined by the indicator LND will be presented together with the other NTR reservoirs in Section 5.4.

Wildwood Reservoir is located about 33 km upstream of Fanshawe Lake on Trout Creek, a tributary of the North Thames River at river km 48.8. Secchi transparencies and TP concentration indicate slightly eutrophic conditions (Table 5-2, Appendix A). However, transparency was lower in the intensively studied summers of 2004 and 2005 (Figure 5-2) and average TP concentration in 2005 was more than twice as high as ever recorded (Figure 5-3) and represents hyper-eutrophic conditions. Chlorophyll was analyzed at seven dates in 2005 (Appendix A) and the summer average was a large 24.2 µg/L, also borderline hyper-eutrophic (Table 2-2).

Table 5-2. Summer Secchi disk transparency and TP concentration in Wildwood

Year	Secchi (m)			TP (mg/L)	
	Dam	Mid	Upper	Dam	Mid
1973	1.18				
1979	0.78			0.054	0.017
1998	2.50			0.049	
1999	1.84	1.30	1.04	0.016	
2005	0.97	0.78	0.52	0.101	0.107
Average	1.48	1.07	0.75	0.042	0.058

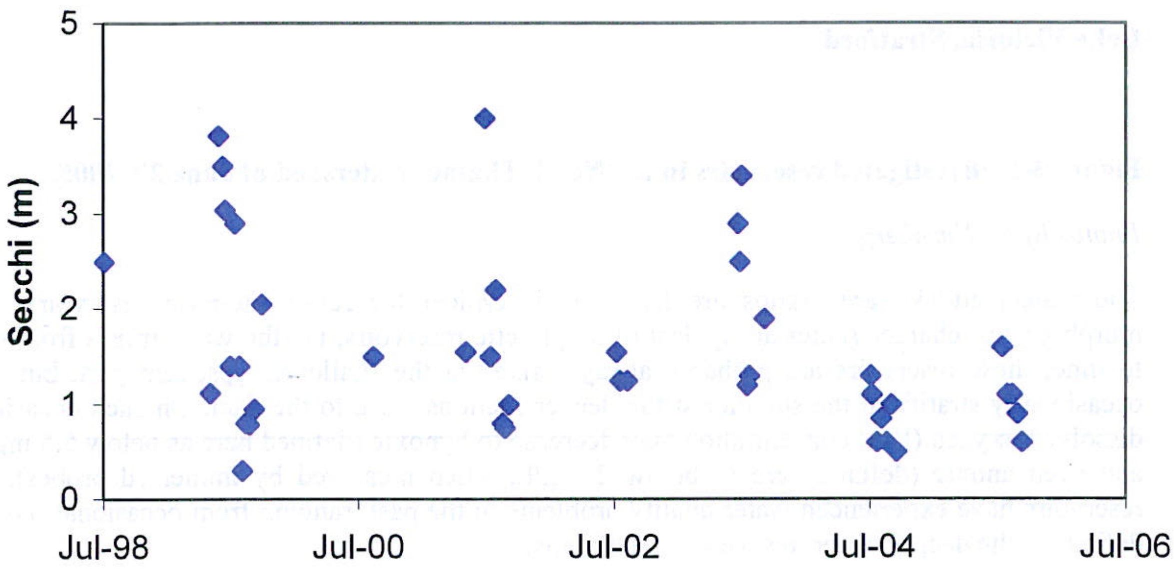

Figure 5-2. Secchi disk transparency near the Wildwood dam, individual readings.

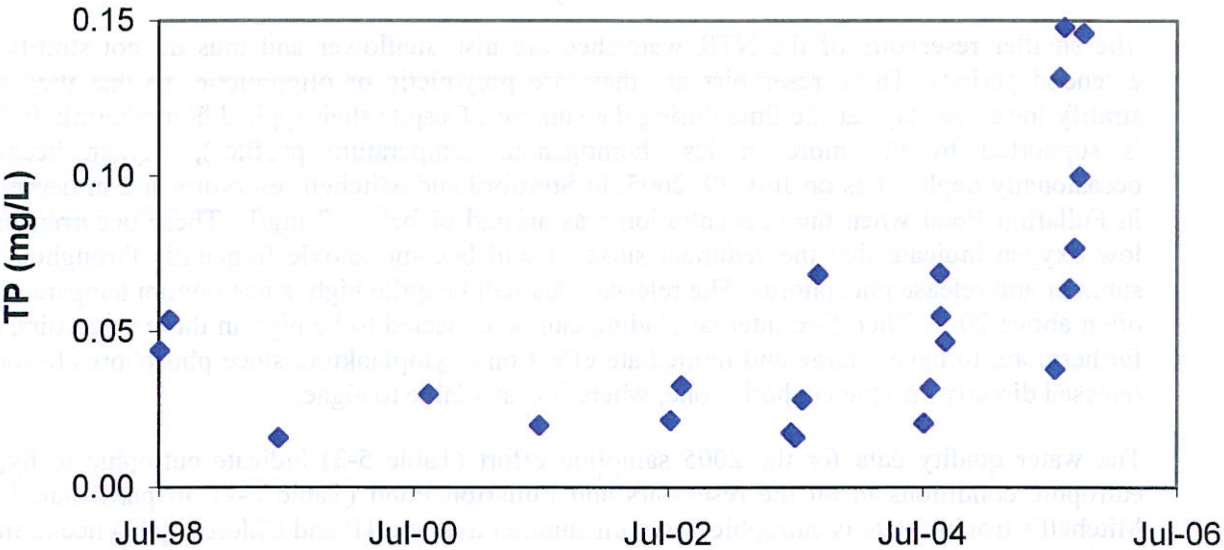

Figure 5-3. TP concentration near the Wildwood dam, individual data.

According to temperature and oxygen profiles, Wildwood stratified in the summer of 2005 at the dam and became anoxic below 5 m in July and below 7 m in August. This was about 1 m higher than in the previous year of 2004. As mentioned before, such anoxia triggers phosphorus release from bottom sediments. The higher TP concentration in 2005 may thus be due to more internal loading. This is supported by the high volumetric outflow concentration average of 0.094 mg/L which is almost 140% of the inflow concentration of 0.067 mg/L in the summer (while annual outflow concentration was smaller than inflow concentration).

Annual export was smaller than input in 2005, as noted before for the previous years by Freshwater Research (2005). In 2005, TP loading was 6.9 t input of which 5.6 t were exported so that about 0.18 was retained (where retention = in-out/in). The 2005 TP budget was similar to the long-term average of a load of 6.2 t and an export of 5.4 t with a long-term average retention of 0.07 and a median retention of 0.18. Even though there has been no net export of phosphorus in Wildwood on an annual basis since 2000, occasional net export was observed for the summer period (average for 2000-2005 was 1.2 exported) that can fertilize downstream waters.

From the analyses presented above it can be concluded that Wildwood does not adversely affect the Thames River water quality on an annual basis, but may do so occasionally in the summer. This means that Wildwood is still retaining phosphorus in its sediment during most of the year.

5.3. Lake Mitchell, Victoria, St. Mary's and Fullarton Pond

The smaller reservoirs of the NTR watershed are also shallower and thus do not stratify for extended periods. These reservoirs are therefore polymictic or oligomictic, so that they only stratify for a few days at the time during the summer. Despite their typical homothermia (which is supported by the more or less homogenous temperature profiles), oxygen becomes occasionally depleted as on July 29, 2005, in Stratford and Mitchell reservoirs at 2 m depth and in Fullarton Pond when the concentration was around or below 2 mg/L. These occurrences of low oxygen indicate that the sediment surfaces will become anoxic frequently throughout the summer and release phosphorus. The release rates will be quite high, since bottom temperature is often above 20 C. Therefore internal loading can be expected to be high in these reservoirs, and furthermore, to have a large and immediate effect on phytoplankton, since phosphorus becomes released directly into the euphotic zone, where it is available to algae.

The water quality data for the 2005 sampling effort (Table 5-3) indicate eutrophic to hyper-eutrophic conditions in all the reservoirs and Fullarton Pond (Table 2-2). In particular, Lake Mitchell's trophic state is eutrophic based on summer average TP and Chlorophyll concentration, while all other examined reservoirs are hyper-eutrophic, based on TP and Chlorophyll (and Secchi transparency for Lake Victoria. Secchi measurements are not available for Mitchell and St. Mary's Reservoir.). There is no consistent spatial gradient along Lake Victoria, and average Secchi disk readings from five locations (Figure 2-2) were not different throughout the summer, except that the station closest to the inflow had the lowest readings, indicating higher turbidity (Table 5-4). TP and nitrate concentrations did not show any pattern with locations S1 versus S2, while chlorophyll showed a large variability, indicating the unreliability of this measure (Table 5-3). It appears that in Lake Victoria water quality is uniformly poor, even at the dam.

Such extremely eutrophic conditions are not only detrimental to the recreational value of the reservoirs themselves and their immediate surroundings, but severely affect downstream waters, especially where outflow volumes are high, like in St. Mary's. Therefore, Section 6 of this report evaluates the water quality at the various locations at the NTR and its tributaries starting at the top at Fullarton Pond and Lake Mitchell down to Fanshawe Lake.

Table 5-3. Water quality data for the NRT reservoirs sampled in 2005.

Date	TP mg/L	Nitrate mg/L	Chlorophyll ug/L	Secchi m	Date	TP mg/L	Nitrate mg/L
	Mitchell Reservoir					**Fullarton Pond**	
13-Jul-05	0.094	2.8			13-Jul-05	0.031	3.3
28-Jul-05	0.084	4.3	18.1		28-Jul-05	0.579	1.6
10-Aug-05	0.090	1.3	15.3		10-Aug-05	0.280	0.3
25-Aug-05	0.085	4.3	5.2		25-Aug-05	0.019	1.4
8-Sep-05	0.042	2.4	35.4		8-Sep-05	0.029	1.5
22-Sep-05	0.126	0.5	19.8		22-Sep-05	0.312	1.1
6-Oct-05	0.105	7.4	14.1		6-Oct-05	0.283	2.3
Average	0.089	3.286	17.983		Average	0.219	1.643
	Stratford - Lake Victoria						
15-Jul-05	0.410	ND	7.7				
15-Jul-05	0.182	0.9	17.1			**Mary's Reservoir**	
28-Jul-05	0.095	1.7	20.4	0.63	13-Jul-05	0.052	1.9
28-Jul-05	0.216	1.8	20.0	0.73	28-Jul-05	0.096	1.1
12-Aug-05	0.258	0.7	97.3	0.51	10-Aug-05	0.201	1.3
12-Aug-05	0.164	ND		0.48	25-Aug-05	0.098	0.9
25-Aug-05	0.161	1.6	259.0	0.33	8-Sep-05	0.118	0.7
25-Aug-05	0.170	1.7	52.8	0.48	22-Sep-05	0.111	0.3
8-Sep-05	0.121	1.0		0.43	6-Oct-05	0.116	0.4
8-Sep-05	0.127	1.0	49.1	0.48	Average	0.113	0.943
22-Sep-05	0.137	0.8	31.4	0.53			
22-Sep-05	0.153	0.6	88.8	0.23			
6-Oct-05	0.089	5.3	14.4	0.43			
6-Oct-05	0.158	4.0	12.1	0.48			
Average S1	0.182	1.9	71.7	0.47			
Average S2	0.167	1.7	40.0	0.48			

Note: For Stratford, the first line is for the dam site, S1, and second line for the upstream site, S2
Secchi for Stratford was determined 1-2 days after sampling date by volunteer
ND, below detection limit

Table 5-4. Lake Victoria Secchi disk readings by volunteer Brendan Knight (Figure 2-2)

Site:	1	2	3	4	5	Average
July 29/2005	0.63	0.73	0.64	0.48	0.28	**0.55**
Aug 13/2005	0.51	0.48	0.43	0.33	0.33	**0.41**
Aug 27/2005	0.33	0.48	0.43	0.53	0.33	**0.42**
Sept 10/2005	0.43	0.48	0.48	0.53	0.33	**0.45**
Sept 25/2005	0.53	0.23	0.48	0.43	0.48	**0.43**
Oct 9/2005	0.43	0.48	0.48	0.43	0.33	**0.43**
Average	**0.47**	**0.48**	**0.49**	**0.45**	**0.34**	**0.45**

5.4. Algal Blooms

2005 monitoring of nitrate concentrations, Secchi disk transparency and chlorophyll concentration (Table 5-3) supported that LND is indeed a bloom indicator also in these reservoirs. At nitrate concentration below 2 mg/L chlorophyll was generally high and Secchi transparency low. So perhaps a slightly higher threshold than used previously in Fanshawe Lake would be more appropriate. LNDs were computed from available nitrate concentration in the lakes and downstream stations. In Wildwood, both values were similar in 2005; the one based on reservoir concentration was 102 days versus 112 days for the one based on the downstream station (#64, Table 2-1). In comparison, the 25-year average LND of the outflow was only 80 days. However in Lake Victoria of Stratford, LND was estimated as 50 days from the data collected in 2005 near the dam, while the downstream station (#25) estimate was zero days. It appears that the downstream station is not representative and underestimates algal blooms in the Stratford reservoir. The reservoir at St. Mary's had a high 102 days according to the lake samples in 2005, no simultaneous nitrate data are available from the downstream stations (#45 or #15), but their long-term values are similar. This indicates that the downstream sites are probably representative for in-lake algal conditions in St. Mary's. Similarly, the Mitchell Lake in-lake LND was small in 2005 (4 days) which is close to that found in the downstream site (#44) of zero days. LNDs of these and other stations are further discussed in Section 6.

5.5. Sediment Analysis

Sediment analysis for Lake Victoria, S1 and S2, Mitchell Reservoir, and the Fullarton Pond (Table 5-5, Appendix G) revealed that Lake Victoria sediments had the highest TP concentration at 1.6 mg/L average, which was also higher than that determined in the previous study for Fanshawe Lake of 1.3 mg/L. Similarly, the organic content was highest at about 10% per dry weight. Hence the sediments reflect well Lake Victoria's generally highest trophic state of all NTR reservoirs.

Lake Mitchell has the lowest sediment TP concentration and organic content of all investigated reservoirs, which is reflected in its comparably better trophic state.

Fullarton Pond has a surprisingly low sediment TP content, perhaps reflecting its comparably low phosphorus loading. It is also more buffered and calcium-rich.

Table 5-5. Sediment concentration of TP and organic matter (Appendix G)

Sample Site	Sediment layer	Organic Matter (% of DM)	TP (mg/gDM)
Stratford, dam	0-5 cm	10.4	1.62
	5-10 cm	10.0	1.62
Stratford, middle	0-5 cm	10.2	1.53
	5-10 cm	9.9	1.60
Mitchell, dam	0-5 cm	6.8	1.18
	5-10 cm	6.9	1.14
Mitchell, middle	0-5 cm	5.9	1.08
	5-10 cm	6.5	1.09
Fullerton, middle	0-5 cm	8.1	0.79
	5-10 cm	7.7	0.69
For comparison (Freshwater Research 2005):			
Fanshawe, dam	0-5 cm	7.8	1.39
	5-10 cm	9.3	1.36

6. NTR Sections, Tributaries and Wastewater Treatment Effluents

6.1. Long-term Stations

There are five long-term stations available with flow and water quality data spanning up to 40 years. Table 6-1 presents a synopsis of these stations including those near Fanshawe Lake (presented in Section 3) and near Lake Mitchell, Lake Victoria and the Wildwood Reservoir (presented in Section 5). While flows did not change appreciably during the period of investigation, there are temporal patterns that indicate much higher TP concentration and loads in the seventies and eighties. Therefore, the last twenty years were summarized separately as they more accurately characterize recent and present conditions. This period does not show any trend in water quality with time and the large variation is probably due to hydrological conditions, as observed for several stations (Fanshawe Section 4.2, Wildwood and Pittock outflow stations, Freshwater Research 2005).

Since water quality issues are most apparent in the summer, all characteristics were also presented separately for the summer period of May through September (Table 6-1, Figure 6-3, Figure 6-4). During these five months, only approximately 14% (Fullarton) to 35% of the flow occurs. Any remediation schemes have to consider that flows and therefore loads are variable throughout the year.

Flow along the North Thames River increases about four-fold from the most northern and upstream station at river-km (Rkm) 81.8 to Fanshawe Lake at Rkm 21.6, while TP load increases only about three-fold. There is a comparably large load at the upper station, which is just downstream of the Town of Mitchell, as reflected by a TP concentration of 0.12 mg/L, which is the largest of the entire NTR section. The next NTR station (downstream of St. Mary's at Rkm 48.3) has a lower TP concentration of 0.12 for long-term average and 0.08 for last 20-year average, despite TP loading from the tributaries of the Avon River and Trout Creek. Especially the Avon River contributes a high TP concentration of 0.30 mg/L for long-term and 0.15 mg/L for the recent 20-year average to the river. Contrarily, Trout Creek has similar as or lower TP concentration than the main stem. While the Stratford reservoir, Lake Victoria, is hyper-eutrophic and contributes to the high TP load of the Avon River (Section 5.3), Wildwood Reservoir on Trout Creek decreases the TP concentration of the creek as it still retains phosphorus (Section 5.2). In the 11 km stretch below St. Mary's Station, the river appears to retain phosphorus so that it enters Fanshawe Lake with the lowest TP concentration (0.069 mg/L last 20-year average) of all examined stations. However, the internal load in Fanshawe Lake causes the TP concentration to increase significantly, by about 30% (to 0.094 mg/L last 20-year average).

The decrease of phosphorus concentration along the North Thames River below St. Mary's is a bit of an enigma and should be investigated further. But evidence from the Watershed Report Card project of the UTRCA indicates that this river stretch, the Plover Mills Corridor, is more natural with good riparian cover and benthic conditions, yielding a benthic score of "B" (http://www.thamesriver.on.ca/Watershed_Report_Cards/Watershed_Report_Cards.htm).

Algal bloom periods are presented in Figure 6-1 and Appendix C and summarized in Table 6-2. There seems to be an improvement since the first recordings in 1968. LNDs are getting shorter until the early eighties. Afterwards, they seem to be highly variable between zero to about 150 days in the investigated reservoirs or downstream stations. It appears that sometimes blooms (e.g. in 1988 and many earlier years) or no blooms (e.g. in 2000) occur in all reservoirs simultaneously.

As observed for TP concentration and load, LND was lower in the more recent (20) years as compared to the period of 1968-2005, when nitrate data are available. The 20-year average of LND in the NTR ranged between 40 and 70 days and was highest downstream of St. Mary's and upstream of Fanshawe Lake. Trout Creek downstream of Wildwood has the highest LND of all measured stations, at 76 days for the 20-year average, while the station above Wildwood has the lowest at 9 days. This means that Wildwood Reservoir, although it is retaining phosphorus, is a creator of algal blooms in Trout Creek. This is explicable by the increase of the water residence time to 47 days/yr when Trout Creek passes through the reservoir (Table 5-1). The more flow is decreased the more settling out of particles and phosphorus happens (hence increased phosphorus retention), but at the same time the conditions for cyanobacteria improve as a lake-like environment is created. In Fanshawe Lake such pattern is not observed probably because its residence time of about 10 days/yr is not long enough for these processes to occur. Nonetheless, LND is quite high in Fanshawe Lake outflow at a 20-year LND average of 45 days, but it has decreased from the inflow station with an LND of 70 days.

As determined for Fanshawe Lake (Section 4.2) and Wildwood and Pittock reservoirs (Freshwater Research 2005), these blooms are somewhat inversely correlated to water flow. In particular, LNDs are correlated with summer flow in the downstream station of Lake Mitchell ($n=29$, $R^2=0.17$, $p< 0.03$) and the Avon River station below Lake Victoria ($n=36$, $R^2= 0.18$, $p<0.01$), even though LND probably underestimates LND in Lake Victoria. At the St. Mary's downstream station the relationship is more simple, so that at summer flows above about 80 10^6 m^3 (or 6 m^3/sec) LND is low, at low flows of below 70 10^6 m^3 (or 5 m^3/sec) LND is high at around 100 days and LND is variable at intermediate flows (Figure 6-2).

It is important to realize that LND in river sections may be low despite algal blooms, especially where point sources may provide nitrate. Here, blooms may occur even if the nitrate concentration is higher than 1-2 mg/L. Therefore the LND of creeks and NTR river sections may underestimate algal bloom periods. Nonetheless, they probably indicate (at least) a minimum of bluegreen bloom periods and were computed for all sites with available nitrate data.

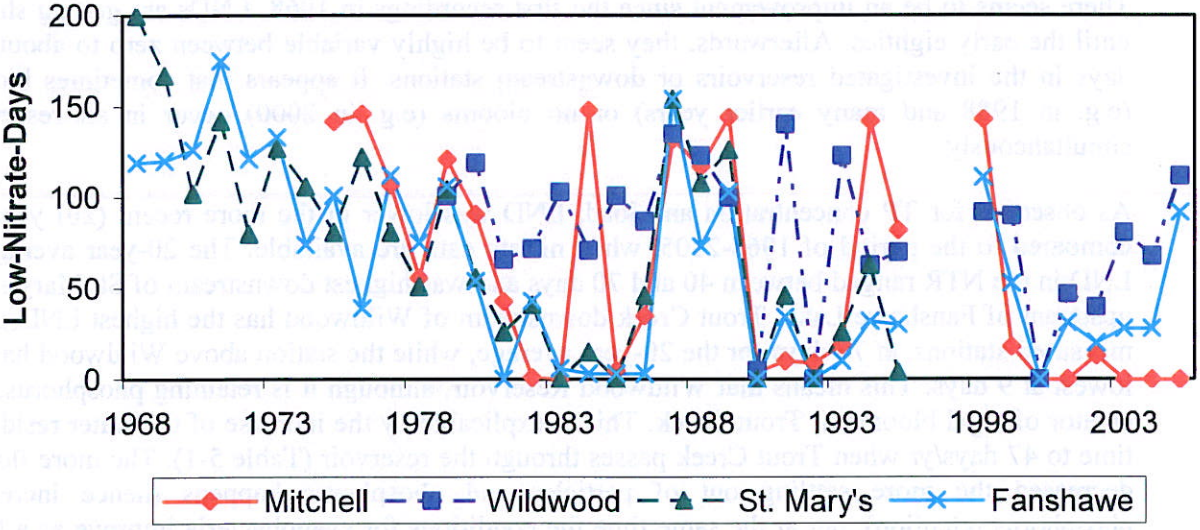

Figure 6-1. Algal bloom indicator, LND, in near downstream stations of some reservoirs

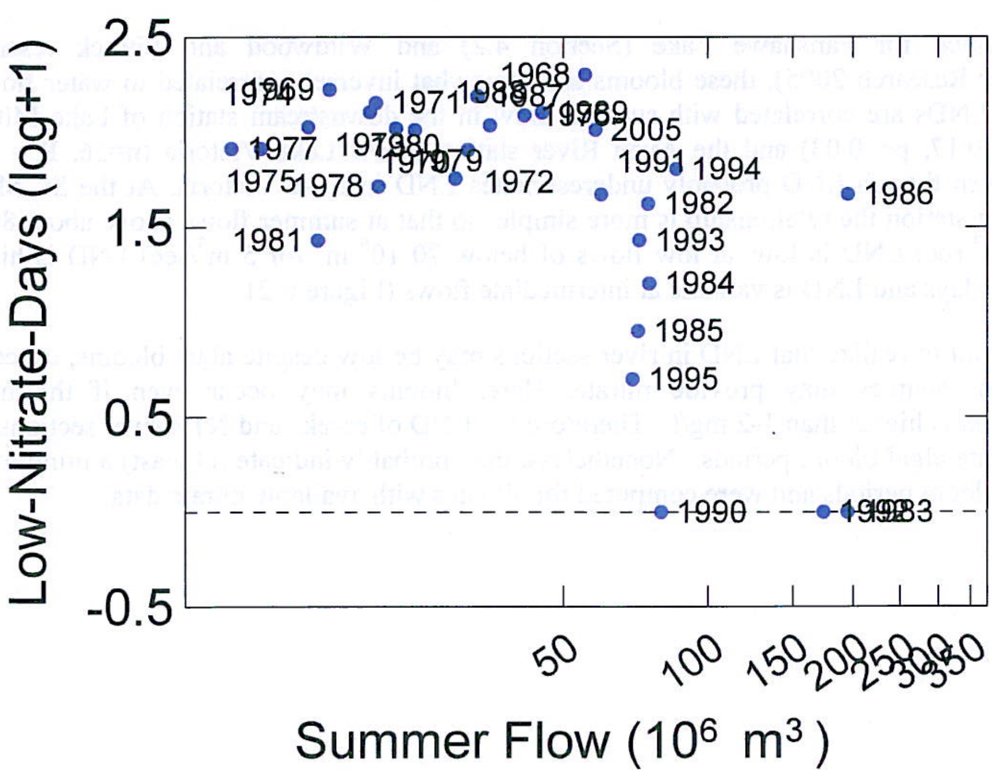

Figure 6-2. LND versus May-Sep flows at the stations downstream of St. Mary's

Note that both axes are log-transformed

Table 6-1. Long-term annual and summer flows, TP concentration averages and TP loads

Rkm	River	Location	Site	1968-2005 ann	1968-2005 summer	1986-2005 ann	1986-2005 summer
		Flow Volume (10^6 m³ per yr or summer)					
81.8	NTR	d/s Mitchell	1	149.7	21.9	146.7	27.3
55.98	Avon River	d/s Stratford	2	64.0	13.1	63.6	14.6
"49"	Trout Creek	u/s Wildwood	5	17.8	2.9	18.1	3.2
48.85	Trout Creek	d/s Wildwood	4	64.1	17.9	64.3	22.4
48.32	NTR	d/s St. Mary's	3	455.6	71.2	460.1	97.6
37.51	NTR	u/s Fanshawe Lake	6	577.0	107.6	577.4	119.3
21.64	NTR	d/s Fanshawe Lake	7	585.4	108.0	569.0	120.6

Rkm	River	Location	Site	Period*	TP (mg/L) ann	TP (mg/L) summer	TP load (t) ann	TP load (t) summer
		Water Quality						
81.8	NTR	d/s Mitchell	44	75-05	0.126	0.122	19.49	3.17
55.98	Avon River	d/s Stratford	25	68-05	0.305	0.363	18.28	3.79
"49"	Trout Creek	u/s Wildwood	66	79-05	0.098	0.079	1.80	0.27
48.85	Trout Creek	d/s Wildwood	64	79-05	0.082	0.077	5.41	1.68
48.32	NTR	d/s St. Mary's	15, 45	68-95, 02	0.116	0.134	50.74	9.16
37.51	NTR	u/s Fanshawe Lake	50	75-95, 03-05	0.077	0.061	46.55	6.72
21.64	NTR	d/s Fanshawe Lake	27	68-05	0.103	0.097	60.72	10.34
			Last 20 years					
81.8	NTR	d/s Mitchell	44	86-05	0.120	0.108	17.30	3.56
55.98	Avon River	d/s Stratford	25	86-05	0.151	0.120	9.02	1.62
"49"	Trout Creek	u/s Wildwood	66	86-05	0.101	0.082	1.77	0.28
48.85	Trout Creek	d/s Wildwood	64	86-05	0.080	0.077	4.96	1.54
48.32	NTR	d/s St. Mary's	15, 45	86-95, 02	0.083	0.077	37.77	6.81
37.51	NTR	u/s Fanshawe Lake	50	86-95, 03-05	0.069	0.057	41.29	6.86
21.64	NTR	d/s Fanshawe Lake	27	86-05	0.094	0.093	53.63	11.27

**There are no WQ data for 1996 and 1997*

Table 6-2. LND in the sections of the NTR

Rkm	River	Location	Site	Period*	LND (days) 1968-200	LND (days) 1986-2005
		Water Quality: LND				
81.8	NTR	d/s Mitchell	44	75-05	59.6	48.2
55.98	Avon River	d/s Stratford	25	68-05	10.0	16.7
49	Trout Creek	u/s Wildwood	66	79-05	13.5	8.7
48.85	Trout Creek	d/s Wildwood	64	79-05	80.4	76.4
48.32	NTR	d/s St. Mary's	15, 45	68-95, 02	75.0	61.4
37.51	NTR	u/s Fanshawe Lake	50	75-95, 03-05	76.2	69.9
21.64	NTR	d/s Fanshawe Lake	27	68-05	61.4	44.6

**There are no WQ data for 1996 and 1997*

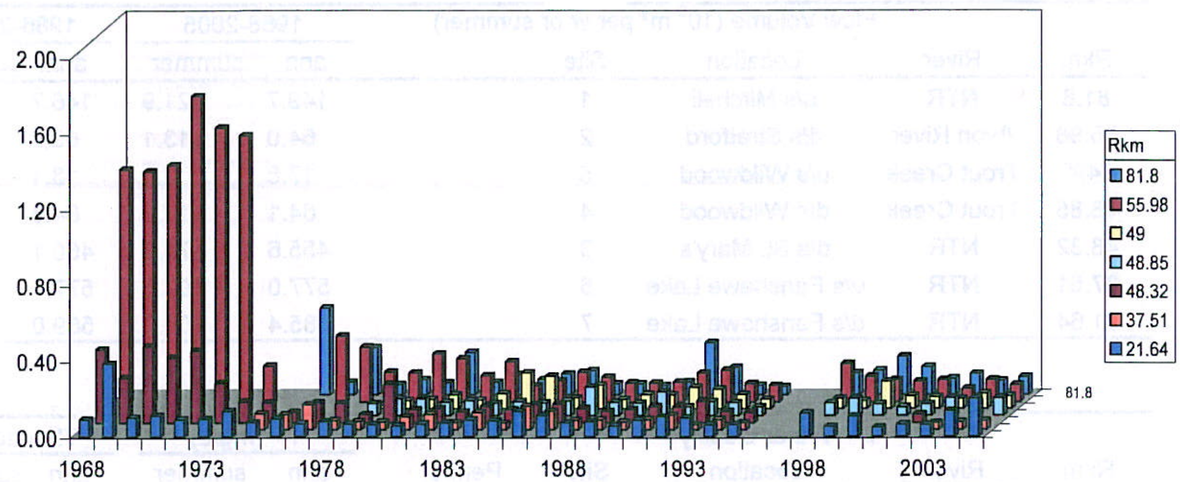

Figure 6-3. Summer volumetric averages of TP concentration for the NTR and its tributaries, for station key (Rkm) see Table 6-1

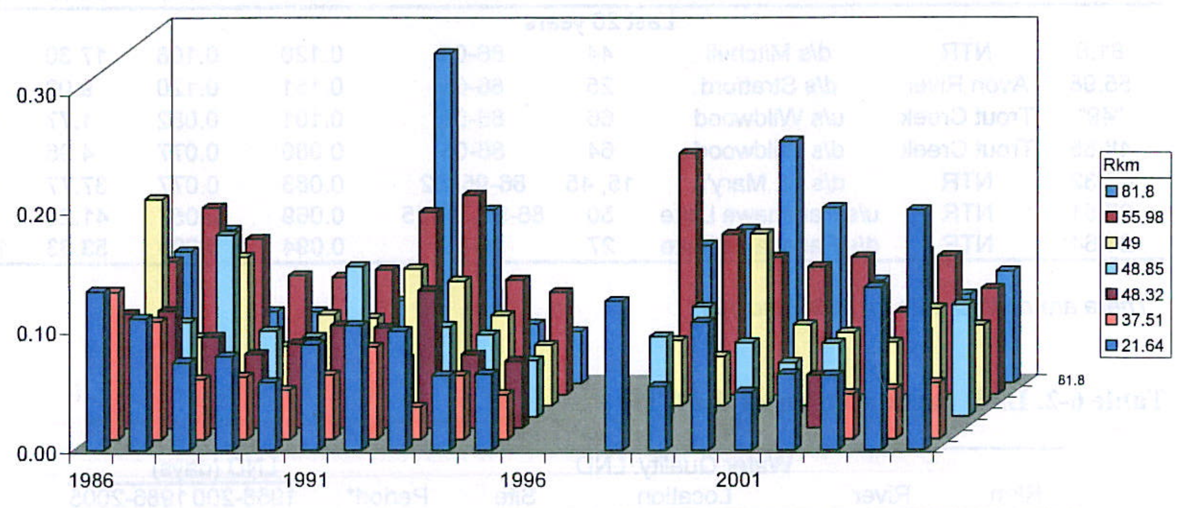

Figure 6-4. Summer volumetric average TP concentration for the NTR and its tributaries, for recent years as presented in Table 6-3.

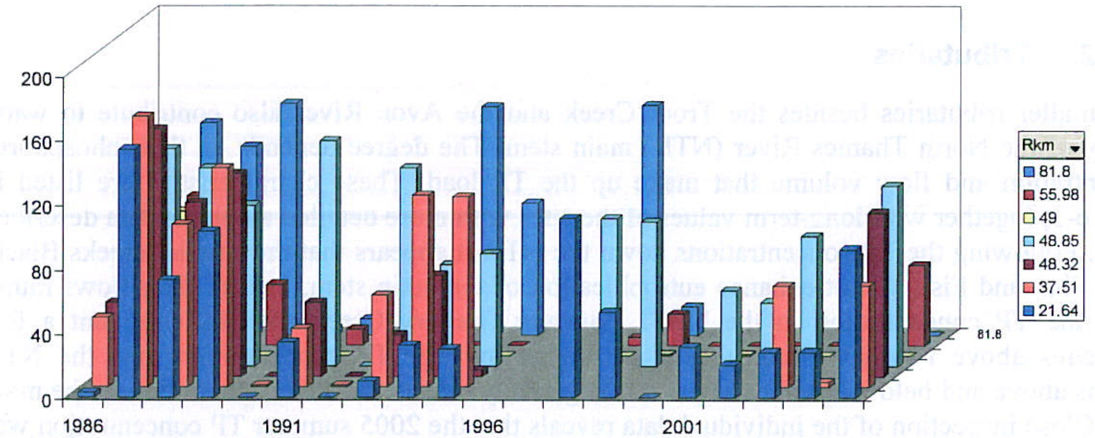

Figure 6-5. Low-nitrate-days for the NTR and its tributaries, for station key (Rkm) see Table 6-1

Table 6-3. Flows and water quality of tributaries and WWTPs compared to main NTR station 20-year averages *(same as Table 3-1)*

Rkm	River	Location	Site	Flow (10^6 m^3)		TP (mg/L)		TP Load (tonnes)		LND	WQ****
			WQ	Annual	May-Sep	Annual	May-Sep	Annual	May-Sep	(days)	Year
82.0	WWTP	Mitchell		1.5	0.6 **	0.493	0.493	0.74	0.31 **	n.a.	2002-03
81.8	NTR	d/s Mitchell	44	146.7	27.3	0.120	0.108	17.30	3.56	48	1986-05
73.5	Neil Drain	Fullarton		1.4	0.2	0.219	0.208	0.31	0.04 ***	121	2005
73.0	Black Creek		92	57.7	19.6 *	0.064	0.044	3.69	0.86 ***	81	2003-05
56.0	WWTP	Stratford		7.6	3.2 **	0.200	0.200	1.56	0.66 **	n.a.	2002-03
56.0	Avon River	d/s Stratford	25	63.6	14.6	0.151	0.120	9.02	1.62	17	1986-05
54.0	WWTP	St. Marys		1.5	0.6 **	0.465	0.465	0.66	0.28 **	n.a.	2002-03
48.9	Trout Creek	u/s Wildwood	66	18.1	3.2	0.101	0.082	1.77	0.28	9	1986-05
48.9	Trout Creek	d/s Wildwood	64	64.3	22.4	0.080	0.077	4.96	1.54	76	1986-05
48.3	NTR	d/s St. Mary's	15, 45	460.1	97.6	0.083	0.077	37.77	6.81	61	1986-05
60.5	Otter Creek		94	22.1	7.5 *	0.046	0.026	1.02	0.20 ***	39	2003-05
61.0	Flat Creek		89	34.1	11.6 *	0.055	0.051	1.87	0.59 ***	27	2003-05
39.0	Fish Creek		90	59.9	20.4 *	0.065	0.056	3.89	1.14 ***	10	2003-05
40.0	Gregory Creek		95	22.1	7.5 *	0.084	0.085	1.85	0.64 ***	81	2003-05
37.5	NTR	u/s Fanshawe	50	577.4	119.3	0.069	0.057	41.29	6.86	70	1986-05
21.6	NTR	d/s Fanshawe	27	569.0	120.6	0.094	0.093	53.63	11.27	45	1986-05

* Summer flow estimated as 0.34 of annual flow (Mark Helsten, UTRCA)

** Summer flows and loads in WWTP (waste water treament plants) were prorated from annual loads

*** Computed as product of average TP concentration and May-Sep flow

**** There are no WQ data for 1996 and 1997

6.2. Tributaries

The smaller tributaries besides the Trout Creek and the Avon River also contribute to water quality of the North Thames River (NTR) main stem. The degree depends on their phosphorus concentration and flow volume that make up the TP load. These characteristics are listed in Table 6-3, together with long-term values of the sites with more detailed available data described above. Following the TP concentrations down the NTR it appears that the smaller creeks Black, Otter, Flat, and Fish do not enhance eutrophication of the main stem, instead their flows rather dilute the TP concentration in the NRT. However Gregory Creek with its confluent a few kilometres above Fanshawe Lake has a far higher average TP concentration than the NTR stations above and below it, indicating that it negatively effects the TP concentration in the main stem. Close inspection of the individual data reveals that the 2005 summer TP concentration was highly variable (Figure 6-6). Since the other creeks did not experience such variation though they were sampled on the same dates, it is unlikely that this is a sampling or analytical artefact.

To reduce any negative effect from the smaller tributaries, Gregory Creek may be a candidate to be investigated further so that the source of its relatively high TP concentrations can be determined. In fact, after discussion with UTRCA staff it was revealed that a farmer experienced problems with his manure holding pond (because of a defective pump) around July 22 - 25, 2006. The extreme TP value was measured on July 26. It is interesting to see that routine monitoring actually can pick up such malfunctioning systems.

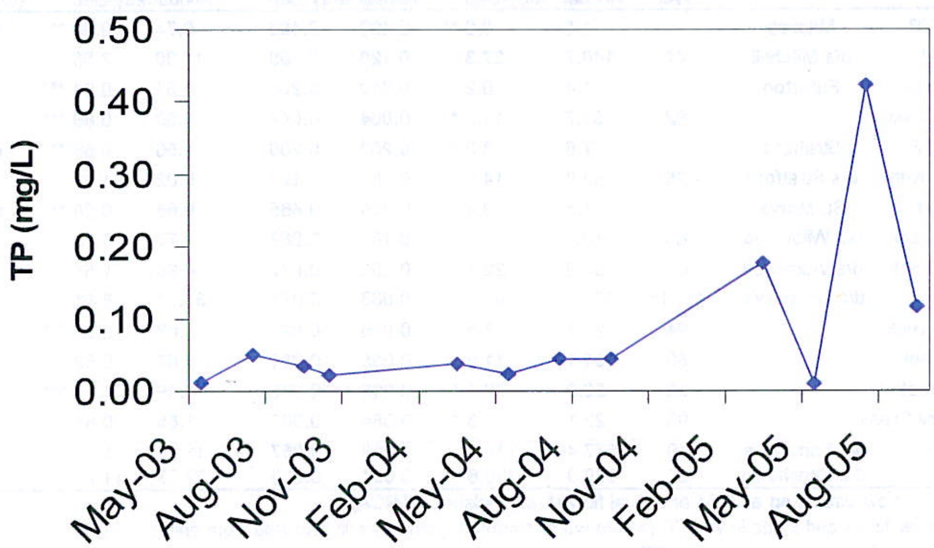

Figure 6-6. TP concentration in Gregory Creek, WQ Station 95, all available data

6.3. Wastewater Treatment Plants

There are three wastewater treatment plants in the NTR watershed, one each in the towns of Mitchell, Stratford and St. Mary's. They are designed for a population of 4,125, 30,660 and 5,560 each. Flows, average TP concentration and loads are listed in Table 6-3 as an average for 2002 and 2003.

Although the Stratford WWTP serves the largest population and therefore has five times the flow of the other plants, its average TP concentration is lowest at about 0.2 mg/L (similar to the average summer concentration of Fullarton Pond) so that its TP load is only about twice as large as that of the other two plants. Nonetheless, the effluent concentration is higher than the relatively high TP concentration in the Avon River and thus contributes to its water quality problems. The two smaller plants emit a high TP concentration of almost 0.5 mg/L which is about five times that of the receiving stream (NTR). Although the total loads are relatively small because of the small population served, improvement to at least a level similar to that of the Stratford Plant would decrease the eutrophication of the NTR. In particular it is important to realize that effluent phosphorus is much more biologically available (orthophosphate) than natural occurring phosphorus compounds (high proportion of particulate phosphorus).

Similarly, evidence of high impact by small waste water treatment plants was found in a British agricultural watershed (Jarvie et al. 2006, Appendix I) using ***boron*** tracing of sewage. Small wastewater treatment plants that serve small communities and therefore are licensed for relatively high effluent concentration contributed more to the eutrophication of the stream than agricultural non-point sources. (Uncannily, the British streams included a Thames, Wye and Avon River.)

7. Pittock Reservoir

Pittock Reservoir is a dam of the South Thames River, which joins the north branch below Fanshawe Lake. Therefore Pittock's water quality does not affect Fanshawe Lake. However, since it is probably the reservoir with the most deteriorated water quality, its limnological analysis has been requested as well.

The previous study (Freshwater Research 2005) corroborated that Pittock has algal blooms and low general water quality. There are now two years of water quality data available for this reservoir, besides transparency measures in form of Secchi disc from earlier years (Appendix A). Some of the water quality evaluation can be based on in- and outflow quality, for which several years of nutrient and other chemical data are available. However their usefulness is limited, as (1) Pittock has a bottom outlet, so that outflow water quality probably does not adequately represent the surface water quality during stratified periods and as (2) only 59% of the reservoir inflows are gauged by the South Thames River gage at Innerkip.

Basic morphometric and hydrological characteristics are presented in Table 7-1 (from Freshwater Research 2005). These values represent long-term annual average values. In a reservoir like Pittock, which is operated to have high summer storage capacity (286.7 m elevation) and low winter levels (282.7 m elevation), the seasonal characteristics differ substantially from the annual average.

Table 7-1. Morphometry and hydrology of Pittock

	Pittock
Altitude at average pool[1] (m above sea level)	284.7
Watershed area, A_d (km^2)	245.5
Surface area[1], A_o (ha)	148[2]
Area-Ratio, A_d/A_o	166.1
Maximum depth (m)	8.5
Mean depth[1], z (m)	1.9[2]
Morphometric index, $z/A_o^{0.5}$	1.6
Volume[1] (10^6 m^3)	2.83[2]
Outflow volume[1] (10^6 m^3 per yr)	101.1
Water residence time[1], τ (volume/outflow)	0.031 yr 11.2 d
Annual flushing rate[1], $\rho = 1/\tau$ (per yr)	32.5
Annual water load[1], $q_s = z/\tau$ (m/yr)	68.1
[1]*Longterm average*	*1979-2004*

[2]*Summer average for Pittock: A_0: 200 ha; Mean depth: 2.3 m; Volume: 5.8 10^6 m^3*

Pittock Reservoir is the smallest of the studied reservoirs. Mean depth and morphometric index are low in Pittock indicating highly mixed conditions, even in the summer, when it is operated at a higher water level. Thus morphometry alone indicate that Pittock is the most eutrophic of the reservoirs, with the most severe water quality problems.

Pittock Reservoir was classified as hyper-eutrophic in Freshwater Research (2005) according to Secchi disk transparencies (Table 2-2) The year 2005 transparency average was even smaller, the lowest ever recorded at the dam and the mid-reservoir stations (Table 7-2). As in many reservoirs, transparency improves from the inflow to locations close to the dam. There is still no improvement in recent years, an indication that the zebra mussel has not invaded these reservoirs yet unless the low flows have counteracted any improvement in transparency.

Table 7-2. Summer Secchi disk transparency in Pittock

Year	Secchi (m)		
	Dam	Mid	Upper
1973	0.76		
1999	0.91	0.90	0.75
2001	0.90	0.86	0.77
2002	1.10	0.75	0.70
2003	1.20	0.60	0.60
2004	0.88	0.65	0.46
2005	0.63	0.55	0.46
Average	0.91	0.72	0.62

The summer TP averages that are available (for 1976, 2004 and 2005) in Pittock are high at 0.083, 0.072 and 0.108 mg/L and hence indicate severely eutrophic and hyper-eutrophic conditions. Chlorophyll concentration was measured for the first time throughout the summer of 2005. Variability throughout the summer was high and averaged 53 µg/L (Figure 7-1). Obviously, there was a large algal bloom around August 26, 2005. Indeed the field book conveys that there was a bloom on this date and the one before and after it (Karla Young, UTRCA), whenever the chlorophyll concentration was above 40 µg/L.

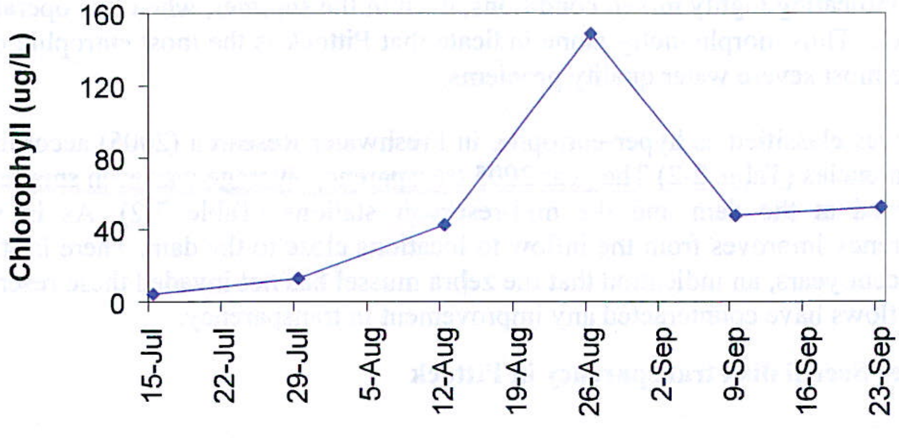

Figure 7-1. Chlorophyll concentration near the dam in Pittock Reservoir 2005.

LNDs were computed for 2005 from available nitrate concentration in the lake, as 72 days, but it may well have been up to 130 days because the last sampling took place on Sept 23 and low nitrate concentration have occurred in previous years until November and December. The 22-year average in Pittock was 83 days (Freshwater Research 2005). As in Fanshawe Lake, and other NRT reservoirs, LNDs were significantly negatively correlated with summer inflow (Pittock: n= 22, R^2=0.49, p<0.001), indicating that water quality in this reservoir is highly controlled by hydrology as well.

Pittock stratified occasionally and exhibited oxygen depletion in the bottom water at 6 m depth throughout the summer of 2005, as it did in 2004. Such occasional anoxic periods can be expected to trigger phosphorus release from bottom sediments. Indeed, phosphorus budgets for 15 years between 1988 and 2004 revealed that Pittock releases significant amounts of TP over and above the incoming load, just as does Fanshawe (Freshwater Research 2005). In 2005 the net release of TP was 6 t computed from an annual load of 13 t and export of 19 t compared to a long-term average of 3 t computed from an average annual load of 9 t and a 12 t export.

Therefore, Pittock Reservoir experiences a net export and hence adversely affects downstream water quality. Not only is the concentration of the limiting nutrient, phosphorus, increased after the flow through the reservoir, but it can be inferred that also algal biomass and other organic material increase downstream. While these events decrease water quality downstream, they prevent increased eutrophication within the reservoir.

8. Treatment Options and Potential Technological Solutions

The main purpose of the studies leading to this report is the determination of feasible treatment options that would improve the water quality of the reservoirs and possibly the Thames River sections that the UTRCA is responsible for. However, water quality improvement cannot be the only goal, since flood control (the dam's main purpose) and other constraints like endangered species, recreational potential, costs and public acceptance all have to be considered. A detailed description of such "treatment option decision criteria" was assembled by the Project Task Force for the previous report (2005) and is included here as Appendix H.

Inverse relationships between the LND algal bloom indicator and summer flows were observed for most of the NTR reservoirs. This suggests that any enhancement of summer flows would decrease their eutrophication. Therefore one treatment suggestion is to maximize summer (May – Sept) flows. Such operational changes should especially be used for those reservoirs where no other direct treatment appears to be possible, like Fanshawe Lake (Section 8.1).

On the other hand, less flow may be expected as a consequence of future climate change with warmer and drier summers; this would mean poorer water quality and higher trophic states in the NTR reservoirs.

The decrease of phosphorus concentration along the North Thames River below St. Mary's (Section 6.1) provides evidence that a river stretch with natural characteristics, including good riparian cover and "B" graded benthic conditions also helps in the abatement of eutrophication. Consequently, all efforts should be made to attain such a state throughout the Upper Thames River watershed. Currently, the Plover Creek watershed and some adjacent sub-watersheds below St. Mary's are the only "B" rated areas upstream of Fanshawe Lake (http://www.thamesriver.on.ca/Watershed_Report_Cards/Watershed_Report_Cards.htm).

8.1. Fanshawe Lake

The overall investigation along the NTR reveals that TP averages are decreasing until Fanshawe Lake, where they drastically and significantly increase (at the downstream station, WQ 27), indicating a TP source in Fanshawe Lake itself. Without the export via the bottom outlet, the lake would likely have (even) more water quality problems as discussed in Section 4.4. However, the increased phosphorus originates in the Fanshawe Lake bottom sediments (about a third of the inflow phosphorus mass) and is much more biologically available (orthophosphate) than phosphorus compounds from other (external) sources, which usually contain a high proportion of particulate phosphorus. Thus, some of the exported phosphorus (third of inflow on average) is comparable to that from WWTP and its treatment would be important if downstream sections are to be remediated. For example, the TP input in 2005 was 35 t while 91 t were exported. 60 t of this export would have been highly biologically available. This is far higher than the loads of the WWTP above Fanshawe Lake combined (Table 6-3).

Freshwater Research (2005) determined that besides the maximization of hypolimnetic withdrawal (Section 4.4), there is no other feasible direct treatment option for Fanshawe Lake. Instead, minimizing its external load by decreasing the inflow TP concentration will slowly improve its water quality, and this study evaluates those options as presented below. (TP load should not be minimized by decreasing flow, because of the water quality-flow relationships discussed in Section 4.2).

8.2. Wildwood Reservoir

Hypolimnetic withdrawal also benefits Wildwood Reservoir, as it is stratified and has high phosphorus concentration in the bottom, although water quality improvement of Wildwood Reservoir may not be as crucial, as it is apparently only slightly eutrophic (Section 5.2). According to Mark Helsten, UTRCA, bottom water withdrawal is currently maximized in the summer and further benefits by this treatment cannot be expected.

Wildwood Reservoir is not a net exporter of TP on an annual basis, so that the TP concentration of Trout Creek does not increase after passing Wildwood dam. Furthermore, the long-term average of the Trout River TP concentration is the same as that for the next downstream NTR station below St. Mary's (Table 6-3), indicating that Trout Creek does not adversely affect the water quality of the NTR. However, it already is a net exporter in recent summers contributing to Trout Creek eutrophication during the most important periods of low flow and high temperature. Accordingly, care should be taken to reduce external inputs into Wildwood Reservoirs, to prevent any further eutrophication that would also enhance phosphorus export.

Because of Wildwood's large size and volume and comparably good water quality no in-lake treatment is recommended at this point. If phosphorus export in the summer becomes more severe, a phosphorus precipitation treatment of its outflow may be recommendable to prevent further downstream impact.

8.3. Mitchell Reservoir

The TP concentration downstream of the Mitchell Reservoir is high at 0.108 mg/L summer average, and it may be influenced by the WWTP effluents that are located just above this station. The flushing rate is quite high, about half a day and the flow volume large (Table 5-1), so that any treatment by adding chemicals is not feasible. The loading at this site warrants further investigation to determine which TP sources could best be treated or diminished.

8.4. Lake Victoria at Stratford

The Avon River downstream of Lake Victoria has the highest TP concentration in the NTR watershed except for the Fullarton Pond and effluents. Although its TP concentration has tremendously improved since the seventies and early eighties as seen by improved TP at the downstream location on the Avon River (Table 6-1), it still contributes to the NTR water quality problems downstream of its confluence (Table 6-3).

Further improvements are also necessary for its recreational and visible appeal. The Town of Stratford attracts visitors from all over the world to its theatre performances in close vicinity of the lake shore. However, before any in-lake treatment is recommendable, there are several phosphorus sources that should be minimized first.

Waterfowl and its feeding can contribute a significant part of external phosphorus loading to an urban lake (Tobiessen & Wheat 2000). Moore et al. (1998) determined a daily TP input from Canada Geese of 0.61 grams per bird from defecation alone. Assuming 90 geese on and around the lake day and night throughout the whole year results in a TP input of 20 kg/yr. Considering that almost all of this phosphorus is in a biologically available form and can be taken up by algae, this is a substantial contribution. (It is half of the TP load from Fullarton Pond, Table 6-3). An exact count of the water fowl population combined with the application of species specific TP egestion rates (e.g. Manny et al. 1994) would provide a more accurate estimate of this source. If any water fowl is to be kept, a more controlled management has to be employed. For example, feeding should only be provided in containers away from the water and the public be discouraged to supplement feeding right in the water.

Fertilizer runoff from the extended grassed areas around the lake may contribute another significant amount, especially if combined with irrigation, which flushes nutrients and pollutants into the lake. There are already attempts to minimize such runoff by buffer strips at the north shore that prevent mowing to the edge. However, natural edgings have to be installed in a wider ring around the entire shoreline, instead of lawns up to the lake shore (Figure 5-1).

The upstream agricultural areas in the watershed can be expected to also contribute significantly to the phosphorus load of Lake Victoria. Load from the upstream watershed could be determined if there were TP concentration available for the upstream Avon River. A comparison of upstream TP concentration in the Avon River with the available downstream values would help estimate how much is created in the vicinity of the Town of Stratford, including the sources from water fowl, fertilizer and internal phosphorus loading from anoxic sediments.

A MOE (1979) mass balance estimated that 47% of the TP load at the Avon River in Stratford was from agricultural sources and 35% from the sewage treatment plant in 1977. However, agricultural practices have changed since then and the waste water treatment plant has been made more efficient so that these estimates unlikely apply today.

8.5. Fullarton Pond

Smaller reservoirs like the pond in the Fullarton Conservation Area could be improved for its own sake, as a small lake with a trail system to accommodate recreational hiking and biking for area residents. In addition there would be some benefit of reduced TP and organic matter export to the NTR section below.

Alternatively, small reservoirs could be led back to the state of natural running water by removing their dams. Current research to identify dams and barriers that are suitable for removal or mitigation is ongoing by UTRCA staff and the Fullarton impoundment could be a candidate for removal and rehabilitation as a natural riverine system.

With or without dam removal an alum treatment is recommended for Fullarton Pond to prevent any phosphorus from being flushed downstream. Alum treatment would bind and precipitate phosphorus and prevent further release from the bottom sediments thus diminishing severe and potentially toxic algal blooms. Because of the relatively high TP concentration in the water column, the alum dose in Fullarton Pond should include the binding and settling of the TP mass in the pond water as well as in the sediment, to provide a barrier on the sediment that prevents future internal loading from anoxic sediment surfaces. In order to assure the treatment's effectiveness, the fish community has to be known. In case that there are bottom dwelling fish, like carp and goldfish, these have to be eradicated first. This can be accomplished by a rotenone treatment (if permitted) or a winter drawdown and exposure of the sediment and water puddles to freezing. Such treatment would also diminish the abundance of non-native macrophytes (Eurasion Milfoil) that are often prolific in such ponds.

Because of its small size (surface area of less than 2 ha, Table 5-1) the cost of an Alum treatment should be reasonable ($2,000/ha, based on US $840-$1,500/ha as noted in Cooke et al. 2005). To assure maximum effectiveness the reservoir's flow rate should be at its minimum (perhaps this can be reached by specific management of the outflow at the dam in a season, when volume and area are smallest), but water temperature should ideally be above 15° C (typically from May to October).

8.6. Pittock Reservoir

Pittock Reservoir experiences a net export and adversely affects downstream water quality (Section 7). Because it is relatively small and has a high trophic state, Pittock Reservoir is a prime candidate for a remediation treatment to reduce algal blooms, turbidity, and the concentrations of TP and chlorophyll. Considering its flow pattern and dam operation it may be feasible to add an aluminum-based compound to bind phosphorus to the sediment and prevent internal loading. ($2,000/ha, total cost about $400,000, US $840-$1,500/ha, Cooke et al 2005). Like with additions to Fullarton Pond, maximum effectiveness may be reached by specific management of the outflow at the dam in a season, when volume and area are smallest, i.e. during winter drawdown, although water temperature ideally should be above 15° C (typically from May to October). More investigation is needed to determine the most promising timing.

8.7. Waste water treatment

The efficiency of the WWTP at Mitchell and St. Mary's should be improved. The average 2002-2003 effluent TP concentrations was 0.5 mg/L, which was five-times higher than the ambient TP concentration of the NTR.

With respect to determining the impact of sewage related phosphorus, a novel technique may be helpful that measures the chemical ***boron*** in the water. Boron tracing of sewage was applied successfully in a British agricultural watershed (Jarvie et al. 2006, Appendix I), as described in Section 6.3.

9. Conclusions, Future Activities

9.1. Treatment suggestions

Looking at a watershed by comparing long-term key variables at various stations of the tributaries and main stem of a river improves the quantitative understanding of problems sources. In particular, flow estimates, TP loads and concentration and an estimate of algal blooms (LND) in impoundments along the way make the determination of water quality and its control more apparent.

This summary and synopsis is a necessary first step to target hotspots of nutrients that warrant remediation treatment. Some suggestions are straight forward and are incorporated in this report. Others have to be explored in more detail. Treatment recommendations are evaluated with respect to the decision criteria (Appendix H) in Table 9-1.

Table 9-1. Treatment Recommendations

Treatment	Impoundment	Decision Criteria[1,2]						
		1	2	3	*	4	5	6
Aluminum- precipitation	Small ponds: e.g. Fullarton	+/-	+	+/-	+	+	-	?
	Pittock	+/-	+	+/-	+	+	--	?
Hypolimnetic withdrawal	Fanshawe Lake	+/-	+	+	--	+/-	+	+
	Wildwood	+/-	+	+	-	+/-	+	+
1. Water fowl management	Lake Victoria	+/-	+	+	+	+/-	-	?
2. Park grounds management		+/-	+	+	+	+/-	+	+
3. Aluminum- precipitation, after 1,2		+/-	+	+/-	+	+	--	?
Further investigation needed	Lake Mitchell Lake Victoria Gregory Creek							

[1]Decision Criteria

1. Flood control operations
2. Water quality
3. Aquatic habitat
4. Recreational opportunity
5. Capital and operating costs
6. Public input / acceptance

* Effect on downstream waters

[2]Key for expected effects:

+ positive
- negative, -- worse, --- worst
+/- none
? not known

9.2. Monitoring suggestions

Monitoring in the reservoirs should be continued. Routinely only profile data have been collected to determine temperature and dissolved oxygen. In addition, monitoring should include other indicators of eutrophication as well, in particular surface and bottom phosphorus concentration and algal biomass indicators (chlorophyll concentration and Secchi transparency). Such data are necessary not only to assess the current water quality, but also to provide baseline conditions, if a treatment is to be conducted in the future.

Both Reservoir Treatment Studies (I and II) support that LND indeed indicates the period of algal blooms throughout the Upper Thames watershed and in particular in the studied reservoirs. Preferably LND is based on nitrate concentration within the reservoir, as the outlet concentration may underestimate LND. However, comparison of LNDs does not show any significant difference for any of the investigated reservoirs versus the next downstream station, except for Lake Victoria. Therefore it is recommended to measure nitrate within the reservoir at Stratford throughout the summer and fall, as algal blooms can occur until late October. In all other reservoirs the routine measurements of nitrate at the MOE water quality stations is sufficient to compute LND.

The keeping of a "Journal" on algal blooms helped corroborate the LND, algal bloom, and hydrological relationships described in this study and should be expanded. Acquiring Secchi transparencies and entries for a bloom journal involves interested and reliable stake holders of the specific reservoirs and river sections. An out-reach plan could be installed similar to the Lake Partner Program by the MOE. (In this plan registered volunteers determine Secchi disk depths throughout the summer and collect nutrient samples in prepared bottles.) Programs like this are established throughout North America and also in Europe and are very successful in producing background and baseline data on eutrophication trends. They are not only cost-effective, as they are based on free labour, but also educate the public and generate environmentally friendly positions and collaboration.

Much of the NTR upstream of Fanshawe Lake has been investigated and crucial data have been summarized. There is some indication that the smaller wastewater treatment plants at Mitchell and St. Mary's contribute appreciably to eutrophication in the summer, when the flow in the river is low. Currently no or only occasional data are available above those plants so that this hypothesis cannot be tested. Similarly, the Avon River increases eutrophication of the North Thames River because of its comparably high TP concentration. Again, it is not clear which are the most important TP sources to the Avon River, since no recent water quality data upstream of the City of Stratford are available. However, that is to change in the future as the MOE will add a flow gage and monitoring station for water quality upstream of Lake Victoria.

With respect to determining the impact of sewage related phosphorus, a novel technique may be helpful that measures the chemical ***boron*** in the water (Section 6.3). This chemical can be determined relatively easily and could probably be done with little extra cost by the MOE laboratories in the routinely collected samples. There also seems to be a boron selective electrode available that measures it directly in a water sample (Wood and Nicholson 1996).

9.3. Further studies

In collaboration with the UTRCA staff, the following water quality issues in the North Thames and potential solutions have been identified and warrant further study.

- High water temperatures exacerbates algae problem and is likely to get worse with climate change. Remedial actions to reverse this trend could include headwater reforestation, buffer strip improvements, and the protection of groundwater discharge and recharge areas.
- Likewise, low summer flows increase algal biomass. Remedial actions as proposed in the previous point are recommended; in addition work to reverse the impacts of agricultural land drainage - tile "blocks or valves", natural channel redesign of drainage ditches, artificial wetlands, increased reforestation and naturalization of marginal lands
- Reduction of TP concentrations throughout the NTR watershed. An extensive list is presented as Clean Water Program activities on http://www.cleanwaterprogram.ca/
- An exercise to list all potential solutions and attempt to quantify their impacts and costs would be a very useful follow-up study.

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