Factors controlling Cyanobacteria blooms in three Grand River Basin reservoirs during 2005

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Abstract

Limnological measurements were made at three reservoirs that flow into the Grand River during the summer and fall of 2005 to help understand why intense blue green algal (Cyanobacteria) blooms sometimes occur on these reservoirs. In September of 2004 a large cyanobacterial bloom on Belwood Reservoir caused considerable public concern. In 2005, chemical, physical and biological measurements were made bi weekly at a central deep station in Belwood, Conestogo and Guelph reservoirs. Detailed profiles of thermal stratification and distribution of Cyanobacteria as well as other dominant algal groups were obtained using a "FluoroProbe" spectral fluorometer. A fall cyanobacterial bloom was again observed in 2005 on Belwood reservoir. While concentrations of total phosphorus were low and similar in all three reservoirs during July and the first half of August, an intense summer storm in late August caused complete vertical mixing in Belwood reservoir and total phosphorus concentrations rose steeply and continuously after that time. Mixing deepened the thermocline in Conestogo and Guelph reservoirs as well but not as deeply and total phosphorus did not rise as dramatically in those two waterbodies in the fall. Shallow surface stratification in September and early October in combination with high total phosphorus concentrations contributed to the high concentrations of Cyanobacteria in Belwood Reservoir. Fewer visits were made to Conestogo and Guelph reservoirs in the fall but it appears that the highest concentration of Cyanobacteria in Conestogo reservoir occurred in late September coincident with highest total phosphorus and a strongly stratified water column. The results of this study point to the importance of physical processes such as deep mixing and shallow stratification as factors that may be useful predictors of intense cyanobacterial blooms.

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Introduction

Cyanobacteria are good competitors in phosphorus rich waterbodies for a variety of reasons. All genera posses gas vesicles which allow them to regulate buoyancy. When a water column is stable and turbulence is low, Cyanobacteria can position themselves in the water column to acquire light or to avoid inhibiting light levels. Similarly, Cyanobacteria can migrate to deeper depths to access nutrients that may be depleted in the upper water column. Many genera have the capacity to fix atmospheric nitrogen (N) which can provide a competitive advantage when N is low. Several genera build up high biomass because they form colonies that are larger than the gape size of the resident invertebrate grazer populations. A few species are capable of producing toxins. The most common cyanotoxin is microcystin. Microcystin is an hepatotoxin which in high concentrations causes liver damage and promotes tumour growth in organisms chronically exposed to lower concentrations. Although it has not been demonstrated that cyanotoxins are produced as a specific defence mechanism by Cyanobacteria, studies have demonstrated that certain grazers appear to selectively avoid or reject toxic strains of *Microcystis*.

Reports of cyanobacterial blooms have been increasing on some reservoirs on the Grand River in the last few summers. This study was undertaken to try and determine if there are particular environmental variables in these reservoirs that can be used as useful predictors of these blooms and to determine steps that could be taken to prevent blooms. This report documents the physical, chemical and biological measurements made at Belwood, Conestogo and Guelph Lakes during the summer of 2005. The data are

summarized in graph format, briefly discussed and some conclusions made. All data are
tabulated in three appendices.

Methods

Study Lakes

Three reservoirs within the Grand River watershed, Conestogo, Belwood and
Guelph Lakes were selected for biweekly examination from July 6 through
September 22, 2005, with an additional visit to Belwood reservoir on October 13
following reports of a bloom. Logistical difficulties made it impossible to sample Guelph
Lake after Sept 5. Sampling stations at each lake were located at a central deep location,
where any temperature stratification would most likely be evident.

Limnological Characteristics

Water was sampled using a 5L Niskin bottle at two discrete depths, 20L was
collected from 2m below the surface (the epilimnetic sample) and 2L from 6-7m below
the surface (the hypolimnetic sample).   In-situ profiles of fluorescence by pigment-
containing microorganisms were made using a FluoroProbe. These data were used to
determine the total chlorophyll fluorescence and bluegreen (cyanobacterial) fluorescence
along with three other algal groups (diatoms, green algae, cryptophytes). FluroProbe also
measures coloured dissolved organic matter (CDOM). The instrument is able to
discriminate between algal groups based on the unique combination of accessory
pigments each possess and their respective fluorescence spectra (Leboulangerm et al.
2002). The FluoroProbe was calibrated at the factory using pure cultures of algae. The
FluoroProbe field measurements are intended to provide detailed information about the

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vertical distribution of algae and the relative proportion of the various algal groups. The concentrations reported by the FluroProbe at 2 m in the epilimnion and at the depth of the hypolimnion sample were compared to chlorophyll concentrations measured using acetone extraction (see below). The Fluoroprobe logs temperature at the same time and these temperature profiles were used to determine the depth of mixing which was taken as the depth of maximum temperature change. Photosynthetically available radiation (PAR) measurements were made throughout the water column using a CTD profiler. The vertical light attenuation coefficient (k_d) was calculated from the slope of depth versus the natural logarithm of PAR. From this k_d value, euphotic zone (Zeu) depth was calculated by:

$$Zeu = \ln 100/k_d$$

Mean water column intensity ($\bar{I}$), as a percent of surface irradiance, was calculated as:

$$\bar{I} = [(1 - e^{-kdZmix}) / (k_d Zmix)] \, 100$$

Secchi disk depth was also measured as an indicator of water transparency. The pH at the surface of the lakes was measured using a portable pH meter and portable logger.

Water Chemistry

Sample water was kept in dark bottles in insulated boxes from the time of collection to the time of analyses in the laboratory which ranged from 4 to 7 hours. Water was prefiltered through a 200 μm nytex mesh screen to remove larger grazers before analyses. This fraction is referred to as the whole water sample (<200 μm). Whole water from the 2 m and deep sample (usually 7 m) was analyzed for total phosphorus (TP) and total nitrogen (TN) using the methods of Stainton et al (1977). Water from the two depths was filtered through GF/F filters and the filters frozen and subsequently

analyzed for chlorophyll a using a passive extraction with 90% acetone. The extracts were quantified by fluorometry on a Turner Designs 10-AU fluorometer that was calibrated annually with pure chlorophyll a using the equations of Stainton et al (1977). A second GF/F filter analyzed for particulate phosphorus (Part P) by persulfate digestion (Environment Canada 19XX). Water collected on a precombusted GF/F filter was frozen for particulate carbon C and N (Stainton et al 1977). Water that passed through the GF/F filters was collected and analyzed for total dissolved phosphorus (TDP), soluble reactive phosphorus (SRP), nitrate (NO_3) and nitrite (NO_2) (Stainton et al 1977). Ammonia (NH_4) was analyzed on water passed through a 0.2 µm polycarbonate filter using the fluorometric method of Holmes et al (2002). Soluble reactive silica (SRSi) was measured on water passed through a 0.2 µm polycarbonate filter (Stainton et al 1977).

Data analyses

Systat version 9 was used to perform regressions and to make most graphs. The FluroProbe profiles were plotted using Excel.

Results

Physical conditions: Stratification and light

All three reservoirs were strongly stratified at about 6 m on July 6 (Fig 1 b and Fig 8a, 9a and 10a). Two weeks later on July 21 surface temperatures were 2 to 4 degrees warmer and the depth of stratification was shallower (Fig 1b. 8b, 9b, 10b). The surface layer continued to warm and deepen to 7 m in Belwood and Conestogo reservoirs by Aug 11. The lakes were visited on Aug 23 around the time of a major summer storm and the mixed layer deepened in all three lakes (Fig 1b). The individual temperature profiles (Fig

8d, 9d, 10d) indicate that the water column mixed completely in Belwood Lake but not quite to the bottom in Conestogo and Guelph Lakes. In Belwood the surface temperatures were actually lower than the deep waters due to the intense mixing. By Sept 5 the surface waters were heating slightly and shallow stratification occurred in Belwood and Guelph Lakes. Belwood and Guelph Lakes were strongly stratified at about 6 m on Sept 22. On Oct 5, the surface waters of Belwood were very warm but most of the water column was cooler and uniformly mixed (Figure 1b, 8g).

Light attenuation decreased over the summer in all three reservoirs as indicated by the decreasing Secchi disk depth (1a), increasing light attenuation coefficient (1c), and decreasing euphotic depth (1e). The mean PAR is the average amount of light in the upper mixed layer of the water column. It is calculated from the light attenuation coefficient and the mixed layer depth. In general mean PAR in the upper mixed layer of all three lakes (Fig 1d) was high (over 15% of surface light), however on Aug 23 when the water columns were deeply mixed the mean PAR was low, less than 10% of surface light. The Secchi disk depth was highly correlated to the light attenuation coefficient (R^2= 0.80, p=0.000, Fig 1f). This indicates that Secchi disk depth measurements could provide reliable light attenuation information in the three lakes.

Chemistry

Total phosphorus (TP) in the epilimnion was relatively low (10 – 15 μg L^{-1}) in all three reservoirs in July and early August (Fig 2a). Epilimnetic TP increased dramatically in Belwood following the deep mixing event around Aug 23. TP in the hypolimnion increased gradually throughout the summer in all three reservoirs (Fig 2f). Particulate P

increased consistently in the epilimnion in all three reservoirs throughout the summer (Fig 2c). Dissolved forms of P in the epilimnion were low initially and rose during late summer and fall (Fig 2b, d). Soluble reactive silica, which is necessary for diatom growth, was high and remained high in Belwood and Guelph reservoirs but decreased in Conestogo reservoir in Sept (Fig 2e).

Total nitrogen (TN) and NO_3 concentrations were very high in July in all the reservoirs (Fig 3 a, b) but concentrations declined as the summer progressed. Ammonia and NO_2 concentrations were on average much lower and did not exhibit strong seasonal trends (Fig 3 c, d) although the deep mixing event in late August resulted in increased NH_4 in the epilimnion. The decrease in TN coupled with increased TP contributed to the consistent decrease in the ratio of TN:TP over the summer and fall in all three reservoirs (Fig 3e).

Chlorophyll concentrations and algal groups

Total chlorophyll a concentrations were measured in epi and hypolimnetic samples (Fig 4 a, b and Appendix 3). These concentrations were obtained by in vitro acetone extraction and represent the total chlorophyll in the water at the depth of sampling. Relative estimates of total chlorophyll and chlorophyll associated with four major algal groups throughout the water column were obtained from in situ "FluoroProbe" spectral fluorescence profiles (Fig 5a-f, 6, Fig 8-10 and Appendix 3). Total chlorophyll concentrations measured by acetone extraction were highly correlated to the in situ FluoroProbe total chlorophyll concentrations (R^2= 0.85, p=0.000). The in situ chlorophyll underestimated extracted chlorophyll by 20% on average. Extracted total

chlorophyll concentrations were relatively low (< 10 µg L^{-1}) in the epi and hypolimnion samples taken on July 5 but rose consistently in the the epi and hypolimnion samples in all three reservoirs through to the end of Spetember (Fig 4a, b). Maximum total chlorophyll (47 µg L^{-1}) was measured in the 2 m epilimnetic sample from Belwood Lake on Sept 22.

The pattern for total chlorophyll at 2 m as detected by the FluoroProbe (Fig 5a) was similar to that for total extracted chlorophyll a at 2 m (Fig 4a) except that the concentrations reported by the FluoroProbe are consistently lower. Cyanobacteria were present in all the reservoirs on each sampling day and the concentration as well as the proportion of chlorophyll associated with Cyanobacteria increased as the summer progressed (Fig 5c, 6 a-c). On Sept 5, Cyanobacteria in the shallow surface layer of Belwood Lake was over 70 µg L^{-1} (Fig 8 E). Cryptophyte algae (Fig 5c) also increased in all the lakes as the summer progressed but were on average lower in concentration than the Cyanobacteria. Other algal groups detected by the FluoroProbe (Diatoms and Greens, Fig 5 b, e, 6 a-c) did not occur in high concentrations and did not exhibit seasonal patterns. The coloured dissolved organic matter (CDOM) detected by the FluoroProbe was highest in Belwood, and lowest in Conestogo (Fig 5f).

Cyanobacterial chlorophyll in the epilimnion was highly correlated to total chlorophyll (R^2 = 0.87, p=0.000, Fig 7c). Total chlorophyll was strongly correlated to total phosphorus (R^2= 0.52, p=0.001) and cyanobacterial chlorophyll was even more strongly correlated (R^2= 0.62, p=0.000, Fig 7a). Total and cyanobacteria chlorophyll were negatively correlated to the TN:TP ratio in the lakes (Fig 7b).

Discussion

       Cyanobacteria formed a significant fraction of the phytoplankton in all three reservoirs in 2005 and achieved concentrations high enough to be considered a nuisance in Belwood and Conestogo Lakes in late September (Guelph Lake was not sampled at that time). Total chlorophyll at the surface of Belwood Lake as detected by the FluroProbe was over 70 μg L^{-1} on Sept 5 and over 25 μg L^{-}1 on Sept 22 and Oct 13. Almost certainly, surface blooms reached high concentrations on other days when we were not sampling as our Oct 13 trip was prompted by reports of bloom concentrations on Belwood Lake several days earlier than we were able to arrange a sampling trip. Total chlorophyll and cyanobacterial chlorophyll concentrations in the epilimnion were highly correlated to the epilimnetic total phosphorus concentration. The highest total chlorophyll and cyanobacterial concentrations in Belwood Lake were triggered by resuspension of P by a deep mixing event in late August. The deep mixing event occurred in Conestogo and Guelph reservoirs as well but temperature profiles indicated that the water columns in those lakes did not mix right to the bottom as appeared to occur in Belwood Lake. Belwood may have been mixed more deeply because of its size and exposure relative to the wind direction or because the wind was stronger over Belwood than the other nearby reservoirs. The morphometry of the lakes would also be expected to influence the amount of resuspension that would occur in response to mixing.

       Although there was a strong correlation between the TN:TP ratio and the concentration of Cyanobacteria in the reservoirs, the absolute concentrations of N remained high in all three reservoirs and it is unlikely that cyanobacterial blooms formed in response to low N availability.

Summary and conclusions

Cyanobacteria concentrations in the three Grand River Basin reservoirs studied were highly correlated to total phosphorus concentrations. Although TP concentrations were low and similar in all three reservoirs in July and early August, an intense summer storm that mixed the lakes to varying degrees resuspended P to different concentrations in each reservoir and this determined the maximum cyanobacterial biomass observed in the fall. Belwood Reservoir, which mixed to the bottom in August had the highest TP concentrations after the mixing and had the largest bloom. Highest surface blooms occurred in the fall in Belwood and Conestogo when TP was high and shallow thermoclines developed on warm fall days.

This study reinforced the findings of others investigating the environmental factors that trigger cyanobacterial blooms (Ferber et al 2002, Giani et al.2005, Huisman et al. 2005). High phosphorus concentrations and stable water column conditions provide optimum conditions for cyanobacterial growth. Several factors contribute to phosphorus concentrations in the reservoirs including external and internal loading. Reduction of external P loading is the desired long term strategy for controlling algal growth. Although deep mixing caused by surface cooling and wind events are not factors that can be controlled, it may be worth investigating whether water level regulation in the fall has any influence on the potential for P resuspension at that time. Depending on the morphometry of the reservoir, decreasing the water levels in the fall may reduce the depth required to mix the reservoir to the bottom and thus inadvertently contribute to increased internal P loading.

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Fig 1. Measurements relevant to the light environment. a) Secchi disk depth, b) mixed depth (Z_{mix}), c) light attenuation (K_d), d) mean PAR as a percent of surface light and e) the euphotic depth (depth to which 1% of surface light penetrates) for the three reservoirs over the summer season. Belwood is represented by open circles, Conestogo by the symbol "X" and Guelph Lake by the open triangles. f) Secchi disk depth plotted versus the light attenuation coefficient.
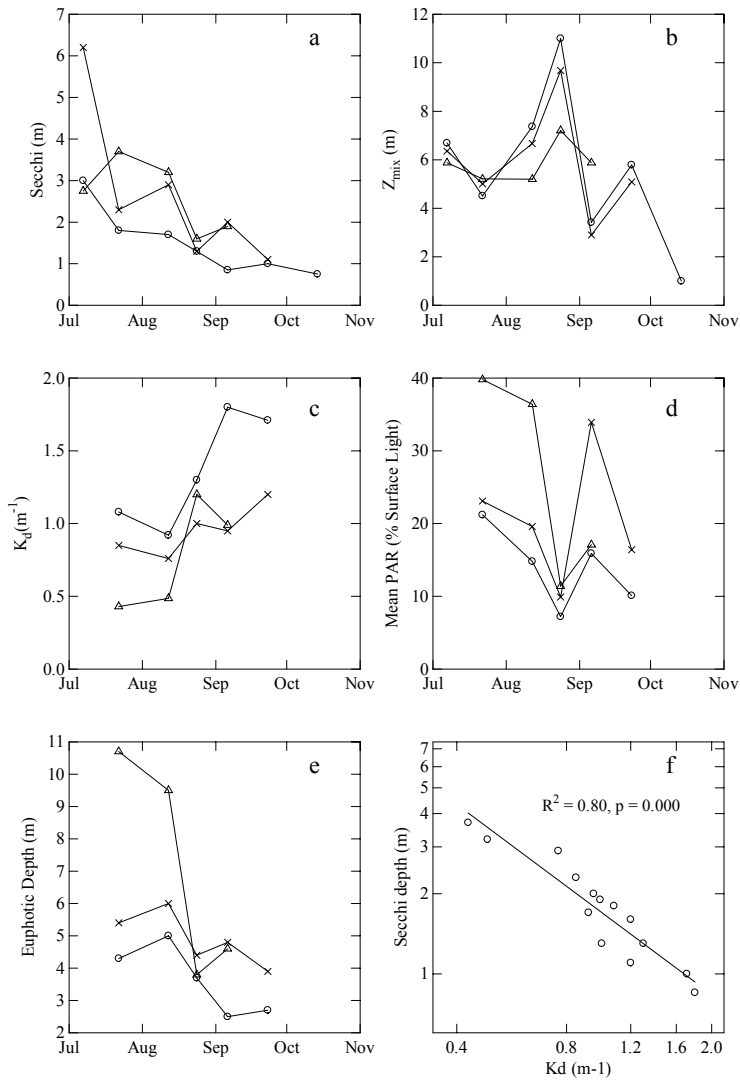
Fig. 2. Seasonal plots related to phosphorus and silica. 2a) total phosphorus (TP), 2b) total dissolved phosphorus (TDP), 2c) particulate phosphorus (Part P), 2d) soluble reactive phosphorus (SRP), 2e) soluble reactive silica (SRSi), and 2f) TP in the hypolimnion for the three reservoirs. Symbols as in Fig. 1.
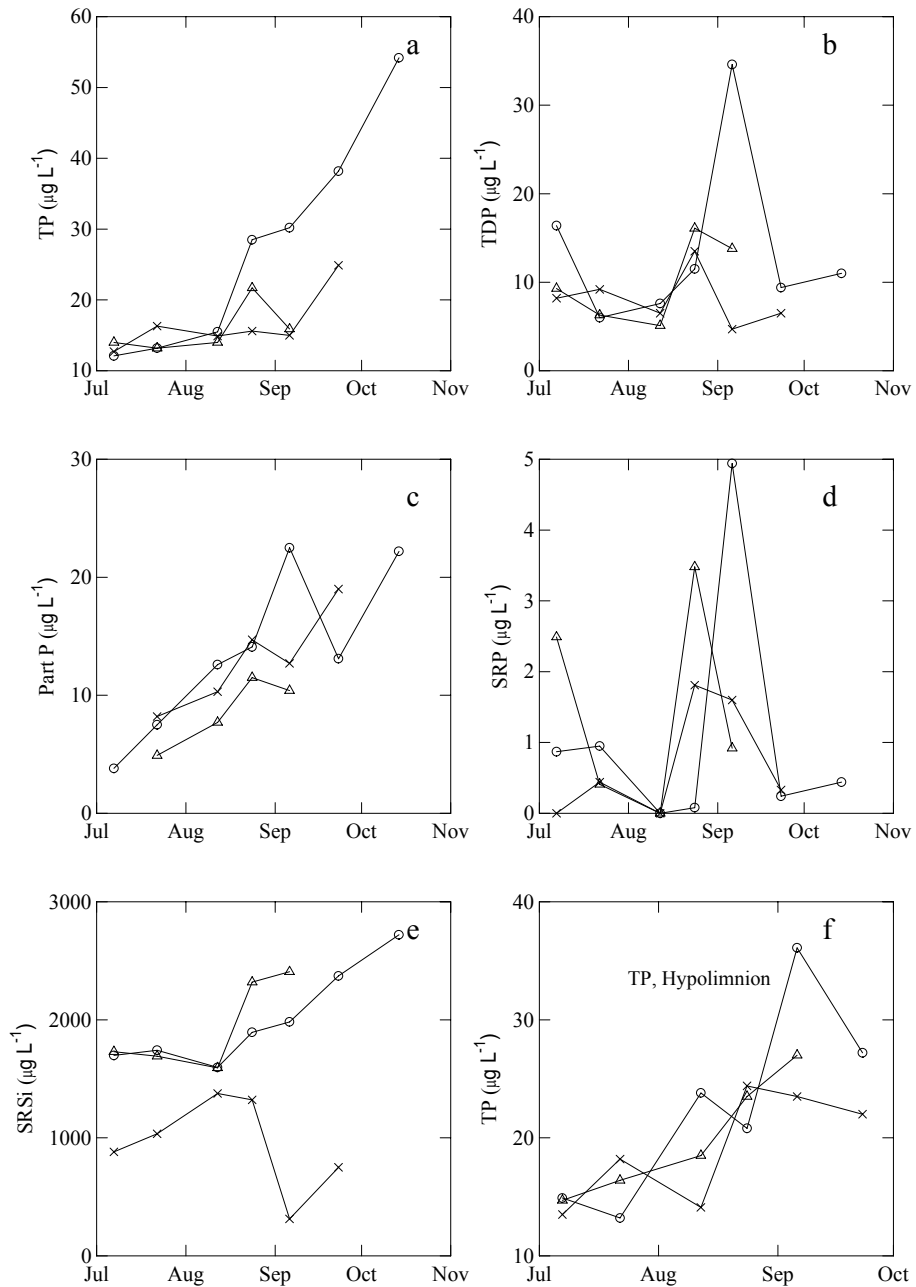
Fig. 3. Seasonal plots of total nitrogen (TN), nitrate (NO$_3$), ammonia (NH$_4$), nitrite (NO$_2$), and the ratio of total nitrogen to total phosphorus (TN:TP) in the three reservoirs. Symbols as in Fig. 1.
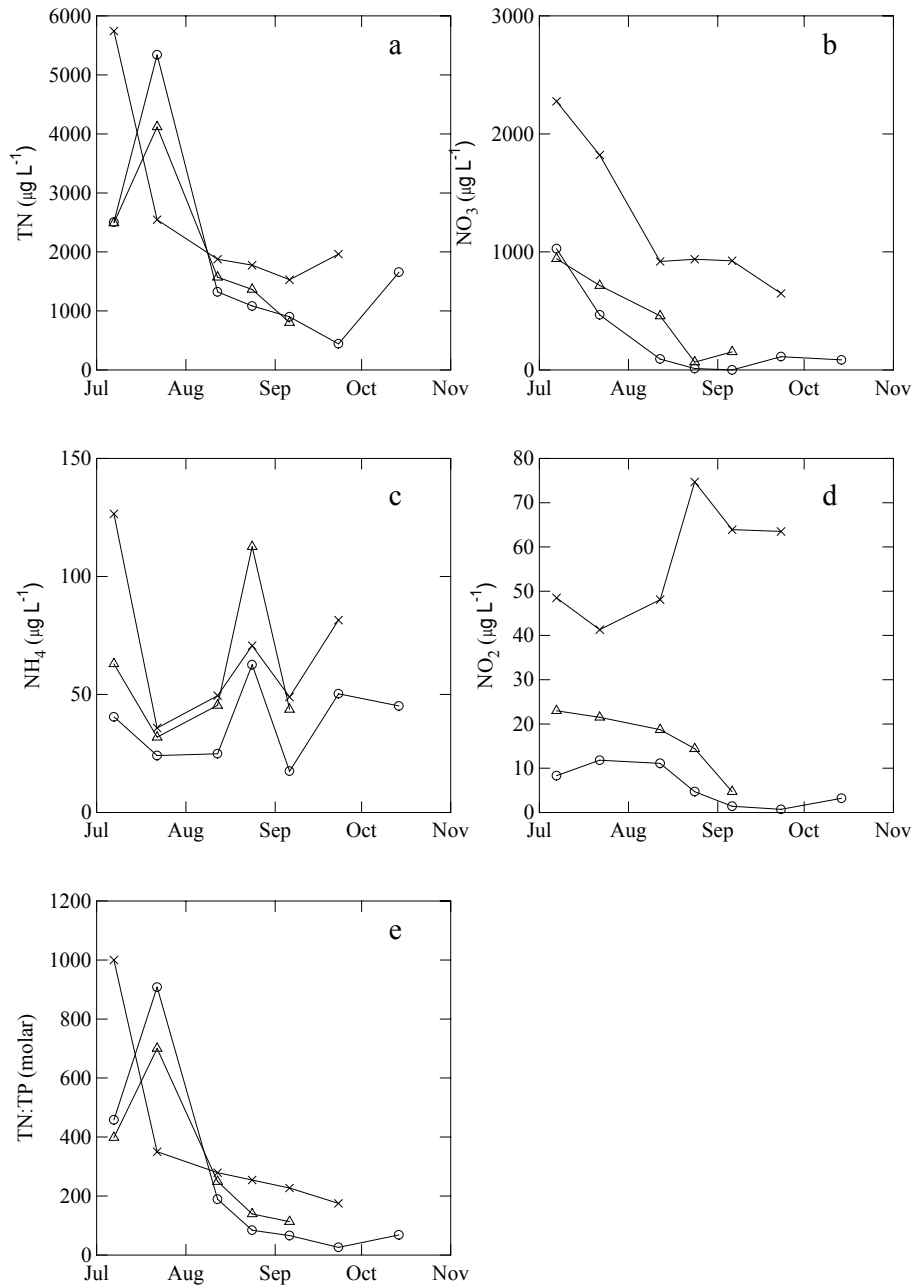
Fig 4 Extracted chlorophyll a in the epi and hypolimnion of the Belwood, Conestogo and Guelph reservoirs. Symbols as in Fig 1.
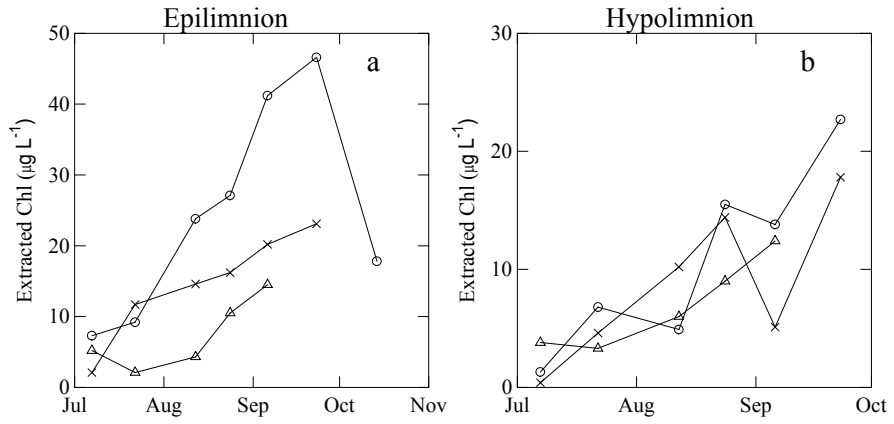
Fig 5. Estimates of total chlorophyll and the relative abundance of the main algal groups and coloured dissolved organic matter (CDOM) at the depth of 2 made using the Fluoroprobe. Symbols as in Fig. 1.
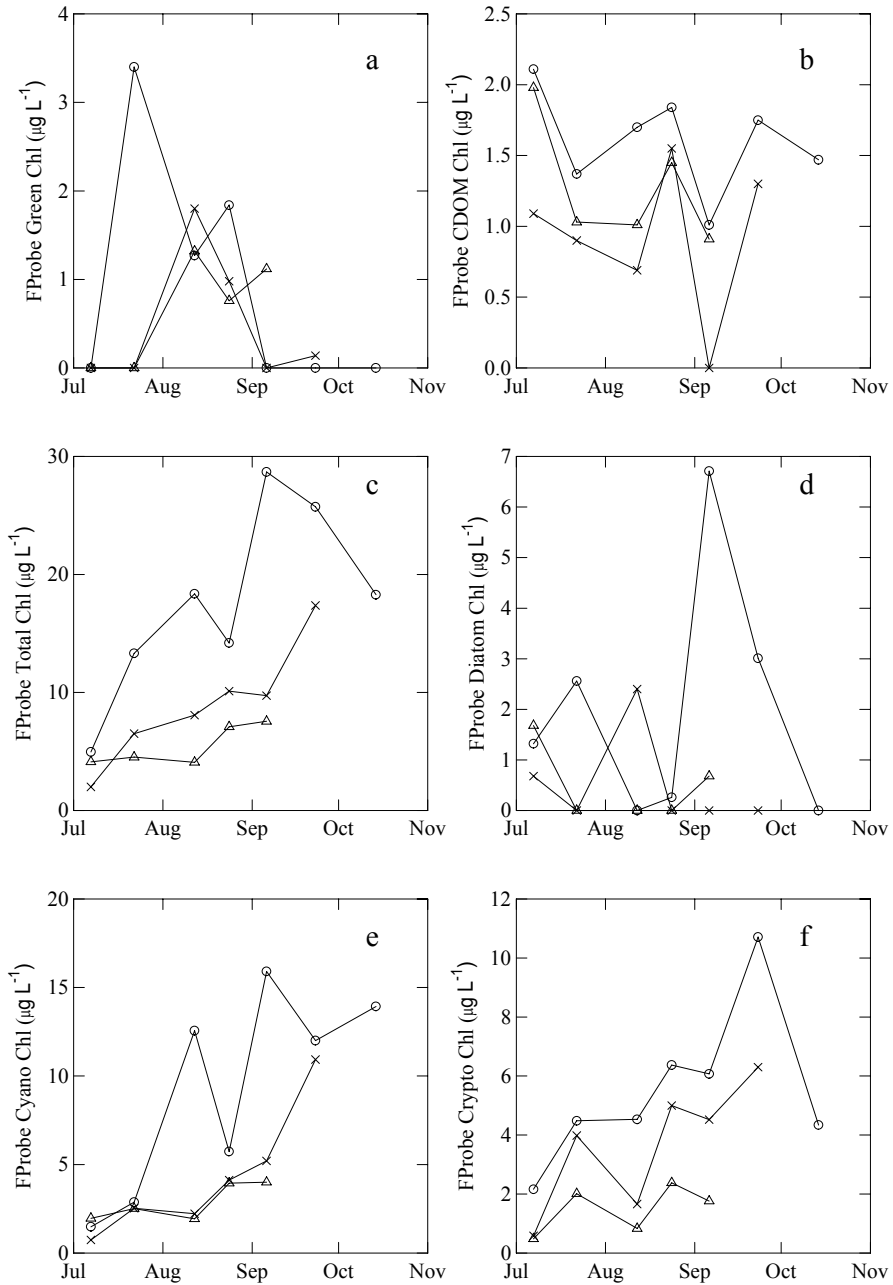
Fig. 6 Proportions of different algal groups at 2 m in the reservoirs over the sampling period as indicated by the Fluoroprobe spectral fluorescence measurements.
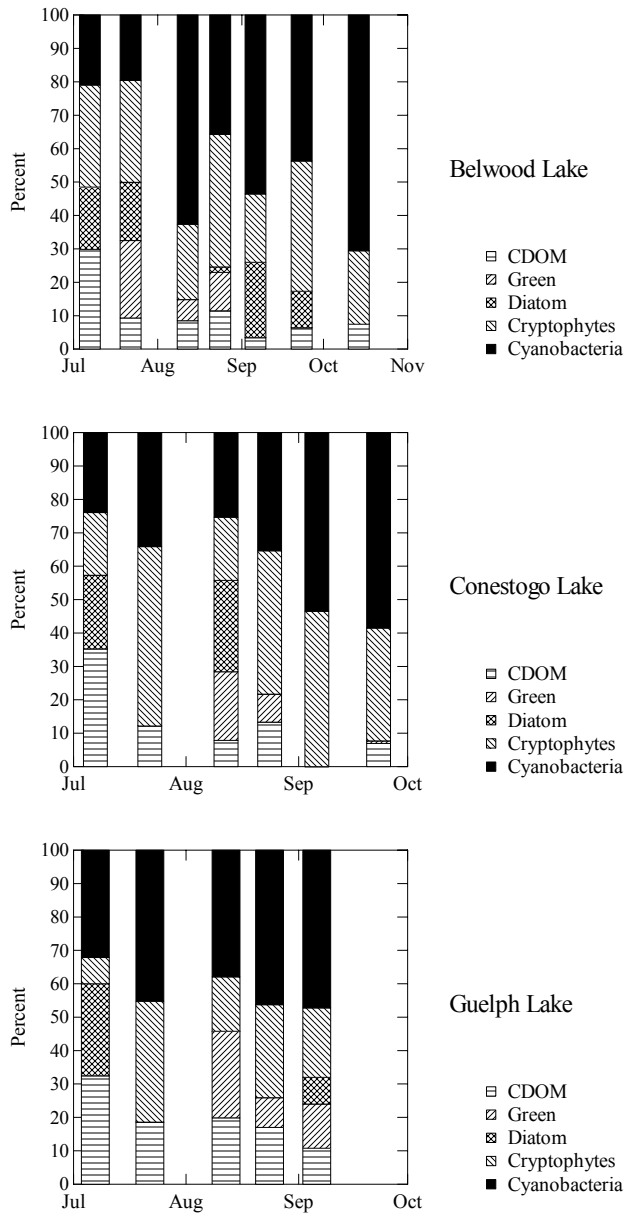
Fig 7. a) Linear regressions between total P and total chlorophyll (open circles) and Cyanobacteria chlorophyll (X) from 2 m samples from all three reservoirs. b) same as a) but plotted against the TN:TP ratio and c) regression between total chlorophyll and Cyanobacterial chlorophyll at 2 m.
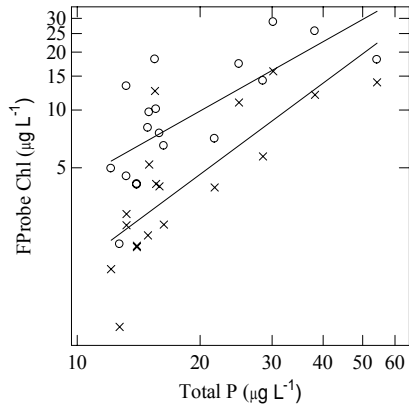
a

Total Chl $R^2 = 0.52$, p = 0.001

Cyano Chl $R^2 = 0.62$, p = 0.000

○ Tot Chl
× Cyano Chl
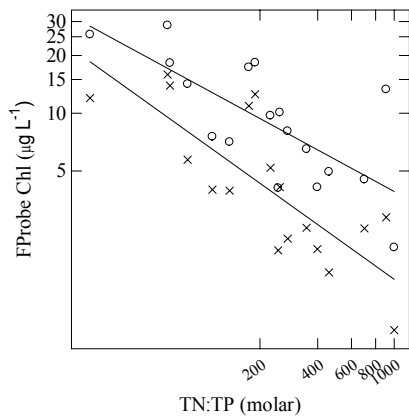
b

Total Chl $R^2 = 0.53$, p = 0.001

Cyano Chl $R^2 = 0.63$, p = 0.000

○ Tot Chl
× Cyano Chl
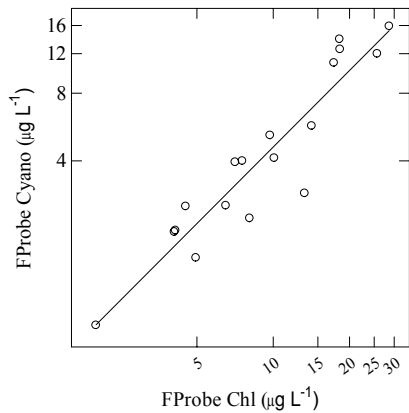
c

Cyano vs Tot Chl $R^2 = 0.87$, p = 0.000

Fig. 8. Fluoroprobe profiles for Belwood Lake. Tot = total chlorophyll, Cyano is chlorophyll associated with Cyanobacteria, Green is green algae, Diatom is diatoms, Crypto is cryptophytes, CDOM is coloured dissolved organic matter and Temp is temperature (degrees celsius).

A.

B.

C.

Fig 8 cont.
D.

Belwood Aug 23, 2005

E.

Belwood Sept 05, 2005

F.

Belwood Sept 22, 2005

Fig 8 cont
G.

Belwood Oct 13, 2005 Cast 1

Chl (ug/L) — legend: Tot, Cyan, Green, Diatom, Crypto, CDOM, Temp
Depth (m) vs Temperature (C)
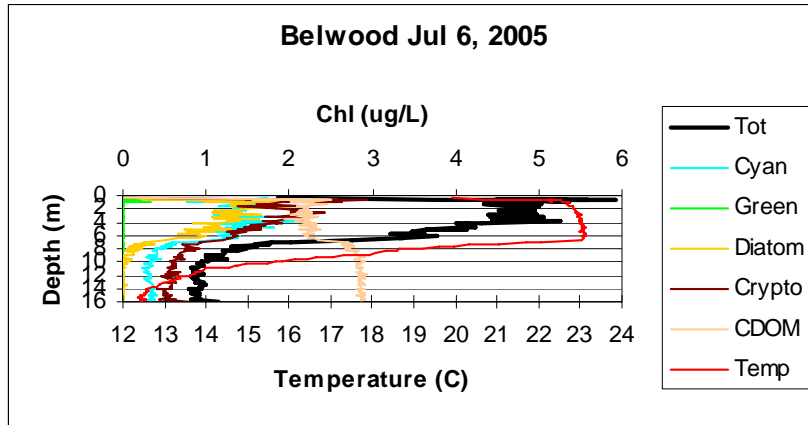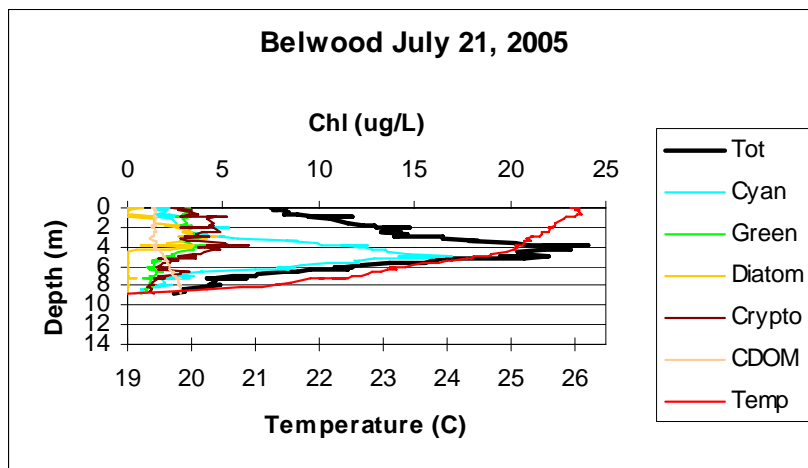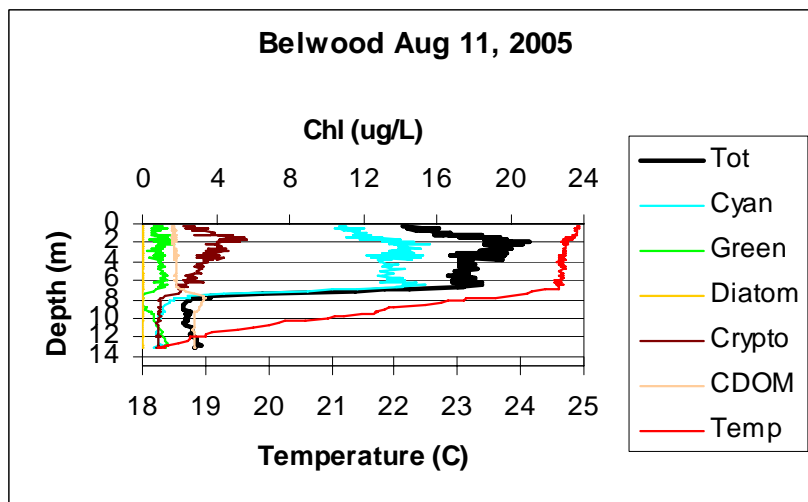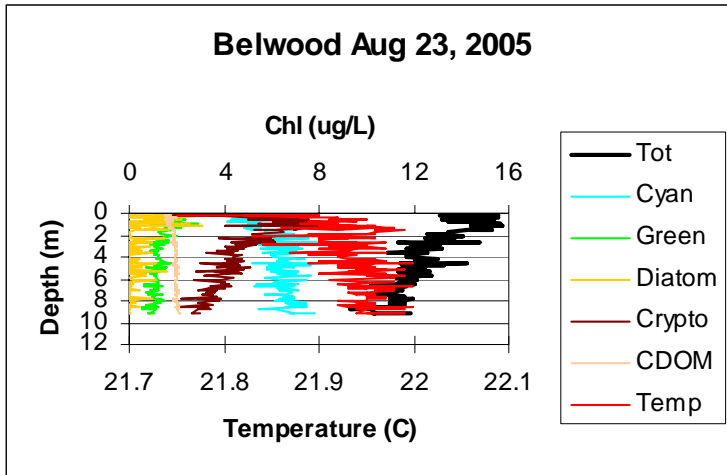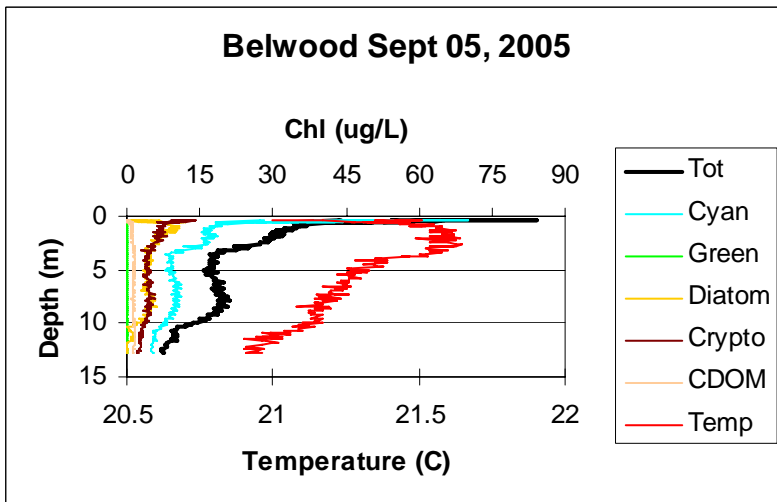
Fig 9. Fluoroprobe profiles: Conestogo Lake

A.

B.

C.

Fig. 9. cont.
D.

Conestoga Aug 23, 2005

E.

Conestoga Sept 05, 2005

F.

Conestoga Sept 22, 2005

Fig. 10. Guelph Lake Fluoroprobe profiles,
A.
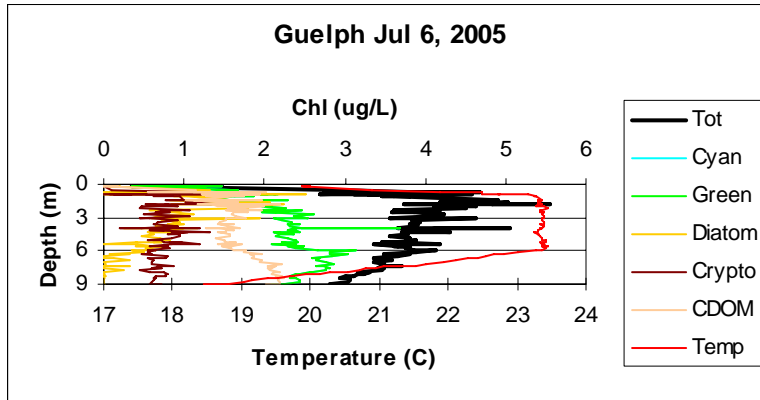
B.
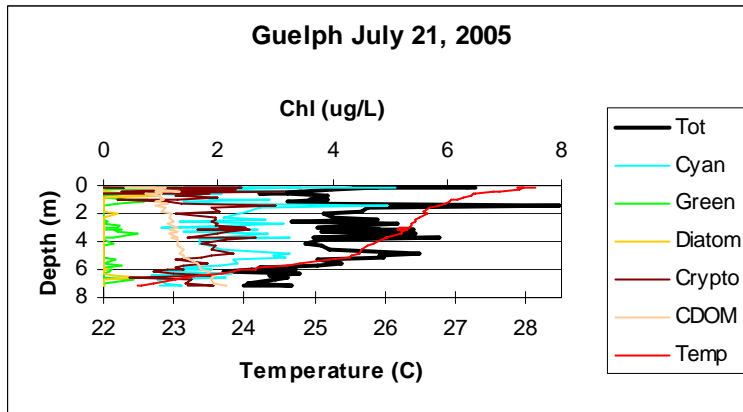
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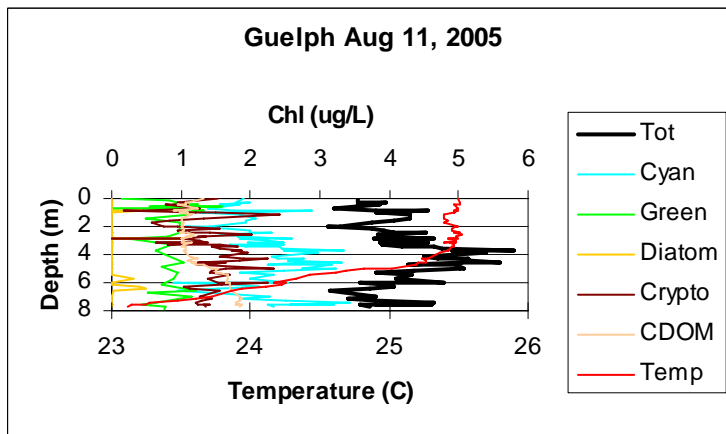
Fig. 10 cont.

D.
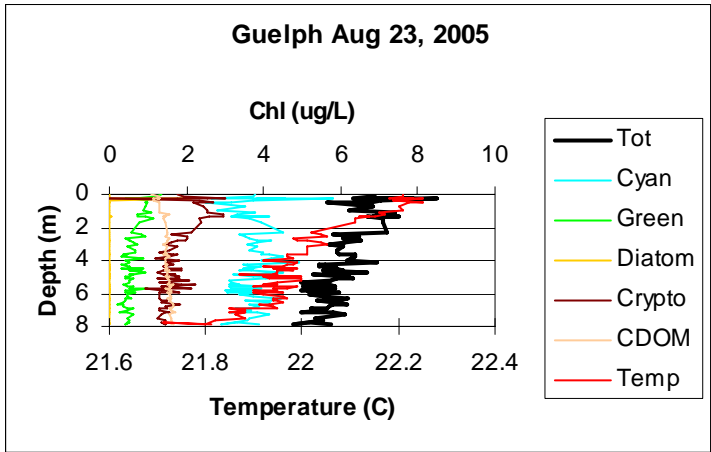
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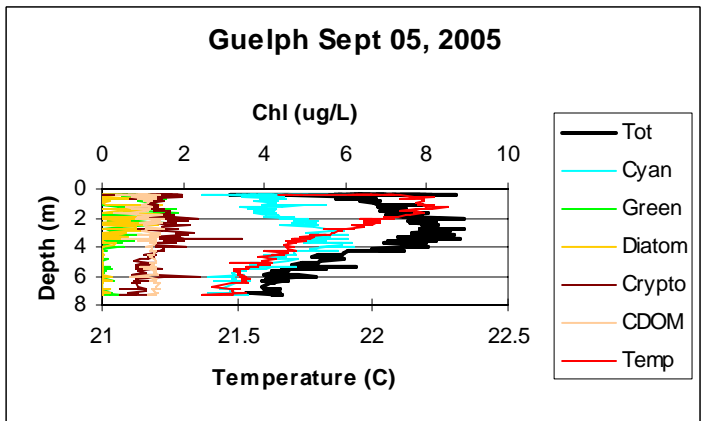
Appendix 1 Physical data

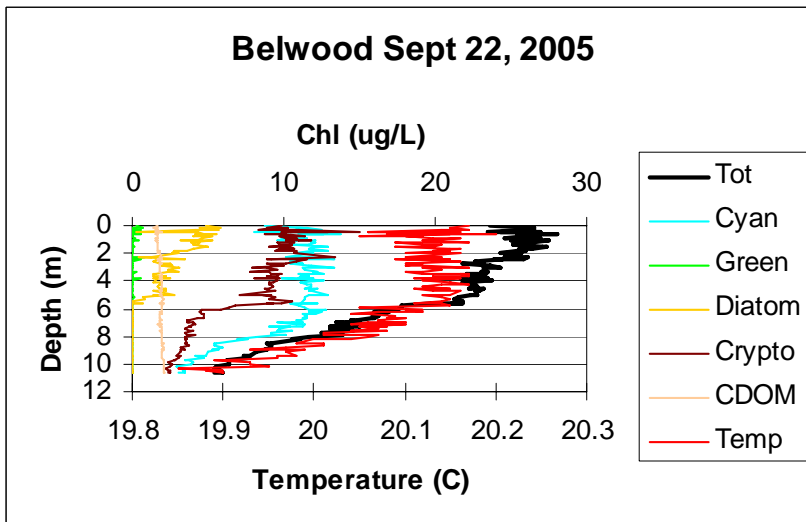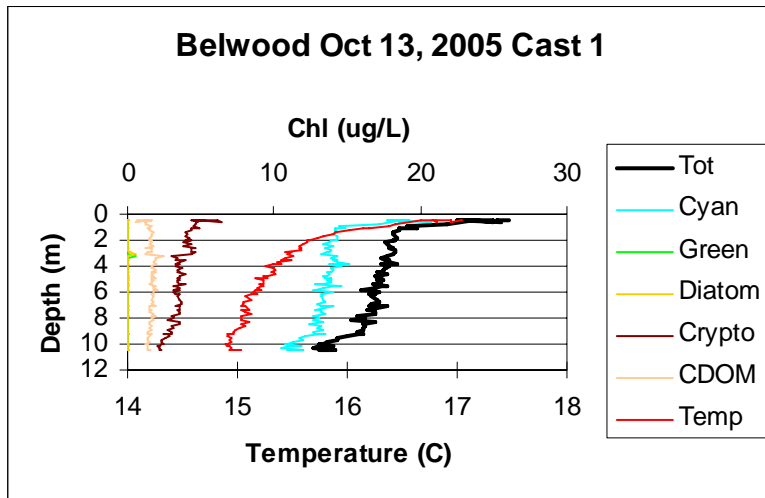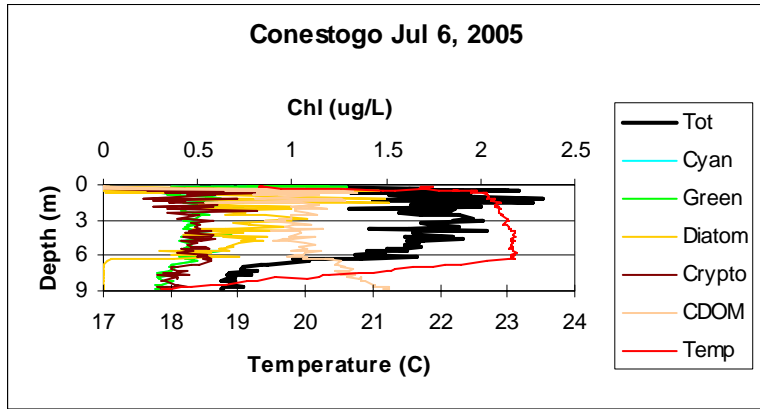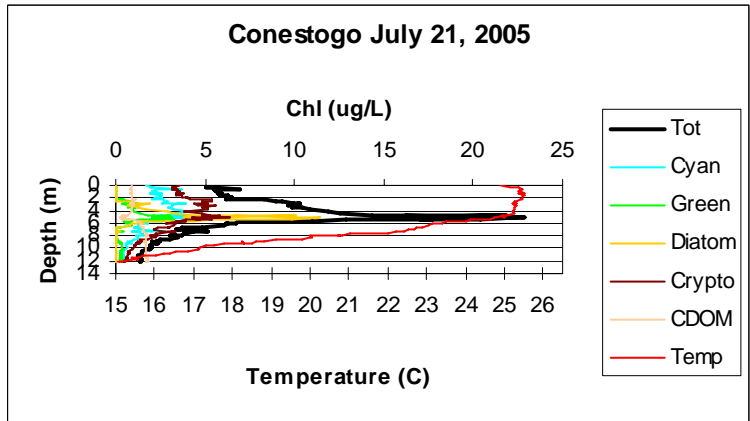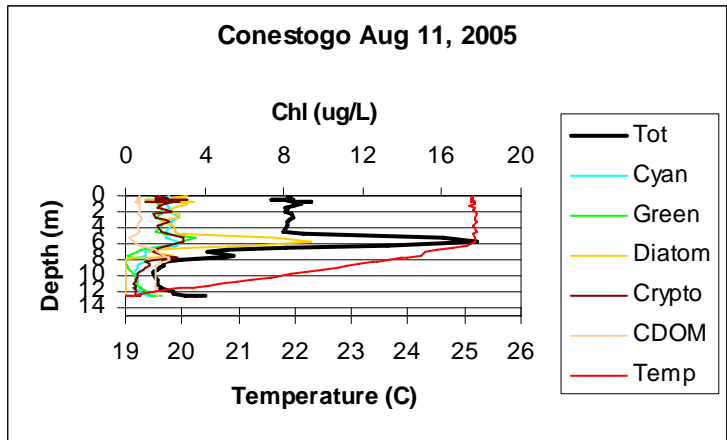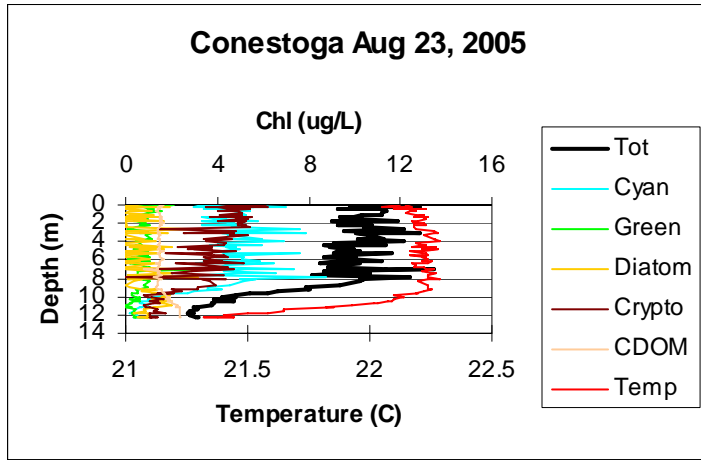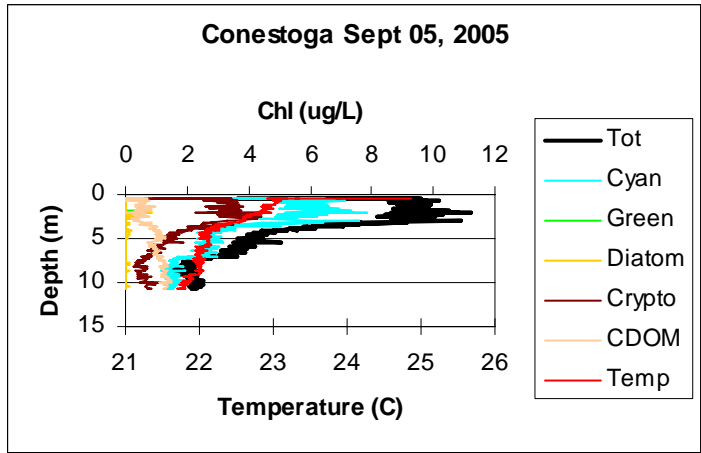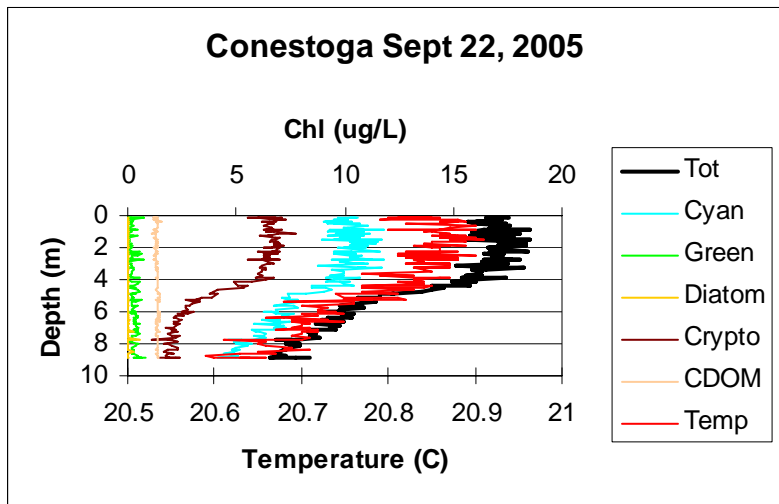| Station Name	Station (#)	Date	Time 24 hr	Station Depth (m)	Sample Depth (m)	Secchi (m)	Kd (m-1)	Euph Depth (m)	Therm Depth (m)	Mean PAR %
Belwood	GR5109	6-Jul-05	11:19:00	17	2	3.0			6.7	
Belwood	GR5110	6-Jul-05	11:19:00	17	10					
Belwood	GR5143	21-Jul-05	10:19:00	11	2	1.8	1.08	4.3	4.5	21.2
Belwood	GR5146	21-Jul-05	10:19:00	11	8					
Belwood	GR5290	11-Aug-05	11:20:00	14	2	1.7	0.92	5	7.4	14.8
Belwood	GR5295	11-Aug-05	11:20:00	14	10					
Belwood	GR5299	23-Aug-05	11:21:00	11	2	1.3	1.30	3.7	11.0	7.2
Belwood	GR5301	23-Aug-05	11:21:00	11	9					
Belwood	GR5346	5-Sep-05	8:35:00	15	2	0.9	1.80	2.5	3.4	15.9
Belwood	GR5349	5-Sep-05	8:35:00	15	10					
Belwood	GR5388	22-Sep-05	11:15:00	13	2	1.0	1.71	2.7	5.8	10.1
Belwood	GR5390	22-Sep-05	11:15:00	13	6					
Belwood	GR5404	13-Oct-05	10:30:00	0	0	0.8			1.0	
Conestogo	GR5107	6-Jul-05	8:45:00	9	2	6.2			6.4	
Conestogo	GR5108	6-Jul-05	9:24:00	9	7					
Conestogo	GR5144	21-Jul-05	8:25:00	11	2	2.3	0.85	5.4	5.0	23.1
Conestogo	GR5145	21-Jul-05	8:25:00	11	7					
Conestogo	GR5292	11-Aug-05	8:51:00	13	2	2.9	0.76	6	6.7	19.6
Conestogo	GR5294	11-Aug-05	8:51:00	13	7					
Conestogo	GR5298	23-Aug-05	8:37:00	13	2	1.3	1.00	4.4	9.7	9.9
Conestogo	GR5300	23-Aug-05	8:37:00	13	7					
Conestogo	GR5347	5-Sep-05	13:15:00	12	2	2.0	0.95	4.8	2.9	33.9
Conestogo	GR5348	5-Sep-05	13:15:00	12	7					
Conestogo	GR5387	22-Sep-05	8:45:00	10.5	2	1.1	1.20	3.9	5.1	16.4
Conestogo	GR5391	22-Sep-05	8:45:00	10.5	5					
Guelph	GR5105	6-Jul-05	13:15:00	10.5	2	2.8			5.9	
Guelph	GR5106	6-Jul-05	13:15:00	10.5	8					
Guelph	GR5142	21-Jul-05	12:35:00	7.5	2	3.7	0.43	10.7	5.2	39.8
Guelph	GR5147	21-Jul-05	12:35:00	7.5	6					
Guelph	GR5291	11-Aug-05	13:42:00	8	2	3.2	0.49	9.5	5.2	36.4
Guelph	GR5293	11-Aug-05	13:42:00	8	6					
Guelph	GR5297	23-Aug-05	13:22:00	8.5	2	1.6	1.20	3.8	7.2	11.4
Guelph	GR5302	23-Aug-05	13:22:00	8.5	6					
Guelph	GR5345	5-Sep-05	10:40:00	10	2	1.9	0.99	4.6	5.9	17.1
Guelph	GR5350	5-Sep-05	10:40:00	10	6					

Appendix 2 Chemistry

Station Name	Station (#)	Date	Sample Depth (m)	SRP ug/L	TDP ug/L	PartP ug/L	TP ug/L	NH3 ug/L	SrSi ug/L	NO2 ug/L	NO3 ug/L	TN ug/L	TN:TP molar
Belwood	GR5109	6-Jul-05	2	0.9	16	4	12	40	1698	8	1028	2505	458
Belwood	GR5110	6-Jul-05	10				15						
Belwood	GR5143	21-Jul-05	2	1.0	6	8	13	24	1742	12	467	5340	908
Belwood	GR5146	21-Jul-05	8				13						
Belwood	GR5290	11-Aug-05	2	0.0	8	13	16	25	1596	11	93	1323	189
Belwood	GR5295	11-Aug-05	10				24					1109	103
Belwood	GR5299	23-Aug-05	2	0.1	11	14	28	63	1894	5	12	1084	84
Belwood	GR5301	23-Aug-05	9				21					745	79
Belwood	GR5346	5-Sep-05	2	4.9	35	22	30	17	1982	1	0	900	66
Belwood	GR5349	5-Sep-05	10				36					1648	101
Belwood	GR5388	22-Sep-05	2	0.2	9	13	38	50	2372	1	113	443	26
Belwood	GR5390	22-Sep-05	6				22					2070	66
Belwood	GR5404	13-Oct-05	0	0.4	11	22	54	45	2720	3	85	1658	68
Conestogo	GR5107	6-Jul-05	2	0.0	8		13	127	881	48	2277	5744	1000
Conestogo	GR5108	6-Jul-05	7				13						
Conestogo	GR5144	21-Jul-05	2	0.4	9	8	16	36	1034	41	1821	2546	350
Conestogo	GR5145	21-Jul-05	7				18					2991	362
Conestogo	GR5292	11-Aug-05	2	0.0	6	10	15	50	1376	48	919	1876	279
Conestogo	GR5294	11-Aug-05	7				14					2445	388
Conestogo	GR5298	23-Aug-05	2	1.8	14	15	16	71	1321	75	938	1775	254
Conestogo	GR5300	23-Aug-05	7				24					1505	136
Conestogo	GR5347	5-Sep-05	2	1.6	5	13	15	49	313	64	925	1528	227
Conestogo	GR5348	5-Sep-05	7				23					2116	199
Conestogo	GR5387	22-Sep-05	2	0.3	6	19	25	82	750	64	648	1964	175
Conestogo	GR5391	22-Sep-05	5				27					813	208
Guelph	GR5105	6-Jul-05	2	2.5	9		14	63	1730	23	943	2491	398
Guelph	GR5106	6-Jul-05	8				15						
Guelph	GR5142	21-Jul-05	2	0.4	6	5	13	32	1692	22	715	4120	700
Guelph	GR5147	21-Jul-05	6				16						
Guelph	GR5291	11-Aug-05	2	0.0	5	8	14	45	1593	19	458	1572	249
Guelph	GR5293	11-Aug-05	6				18					829	99
Guelph	GR5297	23-Aug-05	2	3.5	16	12	22	113	2319	14	67	1365	139
Guelph	GR5302	23-Aug-05	6				23					854	80
Guelph	GR5345	5-Sep-05	2	0.9	14	10	16	44	2407	5	154	804	113
Guelph	GR5350	5-Sep-05	6				27					1277	105

Appendix 3 Chlorophyll and spectral fluorescence of different algal groups

Station Name	Station (#)	Date	Sample Depth (m)	Chl "a" ug/L(ext)	FPB Chl ug/L	FPB 2m Cyano ug/L	FPB 2m Green ug/L	FPB 2m Dia ug/L	FPB 2m Crypto ug/L	FPB 2m CDOM ug/L
Belwood	GR5109	6-Jul-05	2	7.3	5	1	0	1	2	2
Belwood	GR5110	6-Jul-05	10	1.3	1					
Belwood	GR5143	21-Jul-05	2	9.2	13	3	3	3	4	1
Belwood	GR5146	21-Jul-05	8	6.8	5					
Belwood	GR5290	11-Aug-05	2	23.8	19	13	1	0	5	2
Belwood	GR5295	11-Aug-05	10	4.9	3					
Belwood	GR5299	23-Aug-05	2	27.1	13	6	2	0	6	2
Belwood	GR5301	23-Aug-05	9	15.5	12					
Belwood	GR5346	5-Sep-05	2	41.2	30	16	0	7	6	1
Belwood	GR5349	5-Sep-05	10	13.8	15					
Belwood	GR5388	22-Sep-05	2	46.6	26	12	0	3	11	2
Belwood	GR5390	22-Sep-05	6	22.7	23					
Belwood	GR5404	13-Oct-05	0	17.8	25	14	0	0	4	1
Conestogo	GR5107	6-Jul-05	2	2.1	2	1	0	1	1	1
Conestogo	GR5108	6-Jul-05	7	0.4	1					
Conestogo	GR5144	21-Jul-05	2	11.7	6	3	0	0	4	1
Conestogo	GR5145	21-Jul-05	7	4.6	5					
Conestogo	GR5292	11-Aug-05	2	14.6	8	2	2	2	2	1
Conestogo	GR5294	11-Aug-05	7	10.2	9					
Conestogo	GR5298	23-Aug-05	2	16.2	11	4	1	0	5	2
Conestogo	GR5300	23-Aug-05	7	14.4	11					
Conestogo	GR5347	5-Sep-05	2	20.2	10	5	0	0	5	0
Conestogo	GR5348	5-Sep-05	7	5.1	4					
Conestogo	GR5387	22-Sep-05	2	23.1	18	11	0	0	6	1
Conestogo	GR5391	22-Sep-05	5	17.8	13					
Guelph	GR5105	6-Jul-05	2	5.2	5	2	0	2	0	2
Guelph	GR5106	6-Jul-05	8	3.8	3					
Guelph	GR5142	21-Jul-05	2	2.1	4	3	0	0	2	1
Guelph	GR5147	21-Jul-05	6	3.3	3					
Guelph	GR5291	11-Aug-05	2	4.3	3	2	1	0	1	1
Guelph	GR5293	11-Aug-05	6	6.0	4					
Guelph	GR5297	23-Aug-05	2	10.5	7	4	1	0	2	1
Guelph	GR5302	23-Aug-05	6	9.0	6					
Guelph	GR5345	5-Sep-05	2	14.5	8	4	1	1	2	1
Guelph	GR5350	5-Sep-05	6	12.4	5					