Appendix A: Location of flow gauges, water quality stations, and WWTPs

Table 24. Station characteristics for flow and water quality of tributaries and WWTP (TR, Thames River, NTR, North Thames River; STR, South Thames River, provided by UTRCA)

Monitoring Program	WQ-Stn	Flow-Stn[2]	Type	km	Common Name (River km)	Sec-tion	Receiver	Tributary Distance
Mouth[1]	308202	T00B	Computed	0	Mouth (0km)	TR	Lake St. Clair	0
Chatham-Kent	Tilbury		WWTP	1.3	Tilbury WWTP (1.3km)	TR	Tremblay Creek	0
PWQMN-LTVCA	311002		WQ	3.5	Jeannettes Cr (3.5km)	TR	Jeannettes Creek	9.30
Chatham-Kent	Merlin		WWTP	3.5	Merlin WWTP (3.5km)	TR	Foxton Drain	28.51
PWQMN-LTVCA	308202		WQ	14.8	Jacob Rd (14.8km)	TR	Thames River	0
Chatham, ON	Chatham		WWTP	25.0	Chatham WWTP (25km)	TR	Thames River	0.61
PWQMN-LTVCA	308102	E007	WQ	29.7	McGregor Cr (29.7km)	TR	McGregor Creek	10.81
PWQMN-LTVCA_Discontinued	304902		WQ	29.7	McGregor Historic (29.7km)	TR	McGregor Creek	24.78
Town of Ridgetown	Ridgetown		WWTP	29.7	Ridgetown WWTP (29.7km)	TR	Gawne Drain	33.69
Town of Blenheim	Blenheim		WWTP	29.7	Blenheim WWTP (29.7km)	TR	Cameron Drain	23.96
EC	2GC1700		WQ	30.8	Chatham (30.8km)	TR	Thames River	0
PWQMN-LTVCA	305802		WQ	49.7	Kent Bridge (49.7km)	TR	Thames River	0
PWQMN-LTVCA	305702		WQ	65.0	White Ash Cr (65km)	TR	White Ash Creek	0.20
EC	2GE1000	E003	WQ	65.2	Thamesville (65.2km)	TR	Thames River	0
Chatham-Kent	Thamesville		WWTP	65.2	Thamesville WWTP (65.2km)	TR	Thames River	0
PWQMN-LTVCA	310902		WQ	89.8	Fleming Cr (89.8km)	TR	Fleming Creek	2.58
Southwest Middlesex	Wardsville		WWTP	93.4	Wardsville WWTP (93.4km)	TR	Thames River	0
PWQMN-LTVCA	307302		WQ	115.2	Newbiggen Cr (115.2km)	TR	Newbiggen Creek	6.94
Southwest Middlesex	Glencoe		WWTP	115.2	Glencoe WWTP (115.2km)	TR	Newbiggen Creek	12.43
PWQMN-LTVCA	308302	E006	WQ	127.2	Currie Rd (127.2km)	TR	Thames River	0
Strathroy-Caradoc	Mount Brydges		WWTP	185.0	Mt. Brydges WWTP (185km)	TR	Thames River	23.11

Monitoring Program	WQ-Stn	Flow-Stn[2]	Type	km	Common Name (River km)	Sec-tion	Receiver	Tributary Distance
PWQMN-UTRCA	63		WQ	185.7	Komoka Cr (185.7km)	TR	Komoka Creek	3.029
PWQMN-UTRCA	29	E005	WQ	186.5	Dingman Cr (186.5km)	TR	Dingman Creek	23.57
CoL	Dingman-Lambeth		WQ	186.5	Dingman-Lambeth (186.5km)	TR	Dingman Creek	24.89
CoL	Southland Park		WWTP	186.5	Southland WWTP (186.5km)	TR	Dingman Creek	30.51
CoL	Dingman-Ding.Dr.		WQ	186.5	Dingman-Dingman Dr (186.5km)	TR	Dingman Creek	33.279
CoL	Dingman-Well.		WQ	186.5	Dingman-Wellington (186.5km)	TR	Dingman Creek	36.93
CoL	Dingman-High.		WQ	186.5	Dingman-Highbury (186.5km)	TR	Dingman Creek	41.123
CoL	Dingman-OVR		WQ	186.5	Dingman-Old Victoria (186.5km)	TR	Dingman Creek	45.529
PWQMN-UTRCA	47		WQ	189.1	Th. Komoka (189.1km)	TR	Thames River	0
CoL	Komoka		WQ	189.1	Th. Komoka CoL (189.1km)	TR	Thames River	0
Township of Middlesex Centre	Komoka		WWTP	189.1	Komoka WWTP (189.1km)	TR	Thames River	0
Township of Middlesex Centre	Kilworth Heights		WWTP	192.1	Kilworth WWTP (192.1km)	TR	Thames River	0
PWQMN-UTRCA	86	E008	WQ	194.2	Oxbow Cr (194.2km)	TR	Oxbow Creek	1.886
CoL	Ilderton		WWTP	194.2	Ilderton WWTP (194.2km)	TR	Oxbow Creek	30.61
CoL	Oxford		WWTP	200.9	Oxford WWTP (200.9km)	TR	Thames River	0
CoL	Byron	E002	WQ	202.2	Byron (202.2km)	TR	Thames River	0
CoL	Suspension		WQ	204.9	Suspension Br (204.9km)	TR	Thames River	0
CoL	Greenway		WWTP	207.5	Greenway WWTP (207.5km)	TR	Thames River	0
CoL	Coves		WQ	208.0	Coves (208km)	TR	The Coves	0.185
CoL	Wharncliffe		WQ	209.3	Wharncliffe (209.3km)	TR	Main Thames	0
CoL	Dundas		WQ	209.8	Dundas (209.8km)	NTR	North Thames	0
CoL	Medway	D008	WQ	214.1	Medway Cr (214.1km)	NTR	Medway Creek	0.793
Township of Lucan-	Granton		WWTP	214.1	Granton WWTP (214.1km)	NTR	Medway Creek	40.51

Monitoring Program	WQ-Stn	Flow-Stn[2]	Type	km	Common Name (River km)	Sec-tion	Receiver	Tributary Distance
Biddulph								
CoL	Richmond		WQ	214.4	Richmond (214.4km)	NTR	North Thames	0
PWQMN-UTRCA	96	D028	WQ	216.5	Stoney Cr (216.5km)	NTR	Stoney Creek	0.421
CoL	Adelaide		WWTP	217.5	Adelaide WWTP (217.5km)	NTR	Thames River	0
CoL	Clarke		WQ	223.1	Clarke CoL (223.1km)	NTR	North Thames	0
PWQMN-UTRCA	27	D003	WQ	223.1	Clarke (223.1km)	NTR	North Thames	0
PWQMN-UTRCA	98		WQ	226.1	Wye Cr (226.1km)	NTR	Wye Creek	1.981
Township of Thames Centre	Thorndale		WWTP	232.7	Thorndale WWTP (232.7km)	NTR	North Thames	0
PWQMN-UTRCA	50	D015	WQ	232.8	Thorndale (232.8km)	NTR	North Thames	0
PWQMN-UTRCA	95		WQ	241.9	Gregory Cr (241.9km)	NTR	Gregory Creek	0.255
PWQMN-UTRCA	90	D010	WQ	248.6	Fish Cr (248.6km)	NTR	Fish Creek	1.882
Nutrient Management	310002		WQ	248.6	Nineteen Cr (248.6km)	NTR	Nineteen Creek	6.76
PWQMN-UTRCA_Discontinued	15_45	D005	WQ	255.9	St. Marys (255.9km)	NTR	North Thames	0
PWQMN-UTRCA	64	D009	WQ	256.5	Trout Cr ds (256.5km)	NTR	Trout Creek	9.621
PWQMN-UTRCA	66	D019	WQ	256.5	Trout Cr us (256.5km)	NTR	Trout Creek	21.222
St.Marys, Town of	St.Marys		WWTP	256.5	St. Marys WWTP (256.5km)	NTR	Thames River	0.73
PWQMN-UTRCA	94		WQ	262.4	Otter Cr (262.4km)	NTR	Otter Creek	0.184
PWQMN-UTRCA	89		WQ	263.1	Flat Cr (263.1km)	NTR	Flat Creek	0.107
PWQMN-UTRCA	25	D018	WQ	265.9	Avon R ds (265.9km)	NTR	Avon River	16.806
Stratford, City of	Stratford		WWTP	265.9	Stratford WWTP (265.9km)	NTR	Avon River	18.10
Nutrient Management	310302	D026	WQ	265.9	Avon R us (265.9km)	NTR	Avon River	23.848
UTRCA Sites	Glengowan		WQ	268.0	NTR-Glengowan (268km)	NTR	North Thames	0
PWQMN-UTRCA	92		WQ	274.2	Black Cr (274.2km)	NTR	Black Creek	1.56
PWQMN-UTRCA	44	D014	WQ	285.0	Mitchell (285km)	NTR	North Thames	0
Mitchell, Town of	Mitchell		WWTP	285.2	Mitchell WWTP (285.2km)	NTR	North Thames	0.57
UTRCA Sites	Whirl		WQ	286.8	Whirl Cr (286.8km)	NTR	Whirl Creek	2.571
PWQMN-UT_Discontinued	93		WQ	286.8	Whirl Cr Historic (286.8km)	NTR	Whirl Creek	2.571

Monitoring Program	WQ-Stn	Flow-Stn[2]	Type	km	Common Name (River km)	Sec-tion	Receiver	Tributary Distance
CoL	York		WQ	210.2	York (210.2km)	STR	South Thames	0
CoL	Adelaide	D001	WQ	213.3	Adelaide (213.3km)	STR	South Thames	0
CoL	Vauxhaull		WWTP	214.8	Vauxhall WWTP (214.8km)	STR	Thames River	0
CoL	Pottersburg		WQ	217.7	Pottersburg Cr (217.7km)	STR	South Thames	0.515
CoL	Pottersburg		WWTP	217.7	Pottersburg WWTP (217.7km)	STR	South Thames	0
CoL	Whites		WQ	220.3	White's Br (220.3km)	STR	South Thames	0
PWQMN-UT	97	D020	WQ	222.5	Waubuno Cr (222.5km)	STR	Waubuno Creek	3.292
Township of Thames Centre	Dorchester		WWTP	231.0	Dorchester WWTP (231km)	STR	South Thames	2.58
PWQMN-UT	41	D004	WQ	240.3	Middle Thames (240.3km)	STR	Middle Thames River	6.877
Nutrient Management	34		WQ	240.3	Nissouri Cr (240.3km)	STR	Nissouri Creek, Middle Thames	22.729
UTRCA Sites	Mud		WQ	240.3	Mud Cr (240.3km)	STR	Mud Creek	29.888
Township of Zorra	Thamesford		WWTP	240.3	Thamesford WWTP (240.3km)	STR	Middle Thames River	9.29
Mount Elgin	Mount Elgin (Subsurface)		WWTP	241.6	Mt. Elgin WWTP (241.6km)	STR	To septic field	23.11
PWQMN-UT	91	D027	WQ	241.6	Reynolds Cr (241.6km)	STR	Reynolds Creek	2.117
PWQMN-UT	42	D016	WQ	247.0	STR-Ingersoll (247km)	STR	South Thames	0
Ingersoll, Town of	Ingersoll		WWTP	251.3	Ingersoll WWTP (251.3km)	STR	South Thames	0
Nutrient Management	310102		WQ	252.5	Halls Cr (252.5km)	STR	Trib (Halls Ck)	5.103
PWQMN-UT	17	D011	WQ	267.4	Cedar Cr (267.4km)	STR	Cedar Creek	0.681
PWQMN-UT	16	D012	WQ	267.6	Woodstock (267.6km)	STR	South Thames	0
Woodstock, City of	Woodstock		WWTP	269.3	Woodstock WWTP (269.3km)	STR	Thames River	0.20
PWQMN-UT_Discontinued	38	Pit	WQ	270.0	Woodstock Historic (270km)	STR	South Thames	0
PWQMN-UT_Discontinued	80	D021	WQ	282.6	Innerkip (282.6km)	STR	South Thames	0
East-Zorra	Tavistock		WWTP	282.6	Tavistock WWTP (282.6km)	STR	South Thames	28.20
PWQMN-	55		WQ	282.6		STR	South Thames	0

Monitoring Program	WQ-Stn	Flow-Stn[2]	Type	km	Common Name (River km)	Sec-tion	Receiver	Tributary Distance
UT_Discontinued					Tavistock Historic (282.6km)			
Nutrient Management	310202			282.7	Tavistock (282.7km)	STR	South Thames	27.93

[1]Mouth station loads were computed from prorated flows (T00B) of surrounding stations and water quality data from station 308202 at 14.8km
[2]EC flow station (HYDAT). Only the last 4 digits are noted, because they all belong to the subwatershed starting with 02G. T00B is modeled and Pit flows are provided by UTRCA

Map Notes

Water levels are monitored in the Thames River basin at a variety of strategic locations. Stations are funded and maintained by a combination of federal (Environment Canada, Water Survey Division) and provincial (Ministry of Natural Resources) agencies, and directly by Conservation Authorities in some cases (e.g. reservoir monitoring stations). Most of the stations are used for flood control programs, and are located up and downstream of major flood damage centres.

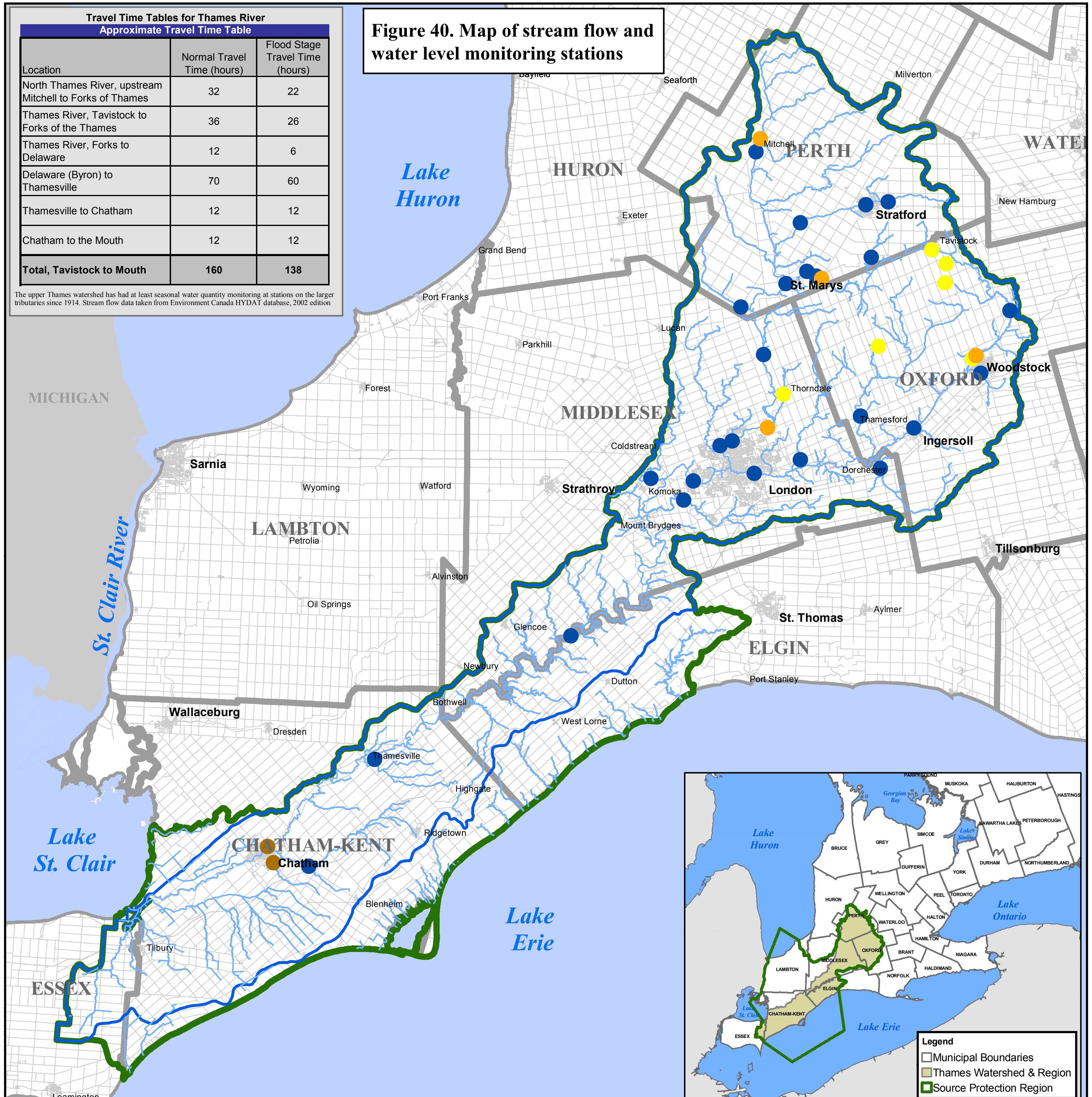
The MNR has recently renewed their interest in the gauge network, adding new stations and bringing some discontinued stations back on line.

Stations are monitored by the UTRCA and LTVCA, with hourly (or finer resolution) data archived. Environment Canada also monitors these stream flow stations, and analyzes and archives data in a mean daily and annual maximum/minimum format. Environment Canada data is also corrected for ice and weed effects, providing a more reliable data set than the CA can maintain, and is available for free as the HYDAT database. HYDAT generally lags behind the current year by a couple of years due to the time required to analyze and quality control the data collected.

Watercourse Information
Due to the complexity of the Thames River watershed watercourse network, only 3rd order and greater watercourses are shown.

Watershed Boundaries
Watershed boundaries shown are not precisely defined. The boundaries were originally created using watercourse and elevation information from 1:50,000 N.T.S. mapping.

Figure 40. Map of stream flow and water level monitoring stations



Travel Time Tables for Thames River

Approximate Travel Time Table

Location	Normal Travel Time (hours)	Flood Stage Travel Time (hours)
North Thames River, upstream Mitchell to Forks of Thames	32	22
Thames River, Tavistock to Forks of the Thames	36	26
Thames River, Forks to Delaware	12	6
Delaware (Byron) to Thamesville	70	60
Thamesville to Chatham	12	12
Chatham to the Mouth	12	12
Total, Tavistock to Mouth	**160**	**138**

The upper Thames watershed has had at least seasonal water quantity monitoring at stations on the larger tributaries since 1914. Stream flow data taken from Environment Canada HYDAT database, 2002 edition

Thames River Watershed Stream Flow and Water Level Monitoring Stations

Water Quality Assessment in the Thames River Watershed

N W E S

0 5 10 20 30 40 km

Legend
- Thames Watershed & Region
- Thames Watershed Boundary
- Municipal Boundaries

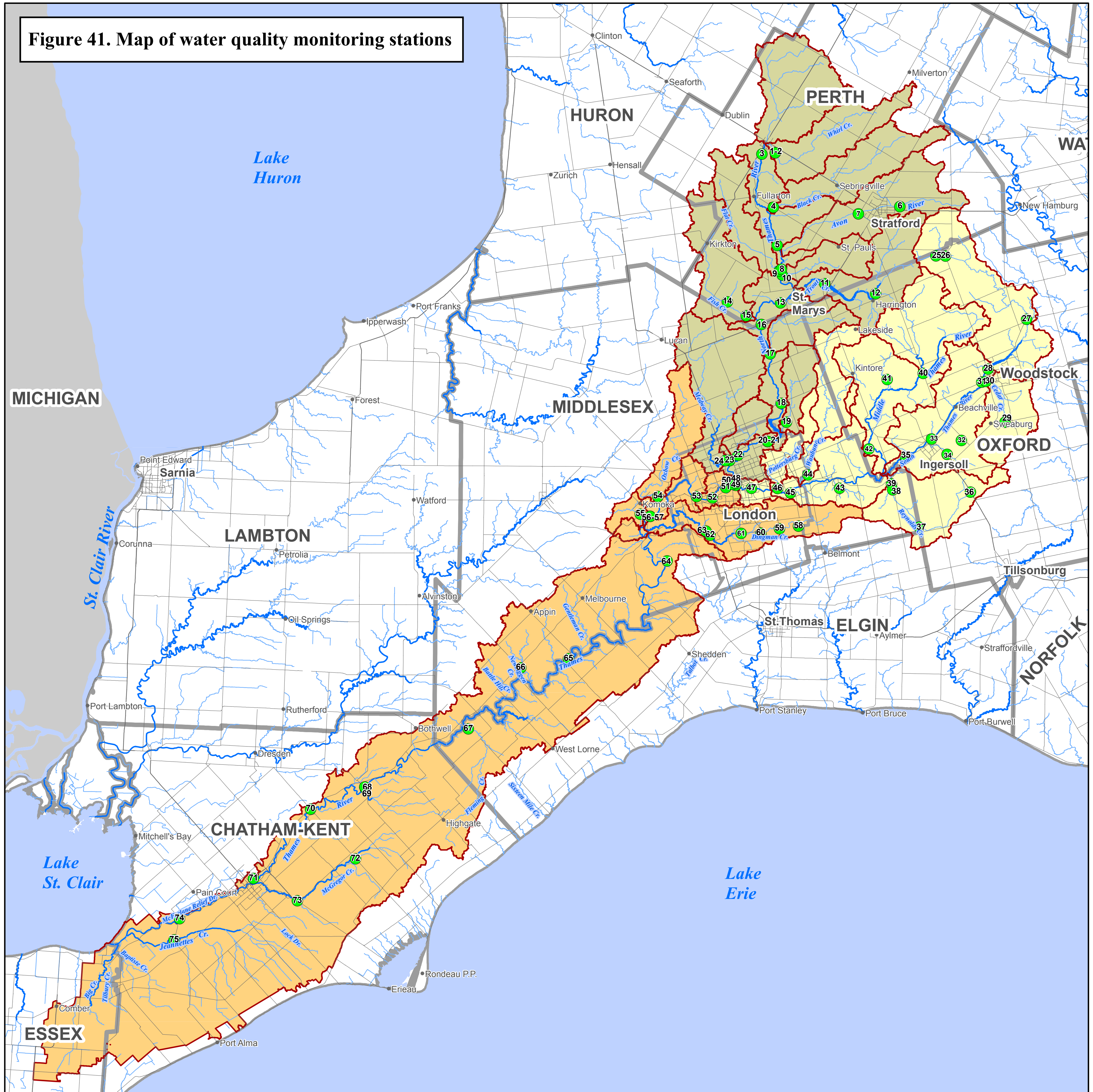
Gauge Site
- Flow
- Water Level
- Reservoir Monitoring
- Historical Stream Gauges

Map Source: Watershed Characterization Report Thames Watershed & Region (Upper Thames River & Lower Thames Valley Source Protection Areas) Document Reference 2.3.3.4 Mean Monthly Flows at Representative Gauges

Map created by UTRCA, August 2007.
Base mapping produced under license with the Ontario Ministry of Natural Resources © 2005.
Stream gauges maintained by Environment Canada and Upper Thames River and Lower Thames Valley Conservation Authorities.

Label	Water Quality Monitoring Site	km from Mouth
1	Whirl Cr Historic	286.8
2	Whirl Cr	286.8
3	Mitchell	285
4	Black Cr	274.2
5	NTR-Glengowan	268
6	Avon R us	265.9
7	Avon R ds	265.9
8	Road 133	263.6
9	Flat Cr	263.1
10	Otter Cr	262.4
11	Trout Cr ds	256.5
12	Trout Cr us	256.5
13	St. Marys	255.9
14	Nineteen Cr	248.6
15	Fish Cr	248.6
16	Dstr St. Marys	247.2
17	Gregory Cr	241.9
18	Thorndale	232.8
19	Wye Cr	226.1
20	Clarke CoL	223.1
21	Clarke	223.1
22	Stoney Cr	216.5
23	Medway Cr	214.1
24	Richmond	214.4
25	Innerkip	282.6
26	Tavistock Historic	282.6
27	Tavistock	282.7
28	Woodstock Historic	270
29	Cedar Cr Historic	267.4
30	Cedar Cr	267.4
31	Woodstock	267.6
32	Foldens Cr	254.9
33	Ingersoll Historic	253.1
34	Halls Cr	252.5
35	Ingersoll	247
36	Reynolds Historic1	241.6
37	Reynolds Historic2	241.6
38	Reynolds Historic3	241.6
39	Reynolds Cr	241.6
40	Mud Cr	240.3
41	Nissouri Cr	240.3
42	Middle Thames	240.3
43	Dorchester Swamp Cr	228.5
44	Waubuno Cr	222.5
45	WhiteÃ¢â‚¬â„¢s Br	220.3
46	Pottersburg Cr	217.7
47	Adelaide	213.3
48	Dundas	209.8
49	York	210.2
50	Wharncliffe	209.3
51	Coves	208
52	Suspension Br	204.9
53	Byron	202.2
54	Oxbow Cr	194.2
55	Komoka Cr	185.7
56	Th. Komoka CoL	189.1
57	Th. Komoka	189.1
58	Dingman-Old Victoria	186.5
59	Dingman-Highbury	186.5
60	Dingman-Wel.Historic	186.5
60	Dingman-Wellington	186.5
61	Dingman-Dingman Dr	186.5
62	Dingman-Lambeth	186.5
63	Dingman Cr	186.5
64	Giles	173
65	Currie Rd	127.2
66	Newbiggen Cr	115.2
67	Fleming Cr	89.8
68	Thamesville	65.2
69	White Ash Cr	65
70	Kent Bridge	49.7
71	Chatham	30.8
72	McGregor Historic	29.7
73	McGregor Cr	29.7
74	Jacob Rd	14.8
75	Jeannettes Cr	3.5

Figure 41. Map of water quality monitoring stations



Thames River Watershed Water Quality Monitoring Stations

Water Quality Assessment in the Thames River Watershed

N S W E

20 10 0 20 km

Legend

- Water Quality Monitoring Stations
- Subwatersheds
- Municipal Boundaries

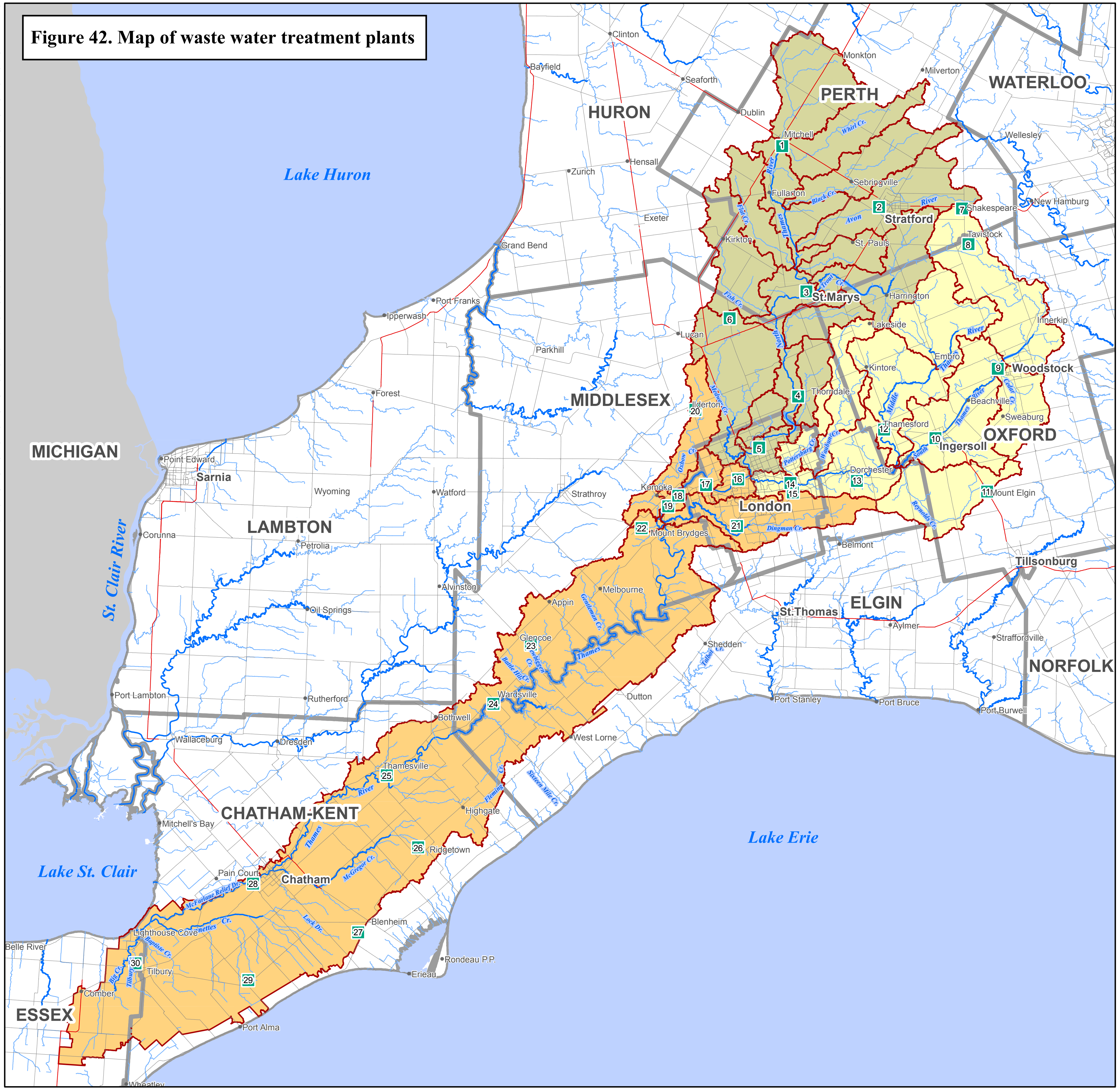
Major Watersheds

- North Thames River (NTR)
- South Thames River (STR)
- Thames River (TR)

Map created by UTRCA, October, 2014
Base mapping provided by Land Information Ontario.

Label	Waste Water Treatment Plant	Km from Mouth
1	Mitchell	285.2
2	Stratford	265.9
3	St.Marys	256.5
4	Thorndale	232.7
5	Adelaide	217.5
6	Granton	214.1
7	Shakespeare	282.6
8	Tavistock	282.6
9	Woodstock	269.3
10	Ingersoll	251.3
11	Mount Elgin	241.6
12	Thamesford	240.3
13	Dorchester	231
14	Pottersburg	217.7
15	Vauxhaull	214.8
16	Greenway	207.5
17	Oxford	200.9
18	Kilworth Heights	192.1
19	Komoka	189.1
20	Ilderton	194.2
21	Southland Park	186.5
22	Mount Brydges	185
23	Wardsville	93.4
24	Glencoe	115.2
25	Thamesville	65.2
26	Ridgetown	29.7
27	Blenheim	29.7
28	Chatham	25
29	Merlin	3.5
30	Tilbury	1.3

Figure 42. Map of waste water treatment plants



Thames River Watershed Waste Water Treatment Plants

Water Quality Assessment in the Thames River Watershed

N W E S

20 10 0 20 km

Legend

- Waste Water Treatment Plants
- Subwatersheds
- Municipal Boundaries

Major Watersheds

- North Thames River (NTR)
- South Thames River (STR)
- Thames River (TR)

Map created by UTRCA, October, 2014
Base mapping provided by Land Information Ontario.

Appendix B: Methods for calculating loads and flow-weighted average concentration

All computations and data analyses were done using R version 3.1.0 (2014, The R Foundation for Statistical Computing) with additional CRAN (Comprehensive R Archive Network) packages.

Data from the period 1986-01-01 to 2012-12-31 was used for analysis.

As high quality hydrology data was usually available in daily increments, we chose daily increments for load calculations, and simply summed the daily load values to reach annual, seasonal or monthly totals. Daily load is total daily flow (L/d) times daily average chemical concentration (mg/L) at the same (or a nearby) location. By far, the major error associated with this calculation is the estimate of daily average chemical concentration, as discussed later.

Hydrology

Not all hydrology stations had complete records over the 1986-2012 period of interest. In particular, the Environment Canada data lacked 2012. However UTRCA data for the Environment Canada stations were available for 2012 and merged.

UTRCA data for Fanshawe, Pittock and Wildwood dam outflows were also examined as Federal data for these stations was not available. The 1990 Wildwood flows were all zero, apparently in error; these were set to “missing”. There was a substantial amount of other missing data as well which could not be easily filled in with data from other sites because of the uniqueness and unpredictability of dam outflow operation. As a result Fanshawe and Wildwood dam outflows were not used in this analysis. Other close downstream flow stations were used instead. But we could not find a close-by downstream flow station to substitute for the Pittock dam outflow; consequently only five years where there are no missing flow records are used in the analysis of the Pittock dam outflow.

To fill in missing data at other stations we used two methods. For short time periods with steady flows or steadily changing flows and no evidence of peaks or dips (at other stations), we used simple linear interpolation (e.g., hydrologic stations: D005, D018). For longer periods of missing data with evidence of changing flows, peaks or dips (at other stations), we consulted with Mark Helsten (UTRCA hydrologist) and also constructed a non-parametric correlation matrix (Kendall's tau) between all hydrology stations to determine a surrogate station to fill in data.

LOWESS regression is one method of using a surrogate station to fill in flow data. According to the USGS Hydrology manual in reference to filling in missing hydrology data: “LOWESS would be a sensible alternative here due to the nonlinearity of the relationship. In studies where many data sets are being analyzed, and individualized checking of multiple models is impractical, LOWESS is the method of choice. It is also valuable when transformation of Y to achieve normality is not desirable” (Helsel and Hirsch, 2002). Since then, newer and faster smoothing techniques have become available. We used GAM regression (General Additive Model) with smoothing as implemented in R's mgcv package. The predictions of the GAM with smooth model are local, and the "degree of smoothness of model terms is estimated as part of fitting". Our GAM linear model used a smoothed function of the surrogate station's flow with the default "isotropic thin plate regression spline" smoother to predict missing data in the station of interest.

Because the surrogate flow station could be missing data on some of the same days we needed to predict, there were stations with missing data even after GAM was used for filling in (Table 1). So we repeated the process. If the remaining, missing time period was short (periods with steady flows or steadily changing flows, no evidence of peaks or dips at other stations), we used simple linear interpolation as before (D009). But for the others we used a second surrogate (usually D004) to fill in (D013, D027, D028, E007, E008).

Table 1. Number of Missing Days and Surrogate Stations used

Station	#NA,days	First run	#NA,days	Second run
D001	0			
D003	1621	Fan	0	
D004	0			
D005	1	Lin. Interp.	0	
D008	156	D004	0	
D009	5513	Wwd	55	Lin. Interp.
D010	4067	D015	0	
D011	35	D004	0	
D012	5389	D016	0	
D013	7895	D008	156	D004
D014	0			
D015	0			
D016	0			
D018	1	Lin. Interp.	0	
D019	1615	D018	0	
D020	449	D004	0	
D021	672	D004	0	
D026	6942	D018	0	
D027	6109	D011	33	D004
D028	6212	D008	156	D004
E002	0			
E003	0			
E005	559	D004	0	
E006	70	E003	0	
E007	2647	E008	1363	D004
E008	6111	D008	156	E002

Further, an additional hydrological station was constructed to represent the mouth of the Thames River where it enters Lake St. Clair. T00B takes the Thamesville flow (E003) and adds flow of the whole watershed area below Thamesville that is prorated from McGregor Creek (E007). The areal pro-rating uses the following formula from Mark Helsten (UTRCA Hydrologist): ((predicted flow drainage area)/(gauged flow drainage area))^0.8.

Chemistry

Data sources and station location for the water quality (chemistry) variables are listed in Appendix A.

Data from stations “45“ and “15“ were merged to form “45M“.

Additional data from the City of London was added to “27“, “47“, “96“ creating “27M”, “47M” and “96M”.

As well, chemistry data from the following stations (abbreviated to six characters) was obtained from the City of London: "Potter", "Whites", "Byron", "Medway", "Spring", "Richmo", "York", "Wharne", "Dundas", "Adelai", "Coves", "Oldvic", "Highbu", "Dingma", "Wellin", "Lambet", "Giles".

The chemical parameters used from these files, with our abbreviations, and summary variables we created (all units are mg/L) are:

tss = “RESIDUE,PARTICULATE"

tp = “PHOSPHORUS,UNFILTERED TOTAL”

drp = “PHOSPHATE,FILTERED REACTIVE” or “PHOSPHATE,UNFILTERED REACTIVE”

tkn = “NITROGEN,TOT,KJELDAHL/UNF.REA”

no2 = “NITRITE, UNFILTERED REACTIVE”

no3 = “NITRATE, UNFILTERED REACTIVE"

no32 = “NITRATES TOTAL, UNFIL.REAC"

no32 = no3 + no2 (Only if no32 is missing. If no3 is missing, no32 remains missing. If no2 is missing, no32 is set to no3.)

tn = tkn + no32 (If either tkn or no32 is missing, tn is missing.)

In subsequent analyses we did not use no3, no2, or tkn, only no32 and tn.

The chemistry data was inspected for extreme outliers which were then deleted (Table 2).

For some stations and years, very little and sometimes no chemistry was available. We discarded all load estimates for years where only 3 or fewer chemical samples were available.

Table 2. Deleted chemical variables

stn	date	Var	stn	date	var
16	1991-10-22	tp	305802	1993-05-25	tp
17	2003-03-26	tn	305802	1993-05-25	tss
17	2003-03-26	no32	Spring	2010-05-03	tp
25	1993-06-22	tn	303402	2006-03-23	tp
25	1993-06-22	no32	303402	2006-04-24	drp
27	1994-01-18	tss	303402	2006-05-08	tp
38	1988-01-20	tp	303402	2007-05-15	drp
38	1994-05-18	tp	303402	2007-05-16	drp
41	1986-09-17	tp	303402	2009-05-08	drp
42	1993-02-17	tss	303402	2007-05-15	nh4
44	1989-07-18	tp	303402	2007-05-16	nh4
44	2000-06-13	tp	303402	2009-05-08	nh4
44	2000-06-13	tss	303402	2007-05-15	no32
44	2002-09-11	tp	303402	2007-05-16	no32
44	2002-09-11	drp	303402	2009-05-08	no32
50	1993-06-22	tn	303402	2007-05-15	tn
50	1993-06-22	no32	303402	2007-05-16	tn
63	2003-08-26	tp	303402	2009-05-08	tn
63	2003-08-26	tss	303402	2011-04-27	tp
64	1998-07-13	tn	303402	2012-10-24	tp
64	1998-07-13	no32	303402	2012-10-25	tp
66	1993-06-22	tn	305802	1993-05-25	tn
66	1993-06-22	no32	310102	2011-06-07	tp
80	1989-03-28	tp	310102	2011-06-07	tss
80	1995-04-27	tp	310102	2006-03-13	tp
89	2010-09-28	tp	310102	2006-04-10	tp
92	2012-10-31	tn	310102	2006-05-08	tp
92	2012-10-31	no32	310102	2006-05-15	tp
95	2005-07-26	tp	29	1990-10-17	tp
95	2005-07-26	drp	29	1999-07-12	drp
96	2005-05-24	tss	305702	2012-08-13	drp
97	2005-09-27	tss	307302	2006-08-30	drp
97	2005-09-27	tp	310002	2006-04-10	tp
98	2005-03-29	tss	310002	2006-05-08	tp
98	2011-09-26	tp	310002	2006-05-15	tp
98	2011-09-26	drp	310002	2006-05-23	tp
303402	2007-05-15	tp	310302	2006-05-08	tp
303402	2007-05-16	tp	308202	2011-05-31	tp
303402	2009-05-08	tp			

Estimates of Daily Loads and Chemistry

Hydrology stations were assigned to chemical stations as shown (Table 3).

Table 3. Assignment of Hydrology to Chemistry Stations

FlowStn	ChemStn	Chem_km	FlowArea	ChemArea	FlowCorrect
T00B	308202	0	4689.3	4689.3	1
E007	308102	29.744	203.8	203.8	1
E003	305802	49.69	4370.37	4534.5	1.029933
E006	308302	127.192	3815.71	3815.71	1
E005	29	186.451	148.84	136.3	0.932011
E008	86	194.213	85.46	87.97	1.023428
E002	Byron	202.225	3082.61	3088.97	1.00165
D008	Medway	214.131	200.94	200.94	1
D028	96	216.479	38.14	38.52	1.007963
D028	96L	216.479	38.14	38.52	1.007963
D028	96M	216.479	38.14	38.52	1.007963
D003	27	223.063	1424.58	1426.72	1.001202
D003	27L	223.063	1424.58	1426.72	1.001202
D003	27M	223.063	1424.58	1426.72	1.001202
D015	50	232.806	1328.65	1344.71	1.009658
D010	90	248.583	151.57	151.57	1
D005	15	255.907	1080	883	0.851196
D005	45	255.907	1080	1071	0.993328
D005	45M	255.907	1080	1071	0.993328
D009	64	256.507	150.39	145.25	0.972563
D019	66	256.507	44	44	1
D018	25	265.944	133.46	107.83	0.843162
D026	310302	265.944	50.36	50.36	1
D014	44	284.953	310.9	310.9	1
D001	Adelai	313.327	1340.42	1345.5	1.003031
D020	97	322.536	97.38	97.38	1
D004	41	340.267	290.58	306.34	1.043159
D027	91	341.594	146.33	146.33	1
D016	42	347.04	514.09	550.23	1.055855
D011	17	367.446	87.28	97.61	1.093613
D012	16	367.579	254	272.82	1.058849
Pit	38	370	244.9	244.9	1
D021	80	382.641	148.23	148.23	1

Not all chemistry stations could be reasonably associated with available flows, and vica-versa, so no loads were calculated for these. When flow and chemistry stations were not at the same location, flows at the nearest flow station were adjusted to correspond to the chemistry station drainage area using the following formula from Mark Helsten (UTRCA Hydrologist): ((chem station drainage area)/(flow station drainage area))^0.8. The only exception was at the mouth of the Thames River where it enters Lake St. Clair. There the chemistry was obtained from a station (308202) upstream and the flow at the mouth was separately calculated as explained earlier.

We used several different methods to estimate daily chemical concentrations for daily loads. The simplest, and the one used earlier in the Upper Thames study (FWR, 2005, 2006), uses linear interpolation between each sampling date without any dependency of chemistry on flow. The daily average chemistry so obtained was then multiplied by the appropriate station's daily flow (Table 3) to obtain daily load. Monthly and annual loads were summed from daily loads. Monthly and annual flow-weighted average concentrations are monthly and annual loads divided by the monthly and annual total flows respectively.

The other methods for estimating daily average chemistry used chemical relationships with flow. Generally, we expect in river systems that tss will increase with flow as sediment and bank erosion increases. tp is expected to increase as well, given phosphate's ability to bind with sediments and soil oxide/hydroxides and the abundance of organic phosphorus in sediment and soil particulate matter. Other variables may decline because of dilution. And all may exhibit unknown complicated relationships with flow.

Preliminary investigation of the Thames River stations showed weak and often non-linear relationships between logarithmically transformed chemistry and logarithmically transformed flow rates. An example from chemistry station 25 and flow station D018 illustrates this (Figure 1a, b). As these plots include data from 1986 to 2012, it is possible that the relationships have changed with time, sampling and analytical methods. Whatever relationship does exist appears complex and not easily described with parametric equations covering the whole data set. It also appears that nitrogen parameters have the least obvious relationship with flow. However chemistry station 305802 versus hydrology station E003 is an example where tn and no32 also vary with flow (Figure 2a, b), perhaps because of biological uptake at low summer flows.

Perhaps the greatest weakness in these flow versus chemistry relationships is the lack of chemical samples at extreme flow rates. Literally every method for analyzing these relationships has some difficulty extrapolating predicted chemistry at flow rates greater or lesser than those for which there is chemical data. In general, chemical sampling with an emphasis on the full range of flows helps define any relationships with flow.

Several methods for estimating flow-based daily chemistry and loads were explored. LOADEST (Runkel, R.L., C.G. Crawford, and T.A. Cohn, 2004) is a commonly used USGS program that provides statistical confidence limits appropriate to the distributional assumptions made. But overall, LOADEST proved unusable for this study: it has difficulty (crashes or returns errors) when extrapolating much beyond the calibration data set; it assumes a flow-chemistry relationship that can be described simply and parametrically (typically a linear or quadratic relationship between logged variables); it assumes a constant flow/chemistry relationship over time; and transforming the data so that the distributional assumptions are met can be difficult and time-consuming.

For our purposes, a more recent USGS program Weighted Regressions on Time, Discharge, and Season, WRTDS) that is implemented in R as the EGRET (Exploration and Graphics for RivEr Trends) library is most useful. (The USGS program is described by Hirsch et al. 2010 and Sprague et al. 2011.)

WRTDS makes no distributional assumptions and no assumptions about the shape of any relationship between chemistry and flow. It explicitly includes long-term and seasonal changes. The EGRET implementation of WRTDS is very demanding of the input data set. The authors recommend a minimum of 20 years of data and at least 200 individual samples. Although we were able to reduce these limits to 7 years and about 100 samples with reasonable results, there were still about twenty stations which EGRET refused to analyze because of low sample sizes. These high data requirements allow EGRET to better extrapolate chemistry in extreme flow situations, but the authors still state that for best results "We would like to see the samples cover much of the full range and be somewhat weighted towards the higher discharges."

As with the simpler, non-flow-based Linear Interpolation method, EGRET estimated daily average chemical concentrations were multiplied by the daily flow to get daily loads. The daily loads were then summed to get monthly and annual loads. Dividing these loads by total flow for the period gave monthly, seasonal and annual flow-weighted average estimates of the chemical parameter.

For all stations and especially those with fewer samples where EGRET did not run, we also used a GAM optimally weighted local regression after log-log transformations of flow and chemistry. The model used the GAM default thin plate regression spline ("s") and GAM default non-isotropic tensor product splines ("te"). We included date and log daily flow as variables in the "te" multi-variable smooth. Sinusoidal seasonal terms could not be added to the multi-variable smoother because of low sample size, so they were separately added to the model and smoothed using the default "s" smoother: log(chem) ~ s(sin(2*pi*t),k=4) + s(cos(2*pi*t),k=4) + te(date,log(daily flow),k=4), where t is the day of the year. The basis (k) of all smooths was set to four which gave a model rank of 22. Examination of residuals and predicted values indicated that k=4 would usually give a reasonable smooth; also, with higher values of k, some stations could not be computed because of low sample size.

Because the GAM model was explicitly created to provide flow-based daily concentrations for stations with low sample size where EGRET would not run, it is not as "robust" or sophisticated as EGRET. Thus loads based on GAM, and flow-weighted averages computed from these loads, should be treated with caution especially when the station has a low sample size.

On average, EGRET estimated loads are higher than GAM (or the simpler method of non-flow-based LINEAR loads), as are the annual flow-weighted averages computed from loads (Figure

3a,b; colours represent different stations). GAM is also generally higher than non-flow-based LINEAR loads and flow-weighted averages (Figure 4a,b). When all data is taken together, the annual flow-weighted average differences are significant (Wilcoxon Signed Rank Test with Paired Samples). For EGRET versus GAM the median annual flow-weighted average differences are tss (+18%), tp (+13%), drp (+34%), tn (+1%), no32 (+4%). For GAM versus Linear Interpolation the differences are tss (+23%), tp (+21%), drp (+35%), tn (+11%), no32 (+11%).

In general, when chemistry has little relationship with flow, as is often the case with tn or no32 (Figure 1b), the differences between estimation methods are smaller. But the flow-based estimates (EGRET and GAM) are always higher on average than the non-flow-based LINEAR method, probably because LINEAR misses too many peak flows with higher concentrations.

The differences in load estimation methods also vary from station to station. This can be seen, for example, in the graphs for individual stations D018 - 25 (on the Avon River, Figure 5a, b) and E003 - 305802 (on the Thames River at Thamesville, Figure 6a, b).

Clearly, when comparing station loads or flow-weighted averages, it is preferable to use the same method (EGRET, GAM or Linear Interpolation) to avoid discrepancies due to the methodology.

References for this appendix

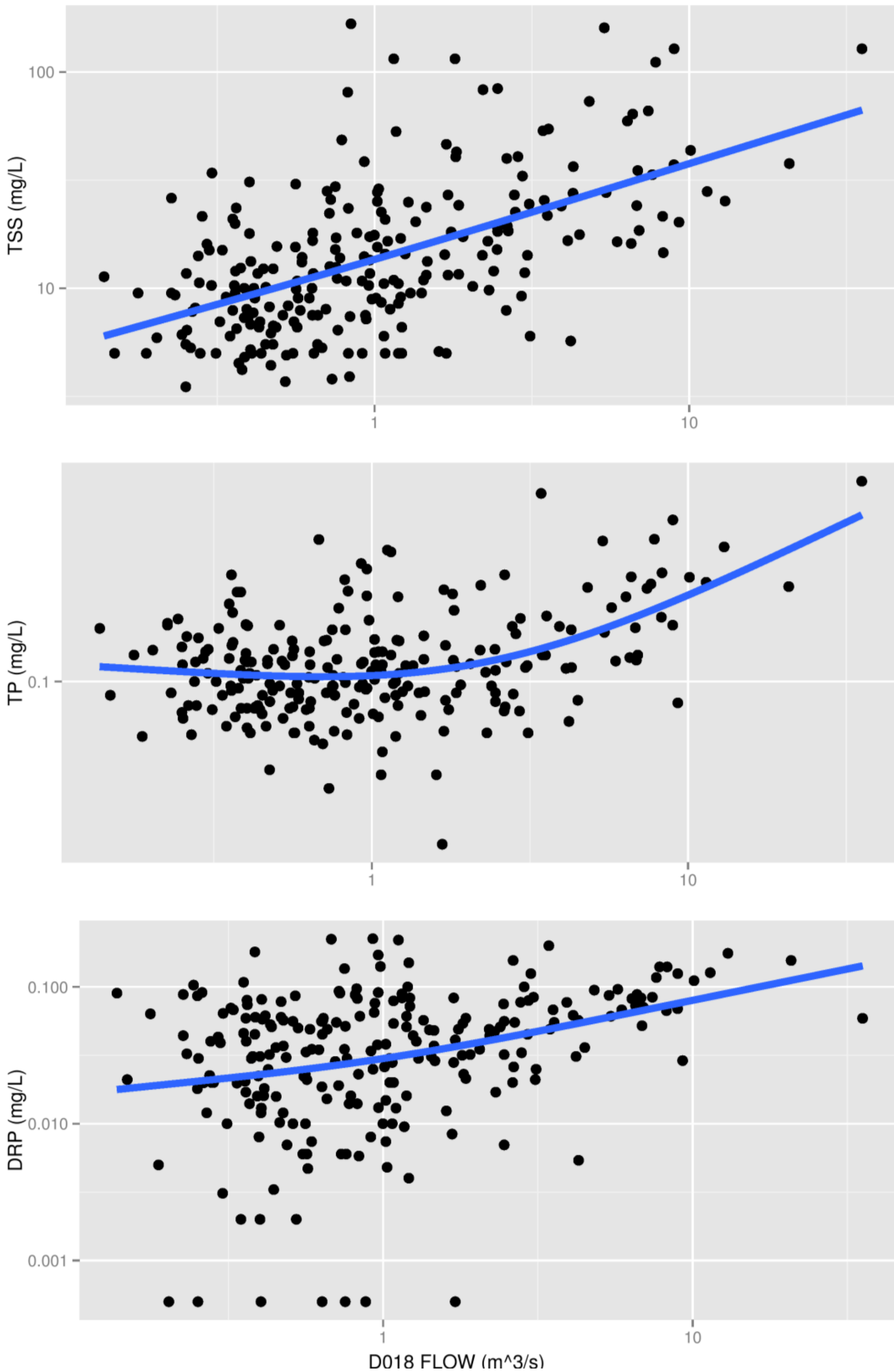
Helsel, D.R. and R.M. Hirsch, 2002. Statistical Methods in Water Resources, Chapt. A3 *Techniques of Water-Resources Investigations of the United States Geological Survey*, Book 4, *Hydrologic Analysis and Interpretation*, 336 p.

Hirsch, R. M., D.L. Moyer and S.A. Archfield, 2010. Weighted Regressions on Time, Discharge, and Season (WRTDS), with an application to Chesapeake Bay River inputs. J. American Water Resources Association (JAWRA) 46: 857-880.

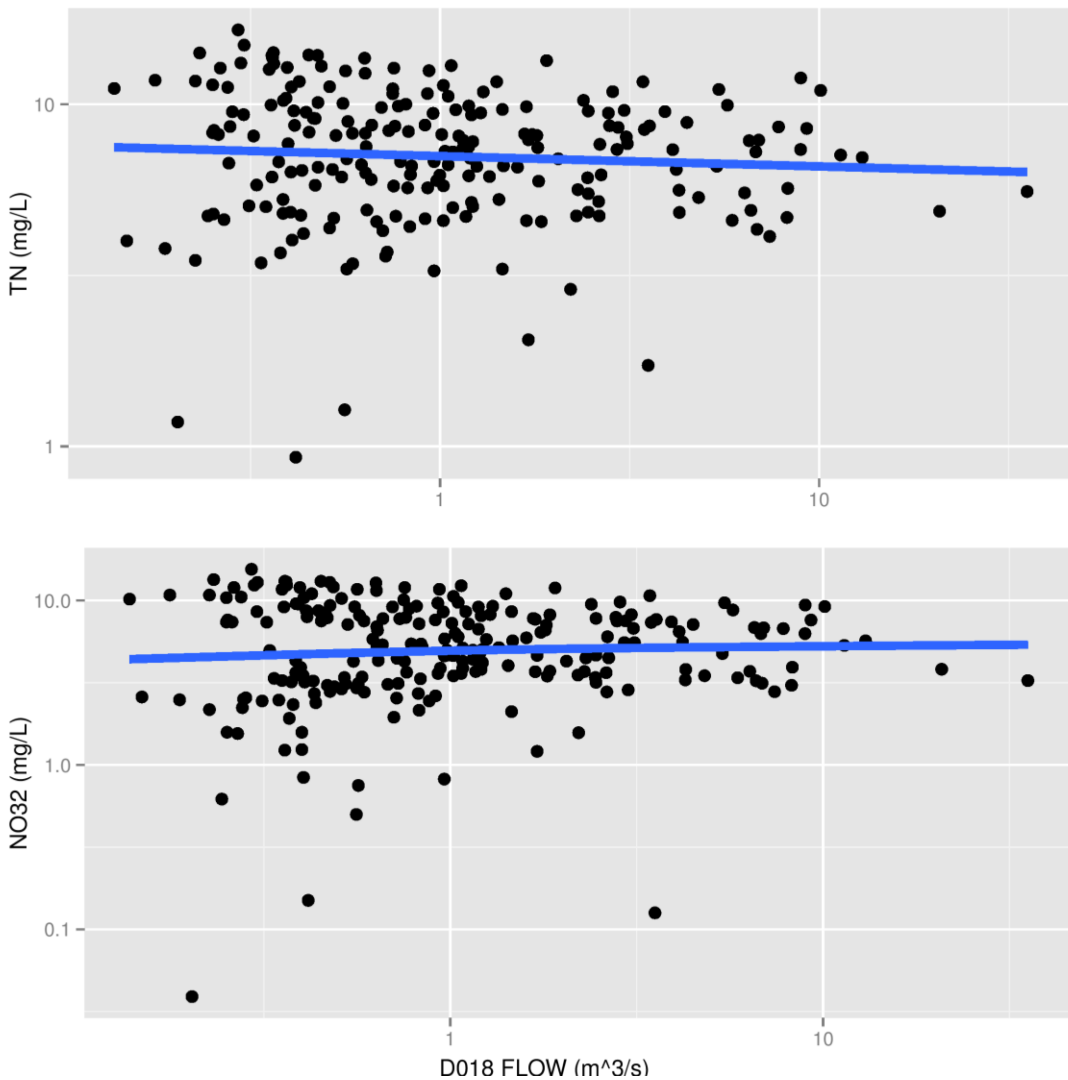
Runkel, R.L., C.G. Crawford and T.A. Cohn, 2004. Load Estimator (LOADEST): A FORTRAN Program for Estimating Constituent Loads in Streams and Rivers, U.S. Geological Survey Techniques and Methods, Book 4, Chapter A5, 75 p.

Sprague, L.A., R.M. Hirsch and B. T. Aulenbach, 2011. Nitrate in the Mississippi River and its tributaries, 1980 to 2008: Are we making progress? Environ. Sci. Technol. 45: 7209–7216.

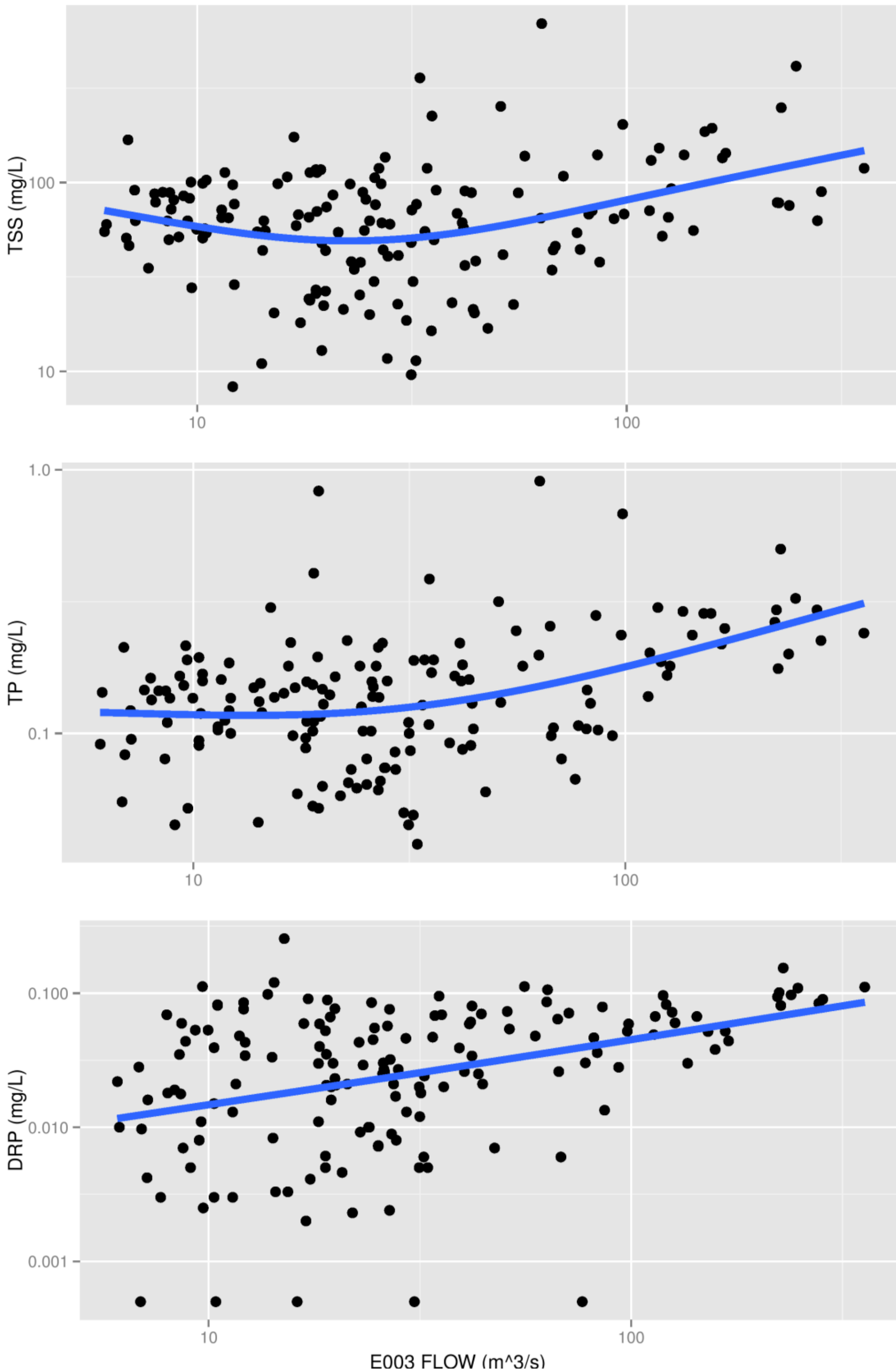
App-Figure 1a. Flow vs TSS, TP and DRP for D018 - 25 with smoothed line



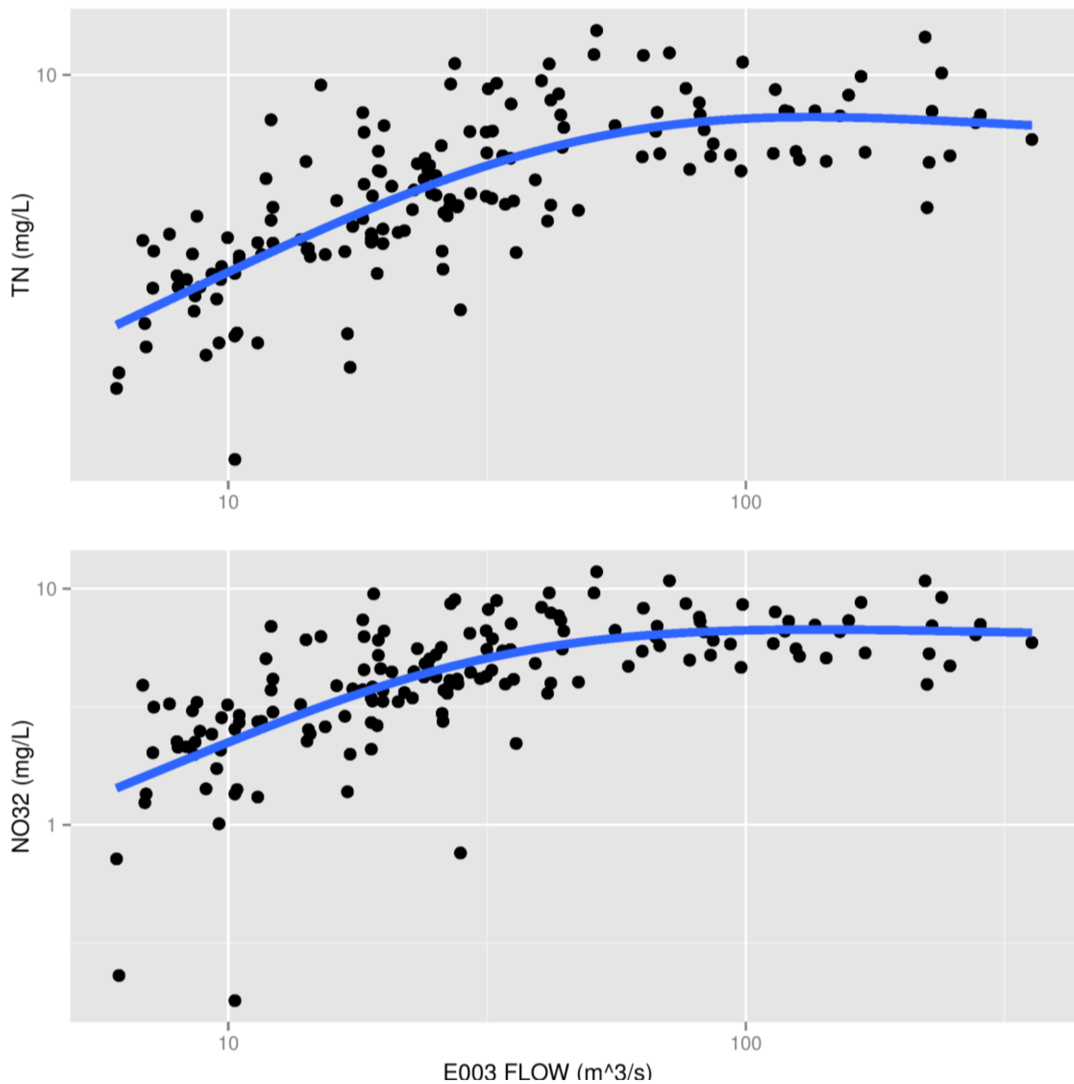
App-Figure 1b. Flow vs TN and NO32 for D018 - 25 with smoothed line



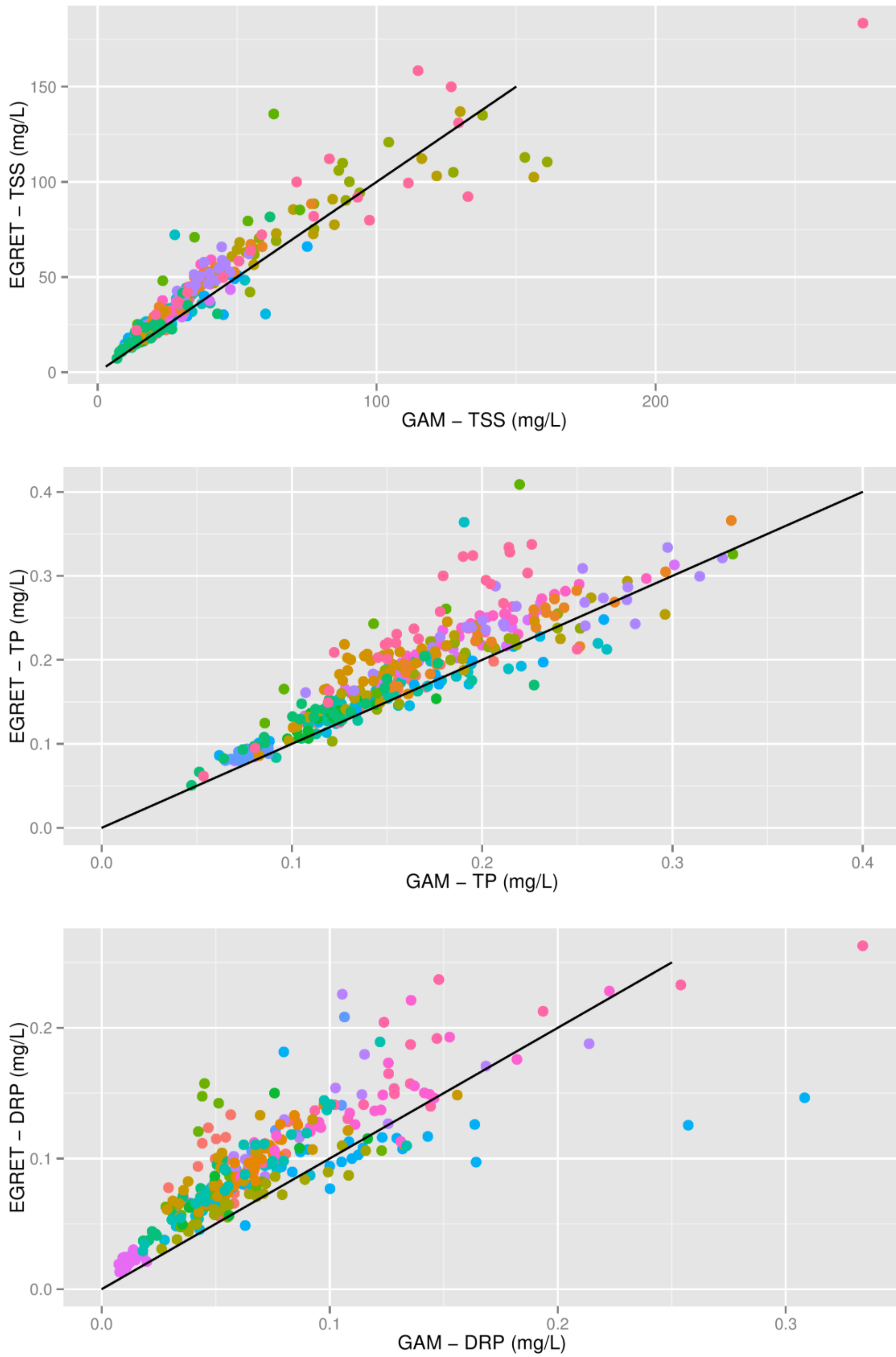
App-Figure 2a. Flow vs TSS, TP and DRP for E003 - 305802 with smoothed line



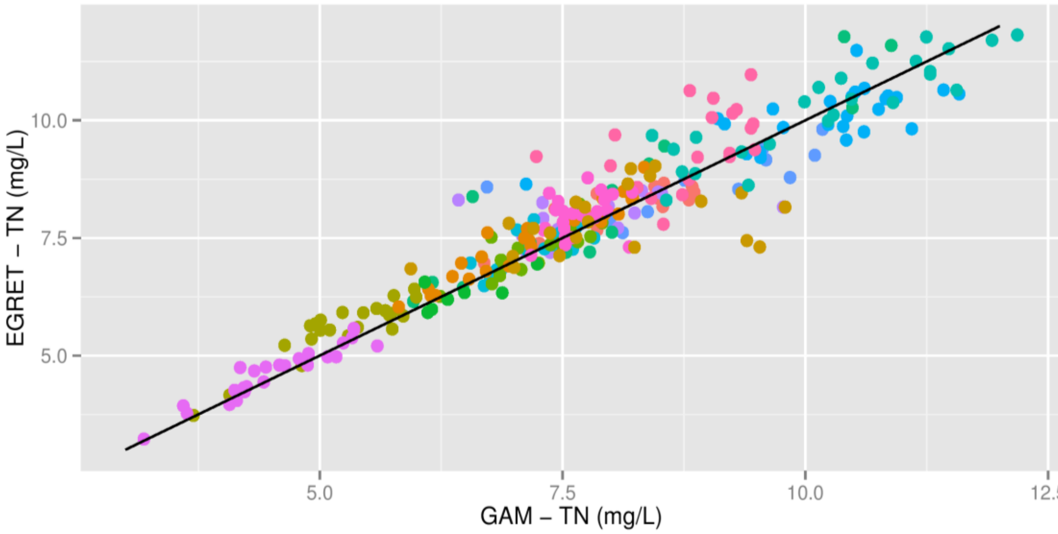
App-Figure 2b. Flow vs TN and NO32 for E003 - 305802 with smoothed line

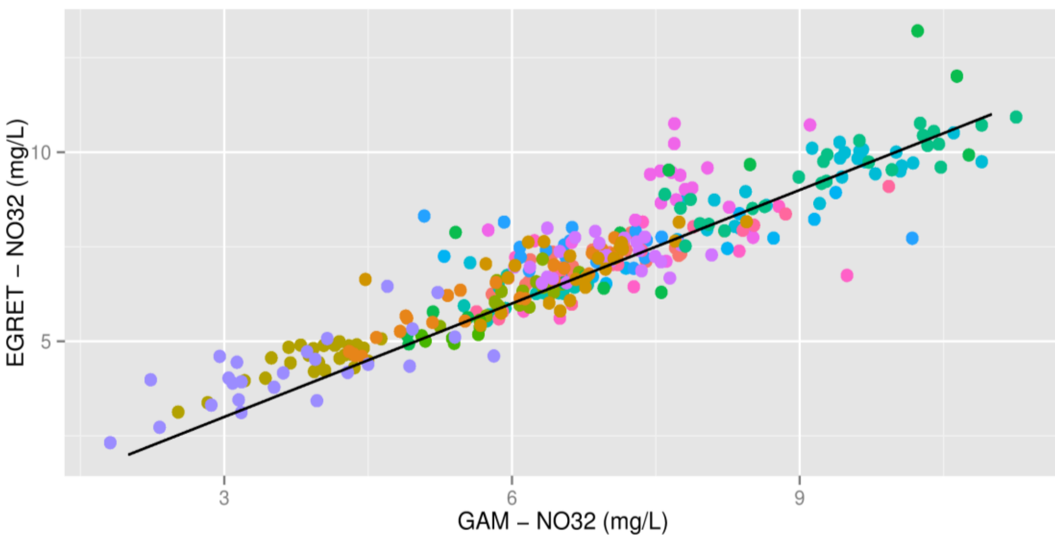


App-Figure 3a. EGRET versus GAM model for TSS, TP and DRP with 1:1 line

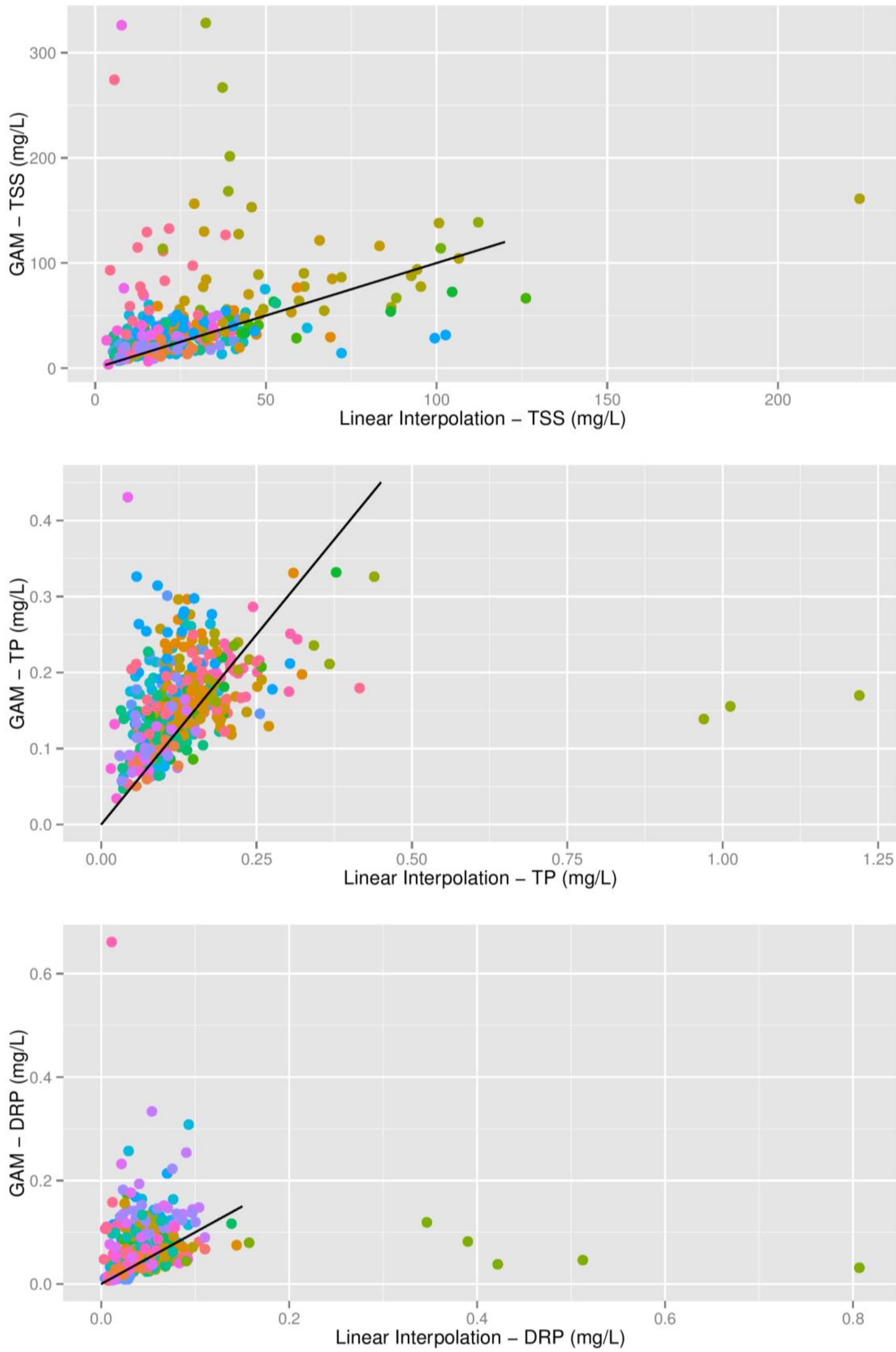


App-Figure 3b. EGRET versus GAM model for TN and NO32 with 1:1 line

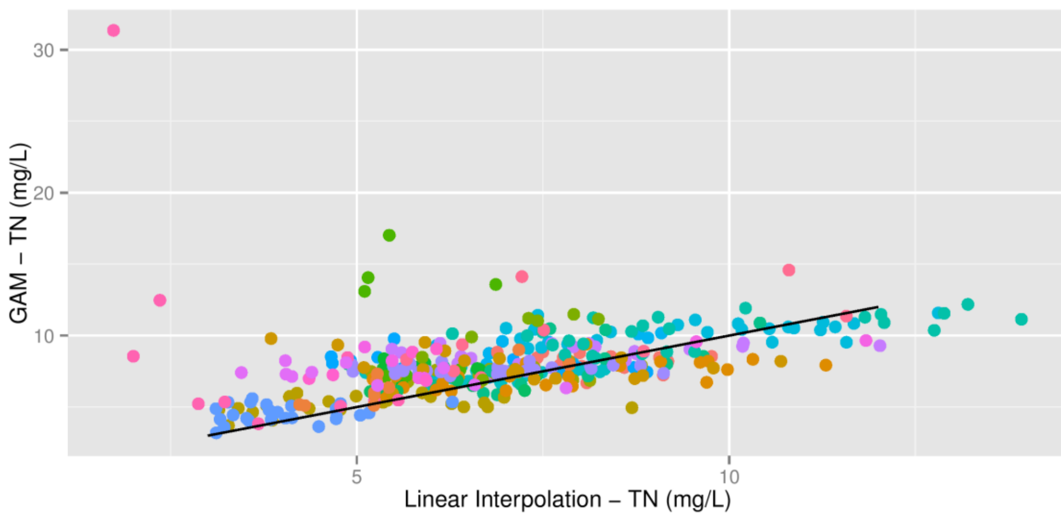


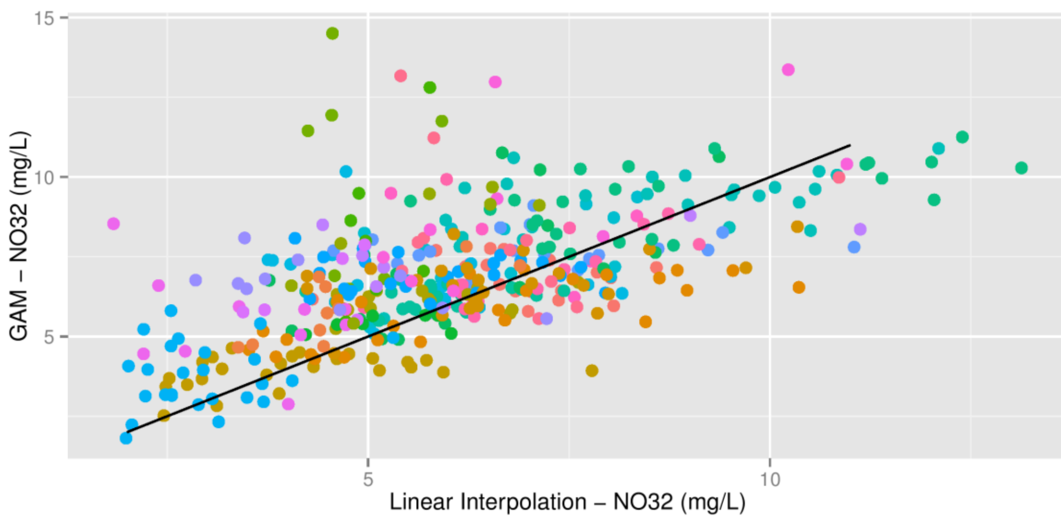


App-Figure 4a. GAM vs LINEAR model for TSS, TP and DRP with 1:1 line

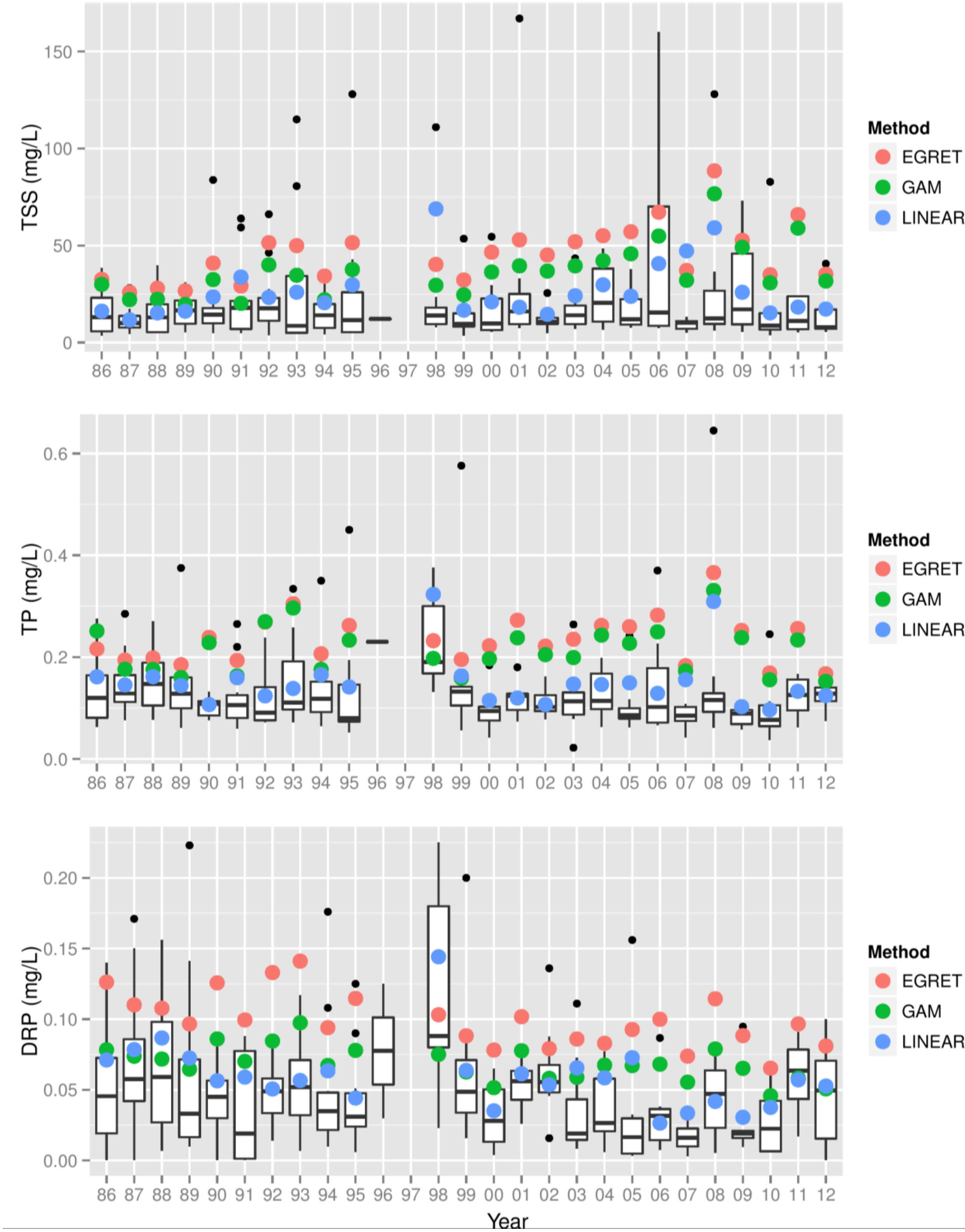


App-Figure 4b. GAM vs LINEAR model for TN and NO32 with 1:1 line

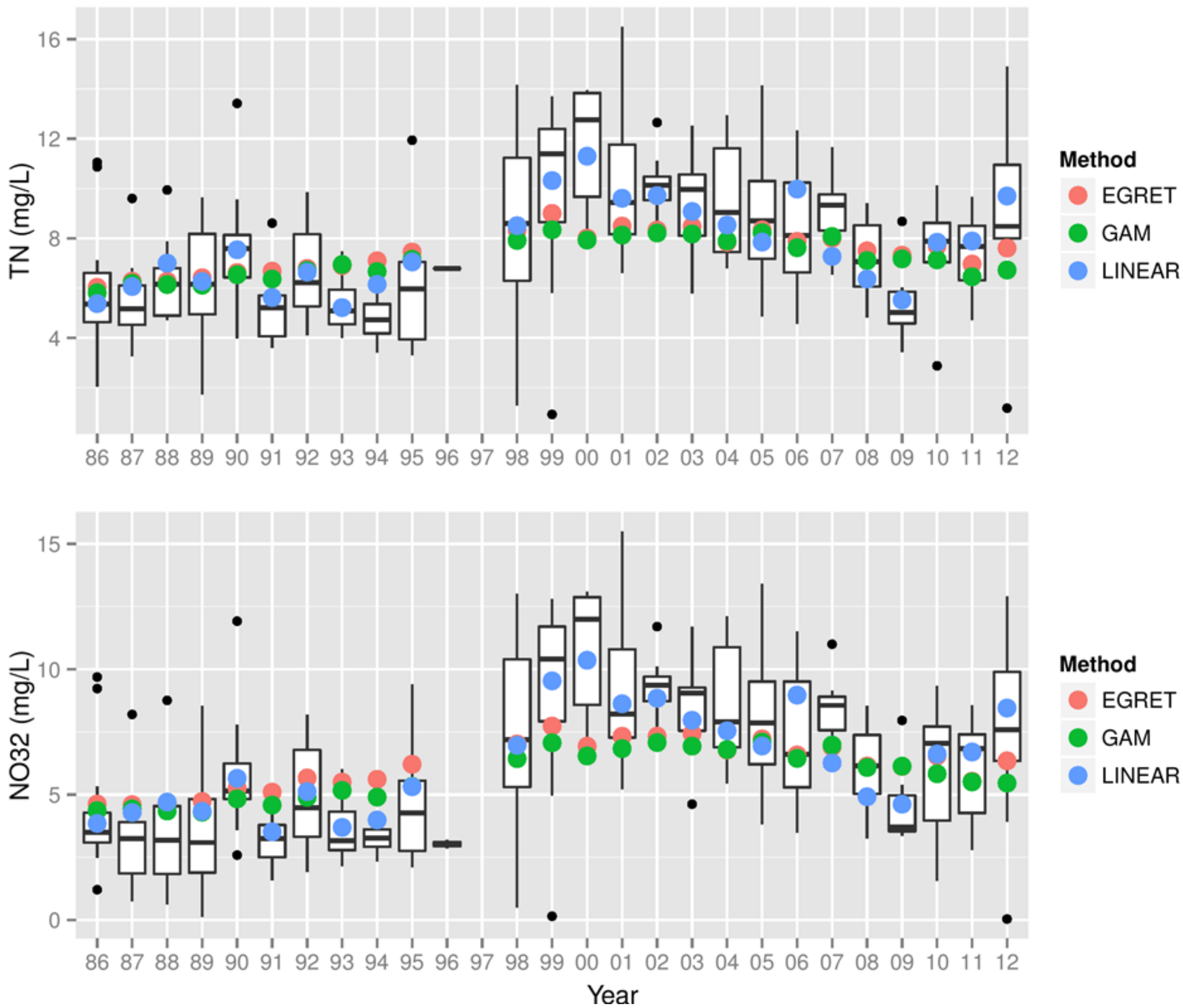




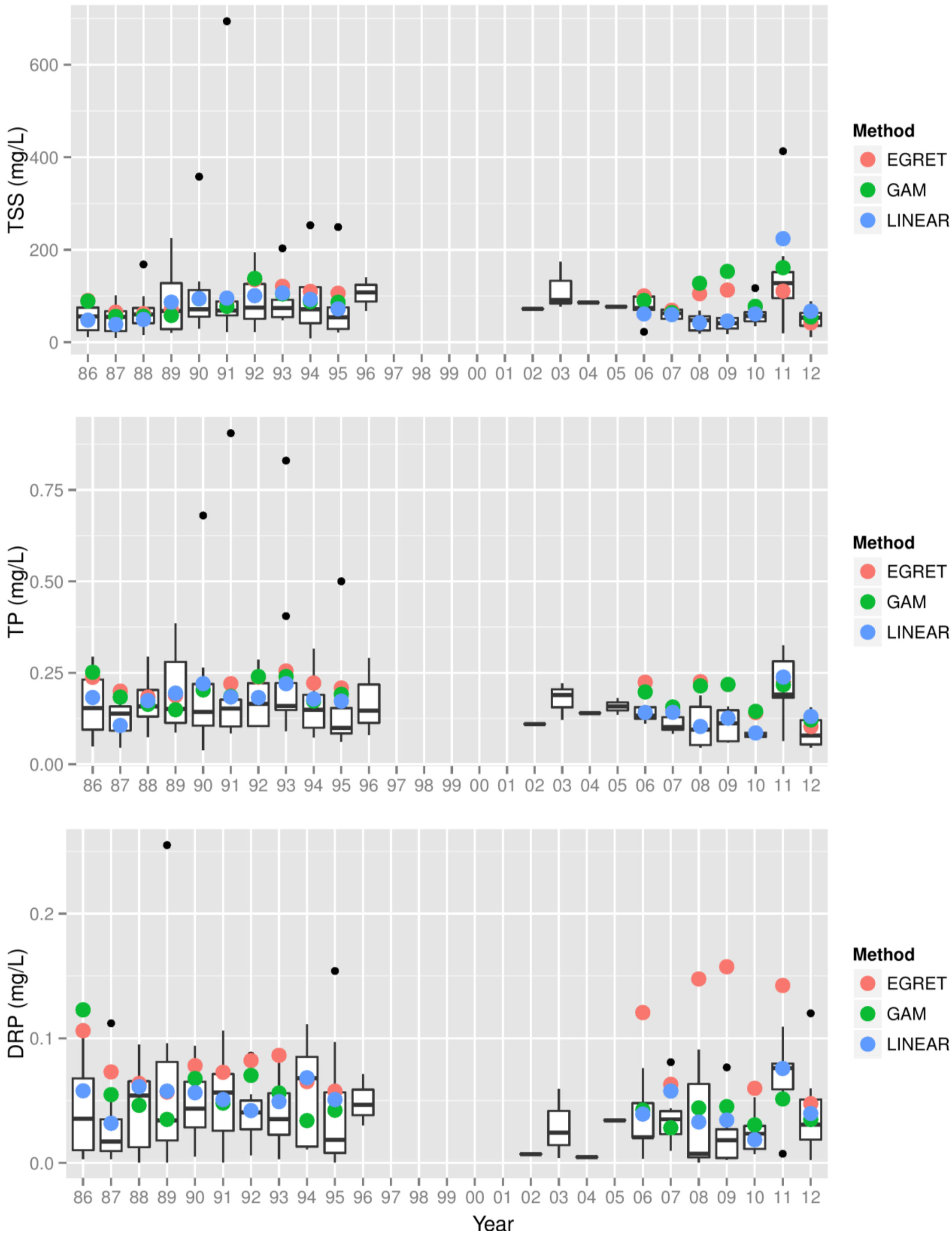
App-Figure 5a. Model/Data Comparison for Station D018 – 25, TSS, TP and DRP



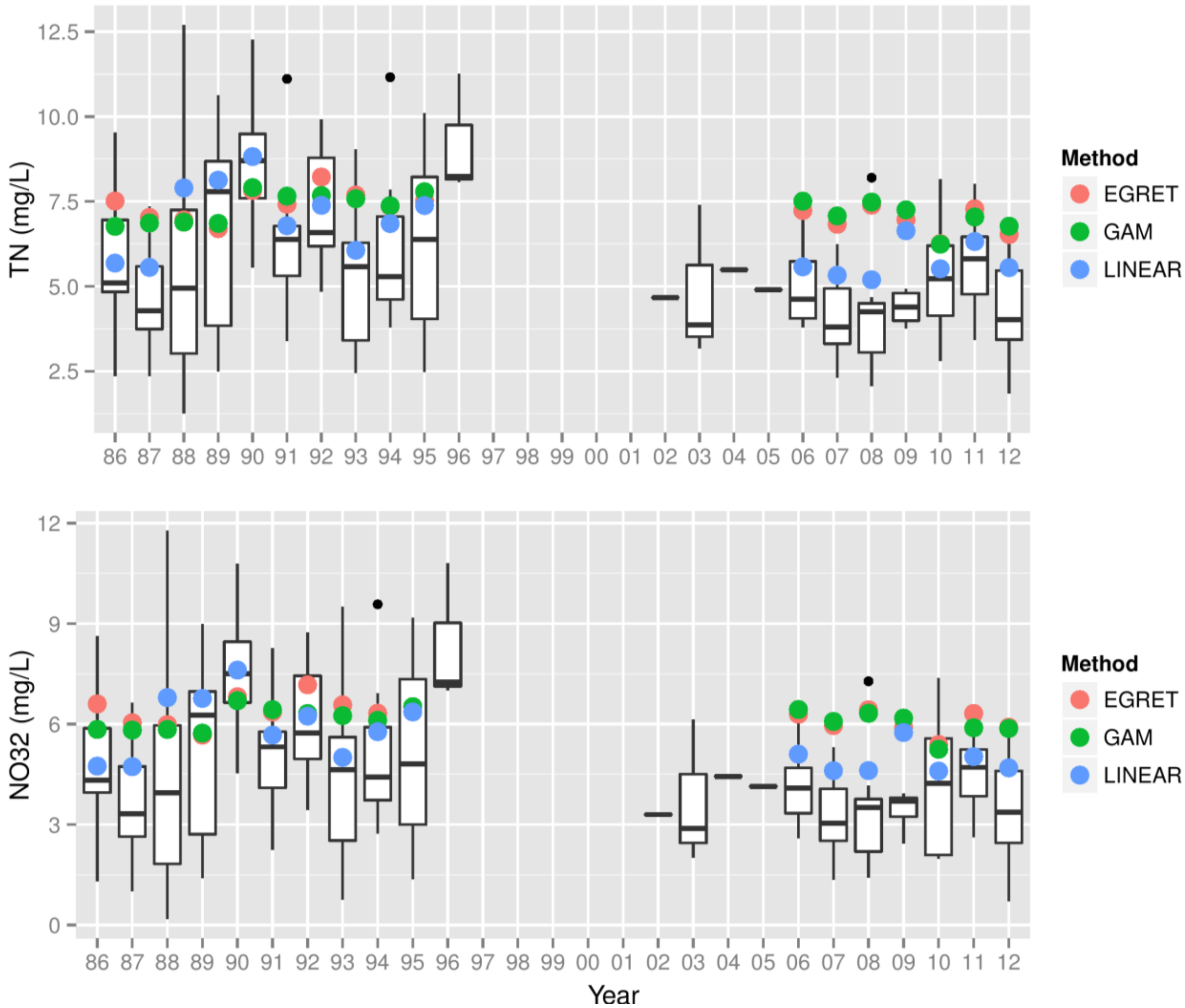
App-Figure 5b. Model/Data Comparison for Station D018 – 25, TN and NO32



App-Figure 6a. Model/Data Comparison for Station E003 – 305802, TSS, TP and DRP



App-Figure 6b. Model/Data Comparison for Station E003 – 305802, TN and NO32



Appendix C: City of London TP monitoring results

All data for similar stations were merged, even though there is a tendency for higher TP values monitored by CoL compared to PWQMN. Merging seemed appropriate for the following reasons:

(1) Follow-up comparison showed no consistent difference (UTRCA results 2014, Table 25)

(2) There are many stations that are only monitored by one of the two agencies and elimination would disregard a lot of information

(3) In the following stations that were sampled by both agencies, a large of amount of data would be disregarded if only one source would be used

Simultaneously monitored stations PWQMN ID (LoC ID):

- WQ-Stn 27 (Highbury-Clarke) on NTR, Flow-Stn D003
- WQ-Stn 47 (Komoka) on NTR, no flow is associated, so no loads were computed
- WQ-Stn 96 (Stoney Creek) on Stoney Creek, NTR, Flow-Stn D028

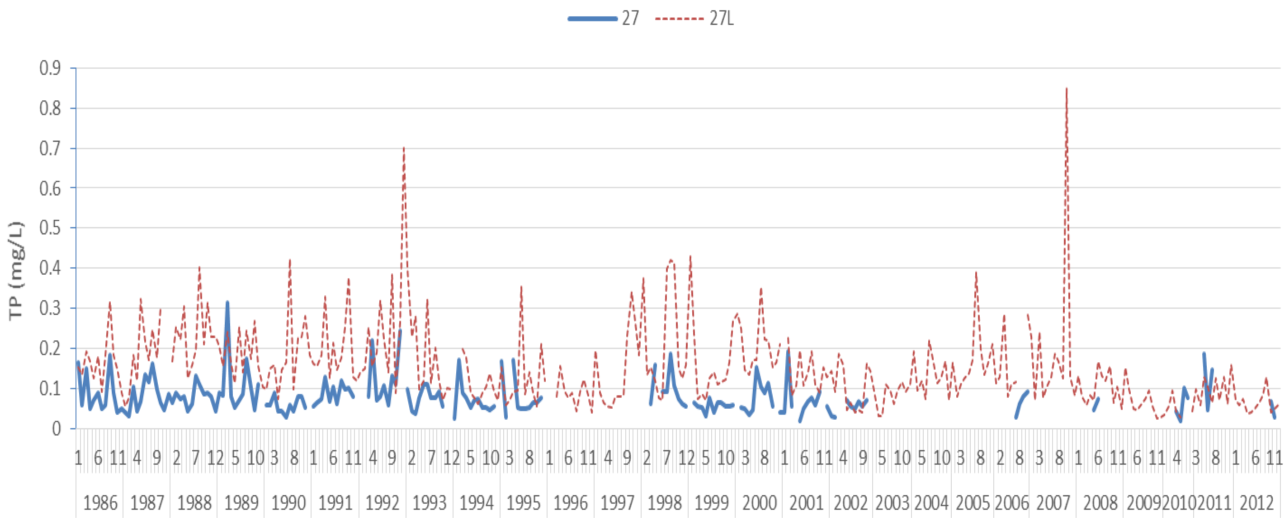
The following figures indicate that differences for TP are severe for Stn. 27, especially for 1986-2001, but not for TSS and nitrate+nitrite concentrations.

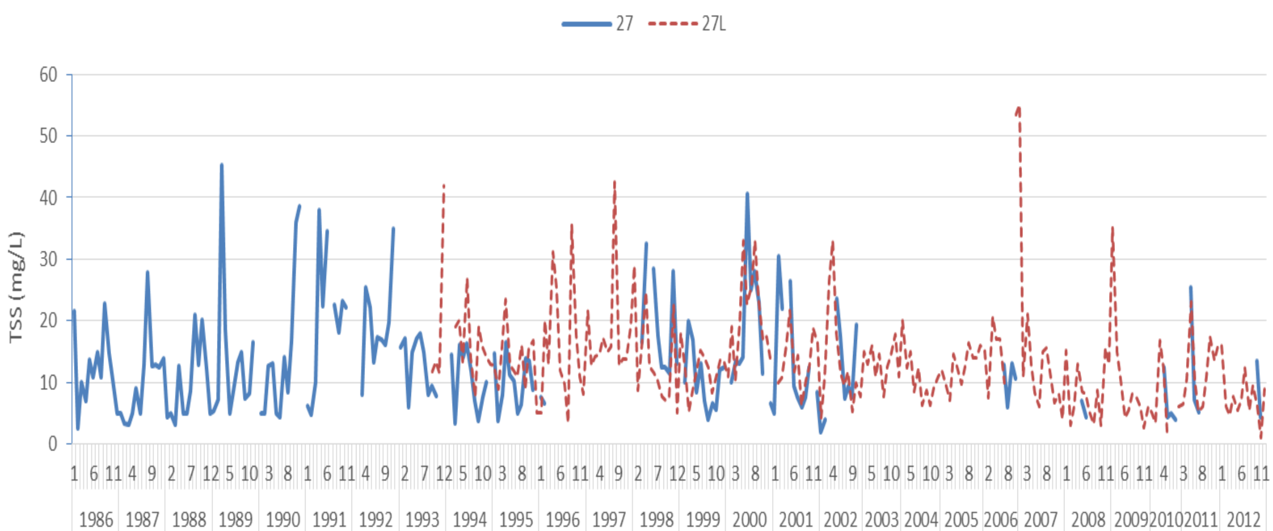
Table 25. Laboratory comparison for TP (split sample analysis, May, June 2014)

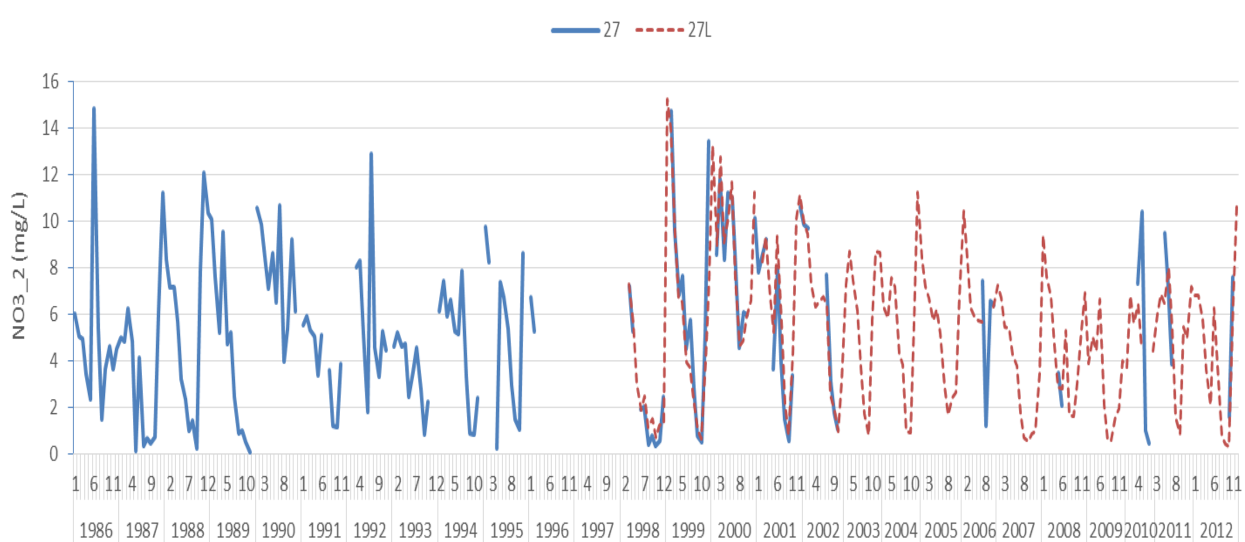
Date	Lab	Station				Detection
		Komoka	Stoney Creek	Clarke Road*	Highbury *	Limits
06-May-14	Maxxam	0.034	0.005	0.042		0.004
	CoL	0.030	<0.01	0.040		0.01
	MOE	0.026	0.005	0.038		0.002
11-Jun-14	Maxxam	0.091	0.026			0.004
	CoL	0.090	0.040			0.01
	MOE	0.078	0.016			0.002
12-Jun-14	Maxxam			0.037	0.041	0.004
	CoL			0.040	0.040	0.01
	MOE			0.025		0.002

* Clarke and Highbury are adjacent

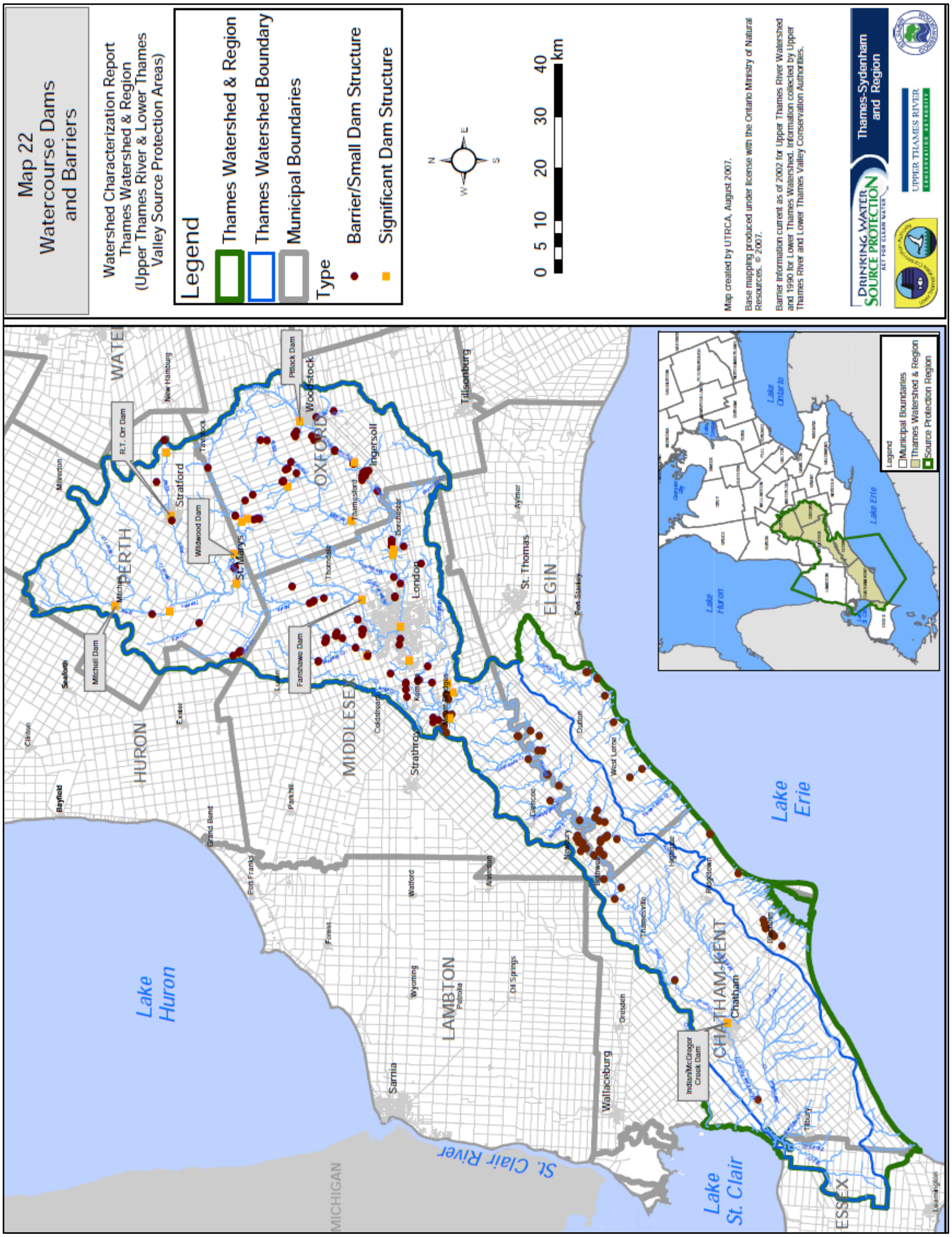
Further notes to the Lab comparison: In most cases MOE are smaller than both Maxxam and CoL values. Further, in the rare case where the stream is relatively nutrient poor, the high detection limit of 0.01 elevates CoL results (i.e., Stoney Creek).


27
27L
TP (mg/L)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012


27
27L
TSS (mg/L)
0
10
20
30
40
50
60
1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012


27
27L
NO3_2 (mg/L)
0
2
4
6
8
10
12
14
16
1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012

Appendix D: Location of impoundments



Appendix E: Characteristics of reservoirs in the Thames River watershed

Source: Tables in Nürnberg and LaZerte 2005, 2006

Table 26. Reservoir morphometry and hydrology

	Wildwood	Pittock	Fanshawe
Altitude at average pool[1] (m above sea level)	322.4	284.7	262.4
Watershed area, A_d (km^2)	129	245.5	1,447.4
Surface area[1], A_o (ha)	200	148[2]	272.6
Area-Ratio, A_d/A_o	64.6	166.1	532
Maximum depth (m)	11.5	8.5	12.1
Mean depth[1], z (m)	4.24	1.9[2]	4.82
Morphometric index, $z/A_o^{0.5}$	3.0	1.6	2.93
Volume[1] (10^6 m^3)	8.48	2.83[2]	13.15
Outflow volume[1] (10^6 m^3 per yr)	65.6	101.1	560
Water residence time[1], τ (volume/outflow)	0.139 yr	0.031 yr	0.026 years
	50.8 d	11.2 d	or 9.5 days
Annual flushing rate[1], $\rho = 1/\tau$ (per yr)	7.2	32.5	38.4
Annual water load[1], $q_s = z/\tau$ (m/yr)	32.7	68.1	205
[1]Longterm average	*1967-2004*	*1979-2004*	*1954-2004*

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

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 m^3)	0.23	0.26	8.48	0.32	0.02
Outflow volume[2,3] (10^6 m^3 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