Ministry of Natural Resources
Lake Erie Management Unit

An Assessment of Aquatic Habitat in the Southern Grand River, Ontario: Water Quality, Lower Trophic Levels, and Fish Communities

Ontario

Cover photo: Looking downstream from an island in the reservoir of the Dunnville dam.
Photo by Janice Gilbert.

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Lake Erie Management Unit
Provincial Services Division
Fish and Wildlife Services Branch
Ontario Ministry of Natural Resources
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Ideas and concepts generated by the Lake Erie LaMP informed the planning stages of this work. The whole process benefited from the input and encouragement of Sandra George (EC).

[1] Sandra Cooke. 2004. Southern Grand River Rehabilitation Initiative: Water Quality Characterization. GRCA Draft Report, 1[ST] Draft, May 10. 46 pages.

Executive Summary

The Grand River is a large Lake Erie basin watershed which drains a variety of land types, is impacted by a multiplicity of land uses and is a major contributor of nutrients to the relatively nutrient-poor eastern basin of the lake. Additionally, it provides habitat for a variety of lake fishes which have a riverine component to their life history. The lower reach of the river, particularly the dynamic interface between river and lake, constitutes a unique environment which many lake and river species utilize and to which they are adapted. Major alterations to the watershed since European settlement have resulted in an ecosystem no longer able to support the full historical compliment of biota. To inform future rehabilitation work, a detailed assessment of the aquatic ecosystem downstream of the city of Brantford (the *Southern Grand River; SGR*) was conducted between 2003 and 2005. The objectives were to assess aquatic habitat (based on water quality, lower trophic levels, and fish community), infer ecological connections where possible, help to inform rehabilitation targets, and guide future monitoring to detect change.

The study area was high in nutrients throughout, surpassing targets for total phosphorus (TP) and most forms of nitrogen (N) and indicative of eutrophic to hyper-eutrophic conditions. The intensity of the surveys expanded the range of documented concentrations beyond what was known from long term provincial data sets. Gradients and break points in nutrient concentrations along the length of the main river channel point to potential areas of differential uptake by primary producers, differential inputs, and deposition and re-suspension zones. The river immediately upstream of Dunnville (dam reservoir) serves as both a deposition zone and resuspension zone depending on proximity to the dam. Tributary waters were seasonally different than the main channel for a number of water quality measures suggesting different types of nutrient input and, among tributaries, differential ability to provide refuges from spring suspended solid loads (e.g. Boston creek) and summer high temperatures (e.g. Rogers creek).

Biomass of planktonic algae increased in a downstream fashion, and reached levels associated with hyper-eutrophic conditions within the reservoir of the Dunnville dam as well as areas downstream. The composition of both benthic invertebrate and fish communities indicated exposure to organic pollution and low oxygen conditions. Indexes of habitat health derived from invertebrate and fish data in most cases showed conditions improving, moving upstream from the Dunnville area to Cayuga and above. Periods of high summer temperatures and low oxygen preclude the use of large parts of the river for some fish species and/or life stages (e.g. walleye; 98% reduction in useable habitat for 12 days). Relief from anoxia is linked to mixing associated with increased flows. Where linked, the river benefits from the dynamic connection to Lake Erie which serves as a source of alternate water quality, quantity, and physical energy. The lake can serve as both a refuge and source of immigration for river populations.

The comprehensive picture that emerges for the SGR is one of a nutrient rich environment where a high biomass of planktonic algae occurs and benthic invertebrate and fish communities are dominated by species tolerant of organic pollution and low oxygen conditions; it is impaired both in terms of general habitat requirements and use by desired species. Many of the factors implicated in reduced aquatic habitat quality are interconnected and likely contribute through more than one pathway, sometimes feeding back to previous stages or compounding other impairments. This interconnectedness poses a problem when attempting to address habitat issues. The multiple negative habitat changes imposed by the Dunnville dam (on: nutrient dynamics; physical movement of biota; hydrology; oxygen and temperature; sediment transport; substrate composition) make it a key target for restoration initiatives. Information on measured gradients and subwatershed characteristics can additionally be used to identify targets and approaches to rehabilitation for specific parts of the SGR. Recommendations for meaningful ongoing monitoring practices are presented.

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Habitat Overview

The Grand River is a large (>6500 km^2) Great Lakes basin watershed which drains a variety of land types and is influenced by a multiplicity of land uses, both urban and rural (OMNR and GRCA, 1998). It is the principal Canadian tributary draining to Lake Erie (after the bi-national Detroit River; Figure A) and serves as both a contributor of nutrients to the relatively nutrient-poor eastern basin of the lake and as habitat for lake fishes which have a riverine component to their life history. In addition to providing spawning habitat (and for some, subsequent nursery and juvenile habitat) to potamodromous fish, the river also provides habitat to resident populations of many species. Use of the river by lake fish can occur on seasonal, diurnal or more irregular time scales (e.g. when lake fish seek forage or thermal conditions which are temporally unique to the river).

The ability of the river to provide suitable habitat for fish has been compromised by man-made manipulations of the hydrology and the physical connectivity of the river. Much of the flow-regulating function of historically present large tracts of wetland has been assumed by reservoirs the operation of which, to date, have been primarily directed at maintaining flows suitable for human uses (primarily water intakes and flood control). The removal of wetlands is an example of manipulations of the system (including straightening sinuosity, armouring banks, and impounding with dams) that has decreased habitat diversity and subsequently impaired the ability of the system to fully support diverse aquatic populations. Compounding problems created by hydrological change are changes to water quality resulting from poor land use practices, in particular high nutrient and suspended solid loads associated with both urban and rural inputs.

The degree to which suitable habitat is available to individual fish species, relative to historic, pre-European settlement conditions, will never be known definitively. Lake sturgeon, a once common Grand river-run Lake Erie species, appears to be extirpated from the system (OMNR and GRCA, 1998) while walleye, though severely restricted, still utilize the lower reach to some extent (MacDougall et. al. 2007). Any restoration of historic fish communities, or rehabilitation of current conditions, will necessarily involve habitat alterations and enhancements. As Roni (2005) reminds us…

> "*Before developing any restoration priorities or strategy, a watershed or ecosystem assessment of current and historical conditions and disrupted processes is necessary to identify restoration opportunities that are consistent with re-establishing the natural watershed processes and functions that create habitat*".

As one step toward an ecosystem assessment a broad program of monitoring was initiated to document the current habitat quality of the lower reaches of the Grand River. This part of the watershed, collectively referred to as the *Southern Grand River (SGR)*, includes the main channel and tributaries downstream of the Cockshutt road bridge in Brantford (Figure B). The SGR encompasses the first fisheries management zone upstream of Lake Erie (Lower Grand River Reach, as defined by the Grand River Fisheries Management Plan; OMNR and GRCA 1998), is characterized by a low gradient relative to the upper watershed (Figure C) and is underlain by poorly infiltrated glaciolacustrine deposits of silts and clays. Functionally it consists of two zones of impounded water (upstream of dams at Caledonia and Dunnville), a zone of free flowing steeper gradient pool-riffle sequences (between the Caledonia and the town of Cayuga), and a "lake-effect" zone where water levels are determined by Lake Erie levels (downstream of

Dunnville). Prior to construction of the Dunnville dam, the lake effect zone would have extended upstream to Cayuga (Figure D; and Gilbert and Ryan 2007).

A thorough assessment of the SGR would result in definitive statements about current aquatic habitat health, potential remediation targets and baseline data from which to monitor change. The intent was to collect data on a finer scale (both spatially and temporally) than would normally be feasible under restricted agency capacities and to do this across a number of trophic levels. As Caledonia represents the current physical limit for most upstream moving lake fish, the main focus area was from Caledonia downstream to Port Maitland. Acknowledging that upstream areas have the ability to influence downstream areas, particularly with regard to water quality, water collections for chemical analysis were extended upstream to Brantford (Figure B).

Parameters measured included: water quality (nutrients & chemistry) physical water attributes (suspended solids, temperature, dissolved oxygen, light attenuation), algal production (as planktonic chlorophyll-*a*), benthic invertebrates (species densities and relative abundance), and fish community (species relative abundance).

Each component is described in a stand-alone manner (water quality, chlorophyll, benthic invertebrates, fish community, temperature & oxygen). Measured values were compared to previously developed targets, objectives, and indices. This is followed by a synthesis section and habitat quality conclusions.

This report is complimented by reporting on wetland assessments conducted during the same period (Gilbert and Ryan 2007) as well as subsequent work on they hydrology of the lower river and ongoing fisheries assessments.

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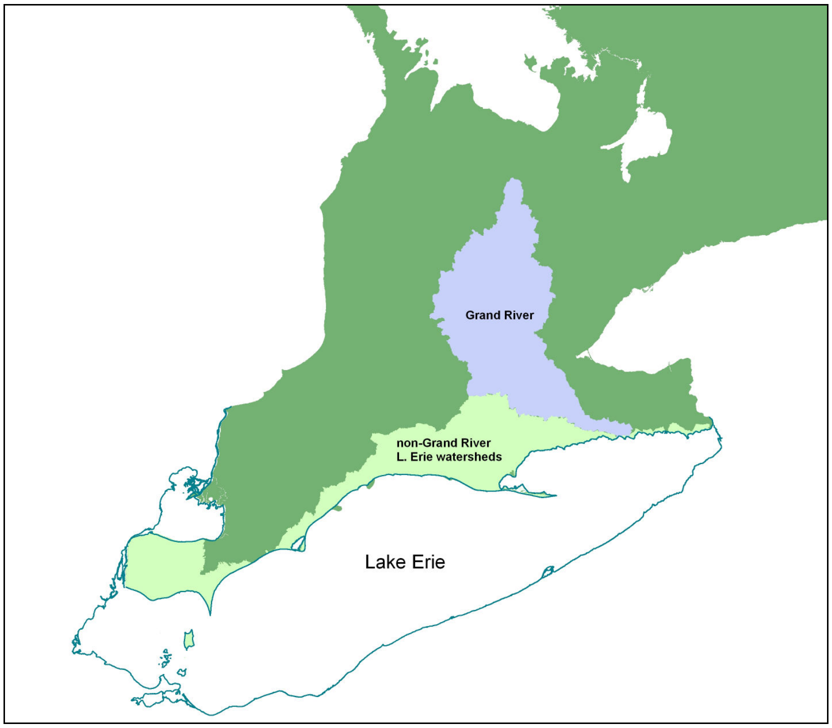

Figure A. The Grand River watershed (blue) in relation to southern Ontario (dark green) and other Lake Erie watersheds (light green).

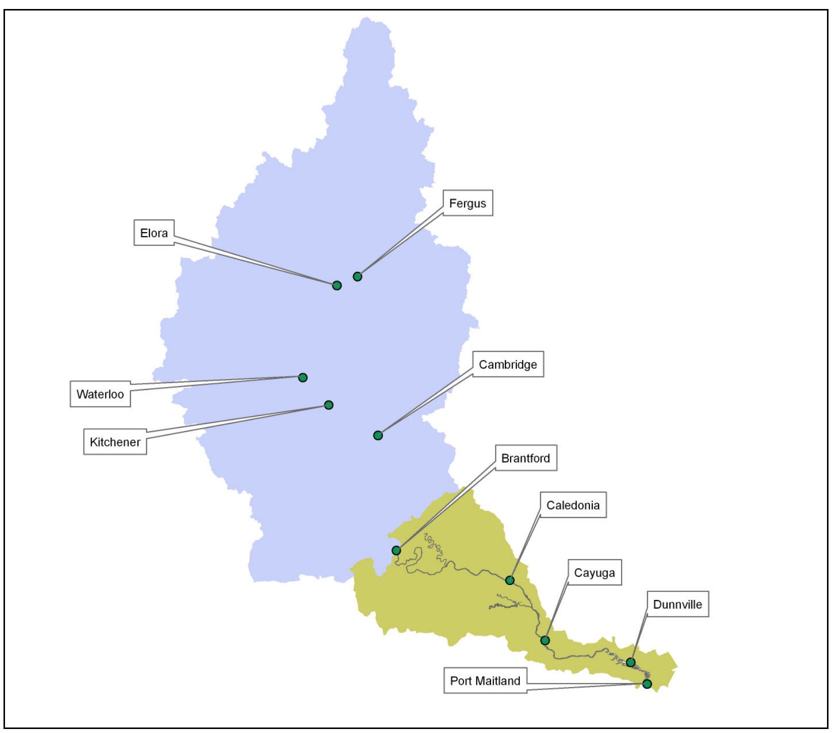

Figure B. The Southern Grand River study area (green) is shown relative to the upper reaches (blue). Select cities and towns are shown for reference.

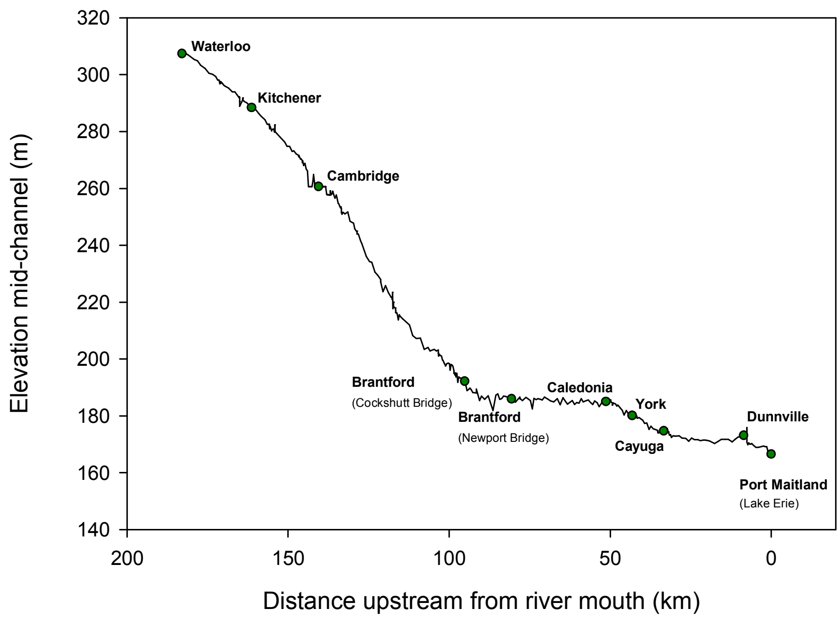

Figure C. Mid-channel elevation of the Grand River from the confluence of the main channel and the Conestogo subwatershed (Waterloo) and the town of Port Maitland on Lake Erie. Select cities and towns are shown for reference. Chainage from Hec-2 cross sections courtesy of GRCA

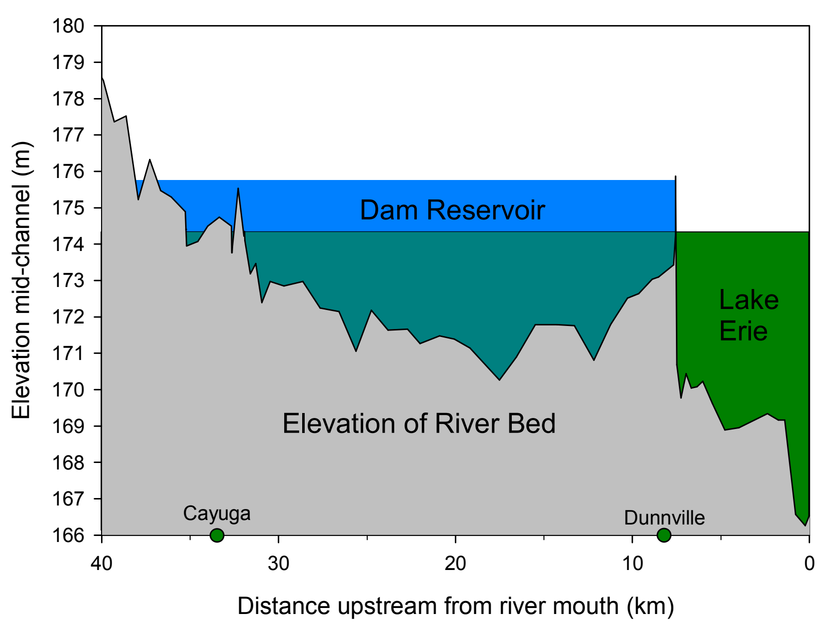

Figure D. Current location of the Southern Grand River lake-effect zone relative to the impounded waters of the Dunnville dam reservoir. The historic (pre-dam) lake effect zone can be inferred from chart datum lake levels relative to the elevation of the river bed.

1.0 Water Quality

1.1 Introduction

The Grand River, as with other southern Ontario watersheds, has high levels of nutrients, due in large part to the concentration of people living and working within its drainage. While a large portion of the watershed (75%) is used for agriculture, high densities of people in the relatively smaller (5%) urban areas are also a source of nutrients; both point- and non-point sources play a role. Further to nutrients, high loads of suspended solids are a recognized water quality problem. Previous (Mason and Hartley 1998) and more recent (Cooke 2006) analyses of water quality point out that while improvements have occurred since the 1960s, several provincial and federal objectives for surface waters are still rarely met.

Much of what is known about the quality of surface waters within the Grand River is the result of long-term monitoring, conducted by the GRCA and MOE, involving the regular sampling of water chemistry at designated stations within the watershed. Provincial Water Quality Monitoring Network (PWQMN) stations within the Southern Grand River (SGR) exist at Brantford, York and Dunnville. Additionally, sub-watershed tributaries emptying into this section of river are measured, as they approach the main channel, at Fairchild Creek, Boston Creek, and McKenzie Creek. Despite limitations imposed by changes in sampling frequency over the years, this dataset provides a good source of information for describing long term trends. However, in order to describe water quality as it applies to rehabilitation needs in the SGR, a more thorough assessment of current conditions was thought necessary. In addition to complimenting the long-term PWQMN trend information, it would be useful to characterize water quality on a scale sufficient to identify patterns associated with season and location.

In 2003 and 2004, working in partnership with the GRCA, a sampling program was devised that would increase the spatial and temporal coverage of water quality information from the SGR. It incorporated current PWQMN stations, added new stations, and increased sampling frequency with the intention of detecting patterns not previously discernable. Of particular interest would be gradients along the length of the river together with localized deviations which might be associated with source inputs or changes in nutrient processing. The higher frequency of sampling might also expand the range of conditions known to occur and thereby refine our knowledge of “worst case scenarios”.

Where possible, the sampling occurred coincident with the sampling of other biological parameters so that, in the end, conclusions might be drawn about the relationship between water quality, lower trophic levels and the fish communities of the lower river. Describing water quality relative to the needs of aquatic biota is a necessary step in recognizing water quality as an integral component of habitat. To a large degree, these relationships have been considered by regulatory agencies when devising targets and objectives. However it is important to consider the original intent of each objective (see Methods, *Comparison to water quality objective;* below) and to recognize potential limitations to relying solely on single measure objectives. Objectives that absolutely protect aquatic life are difficult to formulate, because of the difficulty in capturing both the cumulative effects of multiple, non-lethal but chronic, exposures as well as hard-to-document, episodic but extreme (and lethal), exposures. A consideration of trophic state is one way to approach multiple non-lethal nutrient inputs at the ecosystem level while a careful and detailed assessment of episodes and extremes would be useful for understanding the loss, adversity or lethality of habitat to aquatic life. Together, this will contribute to understanding whether meeting WQ objectives can provide adequate protection to aquatic life in the southern Grand

1.2 Methods

Collection of water samples
Water samples were collected from 19 stations (16 main-channel and 3 tributary) located between Port Maitland and Brantford on 40 separate occasions between 2003 and 2004; not all stations were sampled on all dates (Table 1.1). Seven of the 19 locations correspond with the previously established PWQMN stations (Figure 1.1). Spatial coverage was the greatest in 2003 when sites were accessed by road overpass (lowering a bucket from a bridge), wading from shore, and by boat. In 2004, fewer stations were sampled (almost exclusively bridge sites only) but the seasonal coverage was increased through collective efforts with the Grand River Conservation Authority (GRCA).

On four alternate weeks in 2003, at six of these stations, (WQ3 – WQ8), water was collected at both the surface and at depth (using a Van-Dorn bottle lowered to 0.5 m off of the bottom) in order to identify changes through the water column. During depth sampling, extreme care was taken to avoid contacting and stirring up bottom sediment. If it was suspected that the sampling bottle made contact with the substrate, the boat was moved upstream and sampling delayed for 20 minutes.

At each station, an equal volume of subsurface water was gathered at four locations across the width of the river and then mixed prior to decanting into sample bottles. Samples were placed on ice and transported to an accredited analytical lab (E3 laboratories Inc., Niagara on the Lake, Ontario) within 6 hours. Samples were fixed as necessary according to standard methods (e.g. addition of H_2SO_4 to samples destined for total phosphorus analysis). The following parameters were measured: ammonia, nitrite, nitrate, total kjehldahl nitrogen, chloride, total phosphorus, total suspended solids, pH and E. coli (one date only). Analytical details (method and detection limits) for each parameter are presented in Appendix A-1

Relationship to flows
Flow data to compliment the water analyses, was obtained from gauge stations at Brantford and York operated by the GRCA (unpubl. data, D. Boyd, Grand River Conservation Authority, Cambridge, Ontario)

Comparison to water quality objectives
Values obtained were described relative to objectives or standards that have been established by either provincial or federal agencies (Appendix A-2). The purpose of these objectives range from the protection of all aquatic life (usually based on acute toxic exposure tests) to the protection of "healthy fisheries" or to human health (with regard to drinking water or recreational use). In the case of total phosphorus, the objective is based on the ability of the parameter to affect primary productivity and is designed to limit both aesthetic ("nuisance" algae) and secondary (altered oxygen regime) impacts.

Comparison to trophic state descriptors
Nitrogen and Phosphorus values were used to discuss trophic state. A variety of boundaries values have been proposed for classifying water bodies; most refer to lentic situations. For the purposes of classifying the trophic state of the lower reaches of the Grand River, values were compared to both ranges and mean values (Appendix A-3) as proposed by Wetzel (1983) and Lakewatch (2000). A similar classification by Leach (1977) is used for relating to the

requirements of walleye and yellow perch and fishery objectives set for Lake Erie (Ryan et al. 2003).

Comparison to provincial water quality monitoring network data
PWQMN data was obtained from the Ministry of the Environment (unpubl. data, A. Todd, M.O.E., Environmental Monitoring and Reporting Branch, Toronto, Ontario) for three stations within the lower reach of the Grand; at the Newport Bridge in Brantford, the bridge at York, and the bridge at Dunnville (corresponding to current stations WQ19 , WQ12 , and WQ3 ; respectively).

Analysis
Water quality data, with its seasonal and flow related influences, is notorious for being non-normally distributed and for its high degree of variability (Cooke, 2006). Further compromised by the unevenness in frequency of sampling between sites, simple descriptive statistics and graphical examinations are presented here rather than more robust statistical comparisons which would have necessitated specialized water quality software or cumbersome and questionably appropriate transformations. Summarized values were examined graphically as i) frequency distributions relative to water quality objectives ii) box plots showing mean, median and percentile values, iii) spatial comparison of mean values (bar charts) along the length of the river. Minimums and maximum values were deemed informative for illustrating worst case scenarios.

For individual sampling events where a concentration could not be detected, a constant value equal to the minimum detection limit divided by the square root of 2 was substituted, a common practice as described by Hensel (1990).

Most spatial comparisons were conducted using summer/fall data (2003 and 2004 pooled). Spring values were suspected of being too closely coupled to flow (e.g. see phosphorus/flow regressions in Results; below). For the purposes of this report, samples collected when mean daily flows were ≤ 50 m^3/s were considered comparable; Included were all values except those obtained during spring (Mar-April) 2004 collections (Figure 1.2). Data collected during the spring of 2004 was used in order to describe the range of values possible and to compare spring with summer/fall values.

For the purposes of discussion, sections of river were loosely classified relative to the dams at Dunnville and Caledonia and as main channel vs. tributary stations. In figures, this is often reflected using colours to define sampling stations as follows: brown-below Dunnville, grey-Dunnville to Cayuga, green- Cayuga to Caledonia, navy blue- Caledonia to Brantford and teal-tributary stations.

1.3 Results

Descriptive statistics for overall water quality measures are provided in Table 1.2. A general observation is that, for most parameters, mean values for spring sampling are higher than mean values for summer and/or fall[2]. The exceptions are chloride and pH which are higher during the summer/fall and TKN which does not change appreciably between seasons. A similar listing of select parameters compared to those collected at three main-channel PWQMN stations between 2000 and 2005 is given in Table 1.3 for comparison. Approximately twice as many measures were taken in the current study compared to the long-term program between 2000 and 2005. For

[2] TSS, total P are usually correlated with flow when year round paired observations are analyzed.

TP, NO_3, and pH, the 2-yr intensive sampling captured a wider range of values and higher maximum values. Alternately, fewer samples collected over more years (PWQMN) yielded a wider range of values and higher maximum values for TKN, NO_2 and Cl^-.

Phosphorus (TP)

Total phosphorus values were high in the stretch of river below Brantford, with the overall mean from both years of sampling being 0.1 mg/L (Table 1.2). Only six of 402 water samples (1.6%) met the PWQO of <0.03 mg/L for total phosphorus (Figure 1.3). These PWQO-acceptable samples were collected from tributary sites at Boston Creek (WQ13; two dates) and Fairchild Creek (WQ17; one date) in the late summer /early fall, and from the main channel at Brantford (Cockshutt Bridge; WQ19) in the fall (two dates) and late spring (one date). Values ranged from a low of 0.01 to a high of 1.04 mg/L. Higher values were observed during periods of high flow in the spring at which time daily mean TP concentration was strongly ($p<0.001$) correlated with flows at York (Figure 1.4). This relationship was not significant after flows fell below 50 m^3/s.

Spatial differences in values.

Total phosphorus values differed along the spatial gradient of the river when data from 2003 was examined (summer and fall values; when the broadest range of same-season stations was sampled in the most even manner). What is immediately apparent is that the tributary stations at Boston, McKenzie, and Fairchild creeks (WQ-13, -14, -17; respectively) had higher mean, and median values and broader 25^{th}-75^{th} and 10^{th}-90^{th} percentile ranges than main channel stations (Figure 1.5). Values at McKenzie Creek were notably the highest measured in 2003. Within the main channel, stations upstream of Caledonia (WQ-15, -16, -18, and -19) had broader 25^{th}-75^{th} percentile ranges than those further downstream. The highest mean and median values occurred at stations at either end of the spatial gradient; from Caledonia upstream and from Dunnville downstream. Larger 10^{th} and 90^{th} percentile ranges at WQ3 (Dunnville), WQ6 (midway; Dunnville to Cayuga), WQ9 (just below Cayuga), WQ12 (York) WQ15 (Caledonia) and WQ18 (Brantford-Newport Bridge), tell of the periodic high values which occur at these main channel stations.

Mean values from each station in 2004 were compared for spring and summer/fall separately (Figure 1.6; A). Mean TP concentration during spring sampling at main-channel stations (0.11 to 0.16 mg/L) generally exceeded mean concentrations at the three tributary stations (0.098 to 0.12 mg/L). The highest mean TP concentrations occurred at the three most downstream main-channel stations (WQ12 [York] and downstream) which were all similar (approximately 0.16 mg/L). Mean TP from stations at Caledonia and upstream were lower and showed a general pattern of decreasing as one moved upstream; the lowest mean occurring at WQ19 (Brantford-Cockshutt bridge; 0.105 mg/L).

Mean TP concentrations at main-channel stations during summer and fall sampling (2003 and 2004 combined) were lower than those measured during the spring (Figure 1.6; B). Unlike the spring pattern of values, mean TP was higher at the tributary stations relative to main-channel stations. Mean TP at Boston Ck. and McKenzie Ck (0.18 and 0.17 mg/L; respectively) was higher than any of the spring means. Mean TP at Fairchild creek (0.11 mg/L) was similar during both periods.

The spatial pattern of similarities in TP from the most upstream and most downstream stations, mentioned above, is readily apparent when overall summer /fall means are compared (Figure 1.6; B). Higher means in the Caledonia to Brantford section of river (avg. 0.087 mg/L), decrease through the Cayuga to Caledonia section, reach a low (0.05 mg/L) approximately 3 km below Cayuga (WQ7) and then gradually rise back to values (avg. 0.097 mg/L) greater than those in the most upstream stretch. The exception is the mean value from the most upstream station (WQ19), which is lower (0.064 mg/L) and more similar to mean TP between Dunnville and Cayuga.

Whereas means are similar at the most upstream and most downstream stations during the summer/fall, individual measures from these two areas differ in their range. TP concentration is much more variable in the Caledonia to Brantford stretch (implicit in the noticeably larger standard deviation error bars) and more frequently approaches the PWQO of 0.03 mg/L whereas the opposite is true downstream of Cayuga. As one moves downstream from WQ7, means and individual measures diverge from the PWQO to a greater degree.

Nitrogen (TN, TKN, NH_3, NH_4, NO_2, NO_3, organic)

Nitrogen concentrations are high in the stretch of Grand River downstream of Brantford. Overall, mean total nitrogen (TN) concentration during 2003 and 2004 sampling was 3.77 mg/L. As with phosphorus, TN was higher during spring sampling (mean 4.97 mg/L) than during the summer/fall period (mean 3.26 mg/L; Table 1.2). In both periods, mean TN concentrations at tributary stations were approximately 33-50% lower than overall main-channel means (1.9 mg/L and 3.5 mg/L; respectively).

Spatial differences in values

When means from individual main-channel stations are considered separately it is apparent that, while spring means are high (> 5mg/L) and similar among stations, individual station means from the summer/fall period show a definite spatial pattern (Figure 1.7). Summer/fall mean TN showed a decreasing trend from upstream (high of 4.2 mg/L; WQ18) to downstream (low of 2.75 mg/L; WQ1). Most of this trend in TN is attributable to the trend in nitrate (decreasing means from upstream to downstream), which is the largest component part (59-80%) of the total nitrogen measure (Figure 1.8; B). In contrast, the nitrite component (Figure 1.8; D) shows a spatial pattern similar to what was observed for TP in the main channel during summer/fall (above); a decline in mean concentration from upstream stations to just below Cayuga (low), and then an increase from this point downstream to Port Maitland

Contrasting the spatial trend in summer/fall mean nitrate (and consequently mean TN) concentrations, is the spatial pattern for mean Kjehldahl nitrogen (TKN). TKN concentration increased at main channel stations from upstream to downstream (Figure 1.9; top). Most of this trend appears attributable to the upstream-downstream increase in mean organic nitrogen ($N_{organic}$) which is the major component part of the TKN measure. Whereas $N_{organic}$ concentrations increase steadily from WQ19 (Brantford) to WQ1 (Port Maitland), other, smaller TKN component parts show similar but varying patterns (Figure 1.9). Ammonia increases from 0.07 mg/L at WQ19 (Brantford-Cockshutt bridge) to 0.11 mg/L at WQ16 (Middleport Bridge) before steadily decreasing to 0.04 just below Cayuga and then steadily increasing again to station WQ1 at Port Maitland where the mean summer/fall concentration was 0.10 mg/L. Mean $N_{organic}$ concentration at Cayuga (WQ9) is the exception to this pattern; being higher than its neighboring stations. Unsurprisingly, component parts of the total ammonia value (NH_3 and NH_4) show a similar though slightly varied pattern.

Nitrogen guidelines and objectives

Nitrogen species targeted by agency objectives or guidelines are displayed graphically as frequency histograms (Figure 1.10). Both forms of oxidized nitrogen (NO_2 and NO_3) have the ability to negatively affect aquatic life as does the un-ionized form of ammonia (NH_3^-).

The majority (93%) of water samples collected in 2003 and 2004 met the federal guideline for nitrite (< 0.06 mg/L); measures in excess of the guideline tended to occur in the spring at all stations and in the summer/fall at the most upstream stations.

Fewer (59%) individual water samples met the federal guideline for nitrate (<2.93 mg/L). Most high values occurred during high spring flows; mean spring values at main channel stations and in Fairchild Creek (WQ 17) were all higher than 2.93 mg/L. Mean summer/fall nitrate concentrations were lower but still above the criteria at all main-channel stations from Caldeonia upstream to Brantford.

There were no samples in which NH_3^- values (calculated based on ambient temperature and pH) were close to the federal guideline of 0.0165 mg/L (the highest measure was 0.0139 mg/L at WQ18 on Sept 15, 2003).

Nutrients through the water column
On four dates in 2003, nutrient measures were taken at both the surface and at depth in order to look for evidence of either mixing or stratification /layering of the water column. While nitrate did not differ appreciably through the water column (Figure 1.11; B), total phosphorus was commonly higher at depth than at the surface (Figure 1.11; A). TKN and $N_{organic}$ varied from surface to bottom by as much as 0.5 mg/L, but with no consistent pattern (not shown). Total suspended solids (Figure 1.11; C), varied as TP did (it was generally higher at depth) suggesting a link between the two. A regression of TP on TSS (all measures 2003 and 2004) shows that these two parameters are significantly correlated (r^2=0.728; p<0.001) (Figure 1.12).

Nitrogen to Phosphorus ratios
Nitrogen and phosphorus ratios (TN:TP) were calculated for each sampling event and then averaged for each station in order to facilitate discussion about limiting nutrients. Mean TN:TP at each main channel station displayed a spatial pattern characteristic of TN, decreasing with distance downstream from Brantford (Figure 1.13; bottom). This was of course driven largely by the spatial pattern for TN; the concentrations of which were large, relative to TP (Figure 1.13; top). Individual ratios ranged from 8 to 343 and station means from 32 (WQ19) to 99 (WQ1) all of which, would typically be described as indicating phosphorus limitation (TN:TP>17). The ratio of TN:TP at tributary stations was considerably different, owing to the converse relationship between phosphorous and nitrogen. Ratios at Boston, McKenzie Creek and Fairchild Creek stations were considerably lower with means of 34, 16, and 44; respectively. On some individual sampling dates, TN:TP ratios indicative of nitrogen limitation (<10) were observed at tributary stations; this on 66%, 33% and 1% of sample events at Boston, McKenzie and Fairchild; respectively.

Trophic designation
Overall, the lower reach of the Grand River can be classified as either eutrophic or hyper-eutrophic based on the means and ranges suggested as benchmarks (>0.02 mg/L; Appendix A-3). This is particularly true for the spring. Total nitrogen values are typical of hypertrophic systems.

Total Suspended Solids (TSS)
Overall, total suspended solids are high between Brantford and Port Maitland, exceeding the CCME guideline on 50% of the 402 sampling events that occurred between 2003 and 2004 (Figure 1.14). While many of the higher values correspond to spring values, certain stations, both upstream and downstream, show high values throughout the summer and fall (Figure 1.15). The mean values in summer and fall are lowest in the stretch between Cayuga and Dunnville; likely attributable to sedimentation in the slower moving waters.

Chloride (Cl^-)
All chloride concentrations fell well below the federal drinking water guidelines of 250 mg/L. Conversely, all values are well above those generally found in areas free from anthropogenic influence; this expected in southern Ontario. The stations with the lowest mean Cl- concentrations, both spring and summer, were the tributary sites on Boston and McKenzie Creeks (WQ13 and WQ14) which both had a mean of 29 mg/L in the spring and means of 44 and 38 mg/L, respectively, in the summer. The other tributary site at Fairchild Creek (WQ17) had the highest mean during the spring sampling (68 mg/L) but was lower than means from main channel stations in the summer and fall (Figure 1.16). The range of values and mean values show that, unlike other parameters, values in the spring were lower than summer/fall values and suggest that the source may be a point-source; possibly constant throughout the year but diluted in the spring during high flow periods (Figure 1.16).

pH
Most pH values fell within the range deemed acceptable for the protection of aquatic life by the CCME (6.5 – 8.5). Occasional exceptions occurred (Figure 1.17). More basic outlier values were noted at stations WQ3, WQ6, WQ16, and WQ18. Only one water sample, from WQ3, was more acidic than the guideline lower limit. Station WQ had the highest overall summer mean pH (8.1), while the tributary stations at Boston and McKenzie had the lowest overall mean summer pH (7.8).

Escherichia coli
Water samples from August 31, 2004 were analyzed for *E.coli* at 14 of the WQ stations in order to obtain a rough baseline of values possible within the GR lower reach and to compare with samples collected concurrently within the wetlands adjacent to the main channel between Cayuga and Dunnville. Values ranged from 20 CFU (station WQ12) to 560 CFU (stn WQ17). By way of contrast, concurrently collected samples from adjacent wetlands ranged from 670 to 4900 CFU/100mL (Gilbert and Ryan, 2007). Water from six of the stations had CFU counts higher than the provincial guideline above which human use is discouraged (beach closings; Figure 1.18).

1.4 Discussion

The Grand River downstream of Brantford is high in nutrients and suspended solids. This is consistent what has been reported previously (Mason and Hartley 1998, OMNR and GRCA 1998, MOE 2002, Cooke 2006, Davies et al. 2005, Lake Erie LaMP 2006, Gilbert and Ryan 2007). Intensive sampling over two years (2003-2004) provided a picture of conditions that was similar to that described by the PWQMN dataset (less frequent sampling over a longer time period) as well as allowing for a more detailed spatial description of conditions along the length of the river.

Concentrations of nutrients in the water column will change (spatially or temporally) as they are differentially: loaded or diluted; utilized (e.g. nutrient uptake); chemically altered (e.g. nitrogen cycle under varying pH or O_2 conditions); or are settled / re-suspended. The seasonality observed for most parameters (higher in the spring and lower in the summer and fall months) can likely be attributed to increased loading and erosion/re-suspension associated with increased spring flows.

This seasonal pattern is particularly evident for total main channel suspended solids (TSS), a component of which is eroded or re-suspended fine clay particles but which also includes detritus and phytoplankton, particularly where flows are slowed or water impounded.

Suspended solids have the ability to detrimentally impact aquatic life in a number of ways; in the water column via abrasion of soft tissue and clogging of gills as well as, once settled, via the smothering of sensitive early life stages or critical spawning areas including macrophytes beds (Kerr 1995, Waters 1995, DFO 2000). Assessing risk associated with TSS is problematic and involves not only concentration and duration of exposure but is also species and life stage dependant; many low concentration sublethal effects have been documented (Newcombe and Jensen 1996). The Canadian Council of Ministers of the Environment (CCME) guideline of 25 mg/L was only met 50% of the time in this assessment. Given that the river moves over and through the Haldimand Clay plain, 100% compliance might not be attainable. Additionally, the proportion of occasions on which water meets the guideline might be meaningless if a small percentage of non-compliant occasions occur during critical periods for aquatic life.

Using the alternate criteria (periodic increases of no more than 10% of background) is also problematic because of our lack of understanding about what proportion of the low-flow "background" is natural and what proportion is related to anthropogenic input (e.g. the result of poor land use practices). Currently, values during mean spring flows are 63% higher than overall mean summer and fall concentrations. Periodic spikes, during both spring and summer, of greater than 700% overall median values were observed. While some of the TSS load originates upstream of Brantford, Cooke (2006) suggests that Fairchild, Boston, and McKenzie Creeks are large sources of loading in the lower river reach. Without correcting for flow or land area drained, the spatial pattern in TSS along the length of the river can still potentially provide clues as to where settling and re-suspension is taking place. During periods of lower flow, the main channel experiences its lowest TSS values downstream of Cayuga suggesting that some of the load begins to settles out. This is entirely plausible given that downstream of Cayuga, the river widens and slows in association with the impoundment created by a low-head dam at Dunnville. Retention time is increased substantially (Gilbert et al. 2004). High TSS concentrations at station WQ3 (immediately above the dam) and at WQ1&2 (below the dam; summer) suggest that this is a re-suspension area. Higher TSS downstream of the Dunnville reservoir may be attributable both to re-suspended sediment being transported downstream from WQ3 as well as re-suspension associated with increased boat traffic and Lake Erie seiche effects. The larger concentration of planktonic algae in this section of the river (see section 1.2) probably also contributes to the higher TSS. McKenzie Creek (WQ14) stands out as having considerably higher concentrations of TSS in the summer than the spring, despite lower flows suggesting a source not closely tied to flow. Similarly Fairchild Creek had summer/fall concentrations similar to those observed under higher spring flows.

The location and timing of periods of high concentration/high flow vs. high settling/low flow can be critical in affecting such things as successful reproduction for fish. Many species depend upon low sedimentation during periods of egg incubation followed by flows high enough for the transport of newly hatched larvae but low enough to avoid abrasion in high suspended sediment environments. Mion et al. (1998) have shown that year class strength for walleye in the Maumee River, OH is highly dependant on appropriate spring flows. The relatively lower spring TSS concentrations in Boston and McKenzie Creeks (WQ13 and WQ14) might favour walleye spawning in these areas despite a predominance of substrate in the main channel near York (WQ12) and Caledonia (WQ15). Conversely, the high TSS observed during early summer at station WQ14 might compromise this area as nursery habitat.

Areas of TSS deposition and re-suspension may help to explain spatial patterns in other parameters that increase and decrease in ways similar to TSS. Total phosphorus (TP) also shows a pattern of mean concentrations that "dip" to relative lows around Cayuga from highs experienced at the uppermost and lowermost main channel stations. This is likely due to the ability of fine clay particles to bind negatively charged phosphorus. The area between Cayuga and Dunnville likely represents a deposition, followed by re-suspension area for TP as well as for TSS. Dips in nutrient concentrations within the Dunnville reservoir when they coincide with peaks in algal biomass may also relate to greater uptake from primary production during these periods. While the main channel stations have lower mean TP in the summer than the spring, even the lowest mean of 0.05 mg/L (again in the "dip" just downstream of Cayuga) is well above the PWQO of 0.03 mg/L. Exceptions to this seasonal pattern occurred at the tributary stations; TP at Fairchild creek was similar between spring and summer/fall while Boston and McKenzie creeks during the summer/fall had mean TP concentrations that were 50% higher than spring concentrations. They were higher and more variable, overall than all other stations.

Nitrogen measurements also displayed the seasonal pattern of being high and similar between stations during the spring and being lower and showing differences in mean values along the spatial gradient of the river in the summer/fall. Patterns in mean summer/fall concentrations from Brantford to Port Maitland may be driven by differential input, uptake, and conversion between nitrogen forms. Two summer/fall spatial patterns stand out: 1) the decrease in NO_3 (and subsequently TN) from upstream to downstream and 2) the increase in organic-N (and subsequently TKN) from upstream to downstream.

During summer and fall, mean total nitrogen (TN) values decreased from Brantford to Port Maitland. This is primarily driven by the downstream trend of decline in NO_3 which is the main component of the TN measure. One downstream *increase* in nitrogen between stations WQ19 and WQ18 is likely linked to their position upstream and downstream, respectively, of Brantford's water treatment control plant outflow[3]. While this represents one example of nitrogen input through the southern watershed, Cooke (2006) concluded that the *primary* source of nitrates for the lower section of the watershed originates above Brantford. The decline below Brantford could be driven by: i) increased uptake by primary producers and/or ii) decreased conversion of organic-N and ammonia to NO_2-NO_3 due to low dissolved oxygen conditions. There is evidence of substantial algal production in the lower river reach; While the presence of periphyton and submerged macrophytes decline as one moves below Brantford (due to increased turbidity), planktonic algae increases considerably, also in a gradient from upstream to downstream (see section 2.0; Chlorophyll). The gradually increasing TKN below Brantford represents an increased input of organic pollution. Any subsequent TKN-driven increase in BOD, coupled with O_2 consumption from the increasing deposition of dead algal cells, may be responsible for the periodic low oxygen conditions that have recently been documented (see section 5.0; Temperature & Oxygen). Increasing NH_4-N downstream of Cayuga would fit this scenario.

The downstream gradient of increasing of organic-N relative to NO_2-NO_3-N might be related to changing land use patterns below Brantford where the river moves from a highly urbanized area serviced by large water pollution control plants to more rural, agricultural areas with higher use of septic systems as well as organic nitrogen being directly applied to the (clay based) landscape.

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[3] Note: an increase in both mean and maximum summer concentrations when moving downstream between stations WQ19 and WQ18 is evident for all nitrogen measures as well as for TP, TSS, and Cl-; likely representing the influence of the urban centre of Brantford.

Unlike what was observed for TP, TN values at the tributary stations were markedly lower than those at main channel stations in the summer/fall. Regardless, at station WQ14, where the mean summer/fall TN concentration were the lowest (1.7 mg/L), nitrogen was still at levels indicative of the hyper-eutrophic conditions. Similarly, despite observations of slight long term declines in flow-adjusted TP (Cooke 2006, MOE 2002, A. Todd, MOE; pers comm.) the level of phosphorus in the lower reaches of the Grand River remains above the PWQ objectives; at levels which can negatively impact aquatic life.

The ratio of TN:TP, commonly used to determine which of the two main nutrients is limiting to primary production, is almost meaningless in the context of the nutrient concentrations observed in the lower reaches of the river. Generally, nitrogen is utilized at a rate of approximately 10:1 compared to phosphorus and a ratio of >17 is often said to represent a phosphorus limiting environment. P-limited environments are typical of fresh-water systems. In the lower Grand, TN:TP follows the pattern of decreasing at main channel stations, in a downstream direction; primarily driven by declining TN. While the TN:TP ratios measured here range between 17 and 343 (mean ratios at WQ1 and WQ19 were 32 and 99; respectively), both nutrients occur in such high concentrations that it is doubtful that one or the other is limiting primary production. Primary production is probably more limited by temperature and by light attenuation caused by suspended particles (PAR <10% surface at <1m; data not shown).
The tributary stations, particularly McKenzie Creek, were anomalous in that they did show considerably lower ratios; some individual dates had ratios of as low as 1.4 suggesting that nitrogen might be limiting on some occasions.

The extremely high ratios observed (particularly those at the most upstream stations) highlight the need for recognition of nitrogen compounds as contributors to eutrophication and thus the need for provincial objectives (perhaps similar to what has been devised in Alberta; 1 mg/L) which do not currently exist. As has noted previously (MOE 2000), one of the reasons that long term trends in total nitrogen are not detectable is that that nitrogen was not targeted for point source reduction as phosphorus was.

Chloride concentrations have been increasing in southern Ontario tributaries over the past 30 years, likely attributable to increases in applications of rock salt for road de-icing and water softening (Cooke 2006 and MOE 2002). None of the chloride measures observed in this assessment approached levels dangerous to humans or aquatic life. As an indicator of anthropogenic impact, it highlighted differences between the tributary sites and main channel sites. Boston and McKenzie Creeks have substantially lower mean concentrations of Cl- in both the spring and summer. Fairchild Creek has higher levels of Cl^-, particularly in the spring where, though the lowest, it is more similar to main channels sites.

The waters of the lower reach of the Grand are circum-neutral with pH only rarely ranging moderately beyond the limits (6.5-8.5) defined by the CCME at isolated locations. Slight differences in might help to explain trends in convertible forms of other measures, for example increasing mean pH between Cayuga and Dunnville would slightly alter the $NH_4 = NH_3$ balance.

Fecal colifoms as indexed by *Escherichia coli,* are measurable in the lower Grand. On August 31, 2004 *E.coli* concentrations exceeded levels deemed hazardous to human health (>100 CFU/100mL) at six of 14 WQ stations. All measures were lower than what was measured concurrently in wetland areas immediately adjacent to the main channel between Cayuga and Dunnville (range 670-4900 CFU/100mL; Gilbert and Ryan 2007). The highest concentration (560 CFU/100mL) occurred at the tributary station at Fairchild Creek (WQ17). By way of comparison, *E.coli* samples collected during PWQMN sampling at the Dunnville bridge between

2001 and 2002 ranged from 3 to 200 CFU/100mL; mean= 48; n=28). As these bacteria come from the intestines of warm-blooded animals, sources may include livestock (either through direct defecation into water or indirect runoff from manure-laden fields), septic effluent, and WPCP bypass during storm events.

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1.6 Figures

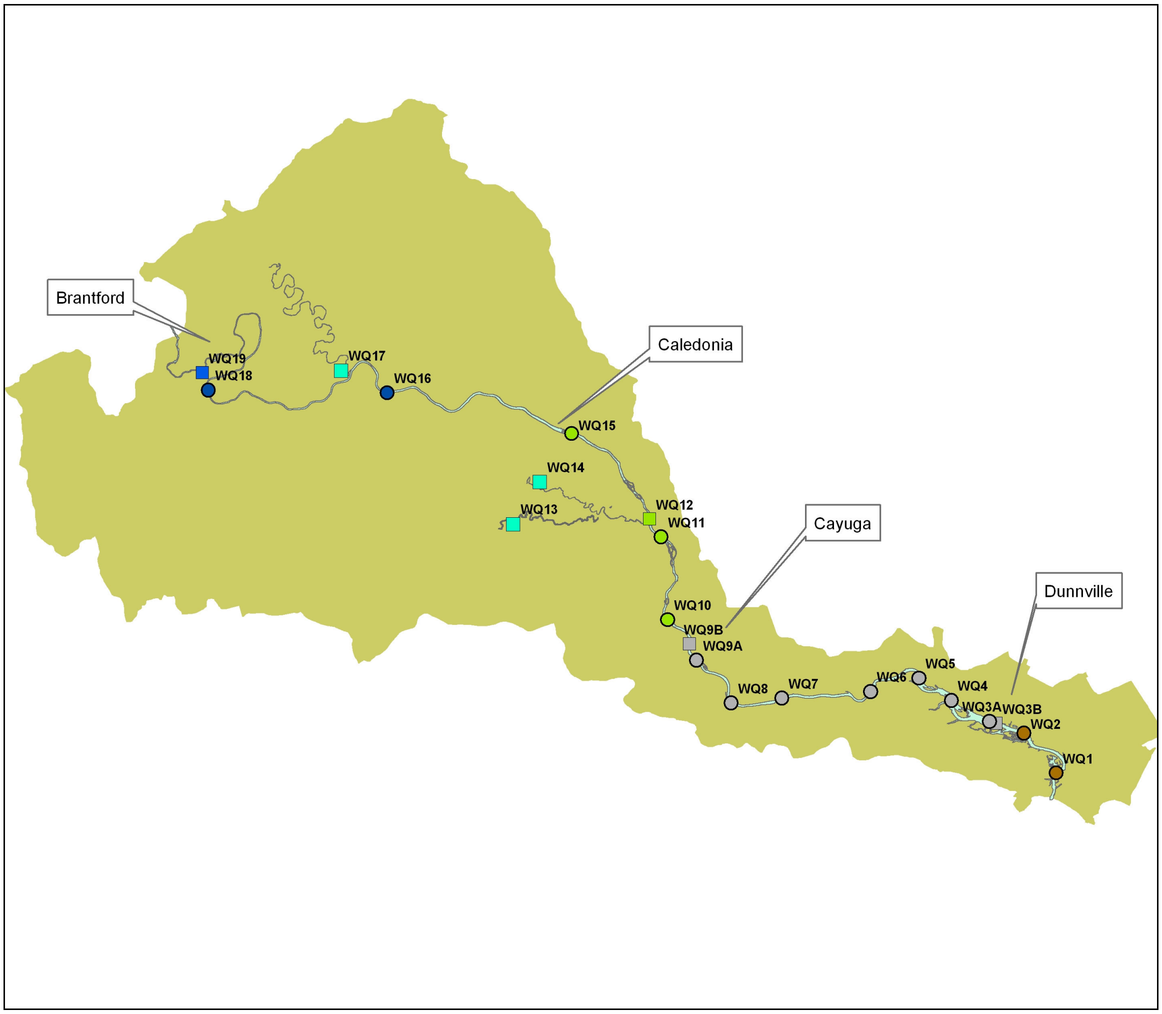

Figure 1.1 Location of water quality sampling stations utilized for water collection during 2003 and 2004. Stations marked with a square symbol indicate locations for which provincial long term data sets are available (PWQMN) while those marked with a circle indicate locations exclusive to the current study. Reference towns and cities are labeled. Stations are colour-coded to aid in discussion of water quality relative to potential functional sections of the river as follows: brown- lake effect zone downstream of Dunnville; grey – the reservoir behind the dam at Dunnville; green – section from the town of Cayuga to Caledonia; blue – the section of river from Caledonia to Brantford; teal – tributary stations.

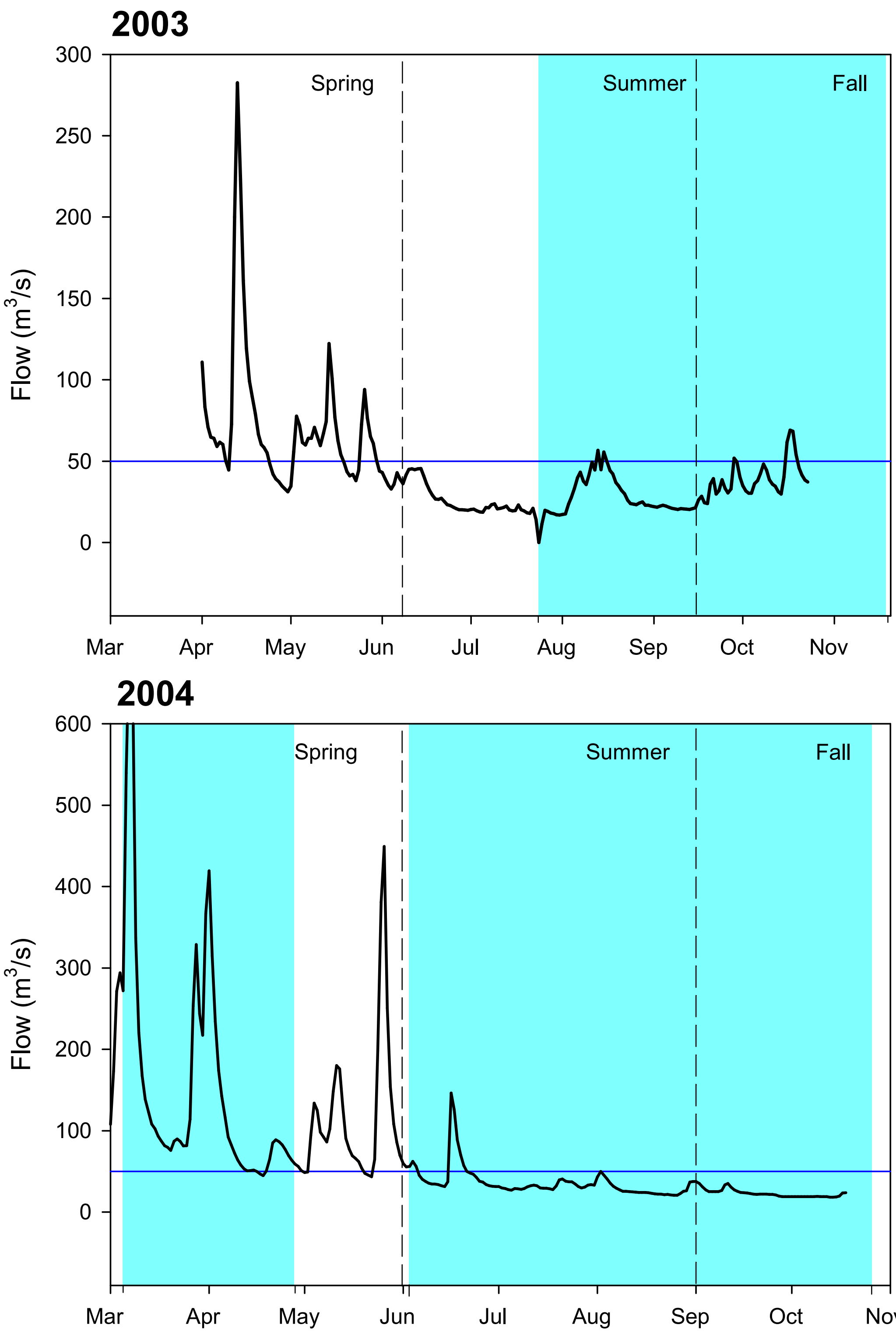

Figure 1.2. Water quality sampling periods (shaded) relative to flows measured at York, 2003 and 2004. Seasonal (spring, summer, fall) boundaries (as suggested by Cooke, 2006) are indicated with dotted lines. A 50 m3/s reference line is shown in blue. Flow data courtesy of D. Boyd, Grand River Conservation Authority.

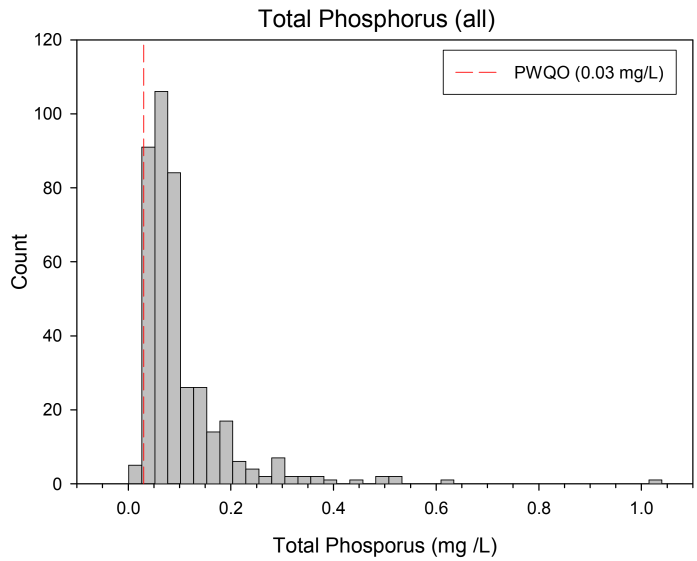

Figure 1.3. Distribution of phosphorus measures from water collected in the Grand River at Brantford and downstream during 2003 and 2004 (all stations, all dates; n=402).

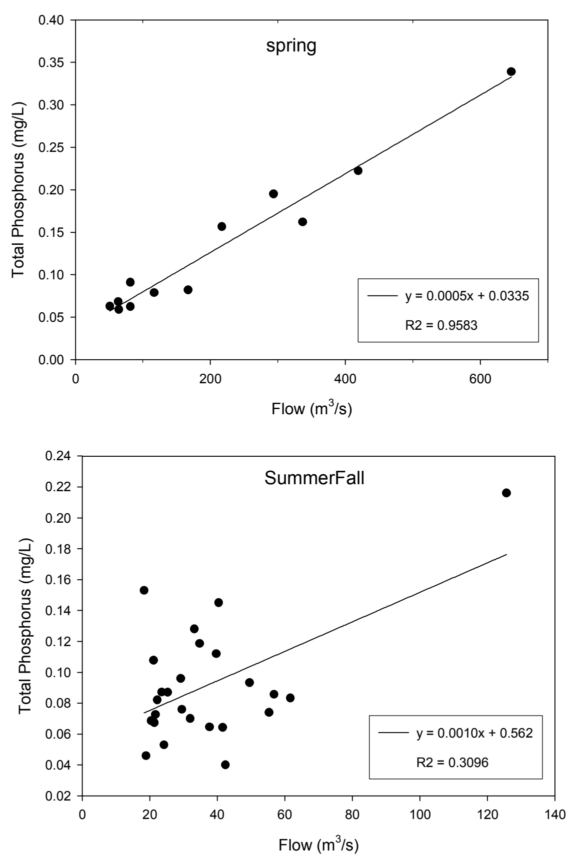

Figure 1.4. The relationship between mean daily river flow at York and mean total phosphorus, from all SGR sampling stations, during two time periods (spring and summer/fall), 2003 and 2004. Flow data from GRCA gauge data; courtesy of D. Boyd.

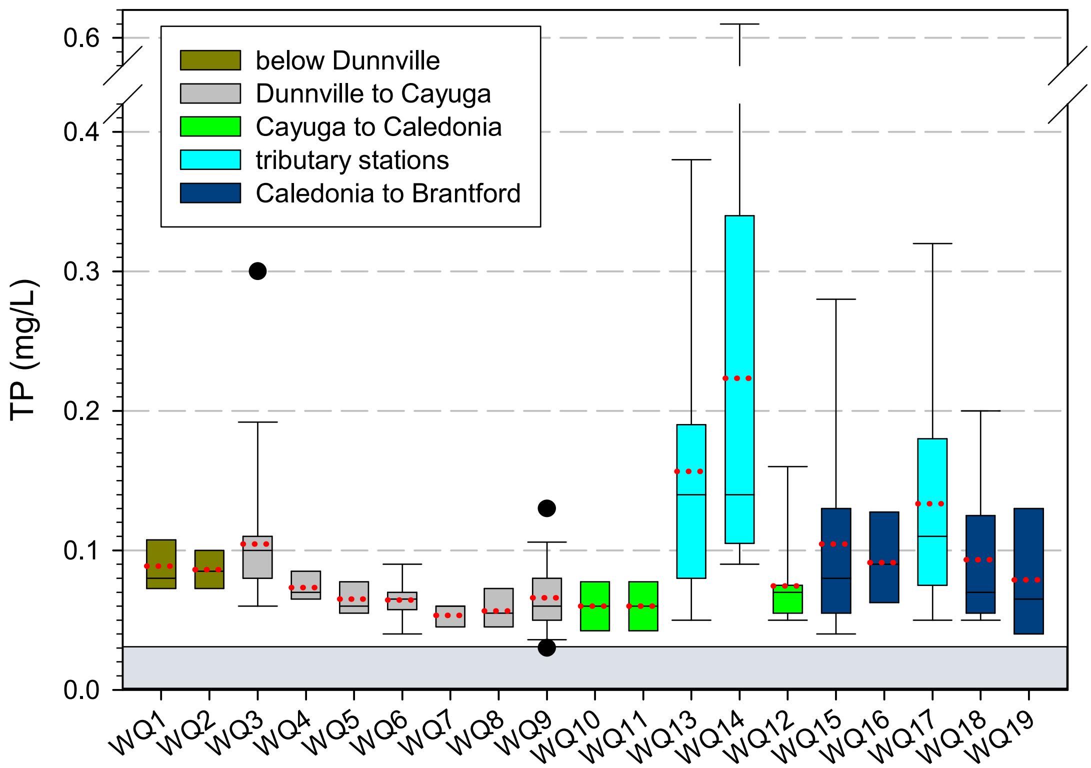

Figure 1.5. Box plots of total phosphorous measures from sampling at 19 spatially separated stations in the Grand River, from Port Maitland (WQ1) upstream to Brantford (WQ19), during summer and fall, 2003. Mean values are indicated with a red, dotted line. Median values are indicated with a straight line. The top and bottom edges of each box define the 25th and 75th percentile value while the whisker bars describe the 10th and 90th percentile values. Outliers, where they exist, are shown with solid dots. The grey background is used to designate values that meet the PWQO 0.03 mg/L. The colour of each box is used differentiate between stations in various sections of the river as indicated in the figure legend.

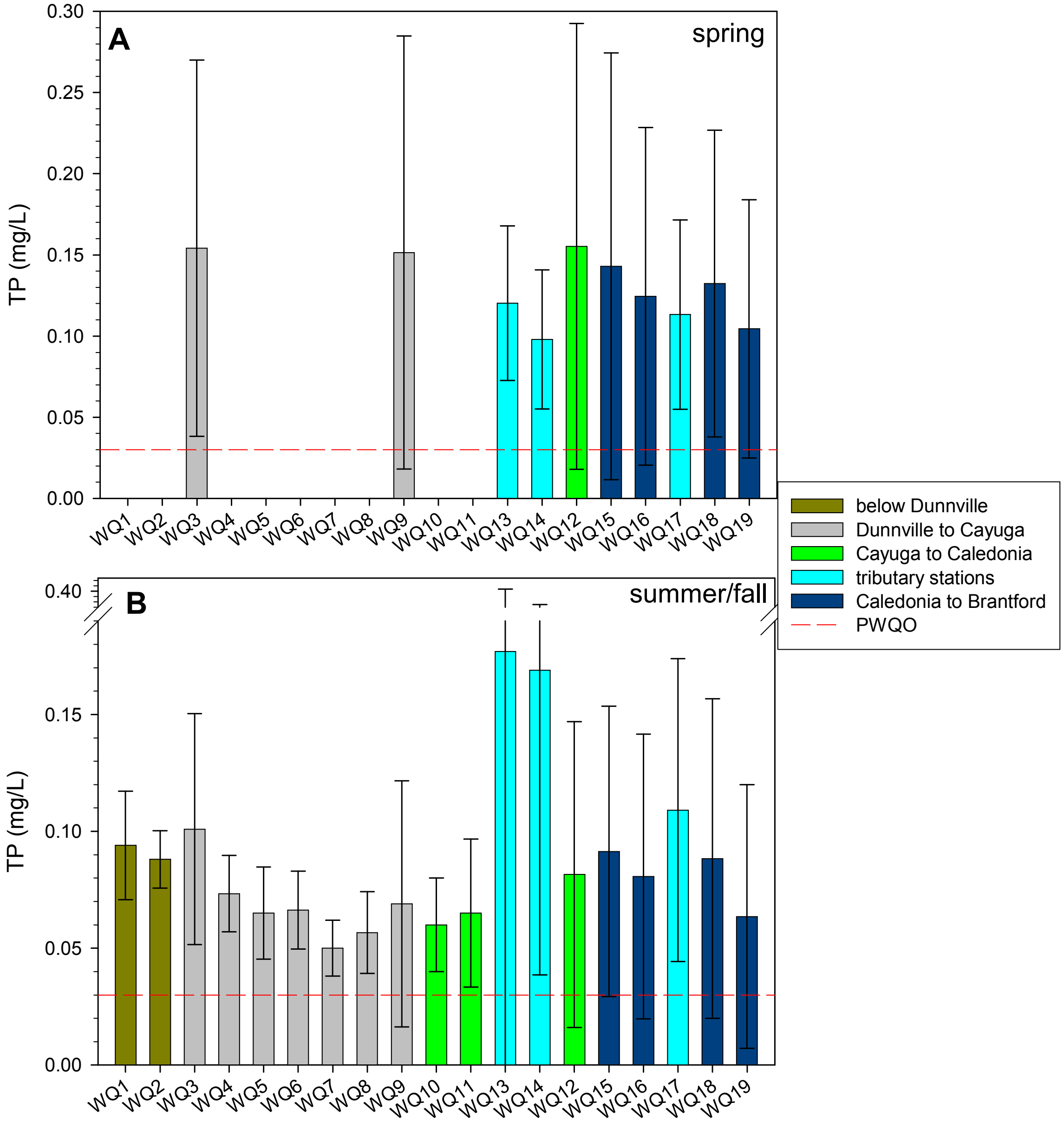

Figure 1.6 Mean total phosphorous concentration from sampling at 19 spatially separated stations in the Grand River, from Port Maitland (WQ1) upstream to Brantford (WQ19), during (A) spring and (B) summer/fall, 2004. Error bars are used to show standard deviation. The colour of each bar is used differentiate between stations in various sections of the river as indicated in the figure legend. The provincial water quality objective for TP (0.03 mg/L) is indicated with a dashed red line.

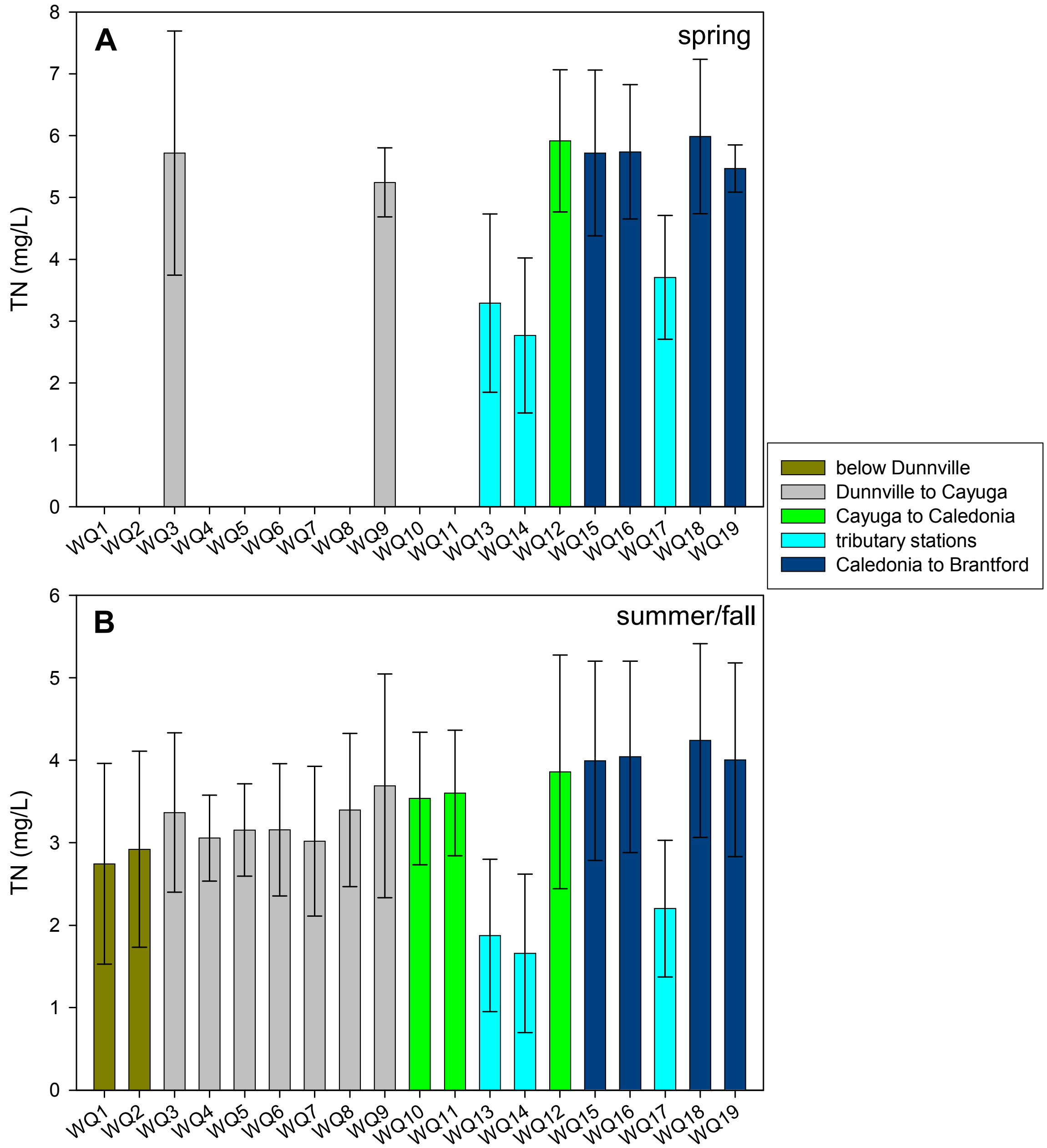

Figure 1.7. Mean total nitrogen concentration from sampling at 19 spatially separated stations in the Grand River, from Port Maitland (WQ1) upstream to Brantford (WQ19), during (A) spring and (B) summer/fall, 2004. Error bars are used to show standard deviation.The colour of each bar is used differentiate between stations in various sections of the river as indicated in the figure legend.

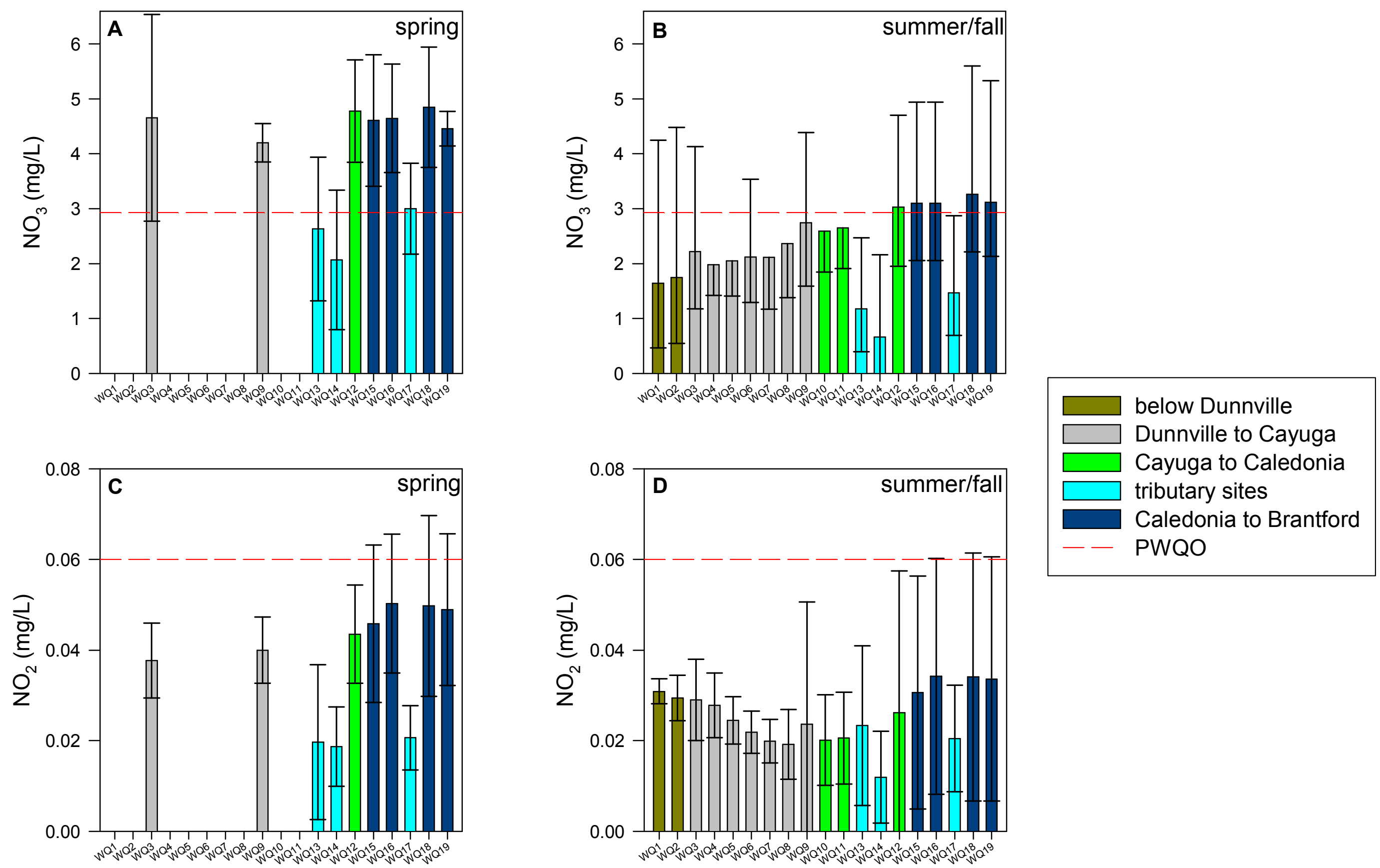

Figure 1.8. Mean nitrate and nitrite concentrations from sampling at 19 spatially separated stations in the Grand River, from Port Maitland (WQ1) upstream to Brantford (WQ19), during spring (A&C; respectively) and summer(B&D; respectively), 2004. Error bars are used to show standard deviation. The colour of each bar is used to differentiate between stations in various sections of the river as indicated in the figure legend. Federal (CCME) objectives for each parameter are shown with a red dashed line.

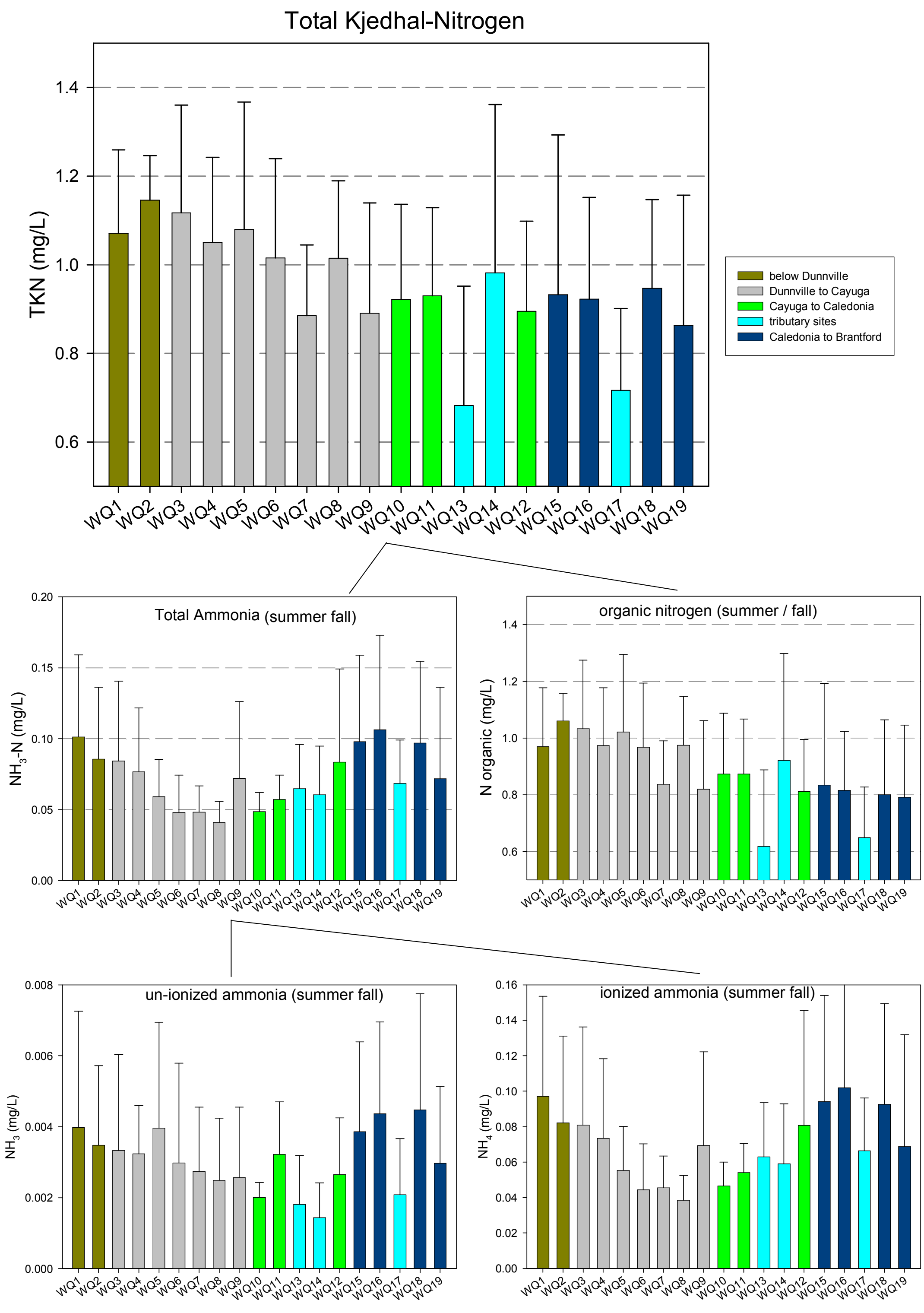

Figure 1.9. Mean values for Total Kjedhal-Nitrogen and its component nitrogen species from sampling at 19 spatially separated stations in the Grand River, from Port Maitland (WQ1) upstream to Brantford (WQ19), during summer and fall, 2003 and 2004. Error bars are used to show standard deviation. The colour of each bar is used to differentiate between stations in various sections of the river as indicated in the figure legend.

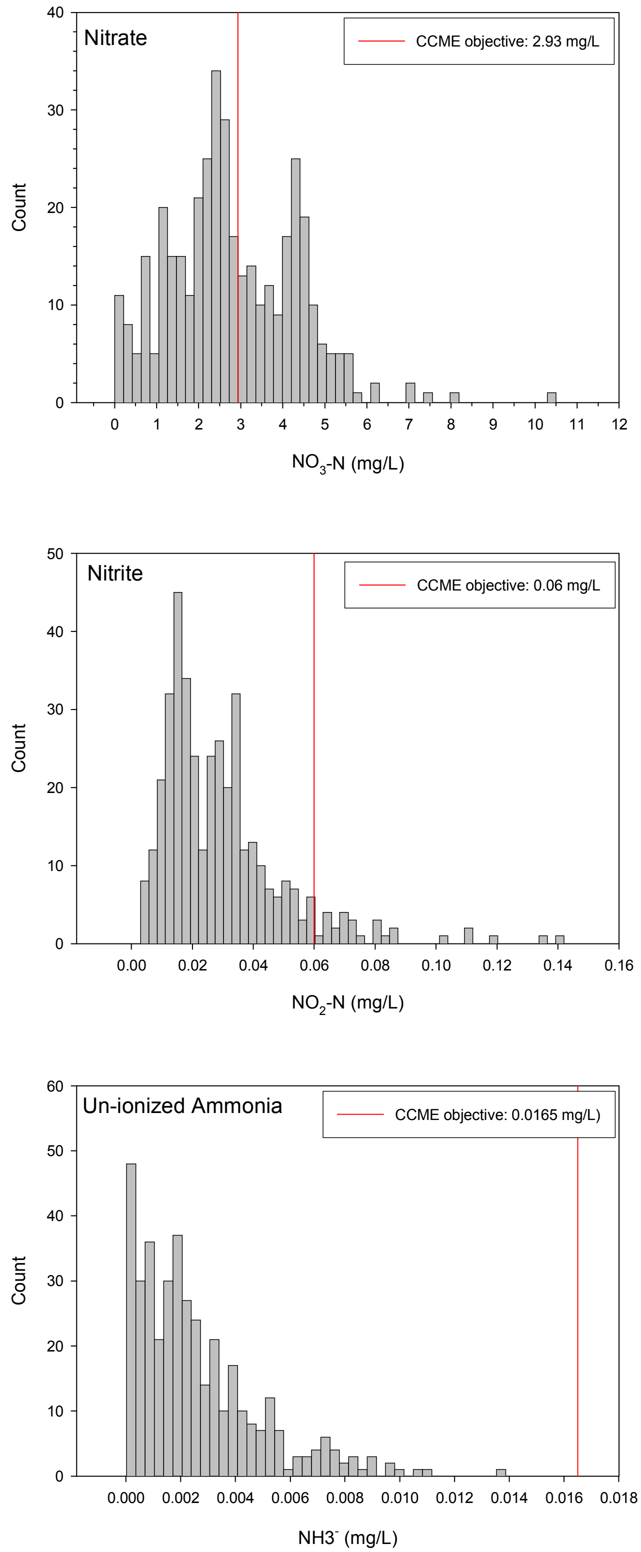

Figure 1.10. Distribution of nitrate, nitrite, and ammonia (un-ionized) concentrations in from water collected from the Grand River at Brantford and downstream during 2003 and 2004 (all stations, all dates; n=389).

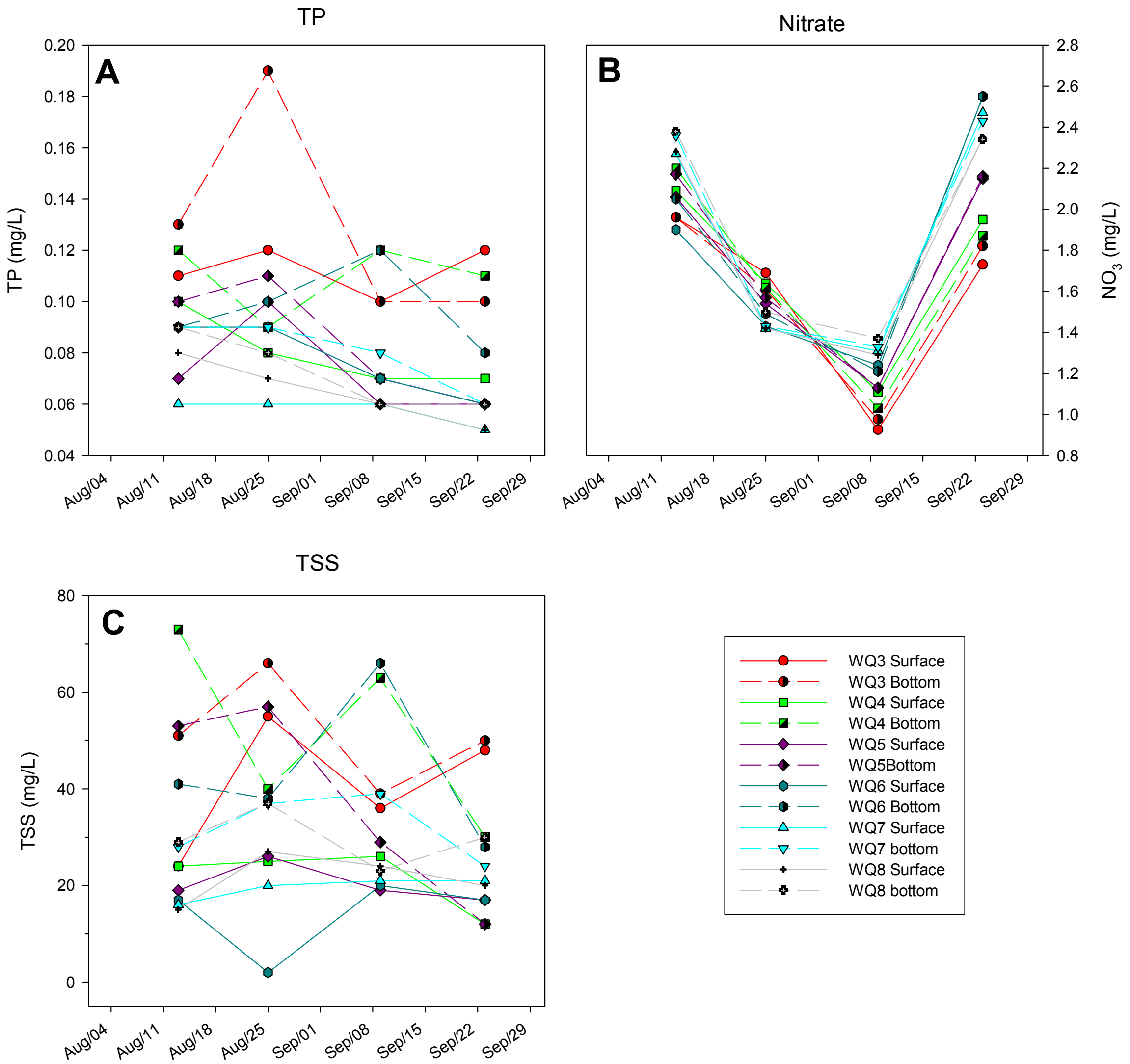

Figure 1.11. Concentration of total phosphorus (A), nitrate (B), and total suspended solids (C) at the surface and at depth, from 6 locations within the Grand River during August and September, 2003. Solid lines are used to represent samples taken just below the surface while dashed lines represent samples collected 0.5-m above the substrate.

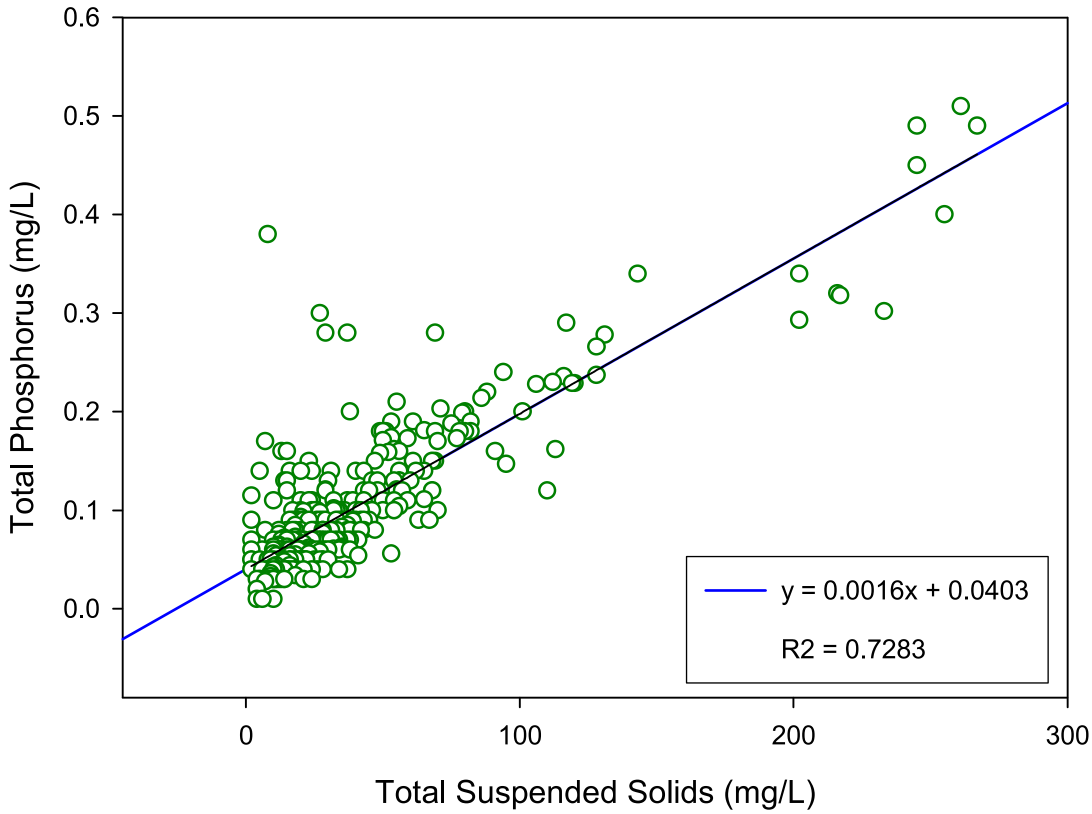

Figure 1.12. Relationship between total suspended solids and total phosphorus in water samples collected in the Grand River downstream of Brantford during 2003 and 2004. (n= 392; $p < 0.0001$)

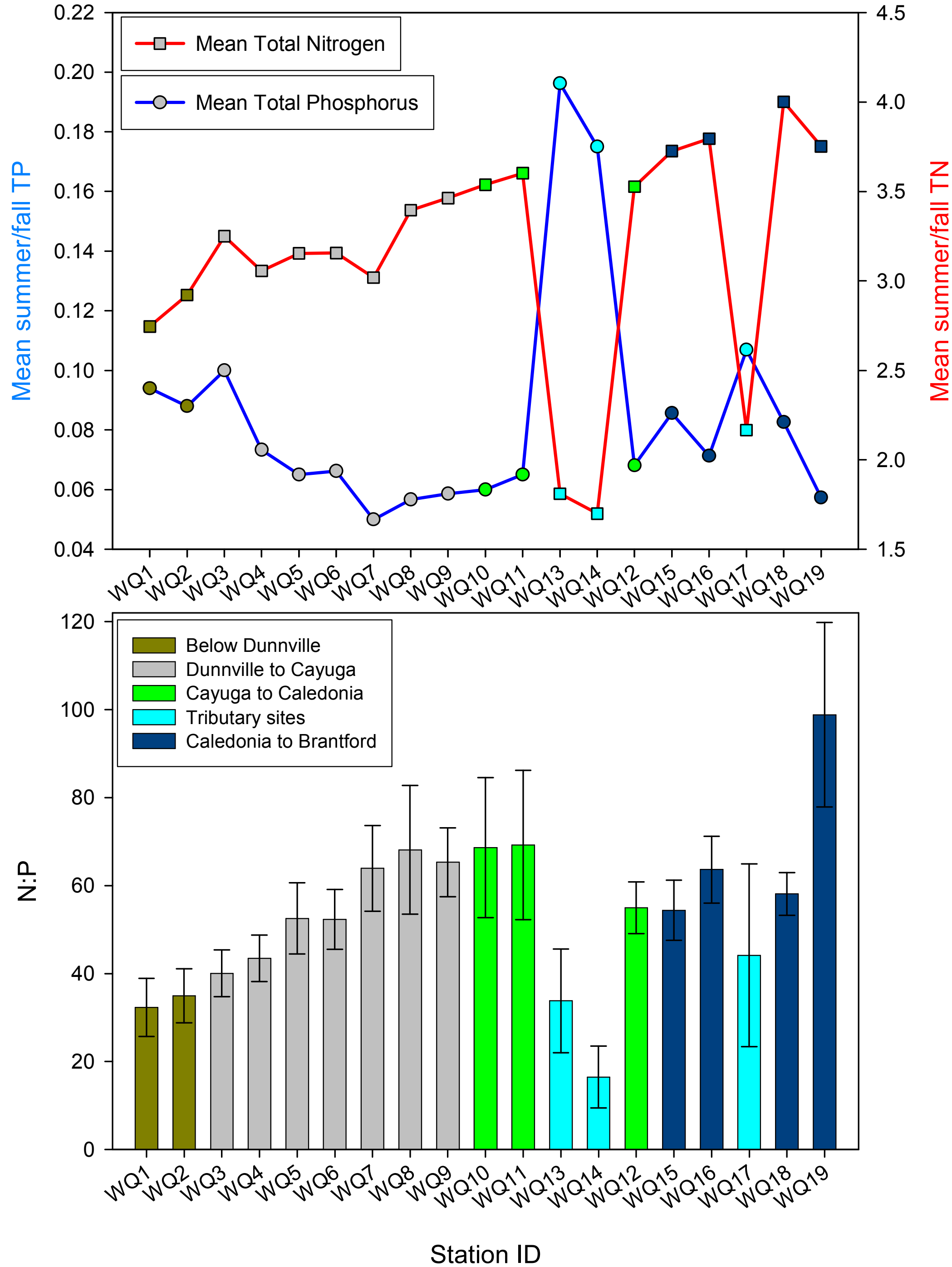

Figure 1.13. The relationship between nitrogen and phosphorus at 19 spatially separated stations in the Grand River, from Port Maitland (WQ1) upstream to Brantford (WQ19), during summer and fall, 2003 and 2004. Total nitrogen and total phosphorus are considered separately as overall mean values at each station (top) and as a ratio (TN:TP). Error bars are used to show standard deviation. The colour of each bar is used to differentiate between stations in various sections of the river as indicated in the figure legend.

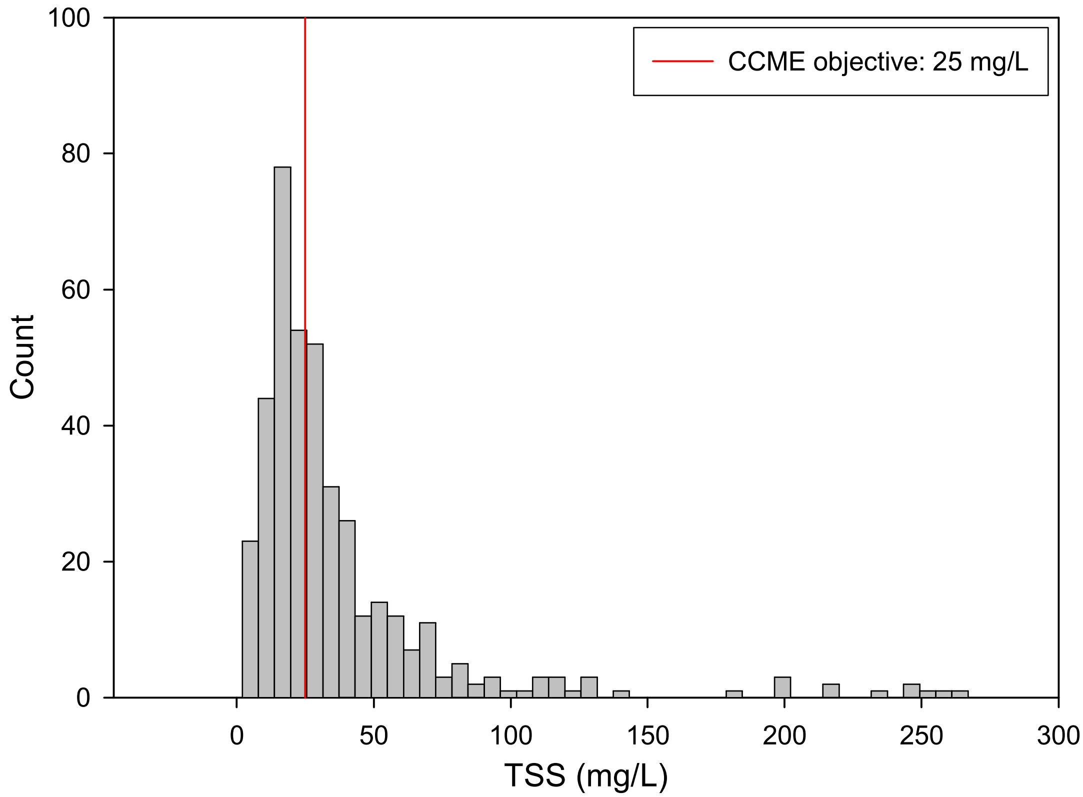

Figure 1.14. Distribution of total suspended solid (TSS) concentrations in from water collected from the Grand River at Brantford and downstream during 2003 and 2004 (all stations, all dates; n=402).

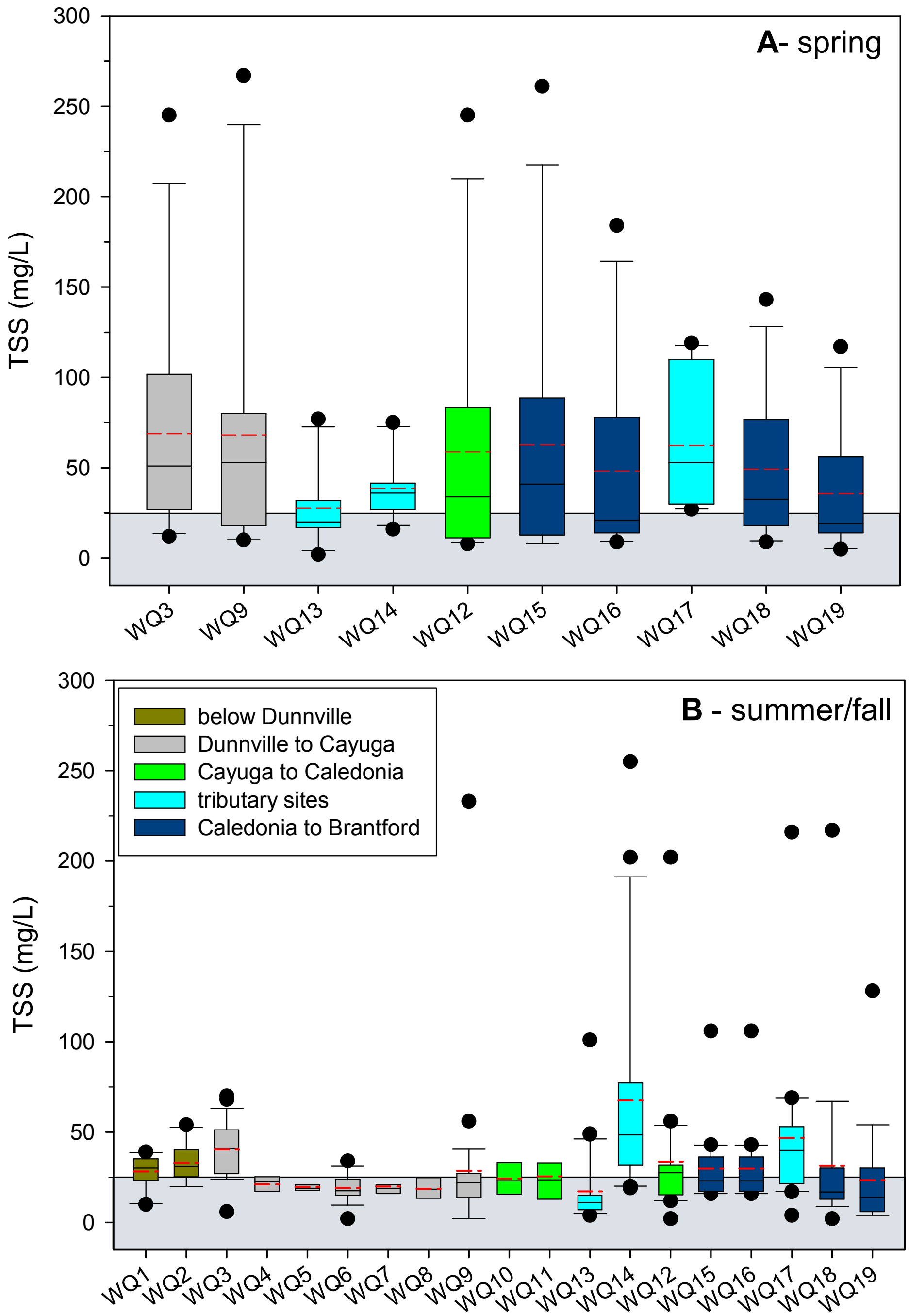

Figure 1.15. Box plots of total suspended solids (TSS) from sampling stations in the Grand River, from Port Maitland (WQ1) upstream to Brantford (WQ19), during A: Spring (2004) and B: Summer and fall (2003 and 2004). Mean values are indicated with a red, dotted line. Median values are indicated with a straight line. The top and bottom edges of each box define the 25th and 75th percentile value while the whisker bars describe the 10th and 90th percentile values. Outliers, where they exist, are shown with solid dots. The grey background is used to designate values that meet the CCME guideline of 25 mg/L TSS. The colour of each box is used differentiate between stations in various sections of the river as indicated in the figure legend.

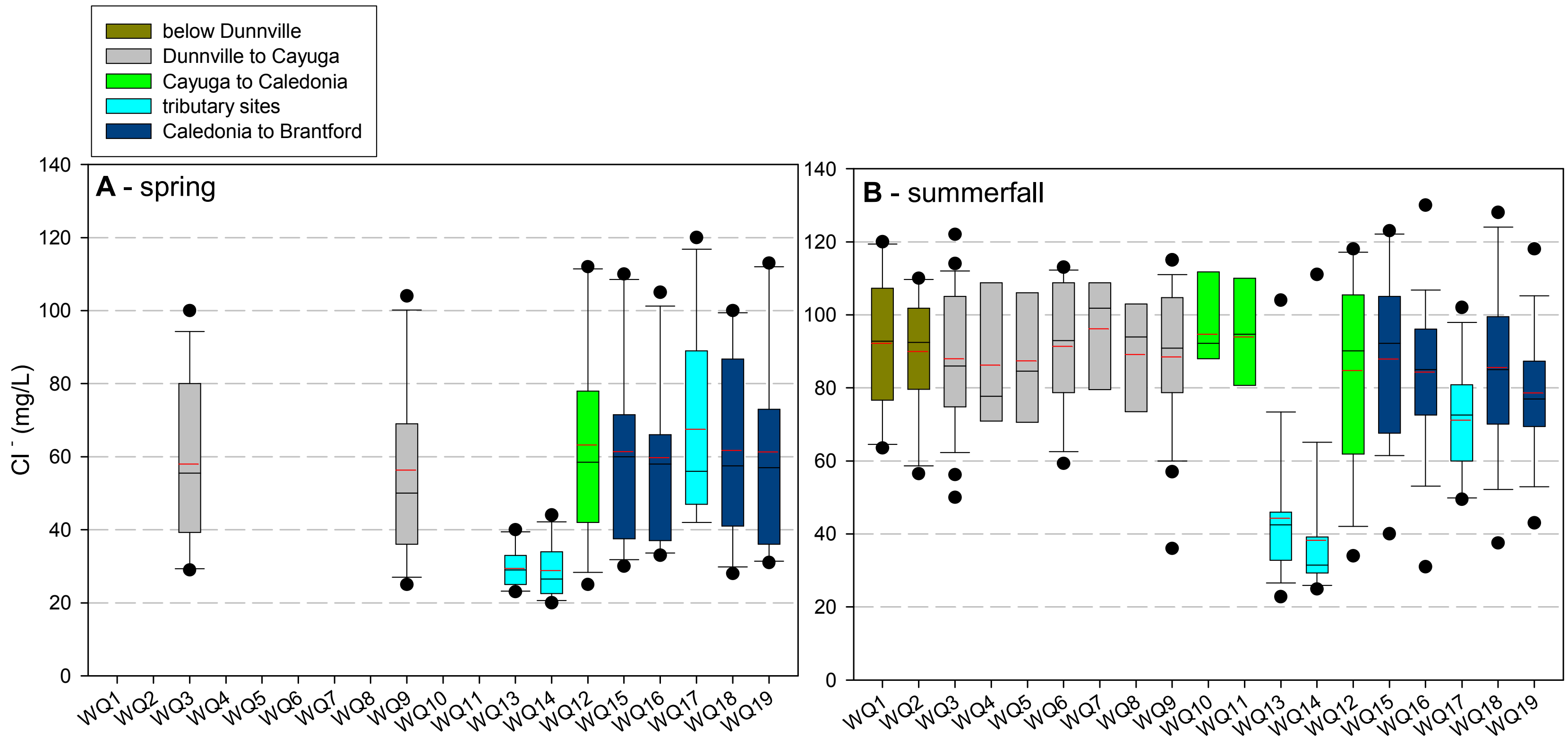

Figure 1.16. Box plots of chloride (Cl-) values from sampling stations in the Grand River, from Port Maitland (WQ1) upstream to Brantford (WQ19), during A: Spring (2004) and B: Summer and fall (2003 and 2004). Mean values are indicated with a red, dotted line. Median values are indicated with a straight line. The top and bottom edges of each box define the 25th and 75th percentile value while the whisker bars describe the 10th and 90th percentile values. Outliers, where they exist, are shown with solid dots. The colour of each box is used differentiate between stations in various sections of the river as indicated in the figure legend.

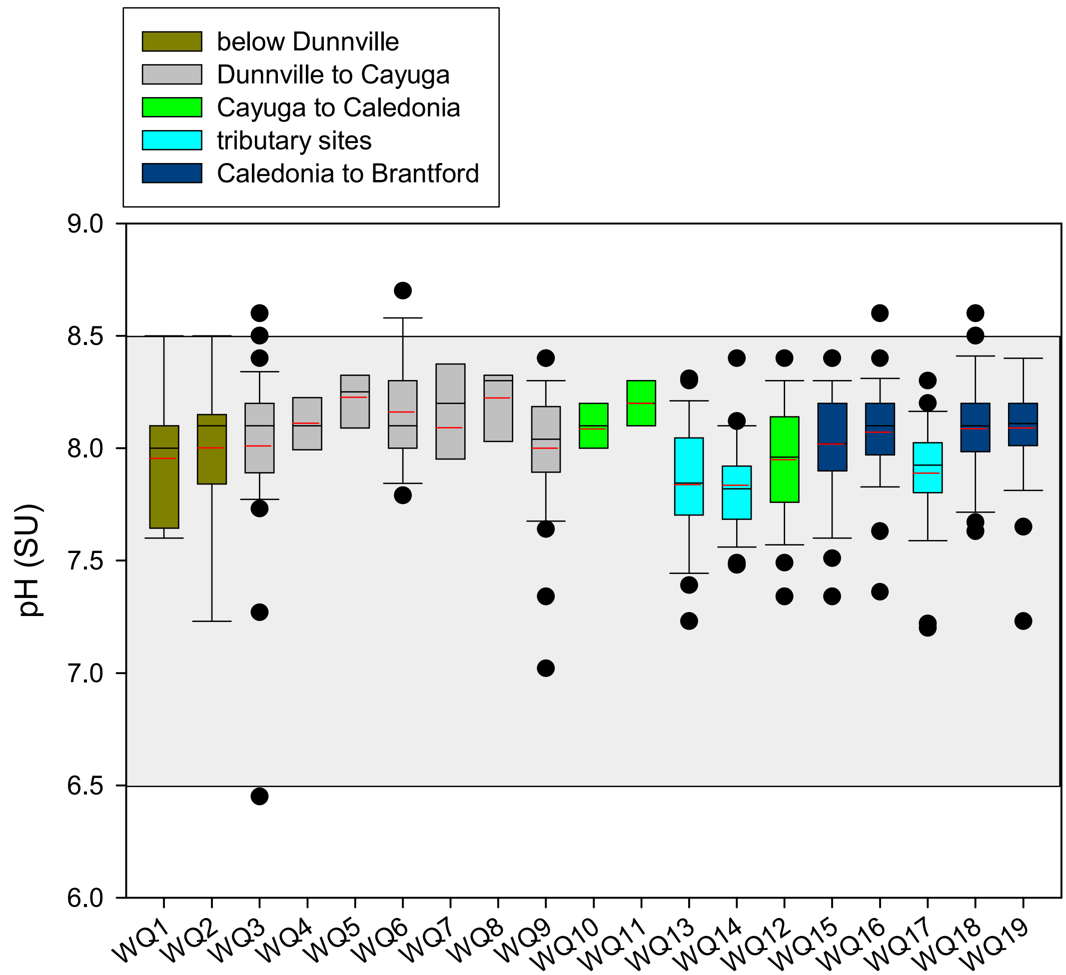

Figure 1.17. Box plots of pH from sampling stations in the Grand River, from Port Maitland (WQ1) upstream to Brantford (WQ19), during summer and fall (2003 and 2004). Mean values are indicated with a red, dotted line. Median values are indicated with a straight line. The top and bottom edges of each box define the 25th and 75th percentile value while the whisker bars describe the 10th and 90th percentile values. Outliers, where they exist, are shown with solid dots. The grey background is used to designate values that fall within the CCME guideline range of 6.5 to 8.5 SU. The colour of each box is used differentiate between stations in various sections of the river as indicated in the figure legend.

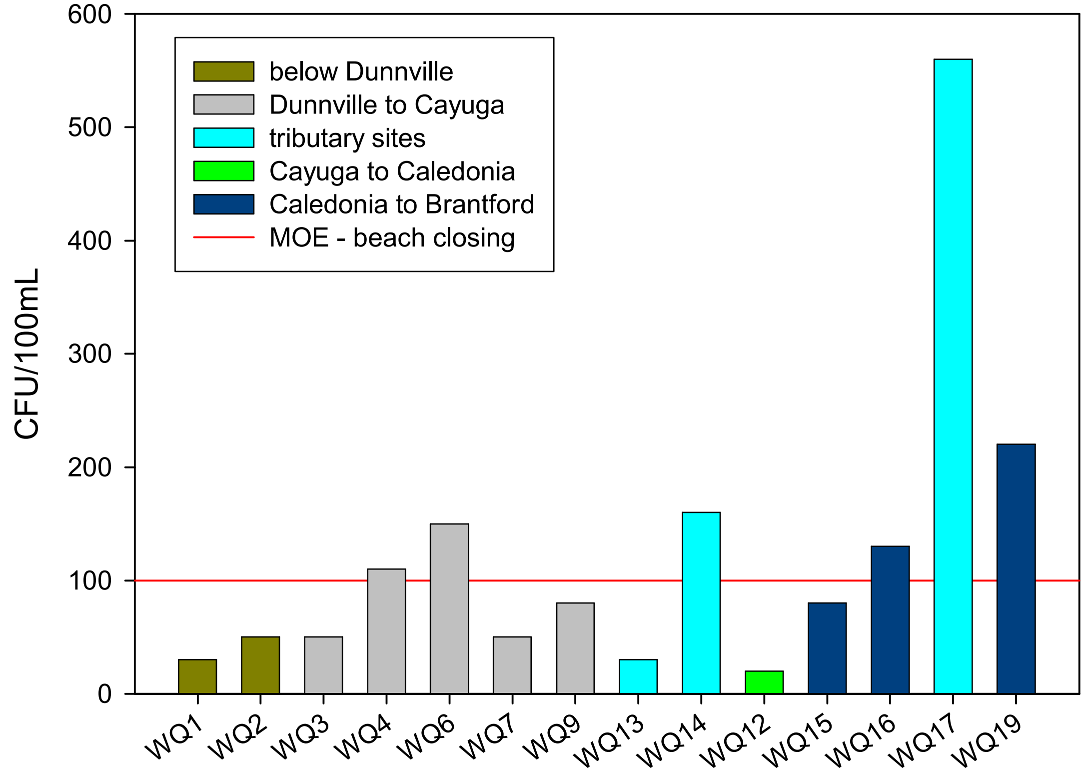

Figure 1.18. E.coli, as indexed by total coliform counts, in samples collected from sampling at 14 spatially separated stations in the Grand River, from Port Maitland (WQ1) upstream to Brantford (WQ19), on August 31, 2004. The colour of each bar is used to differentiate between stations in various sections of the river as indicated in the figure legend.

1. 7 Tables

Table 1.1. Sampling dates on which water was collected for water chemistry analysis from 19 stations located in the Grand River, at Brantford and downstream to Port Maitland, 2003 and 2004. Shaded dates indicate occasions on which water was collected from both the surface and at 0.5-m above the substrate. "A" and "B" are used to designate separate locations in close proximity (<75m).

DATE (dd-mmm-yy)	WQ1	WQ2	WQ3 A	WQ3 B *	WQ4	WQ5	WQ6	WQ7	WQ8	WQ9 A	WQ9 B	WQ10	WQ11	WQ12 *	*WQ13* *	*WQ14* *	WQ15	WQ16	*WQ17* *	WQ18	WQ19 *
22-Jul-03	X	X	X				X			X		X	X	X	X	X	X		X	X	
05-Aug-03												X	X	X	X	X	X	X	X	X	X
06-Aug-03	X	X	X				X			X											
13-Aug-03			X		X	X	X	X	X		X										
20-Aug-03	X	X	X				X			X		X	X	X	X	X	X	X	X	X	X
25-Aug-03			X		X	X	X	X	X		X										
02-Sep-03	X	X	X				X			X		X	X	X	X	X	X	X	X	X	X
09-Sep-03			X		X	X	X	X	X		X										
15-Sep-03	X	X	X				X			X		X	X	X	X	X	X	X	X	X	X
23-Sep-03			X		X	X	X	X	X		X										
29-Sep-03	X	X	X				X			X		X	X	X	X	X	X	X	X	X	X
07-Oct-03			X		X	X	X	X	X		X										
15-Oct-03	X	X										X	X	X	X	X	X	X	X	X	X
16-Oct-03			X				X			X											
21-Oct-03			X		X	X	X	X	X		X										
27-Oct-03	X	X	X				X			X		X	X	X	X	X	X	X	X	X	X
19-Nov-03				X							X			X	X	X	X	X	X	X	X
04-Mar-04				X										X	X	X	X			X	
08-Mar-04				X							X			X	X	X	X	X	X	X	X
09-Mar-04				X							X			X	X	X	X	X	X	X	X
11-Mar-04				X							X			X	X	X	X	X	X	X	X
18-Mar-04				X							X			X		X	X	X	X	X	X
25-Mar-04				X							X			X	X	X	X	X	X	X	X
30-Mar-04				X							X			X	X	X	X	X	X	X	X
01-Apr-04				X							X			X	X	X	X	X	X	X	X
06-Apr-04				X							X			X	X	X	X	X	X	X	X
14-Apr-04				X							X			X	X	X	X	X	X	X	X
20-Apr-04				X							X			X	X	X	X	X	X	X	X
27-Apr-04				X							X			X	X	X	X	X	X	X	X
02-Jun-04				X							X			X	X	X	X	X	X	X	X
17-Jun-04				X							X			X	X	X	X	X	X	X	X
15-Jul-04				X							X			X	X	X	X	X	X	X	X
27-Jul-04				X							X			X	X	X	X	X	X	X	X
10-Aug-04				X							X			X	X	X	X	X	X	X	X
19-Aug-04	X	X	X				X	X			X			X	X	X	X	X	X	X	X
31-Aug-04	X	X	X				X	X			X			X	X	X	X	X	X		X
15-Sep-04				X							X			X	X	X	X	X	X	X	X
29-Sep-04				X							X			X	X	X	X	X	X	X	X
13-Oct-04				X							X			X	X	X	X	X	X	X	X
25-Oct-04				X							X			X	X	X	X	X	X	X	X
	Below Dunnville Dam		Above Dunnville dam to Cayuga									Cayuga to Caledonia						Caledonia to Brantford			

Station ID Number

Table 1.2. Descriptive statistics for water quality parameters measured at 19 stations in the Grand River below Brantford, during 2003 (summer and fall) and 2004 (spring, summer and fall). Values are given in units of mg/L.

	Mean	Median	Mode	Standard Error	Standard Deviation	Sample Variance	Range	Minimum	Maximum	n	Confidence Level (95.0%)
Total Phosphorus (TP)											
Spring	0.13	0.10	0.05	0.009	0.099	0.010	0.48	0.03	0.51	115	0.018
Summer	0.10	0.08	0.07	0.006	0.070	0.005	0.36	0.02	0.38	134	0.012
Fall	0.09	0.06	0.06	0.009	0.105	0.011	1.03	0.01	1.04	153	0.017
SummerFall	0.09	0.07	0.06	0.005	0.091	0.008	1.03	0.01	1.04	287	0.011
OVERALL	0.10	0.08	0.06	0.005	0.095	0.009	1.03	0.01	1.04	402	0.009
Total Nitrogen (TN)											
Spring	4.97	5.26	5.12	0.154	1.655	2.739	10.40	1.42	11.82	115	0.306
Summer	3.14	3.10	NA	0.115	1.254	1.571	5.80	0.82	6.61	119	0.228
Fall	3.35	3.34	3.49	0.110	1.357	1.842	6.93	0.47	7.40	153	0.217
SummerFall	3.26	3.26	2.14	0.080	1.314	1.728	6.93	0.47	7.40	272	0.157
OVERALL	3.77	3.51	2.14	0.082	1.623	2.633	11.35	0.47	11.82	387	0.162
TKN											
Spring	0.93	0.88	1.10	0.031	0.329	0.108	1.64	0.38	2.02	115	0.061
Summer	0.91	0.88	0.88	0.023	0.262	0.069	1.71	0.44	2.14	134	0.045
Fall	0.94	0.91	0.74	0.021	0.262	0.069	1.44	0.33	1.77	153	0.042
SummerFall	0.93	0.89	0.74	0.015	0.262	0.069	1.81	0.33	2.14	287	0.030
OVERALL	0.93	0.88	0.74	0.014	0.282	0.080	1.81	0.33	2.14	402	0.028
Ammonia (NH3-N)											
Spring	0.18	0.16	0.02	0.014	0.154	0.024	0.67	0.01	0.68	115	0.028
Summer	0.07	0.06	0.05	0.004	0.048	0.002	0.21	0.02	0.23	149	0.008
Fall	0.08	0.06	0.06	0.004	0.054	0.003	0.27	0.02	0.28	153	0.009
SummerFall	0.07	0.06	0.05	0.003	0.051	0.003	0.27	0.02	0.28	302	0.006
OVERALL	0.07	0.06	0.05	0.002	0.050	0.002	0.27	0.02	0.28	451	0.005
Nitrite (NO_2)											
Spring	0.04	0.04	0.03	0.002	0.018	0.000	0.08	0.01	0.09	115	0.003
Summer	0.03	0.02	0.01	0.002	0.025	0.001	0.14	0.01	0.14	121	0.004
Fall	0.02	0.02	0.02	0.001	0.015	0.000	0.08	0.00	0.08	153	0.002
SummerFall	0.03	0.02	0.02	0.001	0.020	0.000	0.14	0.00	0.14	274	0.002
OVERALL	0.03	0.03	0.01	0.001	0.020	0.000	0.14	0.00	0.14	389	0.002
Nitrate (NO_3)											
Spring	4.00	4.28	4.42	0.137	1.471	2.165	10.08	0.42	10.50	115	0.272
Summer	2.20	2.09	1.42	0.111	1.218	1.484	5.57	0.00	5.57	121	0.219
Fall	2.39	2.44	2.16	0.100	1.240	1.538	5.84	0.02	5.86	153	0.198
SummerFall	2.30	2.32	1.42	0.074	1.232	1.517	5.86	0.00	5.86	274	0.146
OVERALL	2.80	2.59	1.42	0.077	1.517	2.302	10.50	0.00	10.50	389	0.151
Chloride (Cl^-)											
Spring	54.76	53.00	25.00	2.362	25.332	641.695	100.00	20.00	120.00	115	4.679
Summer	75.73	75.05	107.00	2.359	25.192	634.618	97.20	22.80	120.00	114	4.674
Fall	83.90	86.80	104.00	1.966	24.323	591.594	105.10	24.90	130.00	153	3.885
SummerFall	80.41	83.80	104.00	1.529	24.981	624.026	107.20	22.80	130.00	267	3.010
OVERALL	72.69	74.90	104.00	1.417	27.686	766.520	110.00	20.00	130.00	382	2.785
Total Suspended Solids (TSS)											
Spring	52.22	35	18	4.882	52.356	2741.172	265	2	267	115	9.672
Summer	36.43	26	20	3.495	40.458	1636.879	231	2	233	134	6.913
Fall	27.92	21	15	2.288	28.298	800.770	253	2	255	153	4.520
SummerFall	31.90	24	15	2.049	34.711	1204.884	253	2	255	287	4.033
OVERALL	37.71	26	20	2.070	41.511	1723.184	265	2	267	402	4.070
pH											
Spring	7.98	7.98	7.90	0.021	0.224	0.050	1.27	7.23	8.50	115	0.041
Summer	8.01	8.01	8.10	0.031	0.315	0.099	1.50	7.20	8.70	101	0.062
Fall	8.03	8.10	8.10	0.023	0.283	0.080	2.15	6.45	8.60	153	0.045
SummerFall	8.02	8.10	8.10	0.019	0.296	0.087	2.25	6.45	8.70	254	0.037
OVERALL	8.01	8.03	8.10	0.014	0.276	0.076	2.25	6.45	8.70	369	0.028

Table 1.3. A comparison of descriptive statistics for select water quality parameters measured in the Grand River between Brantford and Port Maitland during i) an intensive survey at 19 stations in 2003 and 2004 and ii) regular PWQMN sampling at 3 stations between 2000 and 2005.

	Mean	Median	Mode	Standard Error	Standard Deviation	Sample Variance	Range	Minimum	Maximum	n
Total Phosphorus (TP)										
Intensive (03-04)	0.10	0.08	0.06	0.005	0.095	0.009	1.03	0.01	1.04	402
PWQMN (00-05)	0.11	0.09	0.06	0.005	0.077	0.006	0.65	0.01	0.66	210
TKN										
Intensive (03-04)	0.93	0.88	0.74	0.014	0.282	0.080	1.81	0.33	2.14	402
PWQMN (00-05)	1.03	0.96	0.92	0.027	0.390	0.152	2.65	0.36	3.01	210
Nitrite (NO2)										
Intensive (03-04)	0.03	0.03	0.01	0.001	0.020	0.000	0.14	0.00	0.14	389
PWQMN (00-05)	0.05	0.04	0.03	0.002	0.032	0.001	0.19	0.00	0.19	204
Nitrate (NO3)										
Intensive (03-04)	2.80	2.59	1.42	0.077	1.517	2.302	10.50	0.00	10.50	389
PWQMN (00-05)	3.24	3.08	3.18	0.107	1.545	2.389	6.88	0.26	7.14	207
Chloride (Cl-)										
Intensive (03-04)	72.69	74.90	104.00	1.417	27.686	766.520	110.00	20.00	130.00	382
PWQMN (00-05)	81.37	79.80	90.40	2.541	35.025	1226.732	278.90	6.10	285.00	190
pH										
Intensive (03-04)	8.01	8.03	8.10	0.014	0.276	0.076	2.25	6.45	8.70	369
PWQMN (00-05)	8.29	8.29	8.34	0.009	0.124	0.015	0.66	7.93	8.59	207

2.0 Primary production – planktonic algae (chlorophyll-*a*)

2.1 Introduction

Phytoplankton play an important role in aquatic food webs; linking nutrients and energy (sunlight) with filter feeders, zooplankton, forage fish and, secondarily, the microbial loop. In extremely productive waters, excessive growth of algae can have detrimental effects. These effects can either be direct, through shading and reduced water clarity (Lorenzen 1972), or indirect when settled, ungrazed, dead phytoplankton provide substrate on which oxygen consuming microbes can thrive thereby reducing or depleting dissolved oxygen (USEPA, 2003). Additionally, photosynthesis and respiration by living algae can drastically alter the oxygen regime of surface waters.

While many studies of algal growth in riverine systems have focussed on substrate-attached periphyton (Chételat 1999, Dodds 2006), algal production in the turbid waters of the lower Grand is necessarily dominated by planktonic algae. Planktonic algal biomass, as represented by chlorophyll-a (Chl-*a*) concentration in the water column, has traditionally been included in the suite of measures used to describe the trophic state of a water body.

Chlorophyll-*a* concentrations in the Southern Grand River (SGR) were measured in 2003 and 2004 to describe trophic status by serving as an analog for planktonic algal production and thus to better characterize the ecosystem and aquatic habitat downstream of Brantford. Knowing the abundance of phytoplankton would help to help to link observations made during water chemistry, benthic invertebrate, and oxygen profiling. Sampling was designed to look for change along the spatial gradient of the river, as well as changes through time and/or with depth.

2.2 Methods

Water sampling
A subset of the water quality sampling stations (described above in 1.1; Water Quality) were chosen for concurrent chlorophyll-a measures. These stations were given labels prefixed with a "C" and which correspond to WQ-station labels (from section 1.0) as follows:

C1 – WQ1 (Port Maitland)
C2 – WQ2 (Betamik Harbour)
C3 – WQ3 (Dunnville; above dam)
C4 – WQ6 (Dunnville to Cayuga; mid-way)
C5 – WQ9 (Cayuga)
C6 – WQ12 (York)
C7 – WQ18 (Brantford; Newport bridge)

In 2003, chlorophyll-a (Chl-a) in surface waters was measured at seven stations between Port Maitland and Brantford on an approximate bi-weekly basis between July 22 and October 27 (6 occasions; Table 2.1). On some alternate weeks, at three of these stations, (C1, C4 and C7), water was collected at both the surface and at depth (0.5m off of the bottom) in order to describe any differences within the water column. In 2004, water for chlorophyll analysis was only collected at stations between Cayuga and Port Maitland (Stns C1-C5) on 13 occasions (bi-

weekly) between June 15 and October 20 (Table 2.1). For logistic reasons not all stations were sampled on all dates.
As described in the methodology for water chemistry sampling (Section 1.2), equal volumes of sub-surface (0.5m depth) water, collected at four locations across the width of the river, were combined and mixed prior to the filling of sample bottles. Samples at depth were collected using a Van-Dorn bottle lowered to a depth 0.5-m above the bottom.

Sample analysis
All water samples were placed on ice in the dark, transported to the lab, and processed within 12 hours. Processing involved mixing of the water sample followed by filtration of 500 mL through a glass fibre filter (Whatman GF/C; median retention size of approx 0.2 um) using a Millipore filter apparatus. Duplicate filter papers were placed into plastic whirl-pac bags with silica-gel absorbent and frozen until analysis (< 4 months) at the OMNR lab in Wheatley.
Samples filters were homogenized in 90% acetone and the resulting extracts were analysed spectrophotometrically as per Strickland and Parsons (1972). The average of the replicate samples was used for comparison.

Results and discussion will centre on chlorophyll-a concentrations which have been corrected to exclude contributions from phaeopigments (which represent the breakdown products of a number of chlorophylls). Uncorrected values, sometimes described as "total chlorophyll" are provided in Appendix B-1 for reference. While recognizing the lack of consensus of the most accurate / least misleading way of quantifying algal biomass/Chl-a, it was felt that the methods used in this study are sufficient for discussing trophic classification, and short term and spatial gradients within the system. The often larger "un-corrected" values in the appendix give an idea of both living and dead phytoplankton and are valuable when considering the ability of all algal cells (living or dead) to contribute to light attenuation in the water column. Attention to specific details of this analytical methodology will be important for future monitoring which involves tracking long term change.

Classifying trophic state based on chlorophyll-a concentration.
Describing water bodies based on their nutrient regimes and productivity has a long history in limnology. The classic lake classifications of oligotrophic, mesotrophic and eutrophic have also been applied to lotic systems. The classification of "eutrophic", carries with it the negative connotation of being "too productive" and usually implies negative aspects of plant (algal) growth (blooms) and disrupted oxygen regimes, particularly due to the metabolism of heterotrophs (microbial loop) consuming abundant dead algal cells and resulting in hypoxia or anoxia.
Placing bounds on each state, using chlorophyll-a, has been done by a number of authors (Appendix A-3). For the purpose of this report, that proposed by Wetzel will be used as follows:

Oligotrophic - 0.3–3 μg/L
Mesotrophic - 2–15 μg/L
Eutrophic - >10 μg/L

Additionally, the concept of Hyper-eutrophic (>15 μg/L) (Ryding and Rast. 1989, Leach et al. 1977) - will be referred to.

Statistical comparisons
For each year, mean station Chl-a was compared between stations using a one-way ANOVA after first log-normalizing the data (Anderson-Darling) and confirming homogeneity of variance (Bartlett's test). *Post hoc* confirmations of significant differences were identified using Fisher's LSD tests.

2.3 Results

Concentrations of chlorophyll-*a*, measured during this survey (both years, n= 117), ranged between 0.74 and 64.49 µg/L. The overall mean, median and mode were 20.05, 18.78, and 16.78 µg/L; respectively.

Spatial gradient in Chl-a concentration
An obvious trend of increasing mean Chl-a concentration was apparent as one progressed downstream from Brantford (2003) or Cayuga (2004) to Port Maitland (Figure 2.1). Upstream stations C7 (Brantford at Newport Bridge) and C6 (York), sampled in 2003 only, had mean concentrations (2.67 - 7.3 µg/L) indicative of oligotrophic to mesotrophic waters while those at downstream stations C5 (Dunnville above dam) to C7 (Port Maitland; 20.4 - 36.0 µg/L) could be classified as eutrophic to hyper-eutrophic (based on Wetzel 2001). Concentrations at Cayuga (C4) fell between these and were indicative of mesotrophic waters. The highest annual mean concentration (36.0 µg/L; n= 13) occurred in 2004 at station C2, located between the Dunnville dam and Port Maitland. The lowest annual mean concentration (2.67 µg/L; n= 6) occurred in 2003 at station C1, located below the Newport bridge in Brantford.

In 2003, mean Chl-a concentrations at stations downstream of Cayuga (C1, C3 and C4; C2 not included) were significantly larger than those at Cayuga (C5) and Brantford (C7). Additionally, the mean at C3 was significantly higher than that at C6; those from C1 and C4 were not (Table 2.2). Similarly, in 2004 mean concentration at the most upstream station measured (Cayuga; C5) was significantly smaller than those at more downstream stations. The next downstream station (C4) was significantly smaller than the highest mean station (C2).

Changes in Chl-a with depth
The brief examination of differences in Chl-a concentration between surface water and that at depth, from four dates in 2003 at stations C3, C4 and C5, showed that planktonic algae were not restricted to surface waters (Figure 2.2). Concentrations at depth, at C3 and C4 were, on average, 10µg/L less than at the surface. Well mixed waters are suggested on August 25 at station C4, where Chl-a at the surface (30.2µg/L) was similar to that at 4m depth (27.6µg/L). At C5, the shallowest station, concentrations on August 13, were actually higher at depth than at the surface. There were no differences between surface and depth concentrations on September 23, at any station. Despite being generally lower, most concentrations at depth were still indicative of eutrophic waters (>10µg/L).

Seasonal changes
In 2003, concentrations at Brantford remained consistently between 2 and 6 µg/L while values at more downstream stations were considerably greater and varied considerably. Chl-a at Cayuga peaked in late August and early September before declining (Figure 2.3). Measures at York (sampled less frequently) were similar to those at Cayuga. Chl-a concentrations mid way between Cayuga and Dunnville and just above the Dunnville dam also peaked (>25µg/L) between Aug 25 and Sep 9 before dropping off to levels comparable to those at Brantford. The two most downstream stations (above Dunnville dam and Port Maitland) peaked a second time in mid October.

In 2004, Chl-a concentration at the most upstream station (C5; Cayuga) again, varied the least, relative to those further downstream (Figure 2.3). Most stations displayed three peaks throughout the season in early-mid July, mid August and late September. The highest measures, in excess of

50 µg/L were observed immediately above (Aug 9) and below (July 6 and Sept. 23) the Dunnville dam.

In both years a clear distinction existed between stations C1-C4 and C5-C7 with regard to maximum values attained and variation; the former being consistently higher and more variable than the latter.

Comparisons with Lake Erie
By way of contrast with the waters that the Grand empty into, Chl-a concentration on individual sampling days at station C2 was compared graphically with values obtained concurrently at a nearshore location in the eastern basin of Lake Erie (Figure 2.4). In addition to the large differences in concentration, it is apparent that there is considerable more variation in the river water measures.

2.4 Discussion

The SGR has very high primary productivity; large concentrations of planktonic algae are produced in the waters downstream of Brantford. Relative Chl-*a* concentration changes not only along the spatial gradient of the river but seasonally at individual locations.

The spatial pattern (increasing Chl-*a* in a downstream direction) does not mirror the spatial patterns seen in total phosphorus (TP). In systems where phosphorus limits production (bottom-up control), TP is usually predictive of chlorophyll (Dillon and Rigler 1974). TP was often just as high at Brantford as it was at Dunnville; other factors are influencing the disparity in the Chl:TP ratio. One obvious difference is the change in flow that occurs downstream of Cayuga. Whereas the river moves faster through Brantford and York, it slows and widens beyond its historic channel where it enters the backwater of the Dunnville dam, the influence of which is measurable upstream to the highway #3 bridge in Cayuga (Kennaley et al. 1979). The reservoir effect results in an increase in retention time to almost 3 days from a calculated historical time of less than 8 hours (Gilbert et al. 2004). Unfortunately absent from the survey were stations in the reservoir formed immediately upstream of the Caledonia dam which would have served as a good comparison to station C3. Deviations in the expected Chl: TP ratio may reflect the alternating predominance of periphyton production vs planktonic algae production as one moves downstream, alternating between lotic and lentic conditions (Vannote et al. 1980).

Although classified as eutrophic based on phosphorus concentrations, the two most upstream stations (at York and Brantford) can be classified as mesotrophic to oligotrophic based on Chl-*a* data. Dodds (2006) however cautions about underestimating trophic state by focussing on planktonic production in lotic waters.

Concentrations of chlorophyll-*a* in the more lentic waters of the Dunnville reservoir and lake-effect zone downstream of Dunnville indicate that these areas are hyper-eutrophic. Phytoplankton turbidity contributes to light attenuation from other suspended particles, further limiting the growth of periphyton and submerged macrophytes (Knapton, R.W. 1993, Gilbert and Ryan 2007). The occurrence of diurnal dissolved oxygen fluctuations in surface waters (see section 5.0; Temperature and Oxygen), in the near absence of periphyton and submerged macrophytes, is further evidence of high planktonic algal biomass and reinforces the designation of “hyper-eutrophic”. Similarly, there is evidence for periods of low dissolved oxygen concentration at depth, consistent with the oxygen demand that would accompany the settling and decomposition of large quantities of unconsumed algal cells (see following sections).

The high planktonic algal biomass of the river estuary stands in stark contrast to the generally nutrient poor and (relatively) low phytoplankton biomass waters of the eastern basin of Lake Erie into which the river flows. Although the nutrient pattern of the river can be detected in nearshore waters for kilometres along the shoreline (T. Howell OMOE; pers comm.) increased water clarity and changes in nutrient cycling in the lake result in a shift in primary production toward attached filamentous algae (Higgins et al. 2005).

Many of the negative effects of high nutrients in the SGR may be attributable to the change in hydrology imposed by the dam at Dunnville. The increased retention time of the lower energy reservoir provides an incubation environment where planktonic algae can flourish resulting in related unfavourable environmental conditions (see following sections). Similar conditions are predicted upstream of the dam at Caledonia. If the Dunnville dam were not creating this reservoir, there would still be a degree of slowing and widening of the river where the river and lake mix however the dynamic aspect of the lake seiche would create a more physically energetic environment unlike that which presently exists above Dunnville.

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2.6 Figures

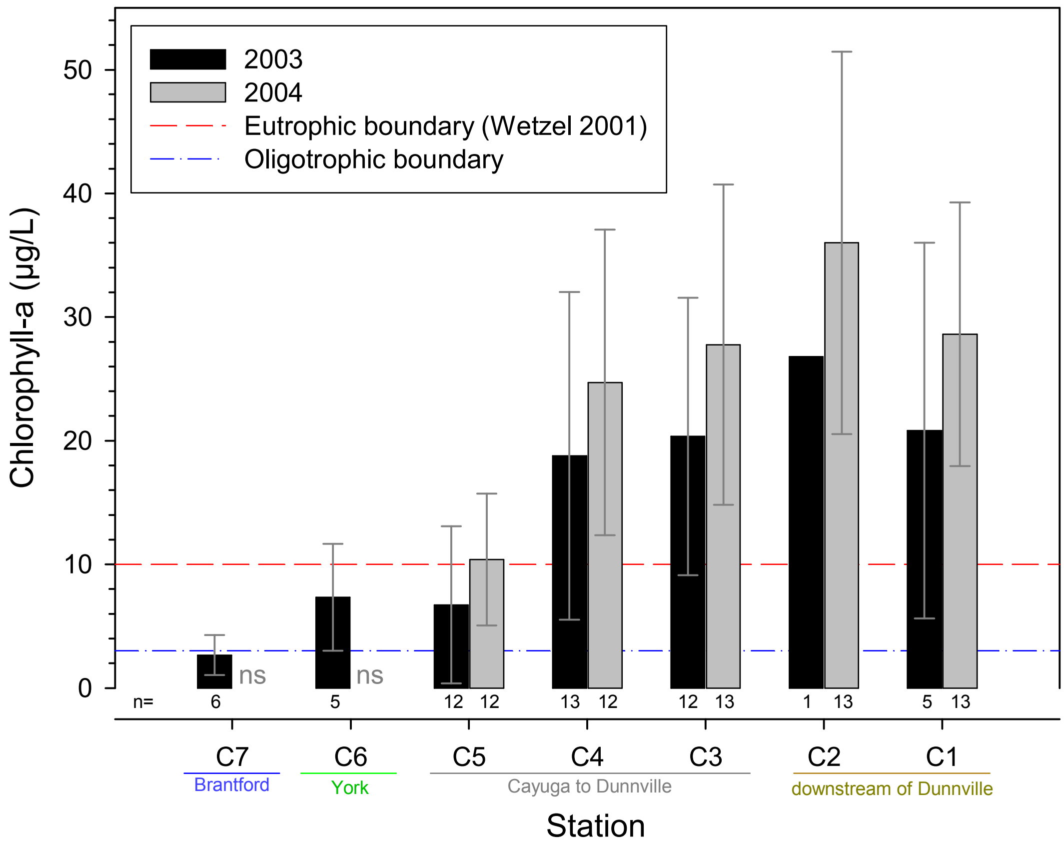

Figure 2.1 Mean chlorophyll-a (Chl-a) concentration at seven stations within the lower reaches of the Grand River, 2003-2004. Stations C6 and C7 were not sampled in 2004. Chl-a values have been corrected to remove the influence of phaeopigments. Error bars represent the standard deviation. Stations are presented (left to right) from the most upstream (C7; Brantford) to the most downstream (C1; Port Maitland at Lake Erie).

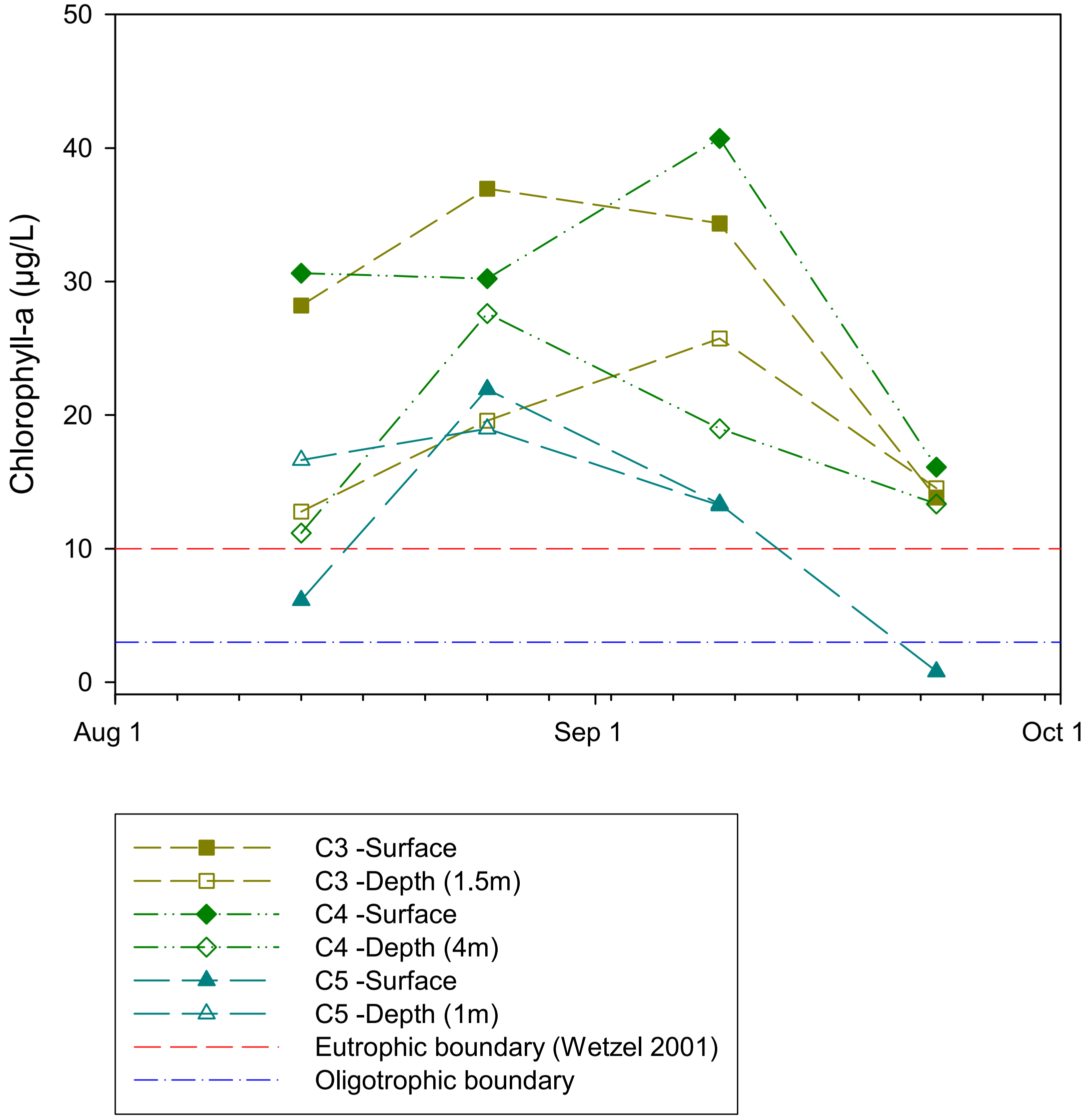

Figure 2.2. Chlorophyll-a (Chl-a) concentration at three stations (C3-C5) within the lower reaches of the Grand River, 2003. Chl-a values have been corrected to remove the influence of phaeopigments and represent the mean of two separate water filtrations and spectrophotometric readings.

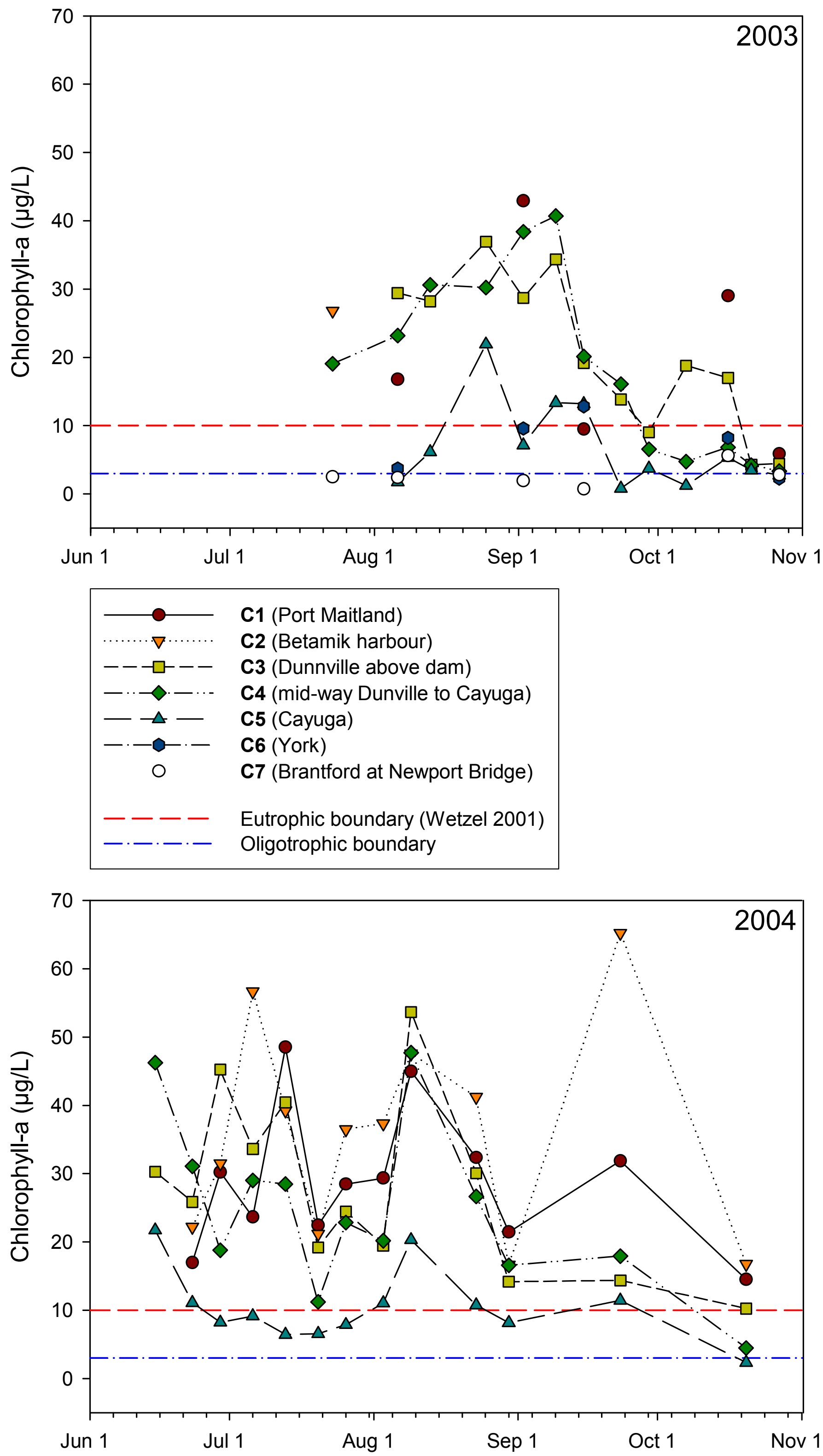

Figure 2.3 Seasonal patterns of chlorophyll-a (Chl-a) concentration at seven stations (C1-C7) within the lower reaches of the Grand River, 2003-2004. Chl-a values have been corrected to remove the influence of phaeopigments and represent the mean of two separate water filtrations and spectrophotometric readings.

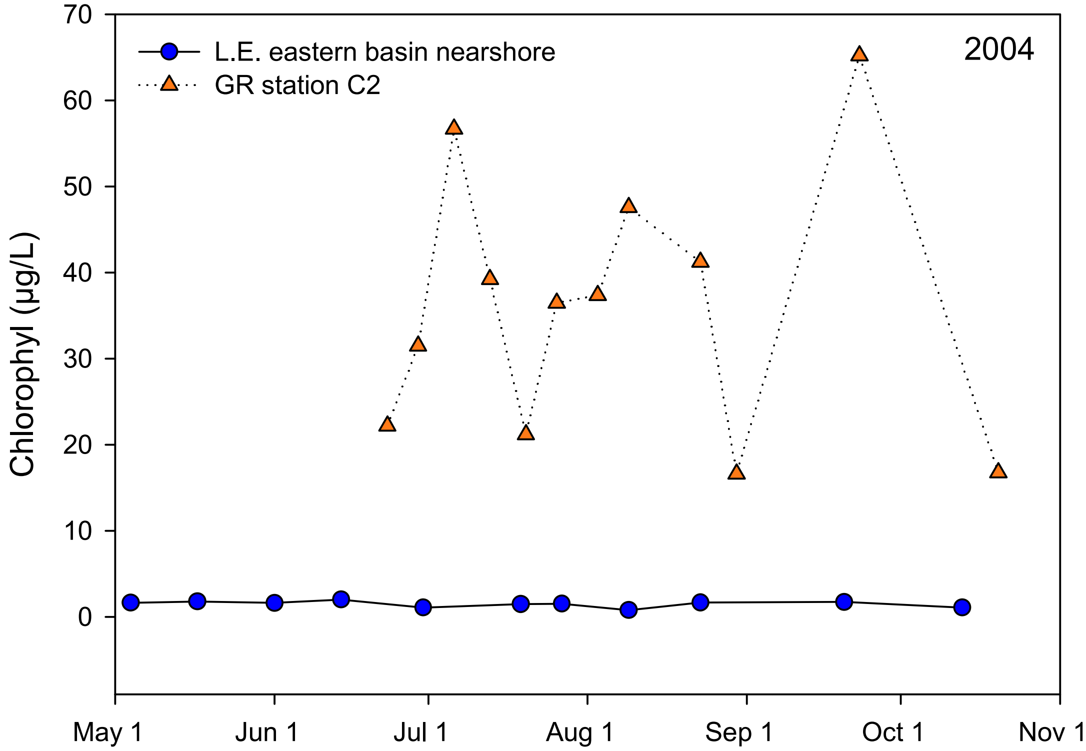

Figure 2.4. Chlorophyll-a (Chl-a) concentration at Grand River sample station C2 relative to concentrations from epilimnetic waters at a nearshore location (Lake Erie Committee, Forage Task Group; LTLA station 15; 7m depth) in the eastern basin of Lake Erie, May- October, 2004. Chl-a values have been corrected to remove the influence of phaeopigments and represent the mean of two spectrophotometric readings.

2.7 Tables

Table 2.1. Dates on which water sampling for chlorophyll-a (Chl-a) occurred at seven stations (C1-C7) within the lower reaches of the Grand River during 2003 and 2004. The portion of the water column sampled is indicated (either surface or at depth). Four sub-surface collections across the width of the river were mixed to create a composite sample for filtering.

	Port Maitland C1		Betamik C2		Dun-above dam C3		mid way (RV) C4		Cayuga C5		York C6		Brantford C7	
Date (dd-MMM-YY)	Surface	Depth	Surface	Depth	Surface	Depth	Surface	Depth	Surface	Depth	Surface	Depth	Surface	Depth
2003														
23-Jul-03			X				X						X	
6-Aug-03	X				X		X		X		X		X	
13-Aug-03					X	X	X	X	X	X				
25-Aug-03					X	X	X	X	X	X				
2-Sep-03	X				X		X		X		X		X	
9-Sep-03					X	X	X	X	X	X				
15-Sep-03	X				X		X		X		X		X	
23-Sep-03					X	X	X	X	X					
29-Sep-03					X		X		X					
7-Oct-03					X		X		X					
16-Oct-03	X				X		X		X		X		X	
21-Oct-03					X		X		X					
27-Oct-03	X				X		X		X		X		X	
2004														
15-Jun-04					X		X		X					
23-Jun-04	X		X		X		X		X					
29-Jun-04	X		X		X		X		X					
06-Jul-04	X		X		X		X		X					
13-Jul-04	X		X		X		X		X					
20-Jul-04	X		X		X		X		X					
26-Jul-04	X		X		X		X		X					
03-Aug-04	X		X		X		X		X					
09-Aug-04	X		X		X		X		X					
23-Aug-04	X		X		X		X		X					
30-Aug-04	X		X		X		X		X					
23-Sep-04	X		X		X		X		X					
20-Oct-04	X		X		X		X		X					

Table 2.2. One-way ANOVA comparison of annual mean chlorophyll-a concentrations at Grand River sampling stations (C1-C7). Data was log-normalized (Anderson-Darling) prior to comparison and tested for homogeneity of variance (Bartlett's). Individual differences were identified using Fishers LSD test. Note Station C2 not included in 2003 due to insufficient replicate measures. ("sd" indicates statistically different at $p<0.05$, "*" indicates no statistical difference.

2003	**C1**	**C3**	**C4**	**C5**	**C6**	**C7**
C1	na	*	*	sd	*	sd
C3	-	na	*	sd	sd	sd
C4	-	-	na	sd	*	sd
C5	-	-	-	na	*	*
C6	-	-	-	-	na	*

2004	**C1**	**C2**	**C3**	**C4**	**C5**
C1	na	*	*	*	sd
C2	-	na	*	sd	sd
C3	-		na	*	sd
C4	-	-	-	na	sd

3.0 Benthic Invertebrates

3.1 Introduction

Benthic invertebrate community structure is a commonly used indicator of aquatic habitat health, particularly as it changes relative to the level of nutrients in the surrounding water. Previous surveys of benthic invertebrates in the Southern Grand River (SGR) have been limited to specific areas below Dunnville dam; in the Dunnville Marshes (Knapton 1993) at the river mouth (MOE, 2002). Wetlands adjacent to the main channel above and below the dam were surveyed in 2004 (Gilbert and Ryan 2007). To further efforts to characterize habitat quality in the SGR, surveys of the benthic invertebrate community in the main channel were conducted in 2002 and 2003.

In designing the sampling strategy, attempts were made to recognize the large number of variables able to impact/shape the benthic community as well as acknowledge the patchiness in distribution characteristic of many benthic species. As substrate type is a strong determinant of community structure, it was decided that sampling sites would be confined to the section of river from Cayuga downstream to Port Maitland where the substrate is comprised mainly of unconsolidated sand/silt and fine grained organic muck. Upstream of Cayuga, there exist large stretches of exposed bedrock, cobble and rubble. Cayuga represents the theoretical upstream limit of the, pre-Dunnville dam, lake effect zone (based on mid-channel elevation and chart datum lake levels; Gilbert et al. 2004).

The objectives of the survey included the following:
i) To compare benthic communities along a spatial gradient of the main river channel (and relative to the dam at Dunnville) with regard to indicator species, common invertebrate indices (e.g. Hilsenhoff index of organic pollution), species diversity and relative abundance,
ii) To make comparisons to previous studies.
iii) To describe densities and available species with regard to diet needs of benthivorous fish species (and life stages).
iv) To describe trophic status based on the presence/absence of indicator species.

With regard to ranking the SGR ecosystem relative to other tributary/Great Lake interface areas; lack of data from an appropriate undisturbed reference sites precluded methods of analysis such as those suggested in the Ontario Benthic Biomonitoring Network protocol (Jones et al. 2004).

3.2 Methods

Five sample sites were chosen to provide a spatial gradient between Cayuga and Port Maitland and to correspond with locations of concurrent sampling for water quality, algal biomass, and temperature/oxygen regimes. Two of the stations were located downstream of the Dunnville dam and the Dunnville water treatment control plant. Three stations were located upstream of Dunnville; one immediately upstream of the dam, one at Cayuga, and one approximately mid-way between (Figure 3.1). These sites, labelled B1-B5; correspond with chlorophyll-a stations C1-C5; respectively (see section 2.0). At each site, four replicate samples were collected at regularly spaced locations across the width of the channel. Figure 3.2 shows relative channel width and shape at each site as well as replicate locations from 2003 sampling (2002 replicate locations were not geo-referenced but followed a similar pattern; a transect perpendicular to the channel).

When attempting to describe the maximum species richness of a benthic community, avoidance of mid-summer sampling is recommended (Rosenberg et al. 1998). Ideally this would involve sampling in either early spring (just after ice-out) or late fall. Attempts to conform to this standard met with limited success due to logistical constraints in each year. In 2002, planned spring sampling was delayed until July 11th. In 2003, sampling was conducted at the end of the field season, on October 1st (above dam sites) and 2nd (below dam sites).

Samples of substrate were obtained using an 8-litre ponar dredge (capture area = 0.215m x 0.245m; Wildco. Ltd) lowered from the bow of a 14-ft Jon-boat. Partial samples, where the ponar misfired or was not full when retrieved, were discarded in favour of 4 complete samples. Substrate samples were sieved through a coarse mesh to remove obvious debris such as twigs or pebbles. The filtrate was then sieved through a 500µm screen before being placed in plastic bottles and preserved in 10% formalin. Samples were subsequently rinsed, preserved in alcohol, and picked under microscopes in a lab setting. All collected organisms were delivered to a recognized consulting service to ensure accurate identification (Bland and Associates, Ltd., London, Ontario).

The following parameters were calculated to describe the benthic community:

Density – expressed as $\#/m^2$ extrapolated from the area captured by the ponar (0.245m x 0.215m = $0.053m^2$); in order to facilitate comparisons to previous studies. Mean density per site is reported.

Species Richness (S) – counts of overall number of unique taxa at each site. To give a more representative picture of an area, replicates were pooled for this count because of the variability between samples and the patchy distribution of several species. These taxa counts were based, for the most part on identification to genus or species; higher order identifications were only counted when no lower classifications occurred within that grouping. Subtotal contributions from individual taxon groupings were also considered.

Shannon-Weiner Diversity Index and associated measures

$$H' = -\sum(p_i)(\log_e p_i)$$

where "p_i" is the proportion of individuals in the "ith" taxon of the community

$H_{max} = \ln(S)$ – represents the maximum H' value given a fixed number of species (assumes equal contribution from each species.)

Species Evenness (E) = H/Hmax – a measure of equitability, commonly used as a community descriptor

Hilsenhoff Biotic Index

Hilsenhoff values were calculated in two ways:

1. HH- the traditional Hilsenhoff whereby all organisms are used with the limitation that each replicate must contain at least 100 individuals. Due to the low densities in the study area, this necessitated the pooling of replicates and the calculation of only one value per site. This methodology emphasises disparities in relative abundance of individual species (diversity).

$$HBI = \sum \frac{x_i t_i}{n}$$

where
x_i = number of individuals within a species
t_i = tolerance value of a species
n = total number of organisms in the sample

2. HH_{10max}- a modified Hilsenhoff described in Mandaville (2002) whereby the effects of extremely abundant species are dampened. This method involves capping individual species counts at 10 and, despite the low densities of the study area, allowed for index values to be calculated for each replicate and thus statistical comparison to be made between sites. This method emphasises species richness.

$$HBI(10\max) = \sum \frac{x_i t_i}{n}$$

where
x_i = number of individuals within a species *up to a maximum of 10*
t_i = tolerance value of a species
n = sum of x_i for all species

In each case, species tolerance values were obtained from Mandaville (2002)

It should be noted that these values reflect tolerance to organic matter and decomposable wastes that generate a biological oxygen demand. Hilsenhoff scores were ranked as follows (Hilsenhoff 1987):

0.00-3.50	Excellent; No apparent organic pollution
3.51-4.50	Very good; Possible slight organic pollution
4.51-5.50	Good; Some organic pollution
5.51-6.50	Fair; Fairly significant organic pollution
6.51-7.50	Fairly Poor; Significant organic pollution
7.51-8.50	Poor; Very significant organic pollution
8.51-10.00	Very Poor; Severe organic pollution

<u>Dominance</u> – The proportion of the top two most abundant species at each site.

<u>Percent Ephemeroptera, Plecoptera, Tricoptera</u> – Proportion of these families based on abundance

<u>Oligochaete-Chironomid ratio (O:C)</u> –used by Carter et al. (2006) to characterize water quality (nutrient enrichment) in a drowned river mouth emptying into Lake Michigan. Higher ratios equate to reduced water quality.

O:C = oligochaete density/(oligochaete density + chironomid density)

Proportion of Oligochaetes – also used by Carte et al. (2006); the proportion of oliochaetes in total benthos. As with O:C, higher ratios equate to reduced water quality.

3.3 Results

A total of 2184 organisms were examined over the two years of sampling between Cayuga and Port Maitland. Overall, 37 unique taxa were observed (Table 3.1); the actual number encountered may have been slightly higher as not all could be identified to species (most were identified to at least the level of *Genus*). A large numbers of tubificid worms were collected in each year which could not be identified below the family-level.
The species assemblage changed slightly between 2002 and 2003 resulting in thirteen taxa unique to 2002, ten taxa unique to 2003, and fourteen taxa common to both years. While some species were rare overall (e.g. a total of three Megalopteran; *Sialis sp*. were observed in only two of the 34 ponar grabs), others were spatially rare (In 2003, Ephemerotpera occurred in each replicate at B5, the furthest upstream station and in one replicate from station B4, but not in any other downstream sample). Conversely, some taxa were ubiquitous. Chironomid species and tubificid species occurred in almost every sample (94% and 97% in 2002 and 2003; respectively). In some cases, gradients were evident in the abundance of several species where replicates were collected across the width of the river channel. In these cases, highest densities occurred at locations associated with the river thalweg (deepest part of the channel). Details of taxa and counts from each replicate are provided in Appendix C.

The density of benthic organisms was low (< 1000 individuals/m^2) throughout the study area at most stations, in both years (Figure 3.3) particularly when compared to that observed in a comparable Great Lakes drowned river mouth in Michigan (Carter et al. 2006) and in Lake Erie's eastern basin nearshore (LEC-Forage task group lower trophic sampling database). The exception occurred at station B1, where mean densities were considerably higher (2-fold and 4-fold higher than more upstream stations in 2002 and 2003; respectively). High variability between replicates resulted in no statistically significant differences between stations. Overall mean densities were higher in 2003 than in 2002.

Less than half of the overall species richness (37 taxa) was present at any individual sampling station in any one year. The highest number of species observed at a sampling event (17) occurred in 2002 at the furthest upstream station (B5); the lowest occurred in 2003 at station B3 (Figure 3.4). Species contributing to the richness at each station were categorized based on Order. In 2002 most of the species from each station were from either Dipteran families (primarily Chironomidae) or, to a lesser extent, Oligochaete families (primarily Tubificidae). The community at each site represented between 4 and 5 invertebrate families. While the same two families predominated in 2003, there were more families represented, particularly at the most downstream (B1; 6 families) and upstream sites (B4 and B5; 5 and 7 families respectively). Live molluscs (sphaerid clams) were only found at stations B1 and B5. Species belonging to the family Hirudinea only occurred at station B5. Ephemeroptera were observed at all stations except B3. Megaloptera were only observed at stations B4 and B5. Hemiptera and Coleoptera species were not observed below the dam (at B1 or B2).

Individual abundance counts at each station reveal the predominance of Chironomid and Tubificid species within the communities examined (Figure 3.5). The relative contributions from these two families changed notably between the years. In 2002 communities were dominated by Chironomids at all sites (56-69% of total counts) while in 2003, Tubificid worms dominated at the more downstream stations (B1-3; 77, 80, 90% respectively) and Chironomids at B4 and B5 (46 and 76% respectively).

The relatively low species richness and numerical dominance by a few species is reflected in the low diversity index values calculated for each site/year (Figure 3.6). Shannon Weiner diversity index values ranged between 0.8 and 2.3. In most cases the dominance by chironomids or tubificid worms resulted in Evenness values of 0.5 or less. Species contributed more equitably (E > 0.5) at downstream stations (B1-3) in 2002, and at B4 in 2003 (Figure 3.7).

Hilsenhoff scores generated by considering replicates separately (H'_{max10}) and those using counts pooled per site (H') yielded similar results. Index scores reflected fairly-poor to poor interpretations at all sites. For H'_{max10} scores, no significant differences were detected between any of the sites although a general trend of decreasing index value is apparent when considering stations from downstream to upstream (Figure 3.8). In both years, stations B2 and B3 displayed the highest values (>8.5; very poor). Station B5 is ranked "poor" in each year, while station B1 was ranked "poor" in 2002 and "very poor" in 2003. Pooling the data for each station results in similar results (Figure 3.9), the exception being the lower index value of given to station B1 in 2002 which earned it the distinction of being the only site/time to be ranked only "fairly poor".

Plans to employ the commonly used index of percentage Ephemeroptera/ Plecoptera/ Tricoptera were complicated by the complete absence of Plectopteran or Tricopteran species and the rarity of mayflies. EPT scores were zero for all station and times except for 0.7% and 3.0 % in 2002 at stations B1 and B2 (respectively) and 5.1% and 3.4% in 2003 at upstream stations B4 and B5 (respectively).

As noted above, live molluscs were rare; live specimens were only observed at the two most upstream stations (7 sphaerid clams and 1 gastropod) and the most downstream station (1 sphaerid clam). Large numbers of empty mollusc shells were observed at most stations,

A wide variety of empty shells were observed at all stations (Table 3.2). Dreissenid shells were observed at station B1 (all replicates).

3.4 Discussion

The area sampled for benthic invertebrate community structure in 2002 and 2003 posed a challenge when deciding how to approach an analysis that involved index ranking or comparison to literature values. Traditional benthic invertebrate investigations have primarily focussed on two types of environment; i) streams and rivers of lower order ranking, specifically areas of riffle and well-oxygenated water or ii) lake and reservoir environments.

The lower reaches of the Grand River, while part of a large lotic system, display traits more characteristic of lake or reservoir systems. The two most downstream benthic collection stations in this study (B1 and B2) are directly influenced by Lake Erie, while the next two upstream stations (B3 and B4) are within the impoundment area of the Dunnville dam. The most upstream station (B5), while still within the theoretical backwater of the Dunnville dam, is likely influenced by invertebrate drift as it lies immediately downstream of shallow, bedrock lined, riffle-like areas. Additionally it should be noted that this station is upstream of the most immediate source of potential human influence - the discharge of the water pollution control plant at Cayuga.

Gerritsen et al. (1998) discusses the most appropriate portion of a lake or reservoir to target sampling efforts. Of the three physical zones within a lentic system, the littoral zone tends to have the highest abundance and diversity of benthic invertebrates however this tends to be influenced by the diversity of habitat, especially with regard to macrophyte community, which adds unwanted variability when comparing between sites. The profundal zone, subject to hypoxic events during thermal stratification in some lake systems, precludes many species unable to tolerate low oxygen events. The sublittoral zone, where substrate tends to be more uniform, fine grained and where rooted plants are absent or infrequent, is most appropriate for site to site comparisons (Gerritsen et al.1998, Mandeville 2002).

While most of the replicate locations sampled during 2002 and 2003 were at depths typical of lake littoral zones, the environment of the river between Cayuga and Port Maitland is more characteristic of lake sublittoral zones; there is a paucity of submerged macrophytes, course grained substrate is rare and the topography in general is uniform throughout. Differences in community makeup between sites could therefore be driven by differences in exposure to pollution (i.e. high biological oxygen demand). Since substrates are homogenous, the differences in community structure between sites are likely driven by differences in parameters such as oxygen regime.

Despite relatively shallow depths (< 5 m), the benthic community downstream of Cayuga is characteristic of what one would find in the profundal zone (hypolimnion) of lakes that thermally stratify. It is dominated by two groups generally tolerant of low-oxygen: Dipteran chironomids and oligochaete tubificid worms. Chironomids and Tubificids tend to dominate in lake profundal zones where the hypolimnion becomes hypoxic in summer. Relative proportions of these groups can attest to the severity and/or duration of low oxygen events; as hypoxia becomes more severe, tubificids become dominant over chironomids and as the duration of anoxia increases, profundal assemblages can entirely disappear (Gerritsen et al., 1998). In the current survey, the shift between years in the relative proportion of tubificids and chironomids may be explained by the seasonality of the sampling. Compared to the 2002 spring sampling, the 2003 fall sampling is expected to be more reflective of summer conditions, when low oxygen events are most likely to occur. The fact that tubificids dominate in only stations B1-B3 in 2003 suggests that low oxygen events may have been more severe there than at the two more upstream sites. Bi-weekly oxygen monitoring in 2002 and 2003 did not detect significant oxygen depletion in the lower Grand River. However, subsequent intensive oxygen monitoring in 2005 showed that periods of anoxia do occur in the study area, that they can be extensive (up to 12 days) and that they can be easily missed with point-in-time sampling (see section 5.0; Temperature and Oxygen). Examining the fall proportion of tubificids to chironomids may be a quick indirect (post-hoc) way of assessing the severity of summer oxygen conditions.

In reviewing the literature Johnson et al. (1993) suggest that most chironomid communities are structured not simply by oxygen conditions but by the broader trophic environment and that most indices correlate with associated measures (e.g. eutrophy: total phosporus, chlorophyll-a, algal biovolume). The predominance of oligochaetes in benthic samples taken near the river mouth in 1998 was interpreted as indicative of eutrophic conditions of the lower Grand River (Ministry of the Environment 2002). A similar ranking was given to the mouth of the Thames River (another large, nutrient rich, southern Ontario river system emptying into Lake St. Clair) and the nearshore of Lake Erie's western basin. While the nearshore of the eastern basin of Lake Erie is typically considered to be oligotrophic (MacDougall et al. 2001) there is evidence that the eutrophic conditions evident in the lower Grand River are affecting sections of nearshore that are directly influenced by the river plume (Higgins et al. 2005)

There were no statistically significant differences in any of the parameters measured along the spatial gradient of the river. This is perhaps not surprising given that high nutrients and eutrophic conditions exist throughout (Section 1.0 and 2.0; above) and that most of the important tubificidae taxa could not be identified to species. Species directly linked to eutrophic conditions were identified at all 5 stations (Table 3.1).

Despite this, several parameters point to a trend of improving conditions when moving from downstream to upstream. While the lower three stations (B1, B2, B3) ranked the poorest for most of the measures considered (family and species richness, proportion dominant, Hilsenhoff index and H'_{max10}) the station closest to the mouth (B1) was, for some measures (H' in 2002), an exception to the rule. A key eutrophic indicator species, *Limnodrilus hoffmeisteri* was present in 7/8 replicate samples from B1 but rare at other stations. It is possible that most of the immature hairless, no-chaetae tubificids, which predominated at stations B1-B3, were also *L. hoffmeisteri* (as this hairless trait is one characteristic of the species). In some respects, station B3, ranked the lowest of the stations. Low diversity and taxa richness at B3, particularly in 2003, may be due to the high siltation in this broad section of the river, which has been shown to drive community structure (Mandaville 2002). The variety of families represented by the two most upstream stations reflect the general positive ranking of these sites. The only individual species belonging to the "scraper" category of invertebrates, (the Coleopteran *Stenelmis sp,* and the Gastropod *Campeloma decisum*), were found exclusively at the most upstream station. *C. decisum*, considered a eutrophic indicator species, is nevertheless a member of the prosobranch Viviparidae; it utilizes gills and is dependent on well oxygenated waters.

Overall, the benthic community of the lower reaches, is not considerably different from that described for the wetlands downstream of Dunnville in 1993 (Knapton 1993). Diptera and Oligochaete species dominated at the vast majority of sampling stations. Notable differences were the presence of amphipods (probably *Gammais sp*.) and gastropods at a small proportion of the 100 sites sampled in 1993. Much of this can probably be attributed to the shallower, wetland locations and the presence of some macrophytes in 1993. While the Order Acarina made up a significant proportion of the samples in 1993, this was not the case in 2002-03. Subsequent sampling of the wetland complexes above Dunnville in 2004 (Gilbert and Ryan 2007) revealed a much more diverse benthic invertebrate community where chironomids and oligochaetes did not dominate. While differences in sampling methodology preclude drawing explicit conclusions, the presence, and in some cases high relative densities, of Amphipods, Isopods, Ephemeroptera, Hemiptera, Plecoptera and Odonata in 2004, suggest substantial habitat differences between the main channel and backwater areas between Dunnville and Cayuga. Unlike the prosobranch (gilled) gastropod collected at station B5, the gastropod community of these wetlands was exclusively comprised of pulmonate snails, which obtain atmospheric oxygen. The dominant species in the majority of the Dunnville- Cayuga wetlands was *Physella gyrina* a specific indicator of eutrophic conditions.

Conclusions

The benthic community of the lower reaches of the Grand River (downstream of Cayuga) indicates eutrophic conditions, consistent with indications from nutrient and algal biomass measures (previous sections). Low overall species richness is partially attributable to the lack of structure, both horizontally along the uniform, small-grained substrate, and vertically due to a lack of submerged macrophytes. The high turbidity of the water and limited light penetration results in conditions where periphyton, a food-source for many "scraper" invertebrates, cannot grow. Community structure is also shaped by the exclusion of species not tolerant of low oxygen conditions. Low densities and species richness in the main channel area may pose a challenge for some of the more selective benthivorous fish species. The wetland areas between Dunnville and

Cayuga are thought to be superior with regard to species richness however relative densities in these areas are not known. This benthic community near Cayuga is undoubtedly affected by downstream drift from areas of aeration (i.e. riffles at York) and structurally diverse benthic habitat.

3.5 References

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3.6 Figures

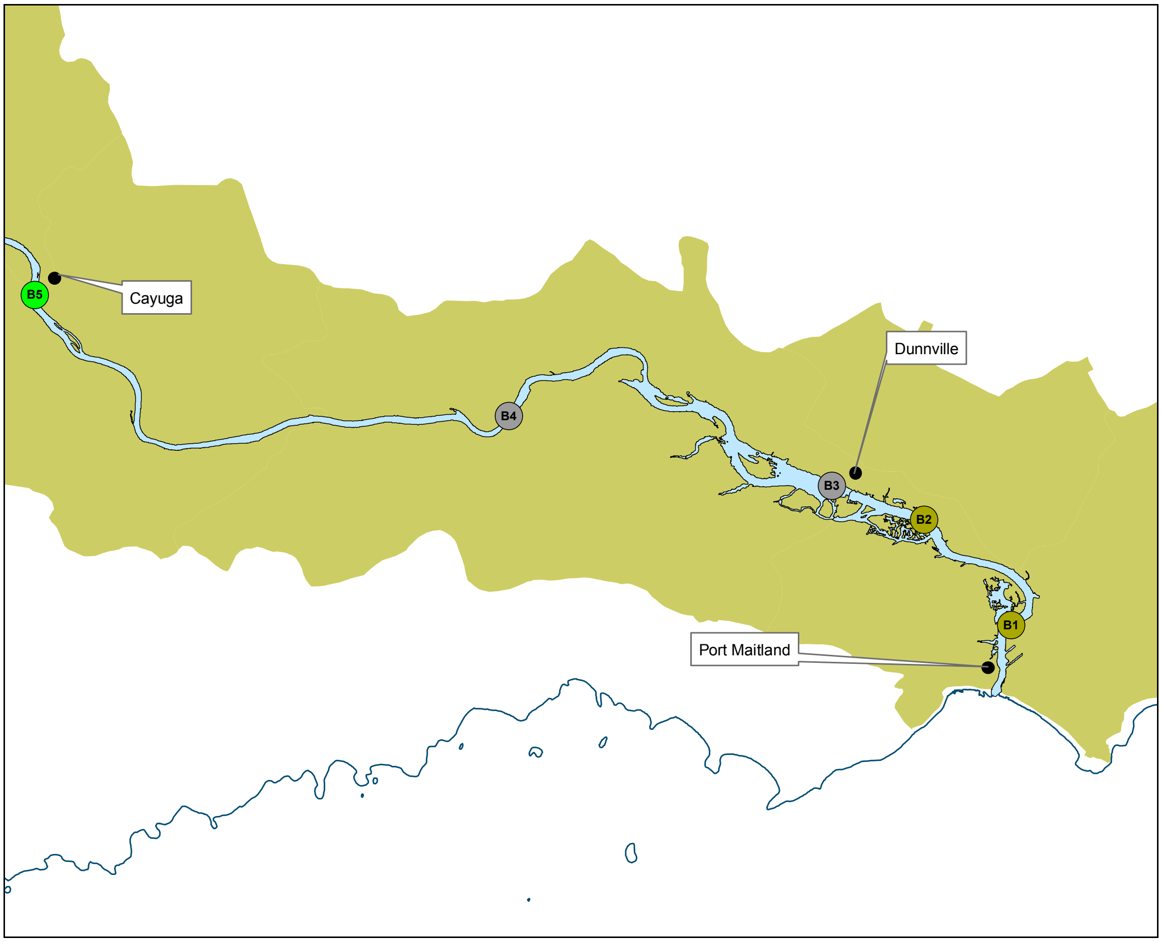

Figure 3.1. Locations of benthic invertebrate stations, sampled in 2002 (July) and 2003 (Oct). Four replicate ponar grab samples (8 litre) samples were collected spanning the width of the river.

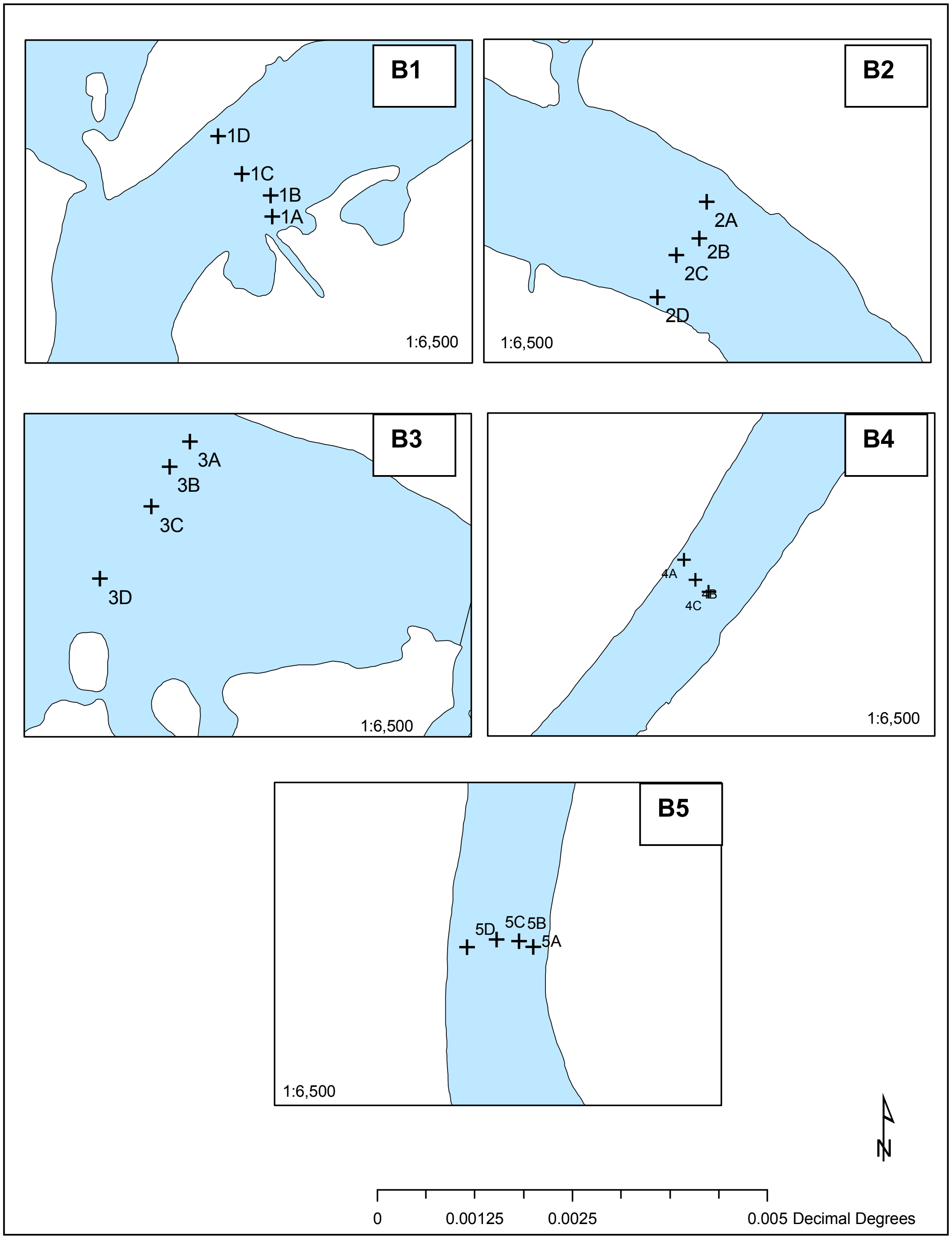

Figure 3.2. Locations of replicate benthic invertebrate samples collected across the river width, at 5 locations (Station B1 to B5) in the lower reach of the Grand River in 2003.

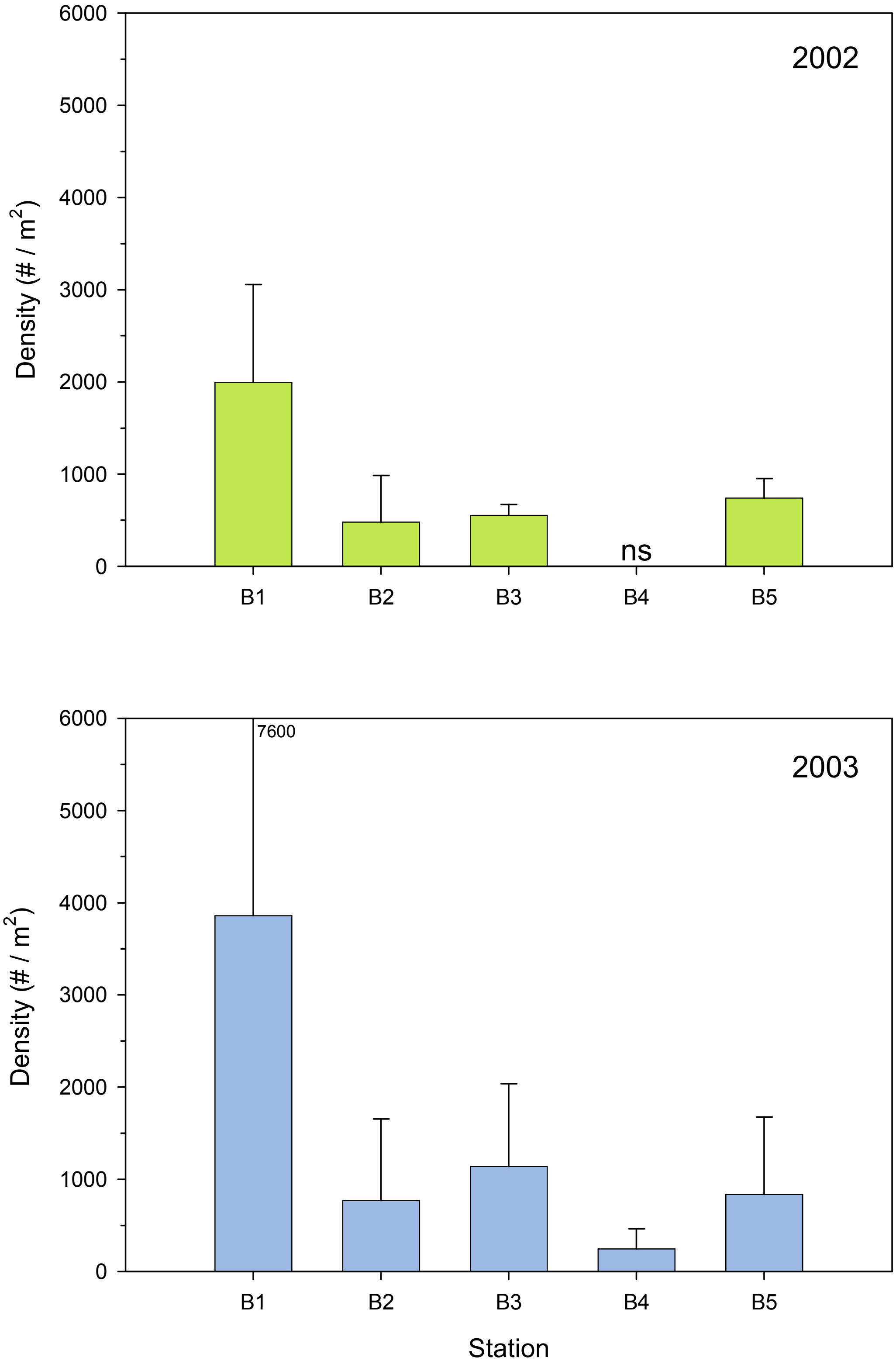

Figure 3.3. Mean density of benthic invertebrates (# / m2) at 5 locations within the lower reach of the Grand River in 2002 and 2003. Error bars represent the standard deviation. ns = not sampled.

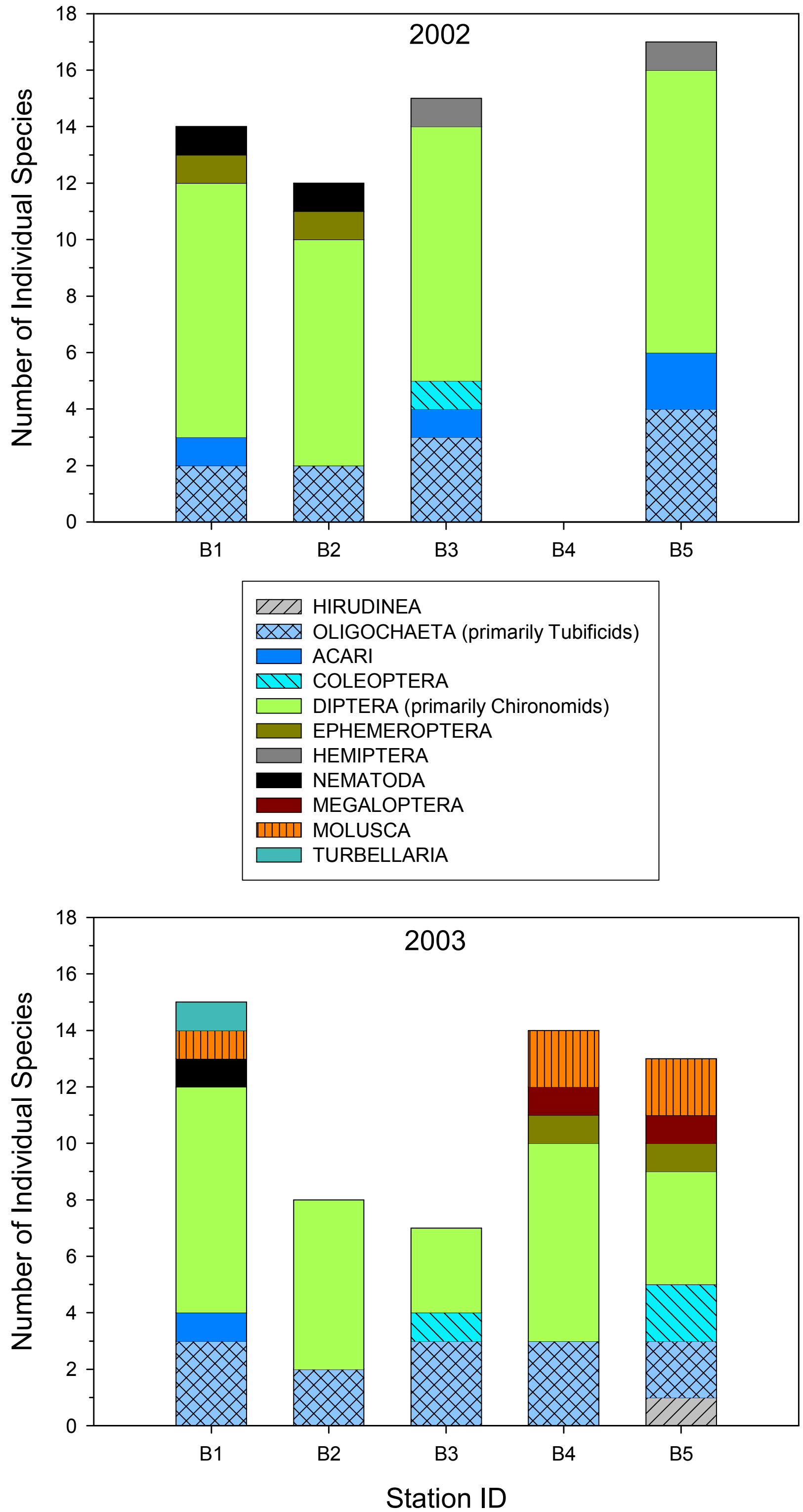

Figure 3.4. Number of benthic invertebrate species, grouped by Order, found at 5 locations within the lower reach of the Grand River in 2002 and 2003.

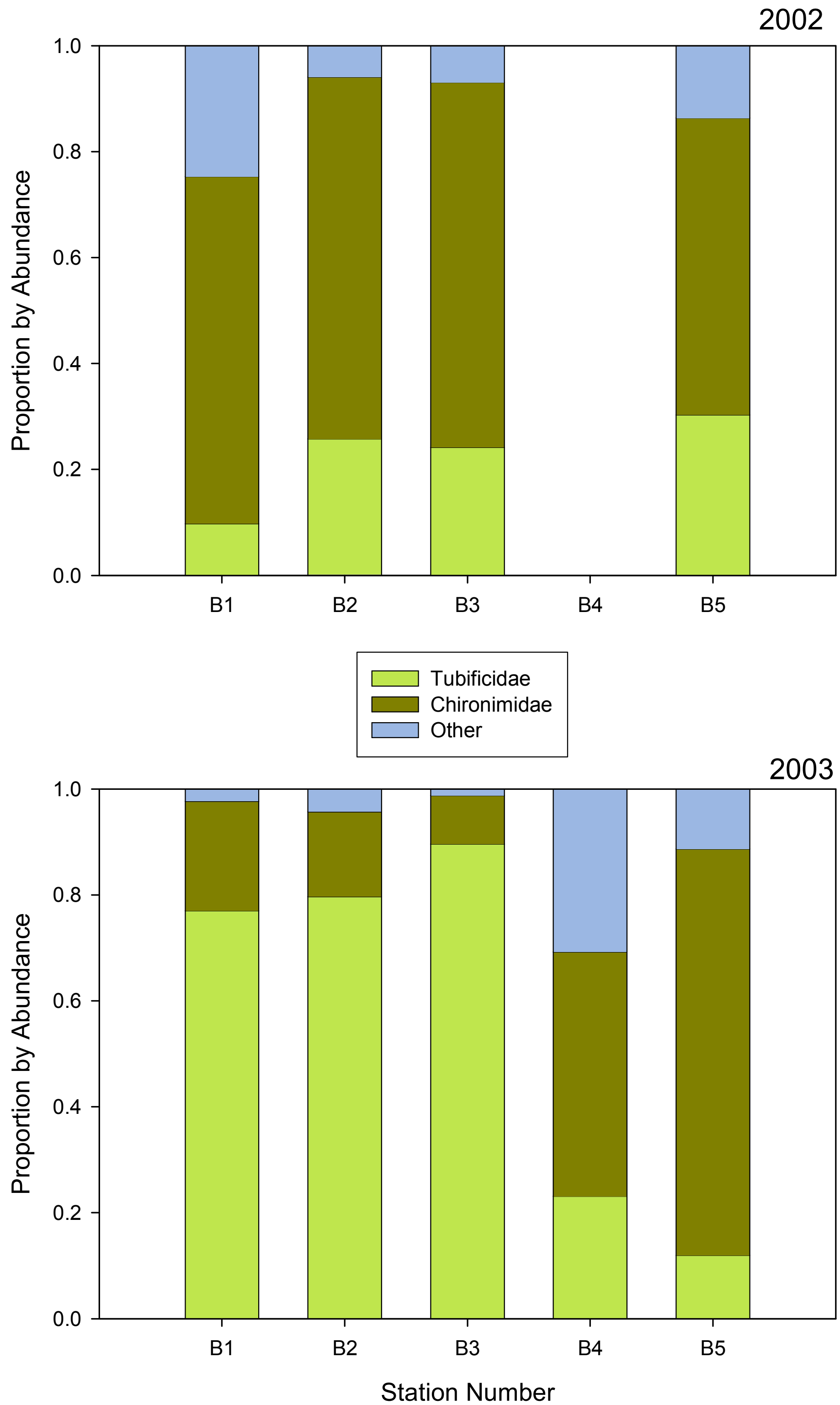

Figure 3.5. Proportion of the total abundance of benthic invertebrates, represented by i) tubificid oligoachaetes, ii) dipteran chironomids, and iii) all other taxa, at 5 locations within the lower reach of the Grand River in 2002 and 2003.

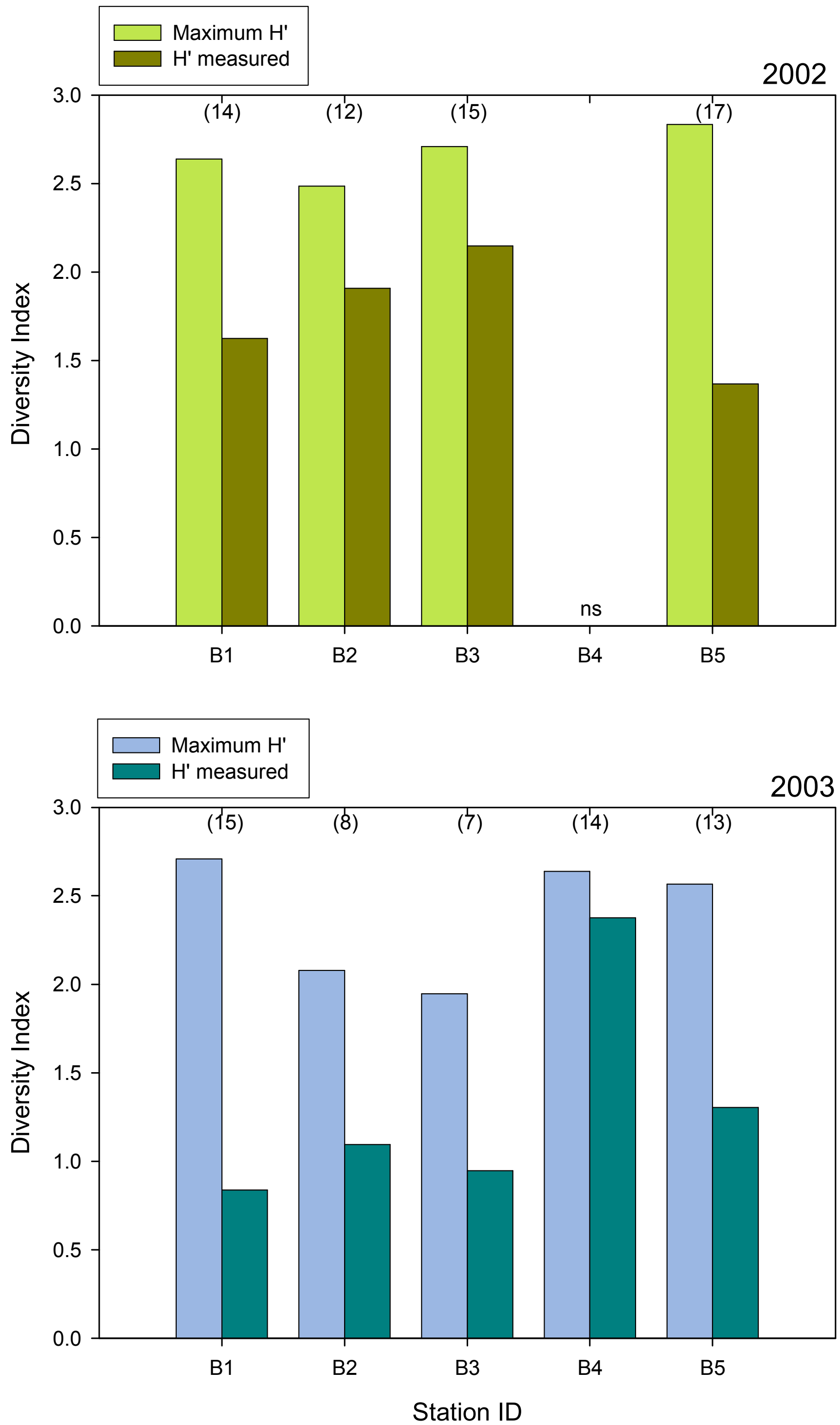

Figure 3.6. Diversity index values assigned to the benthic invertebrate community at 5 locations within the lower reach of the Grand River in 2002 and 2003. H' = the Shannon Weiner diversity index; H'maximum = the maximum H' possible, given an equal contribution from all species present. The number of species present during each sampling occasion is shown in brackets, along the top axis. **ns** = not sampled

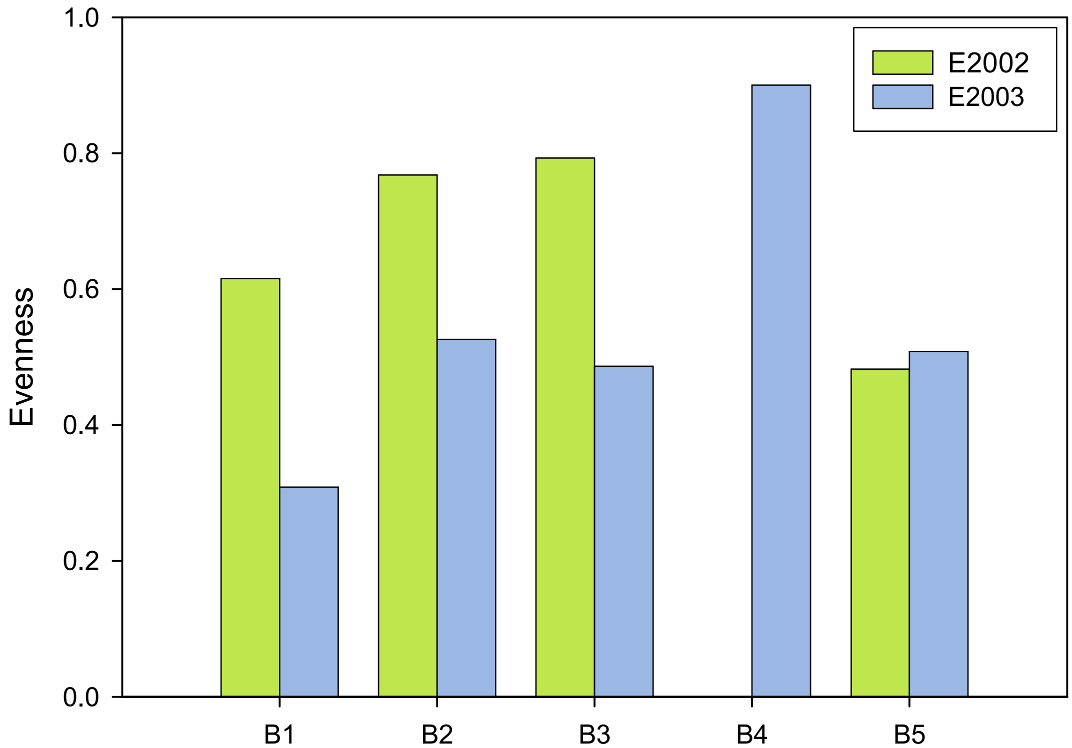

Figure 3.7. Evenness of the contribution (by abundance) of each observed species of benthic invertebrates observed during sampling at 5 locations within the lower reach of the Grand River, 2002 and 2003.

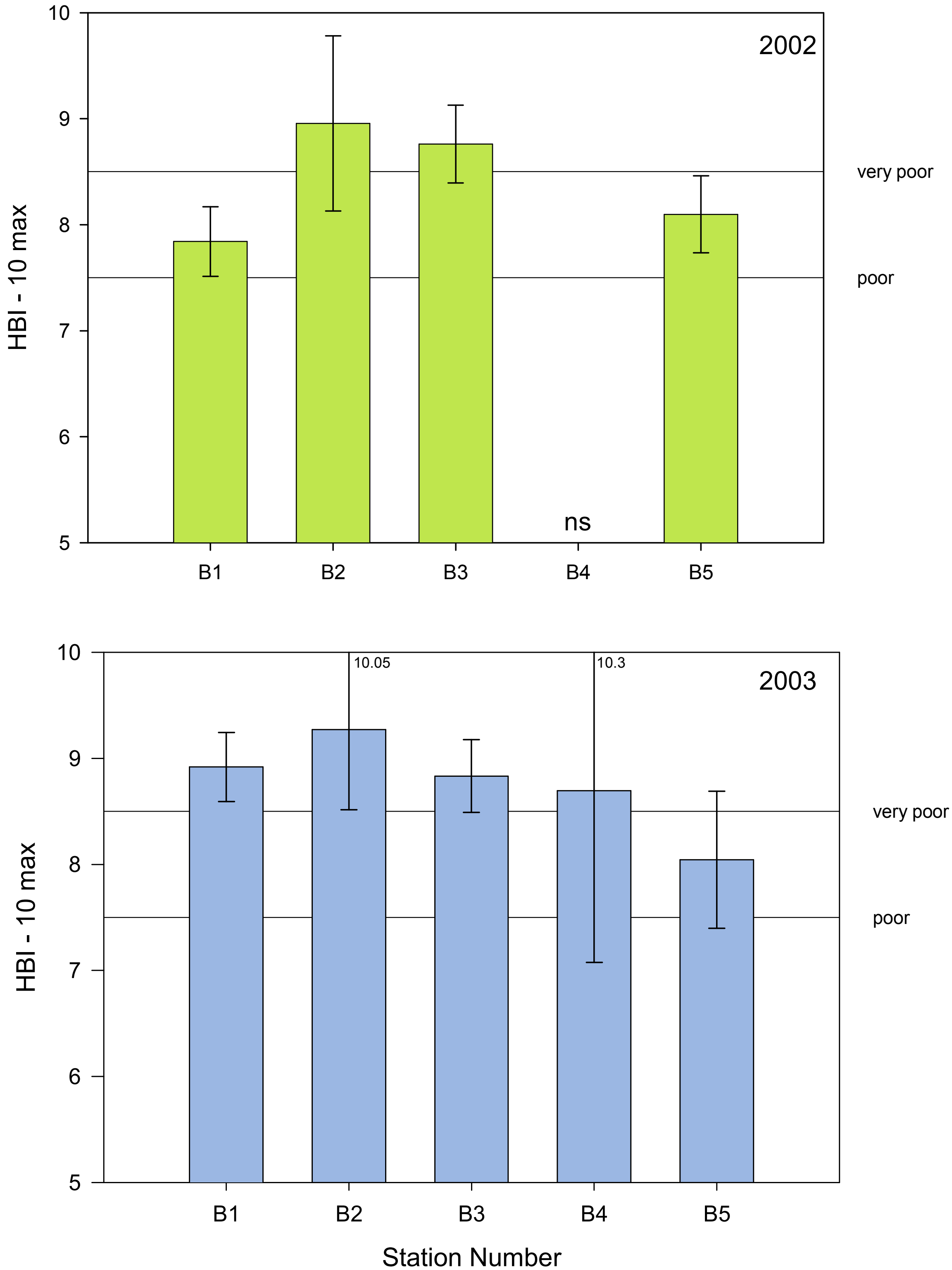

Figure 3.8. Mean Hilsenhoff Biotic Index (10max) values calculated for the benthic invertebrate community at 5 locations within the lower reach of the Grand River in 2002 and 2003. HBI_{10max} is calculated by capping individual species counts at 10. Error bars represent the standard deviation. **ns** = not sampled

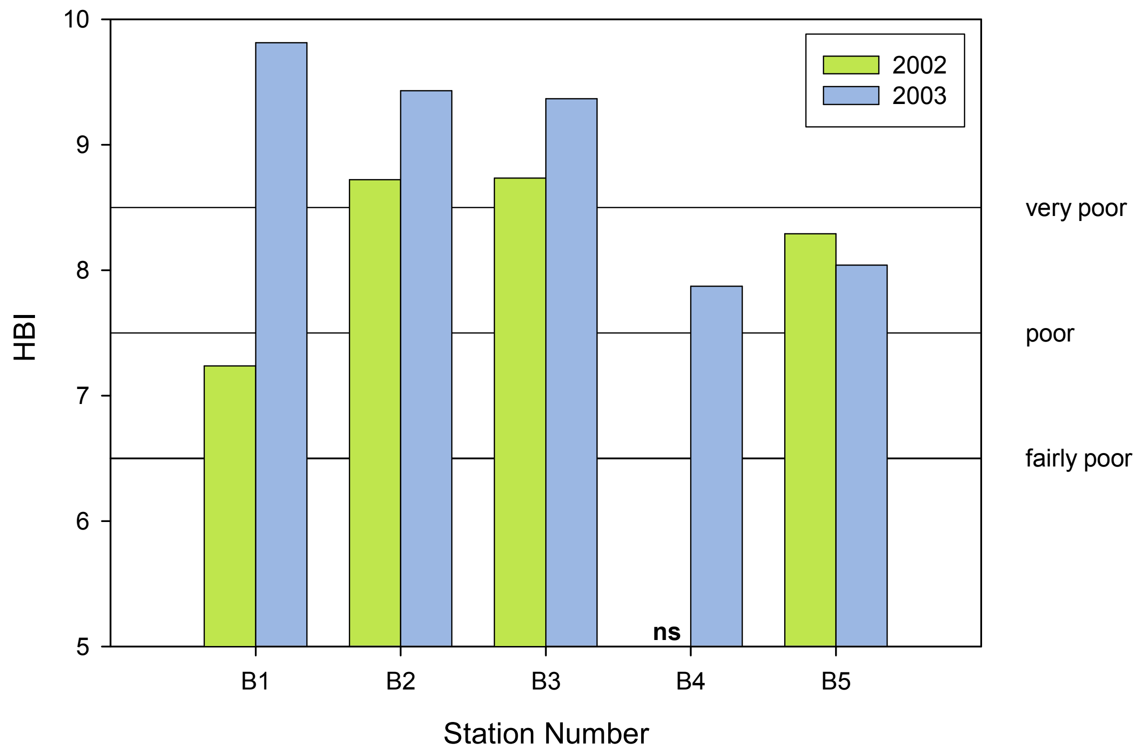

Figure 3.9. Hilsenhoff Biotic Index values calculated from benthic invertebrate counts (4 replicate samples pooled) at each of 5 locations within the lower reach of the Grand River in 2002 and 2003. **ns** = not sampled

3.7 Tables

Table 3.1. Benthic invertebrate species observed at 5 locations within the lower reach of the Grand River, 2002 and 2003. "X" indicates presence in at least one of 4 replicate samples taken in each year.

GROUP	FAMILY / TAXON	Genus species		Station B1 Port Maitland 2002	Station B1 Port Maitland 2003	Station B2 Betamik Harbour 2002	Station B2 Betamik Harbour 2003	Station B3 Dunnville Above Dam 2002	Station B3 Dunnville Above Dam 2003	Station B4 Midway (Dunn/Cayuga) 2003	Station B5 Cayuga 2002	Station B5 Cayuga 2003	Feeding Habit [1]	Hilsenhoff Tolerance Values [2]
HIRUDINEA	Glossiphoniidae	*Helobdella stagnalis*										X	prd	8
OLIGOCHAETA	Lumbricidae	*Sparganophilus sp*								X			c-g	5
		Lumbricidae incomplete						X			X		c-g	5
	Tubificidae *e	*Immatures with hair chaetae*			X	X	X	X	X	X			c-g	10
		Immatures without hair chaetae		X	X	X	X	X	X	X	X	X	c-g	10
		Branchiura sowerbyi		X	X	X	X	X	X	X	X	X	c-g	6
		Limnodrilus cervix			X	X		X	X		X		c-g	10
		Limnodrilus hoffmeisteri	*e	X	X				X		X		c-g	10
ACARI	Krendowskiidae	*nr Geayia sp*									X		prd	6
	Limnesiidae	*Limnesia sp*		X	X						X		prd	6
	Unionicolidae	*Unionicola sp*						X					prd	6
COLEOPTERA	Elmidae	*Dubiraphia sp larvae*						X	X			X	c-g	6
		Stenelmis sp larval casts only										X	scr	5
DIPTERA	Ceratopogonidae	*Ceratopogonidae type III*		X	X	X	X	X	X	X	X	X	prd	6
	Chironomidae													
	Chironominae	*Chironomus sp*	*e		X	X	X	X	X	X	X	X	c-g	10
		Cladopelma sp						X					c-g	9
		Cryptochironomus sp	*e	X	X	X	X	X		X	X	X	prd	8
		Dicrotendipes sp	*e								X		c-g	8
		Glyptotendipes sp gp "A"		X									shr	10
		Microchironomus sp		X	X	X		X		X			c-g	8
		Tribelos sp										X	c-g	7
		Parachironomus sp		X									prd	10
		Polypedilum sg Tripodura sp		X		X					X		shr	6
		Cladotanytarsus sp		X	X	X							c-f	5
	Orthocladiinae	*Orthocladius sp*		X							X		c-g	6
	Tanypodinae	*Ablabesmyia annulatum gp*	*e		X		X			X	X		prd	8
		Coelotanypus sp				X		X			X		prd	4
		Clinotanypus sp			X		X		X	X		X	prd	8
		Procladius sp	*e	X	X	X	X	X		X	X		prd	9
		Tanypus "concavus"						X			X		prd	10
		Tanypus neopunctipennis	*e					X					prd	10
EPHEMEROPTERA	Caenidae	*Caenis sp*		X									c-g	6
	Ephemeridae	*Hexagenia sp juv*				X				X		X	c-g	6
HEMIPTERA	Corixidae	*Palmacorixa nana*						X			X		prd	5
NEMATODA		Unidentified nematode		X	X	X								5
MEGALOPTERA	Sialidae	*Sialis sp*								X		X	prd	4
GASTROPODA	Viviparidae	*Campeloma decisum*										X	scr	6
BIVALVIA	Sphaeriidae	*Musculium sp*								X			c-f	6
		Pisidium sp			X					X		X	c-f	6
TURBELLARIA	Plagiostomidae	*Hydrolimax sp*			X								c-g	4
		Species counts [3]		14	15	12	8	15	7	14	17	13		

taxa found only in 2002
taxa found only in 2003
taxa common to both years

*e eutrophic indicator species

[1] Feeding Habit Codes (from Mandaville 2002): c-f: collector-filterer, c-g: collector-gatherer, prd: predator, scr: scraper, shr: shredder

[2] Hillsenhoff Tolerance values from Mandaville (2002)

[3] Species Counts: unknown tubificids (both with and without chaeata) are counted as one species where no other tubificids are present

Table 3.2. List of empty mollusc shells observed during benthic invertebrate sampling at 5 locations in the lower reach of the Grand River, 2002 and 2003. P= present; na = not available; missing dataset.

2002			Station B1				Station B2				Station B3				Station B4			Station B5		
GROUP	**FAMILY**	**TAXON**	R1	R2	R3	R4	R1	R2	R3	R4	R1	R2	R3	R4	R1	R2	R3	R1	R2	R3
GASTROPODA	Hydrobiidae	*Amnicola sp*				P		P		P										
		Birgella sp								P										
	Lymnaeidae	*Fossaria sp*							P											
		Pseudosuccinea sp						P		P										
	Physidae	*Physella sp*								P										
	Planorbidae	*Gyraulus sp*				P		P		P										
		Helisoma sp				P		P												
		Planorbella sp				P				P		na				na			na	
	Pleuroceridae	*Elimia = Goniobasis sp*	P			P														
		Pleurocera sp	P			P	P	P		P	P									
	Valvatidae	*Valvata sp*			P	P		P	P	P										
	Viviparidae	*Campeloma sp*				P	P	P	P											
BIVALVIA	Sphaeriidae	*Musculium sp*								P										
		Pisidium sp	P		P		P													
		Sphaerium sp				P														
		Unique species count per replicate	3	0	2	9	3	7	3	9	1									
		Unique species count per station	10				13				1									

2003			Station B1				Station B2				Station B3				Station B4			Station B5			
GROUP	**FAMILY**	**TAXON**	R1	R2	R3	R4	R1	R2	R3	R4	R1	R2	R3	R4	R1	R2	R3	R1	R2	R3	R4
GASTROPODA	Ancylidae	*Ferrissia sp*																			
	Bithyniidae	*Bithynia sp*		P	P					P						P					
	Hydrobiidae	*Amnicola sp*						P		P											
		Birgella = Somatogyrus																			
			P	P	P	P	P	P	P	P	P			P	P	P	P				P
	Lymnaeidae	*Fossaria sp*																	P	P	P
		Pseudosuccinea sp																			
		Stagnicola sp		P		P	P		P	P						P	P		P		P
				P	P		P														
	Physidae	*Physella sp*		P																	
	Planorbidae	*Gyraulus sp*	P	P	P		P	P	P	P						P			P		P
		Helisoma sp																			
		Planorbella sp	P	P	P	P		P	P	P	P			P		P				P	
		Planorbula sp	P							P									P		
		Promenetus sp		P															P		
				P	P											P	P				
	Pleuroceridae	*Elimia = Goniobasis sp*		P	P			P		P											
		Pleurocera sp																			
									P							P		P	P		P
	Valvatidae	*Valvata sp*	P			P	P	P	P		P		P	P		P	P	P	P	P	P
	Viviparidae	*Campeloma sp*	P	P	P	P	P	P	P					P		P	P		P	P	P
BIVALVIA	Dreisseniidae	*Dreissenia sp*							P										P		
	Sphaeriidae	*Musculium sp*	P	P	P	P															
		Pisidium sp																			
		Sphaerium sp					P											P			
			P	P	P	P	P	P	P	P	P			P		P	P		P		
	Unionidae	Shell pieces					P	P	P							P			P	P	P
							P				P								P		
		Unique species count per replicate	8	13	10	7	10	9	10	9	5	0	1	5	1	11	6	3	12	5	8
		Unique species count per station	15				17				6				11			15			

4.0 Fish Community

4.1 Introduction

The Grand River Fisheries Management Plan (OMNR and GRCA, 1998) recognises 80 fish species confirmed to occur within the Grand River watershed. The lower reach of the Grand River can potentially support a subset of these 80. Due to a relative lack of cold, groundwater input, summer temperatures determine that the populations in this stretch can generally be described as warm-water communities. Migratory cool and coldwater species can also make seasonal use of this area.

Diversity and structure within these warm-water communities can be influenced by habitat diversity. While the river generally meanders across a low gradient in this part of the watershed, diversity of habitat can be provided by other factors: flow rates, substrate types, vertical structure, submerged macrophyte density and range of depths. Types of fish found in any particular section can also be further constrained by access or seasonality, particularly for those species which migrate for spawning purposes or move relative to forage availability. Intuitively there is the potential for considerable species diversity in the lower section of a watershed, based on the River Continuum Concept (RCC; Vannote et. al. 1980, Minshall et. al. 1985) and on the proximity to fish communities which utilize the closely linked Lake Erie nearshore.

This section describes the results of a fish sampling program initiated in 1999 in order to characterize the fish community in different sections of the lower river reach. Initially focussed on the waters below Dunnville dam, it was expanded to include sites upstream to Caledonia with limited exploratory fishing between Caledonia and Brantford.

As with other trophic levels, the diversity of the fish population can give an indication of relative habitat health; whether influenced by water quality or habitat diversity. Further, structural and functional characteristics of particular taxa or trophic guilds can be used to index the community relative to expectations derived from a healthy or minimally disturbed system.

The index of biotic integrity (IBI) strategy, proposed by Karr (1981) has been adopted by a variety of researchers and resource managers to not only characterize habitat quality but to monitor change, especially as it relates to rehabilitation efforts (Schleiger 2000, Yoder and Kulik 2003, Minns et al. 1994, Leonard and Orth, 1986). While acknowledging the limitations to this method, particularly as a stand alone tool, it is used here to compliment habitat quality sampling at other trophic levels and to help round out the discussion on habitat quality. As Karr and Chu (1999) point out, from their position at the top of the aquatic food web (relative to plankton and invertebrates) fish can provide an integrative view of the watershed environment.

4.2 Methods

Standardized boat electrofishing, supplemented by backpack electrofishing and limited seine fishing, took place in the lower reach of the Grand River between 1999 and 2005.
Figure 4.1 shows the location of samples sites. Sampling occurred between late May and mid-November. All sites were not sampled in all years. Boat electroshocking involved fishing along transects which ran parallel to the shoreline in water depths between 0.5 and 2.5 m. Fishing time

was targeted at 1000 electro-seconds which roughly translated to 1-km of shoreline. When catch rates were high, fishing was occasionally terminated early in order to avoid overwhelming live-well holding tanks. All catch results were standardized by number of seconds in which current was in the water and reported as #/sec. Electrofish controls were adjusted in order to maintain power output of approximately 3000 watts (e.g. 10 amperes and 300 volts).
While some daytime boat electrofishing took place for comparative catch purposes, all data reported here was collected at night when catch rates and diversity of catch was highest.

A Smith-Root, SR-20 electrofish boat with dual anodes was used for fishing in waters deeper than 0.5m (most areas from Cayuga downstream). A 2-person wooden dory equipped with a Smith-Root electroshocker and single anode was used in areas where the larger boat could not access (e.g. the reach of river between Caledonia and Cayuga where deeper pool areas were interspersed with shallow riffle areas). Both electrofish configurations used the boat hull as a cathode (a large metal plate in the case of the wooden dory). Some back water areas below Dunnville were fished with seines and backpack shocker.

All catches were held in an aerated, flow through holding tank prior to processing. Fish were identified, measured for total- and fork- (where applicable) length and returned to the water. A maximum of 20 of any individual species were measured after which a tally of remaining fish was taken. Fish were returned to the general area of capture. Voucher specimens of species of questionable identity were sacrificed and held on ice for lab identification. If identification was not resolved samples were transported to the Royal Ontario Museum for species identification by Erling Holm, curator of fishes[4].

Data from all years and all fishing methods were used to create a complete species list for the waters downstream of Brantford (primarily below Caledonia). Similarly, a presence/absence species list was created for individual sections of this reach of the river. The river sections were defined based on the location of barriers or boundaries between river-proper and potential impoundment area as follows:

Section 1. Port Maitland to Dunnville – directly connected to Lake Erie
Section 2. Dunnville to Cayuga – indirectly connected to Lake Erie by a fishway at occurring within the impoundment created by the Dunnville dam.
Section 3. Cayuga to Caledonia – upstream of the Dunnville dam impoundment and potentially less of a depositional zone; more exposed rock and riffle areas. Upstream limit for most migratory Lake Erie fish.

In order to use the fish community as an index of habitat quality, a specific subset of the data from 2003 and 2004, was created. These catch events were chosen because they represent within-year periods when information from the largest number of stations, across the broadest geographical scale and within the smallest range of dates (late July to early September) and water temperatures (21-25^{o}C), was available. More stations were chosen in section 3 in order to standardize for length of river sampled (approx 7 km) and total effort (approximately 3000 electroseconds / year).

To describe fish species diversity, a Shannon Weiner diversity index (see Section 3.2; methods) was applied to the 2003 and 2004 data.

[4] All field staff were trained by Erling Holm, at ROM. A variety of fish from this sampling have been archived at the ROM.

An IBI was used to describe habitat quality. A properly designed IBI would ideally be comprised of region-specific metrics, ranges of values, and a scoring scheme that could account for the full range of potential habitat quality, from pristine to heavily impacted, in a localized area or watershed. Karr and Chu (1999) caution that creation of a broad scale, generalized IBI may not be sensitive to change or variation in localized areas. In the absence of detailed historical Grand River data or data from non-impacted but comparable southern Ontario watersheds, a previously developed IBI was chosen. While a large number of IBIs have been proposed for different Great Lakes areas (e.g. Minns et. al, 1994) a methodology based on Karr (1991) and modified by the Ohio-EPA (Thoma, 1999) based on expectations for the shoreline and drowned river mouth tributaries of Lake Erie was deemed appropriate for the lower Grand River. Metric definitions are provided in Appendix D-1. The DELT metric (externally observable deformities, eroded fins, lesions and tumours) was not used due to inconsistent field notation; IBI scoring was adjusted accordingly. Discussion of species relative to tolerances and trophic guilds will use designations presented by Barbour et al. (1999).

4.3 Results

Overall, 59 species of fish (including one hybrid) were observed in the lower reach of the Grand River between 1999 and 2005. The highest richness (30) occurred in the section of river between Cayuga and Caledonia (Table 4.1). Many of the most abundant species from the 2003 and 2004 subsample were similarly the most abundant in the overall 6 year survey suggesting that conclusions drawn from the diversity and IBI indexes can be appropriately generalized. In select cases (e.g. goldfish and brown bullheads in river section-1) species abundant in the overall survey were not similarly abundant in the 2003-04 selection.

Species only found in section-1 include: alewife, rainbow smelt, yellow bullhead, tadpole madtom, white bass, yellow perch, and carp **x** goldfish–hybrids.
Species only found in section-3 include: black- and river- redhorse, longnose dace, creek chub, stonecat, eastern sand darter, rainbow darter, least darter and blackside darter.
No species were exclusive to the middle section of river.

Shannon-Weiner diversity indices, calculated by pooling results for the standardized subset of catch events (summer 2003 and 2004), showed an increase in section diversity in an upstream direction; from 0.9 to 2.0 to 2.4 (Figure 4.2). Recognizing that the large abundance of gizzard shad might be skewing the index, especially in section 1, the indexes were recalculated after excluding this species. This made little difference (not shown; 1.1, 2.4, 2.5). The predominance of a few species in each section is evident in comparisons of H' to H'_{max} (Figure 4.2). The most evenly distributed abundance (H' = 70% of H'_{max}) occurred in section 3.

A similar pattern of increasing value, moving from downstream section to upstream section was noted when IBIs were calculated for the subset data (Figure 4.3). River sections 1 (IBI=22) and 2 (IBI=30) were categorized as having "poor" integrity, while section 3 (IBI=38) was categorized as having "fair" integrity.

Examination of individual IBI metrics suggests that some were more sensitive than others and that some did not seem to reflect the community known to exist from the longer time series data. All sections scored high for the *# native species* metric indicating that a desirable number of native species still exist within the lower river reach though some may exist in low abundance. The number of native species within sections 1-3 was 20, 24, and 28; respectively. Conversely, the *% non-indigenous* metric (which accounts for relative abundance) ranked the section-1 low

(80%) and section-3 high (30%) with section-2 intermediate (5%). This was primarily driven by the large numbers of gizzard shad in the lower sections. While carp abundance was similar throughout, goldfish and white perch were only observed in section-1.

Counts of 2, 4 and 6 *cyprinid species* in sections 1, 2 and 3 respectively established an increasing upstream score for this metric. The *# benthic species* metric was noticeably larger (6) in section-3 relative to the other two sections (1). Relative to the range of values observed in other Lake Erie lower tributaries, *% top carnivore* values in sections 1-3 (6, 9 and 7% ; respectively) resulted in poor scores for this metric. Similar to benthic species, the # of *intolerant species* was high in section-3 (8), but low in the other two sections (1). Scores for the omnivorous individuals metric also increased in an upstream manner due to decreasing proportions of the non-selective feeders (78, 30, 12%). Conversely, the *% tolerant* metric scored well for all sections. The *% phytophillic* metric scored very low throughout (0.3 to 3%); the section with the highest percent of phytophyllic individuals was section 2, perhaps reflective of the presence of macrophytes in backwater wetland areas hydrologically linked to the dam reservoir. *Relative numbers* of fish – decreased in an upstream manner. This could be related to the degree of direct lake connection.

4.4 Discussion

A diverse group of fish utilize the lower reach of the Grand River. During sampling in this section of river between 1999 and 2005, 59 species were observed. Some seemed ubiquitous (e.g. *Dorosoma cepedi*anum; gizzard shad) while others were more cryptic (e.g. *Ammocrypta pellucida;* eastern sand darter). Historically present lake sturgeon and muskellunge were absent and yellow perch were very rare despite being abundant in the eastern basin of Lake Erie winter[5].

Diversity, as quantified with the Shannon-Weiner diversity index, increased as one moved upstream due to both increasing species richness and more equitable representation by each member. Relative numbers in the lower two sections of river were dominated by gizzard shad, an omnivorous detritivore, alluding to a predominant food type in this section of river. The degree to which the hyper-eutrophic nutrient conditions have shifted the composition of the planktonic community (from perhaps diatoms to green algae), thus excluding more selective planktivores, is not known. Insectivorous fish, by contrast were more rare (see benthic invertebrates; section 3.0).

In a general way, this increasing diversity mirrors the increasing habitat diversity which occurs as one moves from the course sediment-deprived main channel and wetlands below Dunnville to the sediment heavy reservoir and backwater wetlands above Dunnville (with occasional large woody debris and backwater macrophytes), to the river upstream of Cayuga where deep areas are interspersed with shallow riffles, and mud deposition zones are interspersed with areas of exposed bedrock and occasionally cobble and gravel. The availability of rough, hard, gravel, cobble areas above Cayuga as well as increased subwatershed input, helps to explain why most darter species appear to be restricted to this area.

Some lake species that were likely encountered further upstream historically (e.g. yellow perch) were confined to the waters downstream of Dunnville. This may be partially attributable to limited upstream access through the Dunnville fishway and partly to increasing distance from the dense macrophytes habitat available in the lake proper. The low proportion of phytophyllic species is attributable to the paucity of submerged macrophytes in much of the lower river reach.

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[5] A few yellow perch were observed during this study in section-1, below the Dunville Dam. They are more common during winter as evidenced by an ice fishery that occurs when conditions warrant. This is coincident with increased water clarity (lower suspended solids) during the winter.

As the *top carnivore-* and *phytophillic-* IBI metric lists share a number of species (gar, bowfin, northern pike, largemouth bass, and yellow perch), the low proportion of carnivores, relative to other L. Erie lower tributaries might also be due to the minimal macrophytes cover available; particularly for lurk-and-wait predators. Lack of submerged macrophytes is probably also linked to the absence of muskellunge, historically present in the lower river (OMNR and GRCA, 1998). Regardless of the historic distribution of top predators in the lower river ecosystem, the bulk of this role appears to currently be assumed by walleye. Less reliant on macrophytes cover, adapted to low light conditions (imposed by high suspended solid loads) and able to utilize the abundant gizzard shad as a food source, they are the most abundant top predator. During summer months, the relative abundance of this species decreases as one moves progressively upstream. This is likely attributable to difficulty in by-passing the dam at Dunnville (MacDougall et. al, 2007) together with the need to make forays to the lake during periods of high temperature and/or low oxygen (see *Reductions in available habitat*; Section 5.0). Dissolved oxygen is likely a dominant driver of the species assemblage, particularly in the river downstream of Cayuga. Either directly by excluding low-O2 intolerant species or indirectly by (together with TSS in the depositional zones) reducing the diversity of the benthic food supply.

Species intolerant of adverse habitat conditions (primarily related to low oxygen, suspended sediments, and low food diversity) were almost exclusively confined to the section of river upstream of Cayuga. The one intolerant species observed throughout all sections (*Hiodon tergisus*; mooneye) are known to make regular migratory runs through the fishway (GRCA and OMNR data; not shown) and so may be have been transient when encountered in the lower river sections[6]. While carp and goldfish were observed in all sections, hybrids of the two were only observed below Dunnville; in some years they were relatively abundant. While not specifically a Lake Erie-IBI metric, Karr specifically notes the presence of hybrids as being indicative of poor habitat integrity (Karr and Chu, 1999). Hybrids often result from the overlapping spawning requirements of two closely related species in uniform, low diversity habitats.

Although some cold-water species migrate through this section of river on their way to the colder, groundwater-fed, middle reaches, resident or localized warm-water species, which appear to thrive in the lower reach, are a function of the quality of their environment. Habitat quality issues identified in previous and subsequent sections through individual measures (high nutrients, considerable planktonic algal biomass, eutrophic conditions, suspended solids, low oxygen) are reflected in the fish community and potentially integrated via the derived IBI scores. It is unclear, however, if this modified IBI, developed in tributaries and the nearshore along the US coast of Lake Erie, is sufficient to detect subtle change in habitat quality. In order to be able to use this tool to measure change resulting from habitat rehabilitation efforts, it will be necessary to the refine the metrics and accurately describe undisturbed potential habitat within the Grand River in order to accurately score measured values.

These index tools are often referred to as rapid assessment tools. It is important spend considerable time making sure that the index sufficiently describes the attributes of the fish community and thus indexes the habitat health accurately. Both Karr and Chu (1999) and Yoder and Kulik (2003) point out that development and calibration necessarily must take place over multiple years of methods testing, data collection, index development and index testing. While a carefully developed IBI will provide a vital tool in monitoring change, particularly as it relates to rehabilitation initiatives, it should not be used exclusive of other analysis. Paller et al. (2000)

[6] Anecdotal evidence from the angling community suggests that mooneye are more common in section -3 (between Cayuga and Caledonia), in riffle pool habitat. As insectivores, this would make sense given the paucity of insects in the benthic community in more downstream areas.

suggest that, while IBIs are useful for indicating progress toward an undisturbed state during the early stages of recovery, non-parametric ordination methods will provide the most sensitive measures of progress.

4.5 References

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4.6 Figures

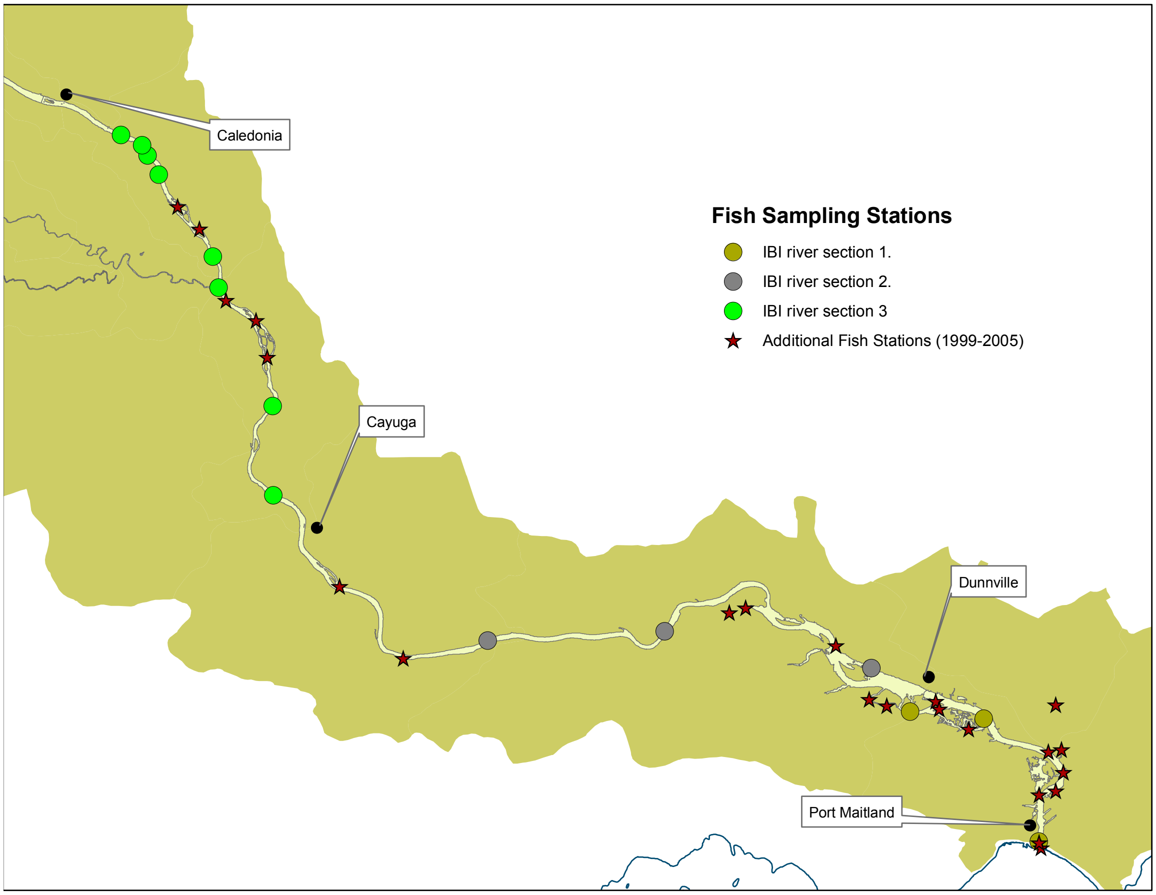

Figure 4.1. Location fish community sampling conducted in the lower reach of the Grand River, 1999-2005. Stations where data was utilized for IBI and diversity indices, in three sections of the river, are indicated. Fishing was primarily night-time boat electrofishing supplemented with backpack electrofishing and seining.

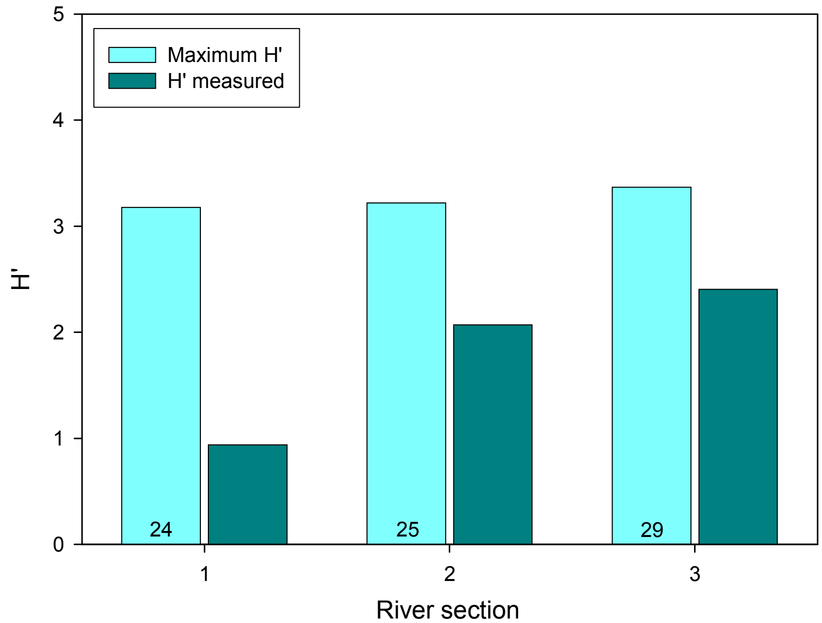

Figure 4.2. Shannon Weiner diversity index (H') determined for the fish community in three sections (1. Port Maitland to Dunnville, 2. Dunnville to Cayuga, 3. Cayuga to Caledonia) of the lower Grand River reach, 2003 and 2004. Maximum H'= the largest diversity possible, given an equal contribution from all species present. The number of species present in each section is shown on each H'_{max} bar.

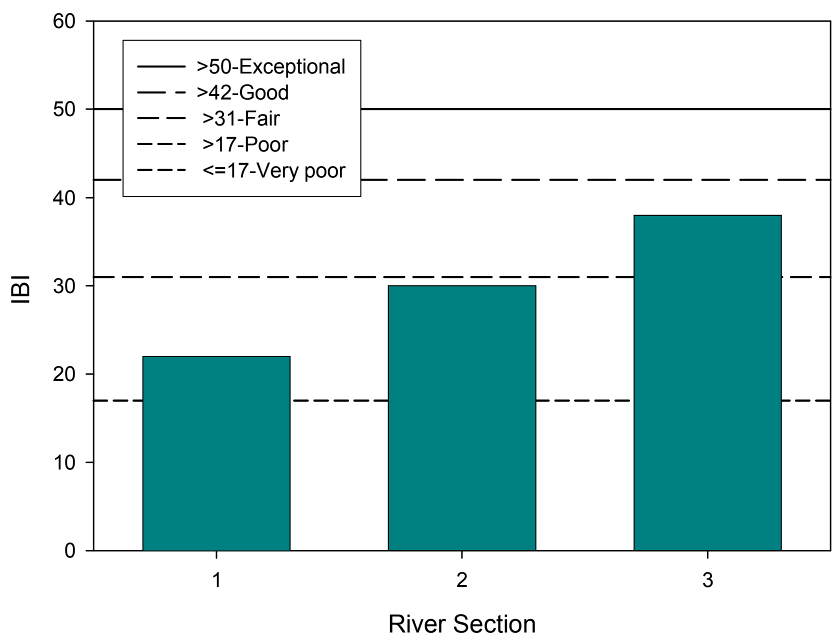

Figure 4.3. Index of biotic integrity (IBI) scores generated for three sections of the lower reach of the Grand River (1. Port Maitland to Dunnville, 2. Dunnville to Cayuga, 3. Cayuga to Caledonia) from fish community data collected in 2003 and 2004. IBI methodology is modified from Thoma (1999)

4.7 Tables

Table 4.1. Fish species observed in the Grand River below Brantford from surveys conducted between 1999 and 2005. Relative abundance (standardized for fishing effort) for three sections of river (1. Port Maitland to Dunnville, 2. Dunnville to Cayuga, 3. Cayuga to Caledonia) from summer 2003 and 2004 are included.

MNR species code	*Genus species*	Common name	Section 1		Section 2		Section 3	
			2003 & 2004	99-05 pres/abs	2003 & 2004	99-05 pres/abs	2003 & 2004	99-05 pres/abs
41	*Lepisosteus osseus*	longnose gar	1	*	1	*	2	*
51	*Amia calva*	bowfin		*	1	*		
61	*Alosa pseudoharengus*	alewife		*				
63	*Dorosoma cepedianum*	gizzard shad	737	*	130	*	30	*
75	*Oncorhynchus tshawytscha*	chinook salmon		*				
76	*Oncorhynchus mykiss*	rainbow trout	1	*				
121	*Osmerus mordax*	rainbow smelt		*				
131	*Esox lucius*	northern pike	1	*	1	*	2	*
141	*Umbra limi*	central mudminnow		*				*
152	*Hiodon tergisus*	mooneye	7	*	9	*	3	*
161	*Carpiodes cyprinus*	quillback	4	*	1	*		
163	*Catostomus commersoni*	white sucker	1	*		*	1	*
165	*Hypentelium nigricans*	northern hogsucker		*			9	*
168	*Moxostoma anisurum*	silver redhorse	3	*	58	*	16	*
169	*Moxostoma duquesnei*	black redhorse					1	*
170	*Moxostoma erythrurum*	golden redhorse	8	*	34	*	99	*
171	*Moxostoma macrolepidotum*	shorthead redhorse	37	*	10	*	60	*
172	*Moxostoma valenciennesi*	greater redhorse		*			3	*
173	*Moxostoma carinatum*	river redhorse					2	*
181	*Carassius auratus*	goldfish	6	*		*		*
186	*Cyprinus carpio*	common carp	5	*	8	*	9	
192	*Nocomis biguttatus*	hornyhead chub		*			2	*
194	*Notemigonus crysoleucas*	golden shiner		*		*		
196	*Notropis atherinoides*	emerald shiner	11	*	2	*	13	*
198	*Luxilus cornutus*	common shiner	9	*	86	*	107	*
201	*Notropis hudsonius*	spottail shiner		*				
203	*Cyprinella spiloptera*	spotfin shiner		*	13	*	29	*
206	*Notropis volucellus*	mimic shiner		*			1	*
208	*Pimephales notatus*	bluntnose minnow		*	6	*	49	*
211	*Rhinichthys cataractae*	longnose dace						*
212	*Semotilus atromaculatus*	creek chub						*
231	*Ameiurus melas*	black bullhead		*				
232	*Ameiurus natalis*	yellow bullhead		*				
233	*Ameiurus nebulosus*	brown bullhead	5	*		*		*
234	*Ictalurus punctatus*	channel catfish	1	*	9	*	5	*
235	*Noturus flavus*	stonecat					1	*
236	*Noturus gyrinus*	tadpole madtom		*				
291	*Percopsis omiscomaycus*	trout-perch	20	*	8	*		
301	*Morone americana*	white perch	16	*		*		
302	*Morone chrysops*	white bass	12	*				
311	*Ambloplites rupestris*	rock bass		*	6	*	20	*
312	*Lepomis cyanellus*	green sunfish		*				*
313	*Lepomis gibbosus*	pumpkinseed		*		*		*
314	*Lepomis macrochirus*	bluegill		*	14	*		
316	*Micropterus dolomieu*	smallmouth bass	1	*	5	*	32	*
317	*Micropterus salmoides*	largemouth bass	1	*	8	*		*
318	*Pomoxis annularis*	white crappie		*	1	*		
319	*Pomoxis nigromaculatus*	black crappie		*	4	*		*
331	*Perca flavescens*	yellow perch		*				
334	*Stizostedion vitreum*	walleye	50	*	27	*	15	*
335	*Ammocrypta pellucida*	eastern sand darter					1	*
337	*Etheostoma caeruleum*	rainbow darter		*			5	*
340	*Etheostoma microperca*	least darter						*
341	*Etheostoma nigrum*	johnny darter		*			7	*
342	*Percina caprodes*	log perch	1	*	2	*	175	*
344	*Percina maculata*	blackside darter					11	*
361	*Labidesthes sicculus*	brook silverside	5	*	4	*		
371	*Aplodinotus grunniens*	freshwater drum	18	*	26	*	13	*
601	*Carassius auratus x Cyprinus carpio*	goldfish x carp hybrid		*				
		TOTAL # FISH	961		474		723	
59	**(Total number of species observed overall)**	TOTAL # SPECIES	25	50	26	32	30	39

[blue shading] Most abundant species overall; making up >60% of total catch
[grey shading] Most abundant species (2003/2004); making up >60% of total catch
[double-line box] Only found in section 1
[thick box] Only found in section 3

5.0 Temperature and Dissolved Oxygen

5.1 Introduction

The Southern Grand River is typically classified as a warmwater system based primarily on the fish community found therein (Wright and Imhof 2001, OMNR and GRCA 1998). The low gradient (Figure A; page 3) of the river's channel, the nature of the surficial geology over which it flows (poorly infiltrated glaciolacustrine deposits of silts and clays) and it's shallow, broad cross-section (Gilbert et al. 2004) and uniform depths result in relatively slow flowing waters that are susceptible to influence from atmospheric temperatures and significant warming through solar input.

While the physical attributes suggest that this section of river historically supported warmwater fish, significant changes since European settlement have altered temperature regimes and thus, necessarily, the fish community. Deforestation and flow modification have resulted in a system that is warmer and "flashier" than in the past. Flow augmentation through reservoir release has compensated for loss of baseflow. Characterizing the current thermal regime is an important part of understanding the overall environment of the lower Grand River and the limitations imposed upon the biota.

Preliminary water temperature monitoring conducted in association with fisheries and habitat assessments in 2000-02 (OMNR 2006) revealed that summer surface water temperatures can exceed 29^{o}C and thus the upper thermal tolerances of a variety of warm- and cool-water fish species common to the system. This was particularly true for shallow, back-water areas (Appendix E-1; Dunnville Marsh temperatures, July and August, 2002). Questions were raised concerning the degree and extent to which the thermal habitat becomes intolerable (lethal) to aquatic species existing in the system. Of particular interest was the summer thermal suitability for walleye, a key top predator in the southern grand fish community whose thermal optima is 22.6^{o}C (Hokanson 1977) and which actively avoids environments warmer than 24^{o}C (Fitz and Holbrook 1978, Armour 1993). Since intolerably warm waters do occur, it would be important to identify cooler areas and attempt to characterize and quantify these potential thermal refuges.

Possible thermal refugia within the river might include tributaries to the main channel, where the tree canopy provides significant shading, or areas of groundwater input. One local tributary source of groundwater, recently identified by the Grand River Conservation Authority, is a section of Mill Creek, upstream of the Taquanyah Nature Centre. The monitoring of water temperatures by the Grand River Conservation Authority in association with the removal of a reservoir on the system provided a good reference point with which to compare water temperatures in the main channel. Groundwater sources on Mill Creek occur coincident with a regional area of exposed bedrock. There is the potential for groundwater contributions anywhere that the bedrock underlying the surface clay is exposed and cracked. In some areas of the lower river reach, the main channel is known to cut through to the bedrock, exposing the deeper deposits of silt/clay till with cobble and boulder (Wright and Imhof 2001).

Bathymetric sampling of the stretch of river from Cayuga downstream to Dunnville identified several areas where the mean depth of the river channel (2.2 m) is exceeded by several metres (max depth 7.2 m). An important factor identified in the 2000-2002 work was that complete mixing of the river water does not always occur; a differential can exist for both temperature and dissolved oxygen through the depth of the water column. In “deep-hole” areas, temperature differentials, between surface and depth, of up to 3^{o}C were observed. This suggested that during periods of high water temperature, under some conditions, thermal refuge for intolerant species may be available in the deeper sections of the river. Often, however, dissolved oxygen decreased with depth concurrent with temperature. Oxygen levels below 4mg/L (a lower behavioural threshold for many fish species) at depth were documented (Appendix E2).

Between 2003 and 2005, monitoring was planned that would compliment and expand upon the work conducted in 2000-2002. Its purpose was to describe the temperature and oxygen regime on a scale suitable for determining habitat volumes available to fish and benthos, temporally and spatially (along the length of the main channel as well as throughout the water column).

This monitoring would include the continuous logging of near-surface temperature at sites established downstream of Caledonia, as well as point-in-time water column profile measures of temperature and oxygen at “deep-hole” sections of the main channel at sites downstream of Cayuga. Continuous logging of temperature and oxygen at depth would provide a measure of parameter variation as well as the duration of any low oxygen events. Together with bathymetric profiling of the river between Cayuga and Dunnville, available habitat volumes could be estimated based on individual species requirements obtained from the literature.

5.2 Methods

Defining acceptable ranges

Dissolved oxygen

Concentrations of dissolved oxygen were compared with the range of values listed in the Canadian Water Quality Guidelines for the Protection of Aquatic Life (Canadian Council of Minsters of the Environment 2003), which are defined as being necessary for the protection of 100% of aquatic species 100% of the time

DO range = 5.5 to 9.5 mg/L

When referring specifically to the effects of low oxygen on the fish community, lower limits of 4 and 2 mg/L will be also be used to define levels intolerable to many and most expected fish species; respectively.

Temperature

Temperatures were compared with the optimal range requirements for the most prominent key predator fish species in the southern Grand River: walleye (*Sander vitreus*) as described by Hokanson (1977) and Houston (1982) as follows:

Adult walleye
-Temperature range (walleye thermal preferendum) = 19 to 23 ^{o}C
-Avoidance temperature > 24^{o}C
-Physiological optima = 22.6^{o}C
-Upper incipient lethal temperature = 31.6 ^{o}C

Young-of-year (YOY) and juvenile walleye
- Growth optimum for small (total length 6.5cm) = 25.2^{o}C
- Growth optimum for larger (total length 8.5cm) = 22.1^{o}C
- Upper incipient lethal temperature (juvenile walleye acclimated to 25.8^{o}C) = 31.6^{o}C

Temperature logging (near surface)
Temperature loggers (Optic StowAway Temp; Onset Computer Corp., MA) set to record ambient temperature on a 1 or 2 hour schedule, were deployed at 10 sites located downstream of Caledonia (Figure 5.1). Attempts were made to locate the loggers in depths of water between 1 and 1.5 metres although maximum depth in some areas necessitated some deployments as shallow as 0.25 metres (Table 5.1). All loggers were protected in an ABS-pipe housing designed to allow flow-through of water, secured to a cement block, and made fast to a pre-existing structure, or iron "t-bar" driven into the substrate. The deployment of ten loggers occurred over a staggered timeline and locations were added or discontinued throughout the length of the study. A table of sites, frequency of logging, and time periods covered is provided (Table 5.2). Included are loggers deployed as early as 2001 (two sites downstream of the Dunnville dam) and four sites within the side tributaries of Mill and Rogers Creeks which were monitored by the GRCA as part of a reservoir draw-down initiative.

Temperature and DO water column profiles
Ten profile sites (TO1-TO10) were chosen based on the locations of the deepest areas of the main channel, located after a preliminary survey of the river downstream of Cayuga using a depth sounder (Figure 5.2). Where possible, sites were located in association with stations where water was being concurrently collected for analysis of water chemistry (Section 1.0), chlorophyll-a (Section 2.0) and benthic invertebrates (Section 3.0).

During 2003-2005, on an approximate bi-weekly basis (Table 5.3) between June and October, the water column was profiled at 1 m intervals for temperature and dissolved oxygen. In 2003, only the seven stations above Dunnville dam (TO4-TO10) were sampled whereas all ten were regularly sampled in 2004-05.

Measurements were taken with a modified Datasonde-4a (Hydrolab: Campbell Scientific, AB, Canada) lowered from the side of a stationary (anchored) jon-boat. Information was manually captured with Surveyor-4a logger (Hydrolab) after allowing for sensors to adjust to subsequent depth conditions. During most sampling events the following additional parameters were also measured (pH, conductivity, and photosynthetically available radiation; PAR).

Graphs of temperature and oxygen profiles, collected in late summer 2002, are presented in Appendix E2 and are used for comparison and discussion.

Temperature and DO: continuous logging at depth
The locations of continuous logging stations (L1-L5) are shown in (Figure 5.2). Dates, depths, coordinates and durations of continuous logging at each station are presented in Table 5.4.

In 2004, logging of temperature and oxygen was directed at conditions relatively close to the surface (0.75 to 3.8m depth). A Datasonde-4a logger (Hydrolab: Campbell Scientific, AB, Canada) secured to pre-existing buoys at fixed depth was used to record temperature and oxygen on an hourly basis.

In 2005 logging of temperature and oxygen was directed at conditions close to the substrate at one of the deeper areas of the lower river; profile station (TO6). Data was logged using an YSI-logger which was protected in ABS-pipe, secured to a pyramidal iron holder (Appendix E3) and lowered to the substrate (0.5 m off of the bottom; approximately 5.5 m below the surface depending on flows/river levels). Data was collected at 1 hour intervals from June 28 to

September 21 (85 days). The apparatus was raised to the surface on 3 occasions to download data, assess bio-film accumulation on the probes, and clean if necessary. Out of water times were < 0.5 hours on each occasion.

Estimating temperature and oxygen constraints to habitat volume

On three dates in 2005, equations describing the relationship between both temperature and oxygen with depth were generated in order to estimate the depths above or below which acceptable values would be found. These dates were chosen because they occurred during the three longest durations of bottom anoxia and (perhaps because of this stability), the relationships could be confidently approximated with linear regressions ($r^2 > 0.70$). As volume estimates were only available for the stretch of river between Cayuga and Dunnville, only regressions from profile stations 5-9 were used for estimating volumes of acceptable temperature and oxygen. It was assumed that profiles taken during periods of relatively stable measures at depth, where all stations showed very similar, regular change with depth (similar slope), would be representative of the water column over the period of stability.

Additional data sources

Relevant hourly measures of air temperature, wind speed, and wind direction at a local Environment Canada weather station (VINELAND STATION RCS; Climate Identifier number-6139148; WMO Identifier 71171) were obtained from website: [http://www.climate.weatheroffice.ec.gc.ca].

Relevant stream temperature data from Mill Creek and Rogers Creek (Indiana road juncture) were provided by the Grand River Conservation Authority (GRCA); courtesy of W. Yerex)

Flow data from GRCA gauge station at York provided by GRCA; courtesy of Dwight Boyd.

Hours of sunrise/sunset obtained from website [http://aa.usno.navy.mil/cgi-bin/aa_rstablew.pl] using coordinates at Dunnville.

5.3 Results

Long Term Temperature Logging

Descriptive statistics for all 2001-2005 logging (minimums, means, maximums, and standard deviations), for each month at each station are provided in Appendix E4.

One typical station (Riverside TL2) over 5 years

Logger TL2, located at Riverside Marina, immediately downstream of the Dunnville dam, provided the longest time series and was used to examine seasonal change over a 5 year period (2001-2005). Graphical representation of daily mean temperature is presented in (Figure 5.3).

A general pattern was apparent in all years: Spring warming above winter lows beginning in late March, climbing through July, peaking in late July and beginning to decrease in mid-August. Lows, approaching zero can occur as early as the beginning of December.
Notable exceptions to the general trend include: i) a rapid spring warming peak in mid-March and mid-April in 2002, ii) rapid cooling periods in early April and early October 2003 and iii) a rapid warming peak in early June in 2005. The year 2001 was notable for its warm winter; not dropping below 5^{o}C until mid-December.

One typical station (Riverside TL2) summer means
Summer (June-August) temperatures were compared at the station with the longest available dataset (TL2) in order to address concerns surrounding maximum temperatures relative to species tolerances and optima (Figure 5.4A). The summer of 2005 was the warmest of the five years, both in terms of mean temperature (25.5 ^{o}C) and maximum measured value (29.7 ^{o}C). This was followed by the summer of 2002 (mean and max of 24.7 and 29.5 ^{o}C; respectively). The coolest summer based on these parameters occurred in 2004 (22.4 and 26.5 ^{o}C; respectively). The year to year pattern of summer air temperatures (Figure 5.4B), was similar to that of the river water at Dunnville. The thermal inertia of the water relative to air is reflected in the higher mean temperatures and narrower range of values of the river.

One typical station (Riverside TL2) summer monthly means
When individual months are examined (Figure 5.5), it is apparent that warm June and July temperatures were the main contributors to the higher overall summer means in 2005 noted above. The uniquely cooler August in 2004 was a large contributor to 2004 having the coolest overall summer mean.

Mean June temperatures (Figure 5.5A) were similar to the 5-yr mean (22.1 ^{o}C) in 2001 and 2002, approximately 1^{o}C below the 5-yr mean in 2003 and 2004 and 2.5 ^{o}C higher in 2005. Maximum June values approached 29^{o}C in 2005 in stark contrast to 2004 when the maximum June value was 24.3^{o}C.

Mean July temperatures (Figure 5.5B) in 2002 and 2005 were 2-2.5 ^{o}C higher than those in the other three years (23.5-24^{o}C). Maximum values in 2002 and 2005 approached 30^{o}C.

Mean August temperatures (Figure 5.5C) were similar, between 25 and 25.5 ^{o}C, in all years except the cooler 2004. The 5-yr August mean temperature is 24.8^{o}C.

Spatial differences- 9 months (winter, spring, summer) of values
The longest period of coincident measures from the largest number of stations (11, including the 6 tributary stations) occurred in the nine month period between November 26, 2004 and September 5, 2005. This was used to compare temperature characteristics at locations along the longitudinal gradient of the lower river reach. A summary is presented in Figure 5.6.

An immediate contrast is apparent between values from main-channel stations and those situated within tributary streams: Tributary temperatures are less broadly distributed, particularly those contained by the 25th and 75th percentiles. This buffering of temperature extremes is particularly evident for the Mill and Rogers Creek system; especially the headwaters of Mill Creek. A gradient of increasing mean values, decreasing median values and increasing range occurs as one progresses downstream to the main channel of the Grand. The thermal influence of Mill Creek on Rogers Creek is apparent when comparing values for Rogers Creek. from stations located above (Stn TQ4) and below (Stn TL7) its confluence with Mill Creek. Temperature characteristics at the Boston Creek station are more similar to those at main channel stations than those from the Mill/Rogers Creek. system.

Mean values were similar at all main channel stations. Differences occurred in the range of values observed; Station TL5 (immediately above Dunnville dam) experienced the broadest range and highest maximum value while the most upstream station experienced the shortest range of values. Frequency distributions of temperature measures are provided in Appendix E5.

Spatial differences- summer temperatures (June-Aug) 2005

Box plots of temperatures from summer 2005 are presented for the same 11 stations (Figure 5.7). The overall mean temperature in the main channel (all stations) between June 1 and August 31 was 25.4°C. The highest mean summer temperatures occurred at the lower three stations; T5, T2, T1 (26.1, 25.5, 25.6 °C; respectively); summer means at Caledonia and York (Stns. T10 and T8) were 0.5 - 1°C cooler (25.1 and 25.0°C; respectively). The surface water temperature differential between upstream and downstream stations may have actually been more pronounced as the downstream loggers were located approximately 0.5m deeper in the water column than those at Caledonia and York. The thermal influence of the Mill/Rogers Ck. system (noted above) was particularly evident in the summer. The spatial pattern of temperature plots from TQ3 to TQ4 suggests a source of cool water downstream of the Mill/Rogers Creek. confluence.

Temperature and DO: bi-weekly water column profiling

Profiling 2003
In 2003, the water column was profiled at six stations (TO4-TO9; only upstream of Dunnville) on seven dates between July 9, and October 21.

On all sampling dates, at all stations, both temperature and oxygen decreased with depth (Table 5.5**)** although on most occasions, these differentials were relatively small. On any particular date, similar patterns of decrease were noted across the survey area. Oxygen differentials (surface to depth), where they occurred, were more pronounced than co-incident temperature differentials.

The largest differences in temperature and oxygen occurred when surface temperatures were the warmest. On July 9th, surface temperatures approached 28°C while those at depth were, on average, 2.5°C cooler (Figure 5.8). Similarly, dissolved oxygen concentrations were supersaturated (144 - 236% saturation) at the surface but dropped to less than 60% saturation at depth. Oxygen concentrations at depth were between 0.5 and 5.1 at the four stations sampled on this date (Figure 5.8).

Relative to the "acceptable" values (outlined in *Methods*): July 9 was the only sampling date where minimum oxygen values below 5.5 mg/L were observed. Surface waters during July and August tended to be supersaturated and oxygen concentrations at shallow depths did not fall below 9.5 until September.

On both July 9, and August 13, the entire water column was warmer than the avoidance temperature for adult walleye but within the optimal range for small, YOY walleye. On August 25, all but the deepest sections of river were >24°C.

Profiling 2004
In 2004, the water column was profiled at nine stations (TO1-TO10; excluding TO4) on sixteen occasions between July 9, and October 21. Profile graphs for all dates are provided in Appendix E6

As in 2003, sampling on most dates in 2004 described a gradual differential (declining values) for both temperature and dissolved oxygen with depth (Table 5.6). For the most part, the slope of change was barely perceptible.

One exception to this occurred on July 13, where oxygen at most stations showed a sharp change from supersaturated conditions near the surface to concentrations < 6mg/L at depth. On two other occasions (July 6, August 9) large drops in DO from surface to bottom occurred. On both occasions, despite the drop, bottom DO was supersaturated, particularly at stations TO5-9.

Supersaturated DO throughout the water column was also noted on August 23 (without a decrease with depth).

Relative to the "acceptable" values (outlined in *Methods*): July 13 was the only sampling date where minimum oxygen values below 5.5 mg/L were observed, and then, only at three stations (TO1, TO5 and TO7). Temperatures were within a range acceptable to adult walleye, either throughout the water column or in deeper areas, for most of the sampling season. On only one occasion (August 3) were temperatures >24^{o}C throughout the water column.

Profiling 2005
In 2005, the water column was profiled at ten stations (TO1-TO10) on 11 occasions between June 15, and September 12. Profile graphs for all dates are provided in Appendix E7.

Similar to what was observed in 2003 and 2004, decreases in temperature and oxygen with depth occurred in 2005 (Table 5.7). In 2005, these differentials tended to be larger- similar to what was observed in the preliminary profiles from August and September in 2002 (Appendix E2). While the degree and pattern of the decrease tended to be similar at all stations on a particular day, there was considerable variation between sample days.

The following three patterns were observed:
i) The water column appears mixed; temperature and oxygen do not change with depth (July 18),
ii) The top of the water column appears mixed ; temperature and oxygen are similar from the surface to several meters depth and then drop to lower values close to the bottom (June 15, August 10 [stns 2, 3, 5],
iii) The water column is not well mixed; temperature and/or oxygen decrease regularly with depth, either gradually (July 20, July 26, August 10 [Stns TO-1, -6, -7, -8,], August 15, August 25, Sept 12 or rapidly (June 27, July 12, August 3 [more so for DO]).

The pattern on any given day was generally the same across all stations. In some instances, the slope of the profiles changed slightly as one moved downstream. However it is important to recognize that several hours often passed between the sampling of the most upstream and most downstream station and that surface conditions (to varying depths) can change relatively rapidly. Continuous sampling at fixed depths (below) was used to gain an understanding of how variable temperature and oxygen conditions were over time.

The most consistent, regular change with depth (for both temperature and oxygen) occurred during prolonged periods, identified during continuous logging at depth (below), of low flow and near anoxic bottom conditions.

<u>Temperature and DO: continuous logging at depth</u>

2004
During continuous logging at depth in 2004 (July 8 to September 10), dissolved oxygen values ranged between 3.32 and 12.44 mg/L and temperatures ranged between 18.58 ^{o}C and 27.12 ^{o}C (Figure 5.9).

For both parameters there was less variation and a narrower distribution of values at the deeper station (L3; 3.8m) when compared with the shallower stations (L1, L2, and L4; 0-2m) which are more readily susceptible to air temperature fluctuations, solar input, mixing and the influence of primary producers.

While acceptable DO concentrations (5 - 9.5 mg/L) constituted a large proportion of the measures taken at both shallow and deep stations (65% and 67%; respectively), considerably more high value, supersaturated events, were observed at the shallow stations (Figure 5.9). Values below 5mg/L only occurred at the shallow stations; the lowest concentration measured being 3.32 mg/L.

The deeper station more frequently (68% of measures) exhibited temperatures optimal for walleye when compared with the shallow stations (50% of measures). Additionally, L3 temperatures tended to occupy the upper half of the optimal range (21-23^{o}C), whereas those at the shallow stations spanned the optimal range (19-23^{o}C). Maximum temperatures measured were 25.5^{o}C and 27.1^{o}C at the deep and shallow stations; respectively.

A regular pattern of change (increases and decreases) in both parameters was apparent for at least a portion of the monitoring period at each station (Figures 5.10 to 5.13). At the shallowest stations (L1 and L4), this pattern corresponded with day and night cycles such that both values would increase from shortly after sunrise until nightfall when they would slowly decline until the following sunrise. This pattern was particularly defined for the entire period of monitoring in Sulphur Creek (L4; Figure 5.13). At the 2m depth station (L2), this pattern, especially for the oxygen parameter, was observed for some time periods but not others. When day/night cycles in oxygen were apparent at L2, they were concurrent with daytime warming and nigh-time cooling cycles (Figure 5.11D, sunrise to sunrise Sept 3-4 and Sept 6-7).

Monitoring at the deepest station (L3) revealed increases and decreases in both temperature and oxygen that occasionally corresponded with each other but quite often did not (Figure 5.12). The day/night patterns observed at the shallower stations were not apparent although there is some indication of the pattern toward the end of the monitoring period (Aug 11-12). Dissolved oxygen, which fluctuated between 6 and 7mg/L for the first week of the monitoring period, rose to >9 mg/L and began fluctuating more rapidly during the second week of monitoring. Surface measurements taken on two occasions (August 3rd, 9th) at nearby profiling station TO7 revealed little temperature variation between top and bottom (1 and 1.5^{o}C; respectively) but a more noticeable differential for oxygen (1.8 and 5.1 mg/L; respectively).

For the two measured parameters overall, temperature showed the least variability. Rapid fluctuations variability in oxygen occurred only occasionally and was particularly apparent in September at station L2. Super-saturated oxygen conditions (>100%) were not uncommon.

2005

In 2005, one station (L5) was monitored continually from July 27 to September 21 (85 days; Figure 5.14). Unlike what was observed in 2004, oxygen measurements below water quality objectives (<5.5 mg/L) were common. The duration of these poor oxygen episodes ranged from 17 days in the early part of the time series (including 11 near anoxic days; Figure 5.14C) to briefer periods in the latter part of the time series (Table 5.8).

Three periods of prolonged low oxygen stand out. These begin on June 26 (start of logging), July 10, and August 1. Water column profiles taken during these periods show strong, regular change from surface to bottom and it is assumed that these differentials existed, in some fashion, for the duration of the period. Surface measures describe supersaturated oxygen levels during these periods[7].

[7] It should be noted that reference to surface measures, which were obtained during water column profile sampling, only occurred during daylight hours (usually mid-day). Any night-time minima in surface waters

As observed in previous years, oxygen was variable, and changed more rapidly than temperature during continuous logging. The largest drops and lowest measures of oxygen occurred during low flow conditions (<25 m^3/s). Sudden increases in flow often resulted in the rapid mixing of the water column with resulting uniformity in both temperature and oxygen from surface to bottom. For periods of strong stratification with depth (July 14-17; Figure 5.14C), flow related water column mixing (July 17) resulted in the cooling of surface waters (32°C to 28°C), the warming of bottom waters (24.5°C to 28.5°C), a decrease in surface oxygen (19-6 mg/L), and an increase in bottom oxygen (anoxia to 6mg/L). Rapid mixing occasionally occurred during near-constant flows but coincident with sudden shifts in wind direction and speed (data not shown). The rapid return to low DO concentrations following some wind-driven mixing events suggests that a strong sediment oxygen demand often existed. Only rarely did regular fluctuations in oxygen at depth correspond with day/night cycles as was observed in shallower waters in 2004.

While surface waters were often above the walleye optima of 20-24°C in 2005, temperatures at depth, for the most part, favoured survival of adult walleye, only occasionally rising above the optima. The highest temperatures at this depth occurred in late July (10 days >25°C; max of 28.7°C) following the July 17, flow-related mixing event described above, when surface waters in excess of 30°C were mixed with bottom waters.

<u>Reductions in available habitat (volume) during temperature and oxygen extremes</u>

Taken together, the information from bi-weekly water column profiles, continuous monitoring at depth and bathymetric surveys was used to estimate the degree to which walleye would be excluded from the available space within the river channel. This analysis was preformed for the section of river between Cayuga and Dunnville (above the dam) where the bathymetry of the river channel was known. Three time periods, representing constant change of temperature and dissolved oxygen with depth, and near anoxic bottom conditions, were chosen as worst case scenarios.

Regressions describing the relationship between both temperature-depth and oxygen-depth, on the three dates of interest, are provided in Appendix E8. Depths below or above which acceptable temperature and oxygen; respectively, could be found were estimated for each water column profile and then averaged.

Both adult and young-of-year walleye were restricted to portions of the water column during the three periods of bottom anoxia. During these periods (total of 24 days) 90-98% of adult walleye habitat volume between Cayuga and Dunnville was lost. The higher thermal optima/tolerance of YOY walleye resulted in a greater availability of surface waters and thus a less restricted habitat volume (Table 5.9); For younger, smaller walleye between 25 and 50% of this section of river was unavailable over the 24 days.

5.4 Discussion

The results presented here thoroughly characterize the thermal and oxygen habitat of the southern Grand River, particularly during summer and early fall months. Long term temperature logging of near-surface waters has shown the range and variation within the system while profiles through the water column and ongoing conditions at depth have highlighted worst-case extremes and

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at station L5 were therefore not captured; a key uncertainty. Continuous logging in shallower waters (L1, L2, and L4) suggests that diurnal fluctuations, with pre-dawn minima, do occur in surface waters.

pointed to the inability of daytime surface measures to quantify the thermal and oxygen habitat volume.

Long term temperature patterns (logging)

Examination of seasonal variation in temperature means, maximums, and minimums, as well as rates of change (spring warming, fall cooling) over the five years of the study, begins to show the range of conditions possible within the lower Grand River. While the biota which utilize this environment are adapted to fluctuations within a range of annual or seasonal temperatures, extreme events, rates of warming/cooling, and the timing of change relative to photoperiod, may be useful in explaining annual recruitment, or relative overall abundance for individual fish species. For example, spring warming rates and summer temperature ranges are important determinants of hatch success, larval survival, first year growth (and related overwinter survival) and subsequent recruitment for most percids (Armour 1993, Fitz and Holbrook 1978). Similarly the timing and duration of fall cooling and winter minimum temperatures are important physiological triggers that influence oocyte growth and maturation in female walleye (Hokanson 1977). Spring warming can also influence successful reproduction relative to artificial bottlenecks. The ability of migrating walleye to surmount the barrier imposed by a dam at Dunnville, by using a fishway, is dependent upon a window of opportunity constrained by waters warm enough to allow for bust swimming (relative to river flows) yet cool enough not to physiologically induce spawning prior to further upstream movement.

While attempts have been made to correlate broad scale climactic patterns to walleye year class strength over large spatial scales (e.g. lower Great Lakes watersheds), localized differences in recruitment between regional stocks is not uncommon. An example of this is the disparity in 2004 between walleye fall recruitment indexes in the eastern end of Lake Erie relative to the west (NYSDEC 2005, Walleye Task Group 2006).

As temperature is linked to a variety of biotic endpoints (e.g. growth, behaviour, reproductive success) a consistent and standardized characterization of the thermal regime in the SGR would have a number of uses in explaining and predicting ecological function. From this point of view, the continuation of (the relatively inexpensive) logging of near surface temperatures in the lower reaches of the river is advisable. Examination of differences along the longitudinal gradient of the river suggests that this could be accomplished with fewer monitoring stations. However, while interpretation is confounded somewhat by uneven monitoring depths, the area from immediately above Dunnville to the mouth appeared different (warmer in summer) than more upstream stations; suggesting at least two logging stations be continued into the future.

Thermal refuges *within* the SGR are important because physical and behavioural barriers currently restrict a number of species from freely accessing the waters of Lake Erie during times of thermal stress. Due to physical and species specific behavioural barriers within the lower river reach, unrestricted access to the cooler deeper waters of Lake Erie is not always immediately available for all fish. Long term logging was helpful in identifying the thermally important tributary system of Mill Creek and Rogers Creek. The obvious groundwater input to this system provides thermal stability and therefore refuge to biota experiencing either summer (heat) or winter (cold) extremes. The extent to which this system influences waters of the main channel into which it flows is not known. However it provides evidence that groundwater input is not impossible within the Haldimand clay plain and therefore other inputs, such as groundwater from cracks in exposed bedrock, could exist elsewhere. Such inputs may explain cool temperatures at depth observed from profiling and would be important in providing refuge for biota.

Profiles (changes in temperature and oxygen with depth)

Profiling the temperature and oxygen conditions of the water column in 2003 to 2005 provided insight into surface- bottom differentials that can exist; thereby confirming concerns raised by high surface temperatures and low bottom oxygen concentrations measured during preliminary sampling in 2002.

A variety of water column conditions were observed, from well mixed to nearly stratified, for both temperature and oxygen. On occasion mixing from high flow conditions resulted in uniform measures from surface to bottom; other sources of mixing probably included agitation from boat traffic. Some correlations could be seen between mixing of bottom oxygen and the speed, direction and sustain of wind patterns (not investigated in depth here).

The large temperature differential established under some conditions (>9^{o}C from top to bottom), may have been driven by groundwater inputs at depth in addition to warming of surface waters.

Oxygen was the more variable parameter; likely because, in addition to input at the air/water interface and probable high sediment oxygen demand, diurnal cycles of consumption and production appear to be occurring in surface waters. As there are little to no submerged macrophytes in this section of river (Gilbert and Ryan, 2007) these cycles are probably attributable to respiration by the large biomass of planktonic algae, documented previously (Section 1.2). Therefore, in addition to surface water constraints imposed by high temperatures, daytime supersaturated oxygen conditions may further constrain habitat volume for some fish species. The settling and subsequent decomposition of large volumes of dead algae could create a large sediment oxygen demand and help to explain the rapid declines in oxygen that often follow oxygenation events.

The interplay of these two variables will determine the habitat volume available for individual species (all other habitat variables being equal). On at least three occasions in the summer of 2005, near-anoxic bottom conditions and high surface temperatures created an environment where habitat was severely constrained for adult walleye over significant time periods (12, 6.5 and 5.5 days). These events may not be uncommon in other years as indicated by the anoxia tolerant composition of the benthic invertebrate community (see Section 1.3). The frequency of these events will determine the relative value of refugia (whether upstream, tributary or lake waters) and the necessity of unimpeded access to them. The paradox that exists is that, as the substrate appears to serve as a source of both oxygen demand and cool temperature, conditions which induce mixing (high flow events, wind, boat activity) will favour suitable oxygen conditions but negate any thermal refuge during times of high surface water temperatures.

Differences in the severity and frequency of differentials between years appeared to be associated with the general warmth and "wetness" of summer and early fall in any given year. The year in which the most severe temperature and oxygen differentials were observed most frequently (2005), corresponded with the warmest summer as described by both air and water temperatures. The second warmest summer of the 5 years (2002) provided (perhaps fortuitously) evidence of steep differentials despite a brief (three days) sampling schedule. Periods of both sustained differential with depth, and rapid changes in degree of differential were observed in 2005.

The extent to which the temperature and oxygen conditions observed in this environment can be deemed "unsuitable" depends to a large degree on the species being discussed. There are a variety of fish species that can tolerate (and can potentially thrive) in conditions of high temperature and low oxygen (e.g. channel catfish, bullheads, carp). Over a long period, the frequency of temperature and oxygen extremes will structure the fish community. A warmwater fish community, by definition, will have a certain proportion of its membership occupied by these high-temperature tolerant species. The relatively large proportion of these types in the fish community (Section 1.4), suggests that the conditions described here, for 2005 in particular, occur with some frequency. As these species are also tolerant of a variety of environmental stressors (they are generalists with re: macrophyte dependence, substrate dependence, turbidity etc), it is unlikely that temperature is the only structuring force.

Walleye is a key fish species for the southern Grand River, both from its ability to occupy the niche of top predator and from the viewpoint of rehabilitation / increased production potential. During the surveys described here, some temperatures and oxygen concentrations were observed that would prove lethal to walleye. Poor habitat conditions occurred frequently, and are likely to decrease the productivity of this stock of walleye by restricting otherwise available habitat and possibly reduce year class size either directly through larval mortality or indirectly by constraining growth and reducing the proportion of individual YOY fish that reach sizes large enough to over-winter (Hokanson 1977)

The thermal regime of the river, relative to Lake Erie, has no doubt structured the natural history of this unique stock of walleye. The presence of young-of-the-year and young walleye through the summer months suggest that conditions within the river can serve as nursery and juvenile habitat. Young percids, including walleye, are known to be more tolerant of high temperatures and their optima are higher than that of adults by 2-3 degrees (Hokanson 1977). The fact that spring migratory walleye return to the lake is likely driven by not only the distribution of food sources but the behavioural search for a thermal environment optimal for growth and, later, gonadal development.

Based on thermal preferenda and oxygen tolerance, there are occasions (exemplified by data from summer 2005) on which the volume of habitat useable by walleye in the section of river from Cayuga to Port Maitland, shrinks by up to 98% (not including restrictions imposed by light penetration, turbidity, or substrate preferences). At these times benthic food sources would have been unavailable; the extent to which pelagic forage could make use of these areas to escape predation, is not known although walleye have been reported to make short-duration forays into oxygen conditions <4mg/L in pursuit of prey (Ryder and Kerr 1978).

5.5 References

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5.6 Figures

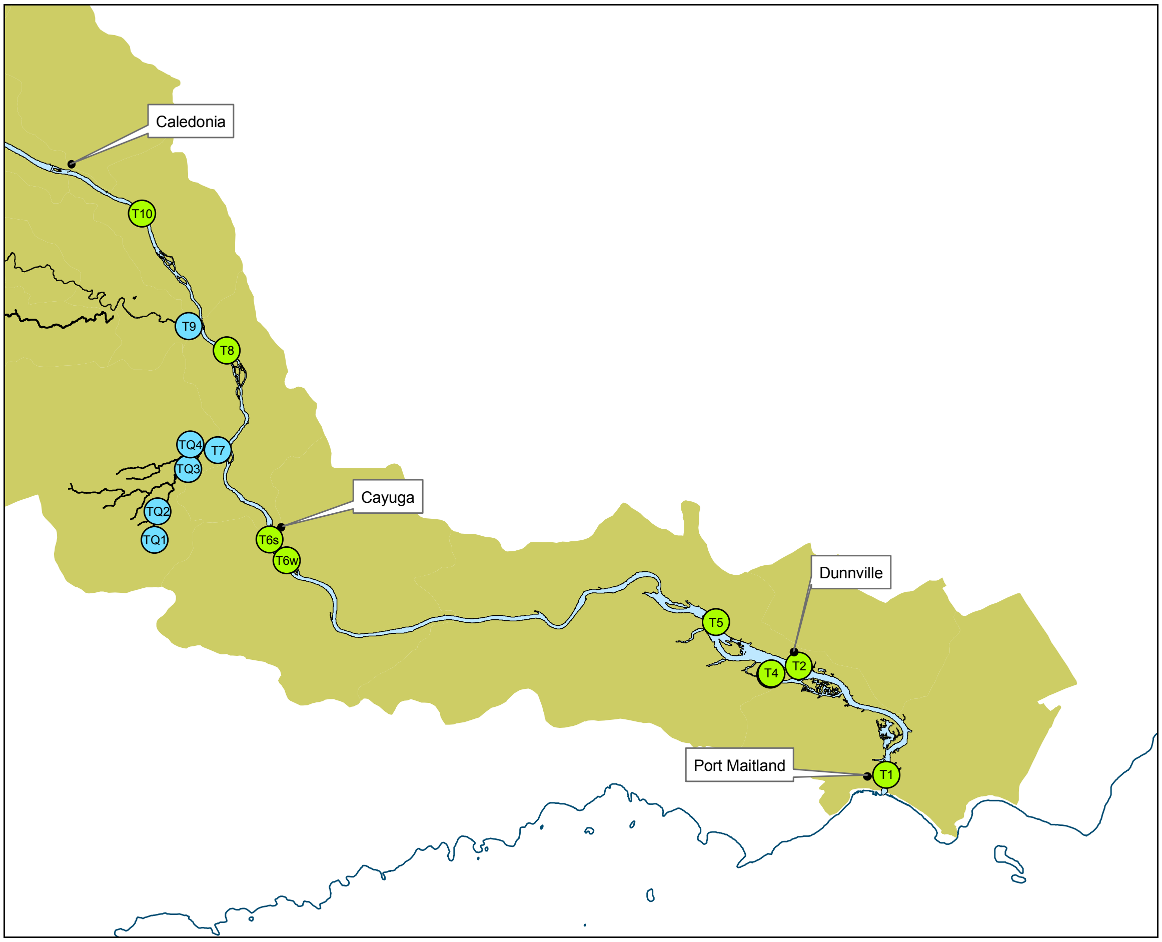


Figure 5.1. Locations of temperature loggers (T1-T10) deployed between 2000 and 2005. Green markers indicate main channel sites. Blue markers indicate tributary sites. Temperature loggers deployed on Mill and Rogers Creek tributary (TQ1-TQ4) are associated with the Taquanyah reservoir project (courtesy of GRCA).

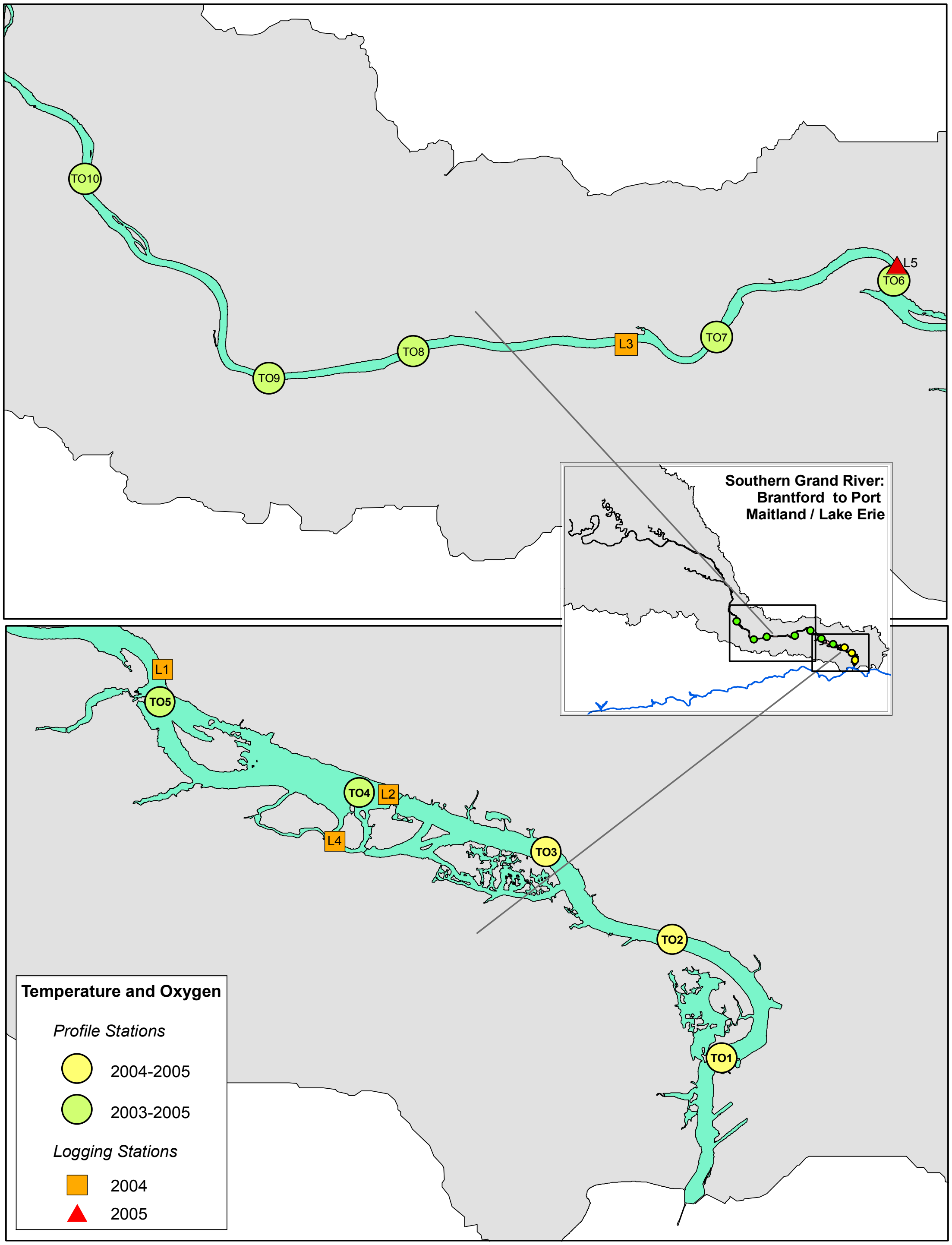


Figure 5.2. Location of temperature and dissolved oxygen measurements from bi-weekly water column profiling stations and logging stations (continuous at depth), Grand River, 2003-2005.

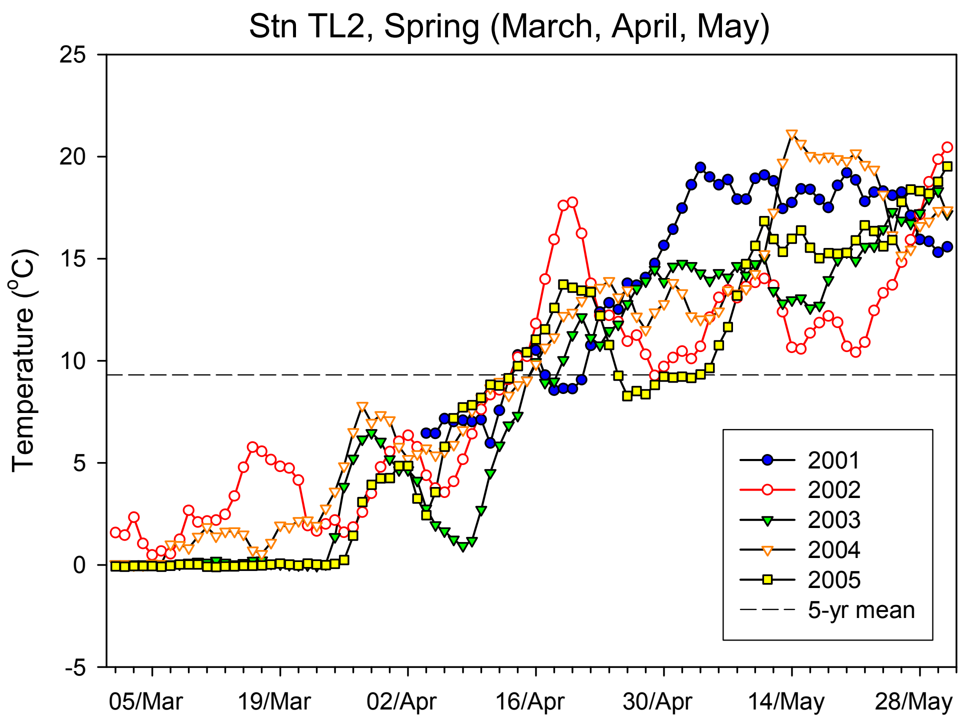


Figure 5.3A. Spring warming trends at logging station TL2 (Riverside Marina, Dunnville). Daily mean temperature and overall 5-yr mean, 2001-2005.

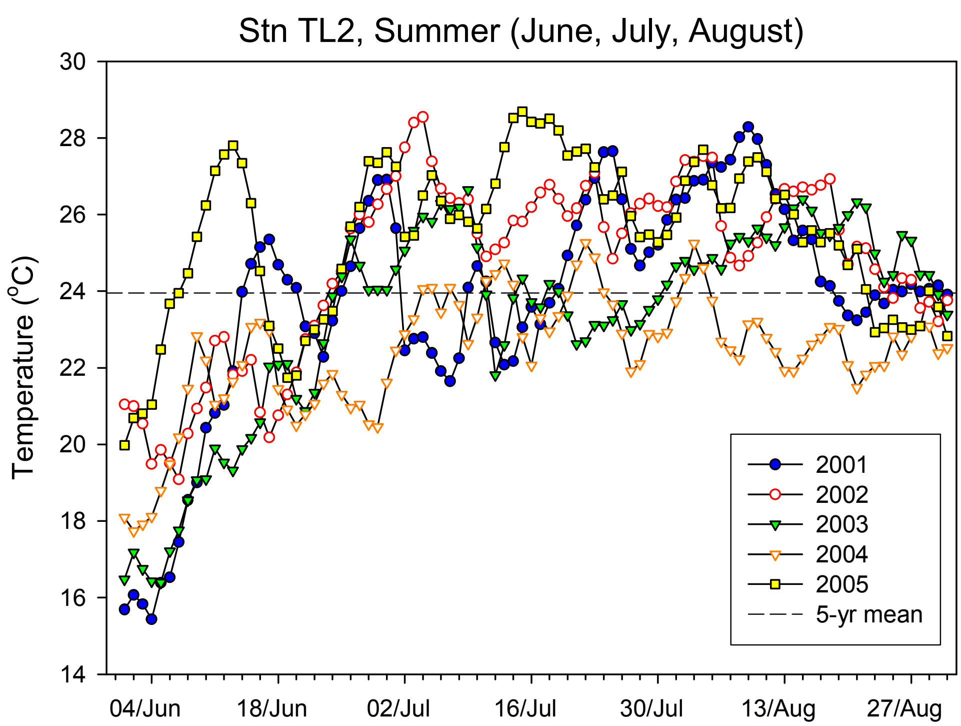


Figure 5.3B. Summer temperatures logging station TL2 (Riverside Marina, Dunnville). Daily mean temperature and overall 5-yr mean, 2001-2005.

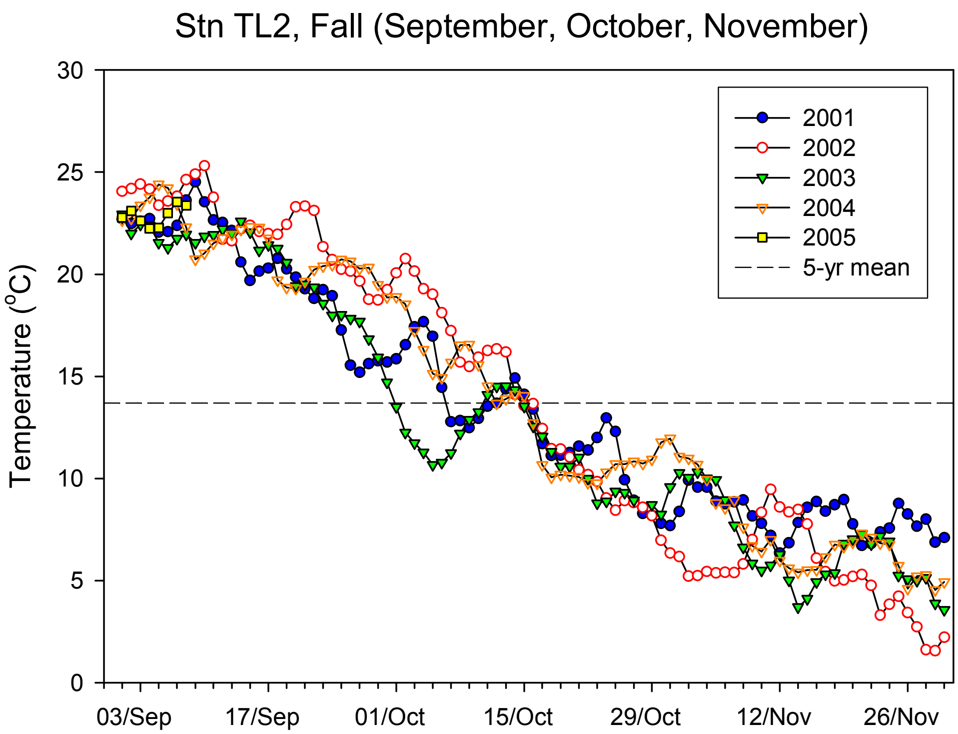


Figure 5.3C. Fall cooling trends at logging station TL2 (Riverside Marina, Dunnville). Daily mean temperature and overall 5-yr mean, 2001-2005.

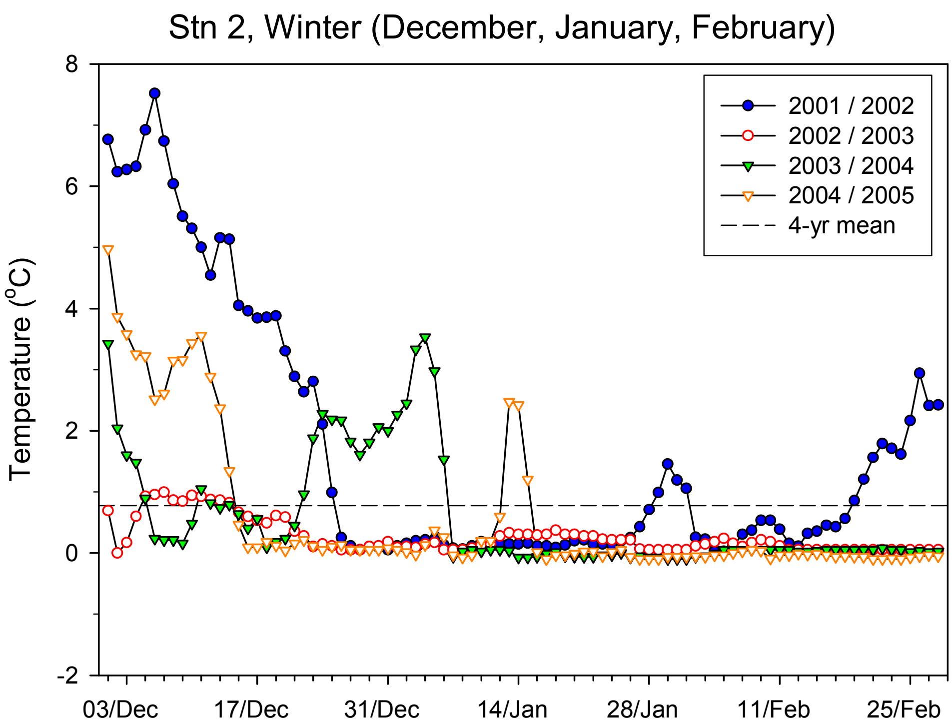


Figure 5.3D. Winter temperatures at logging station TL2 (Riverside Marina, Dunnville). Daily mean temperature and overall 4-yr mean, 2001-2005.

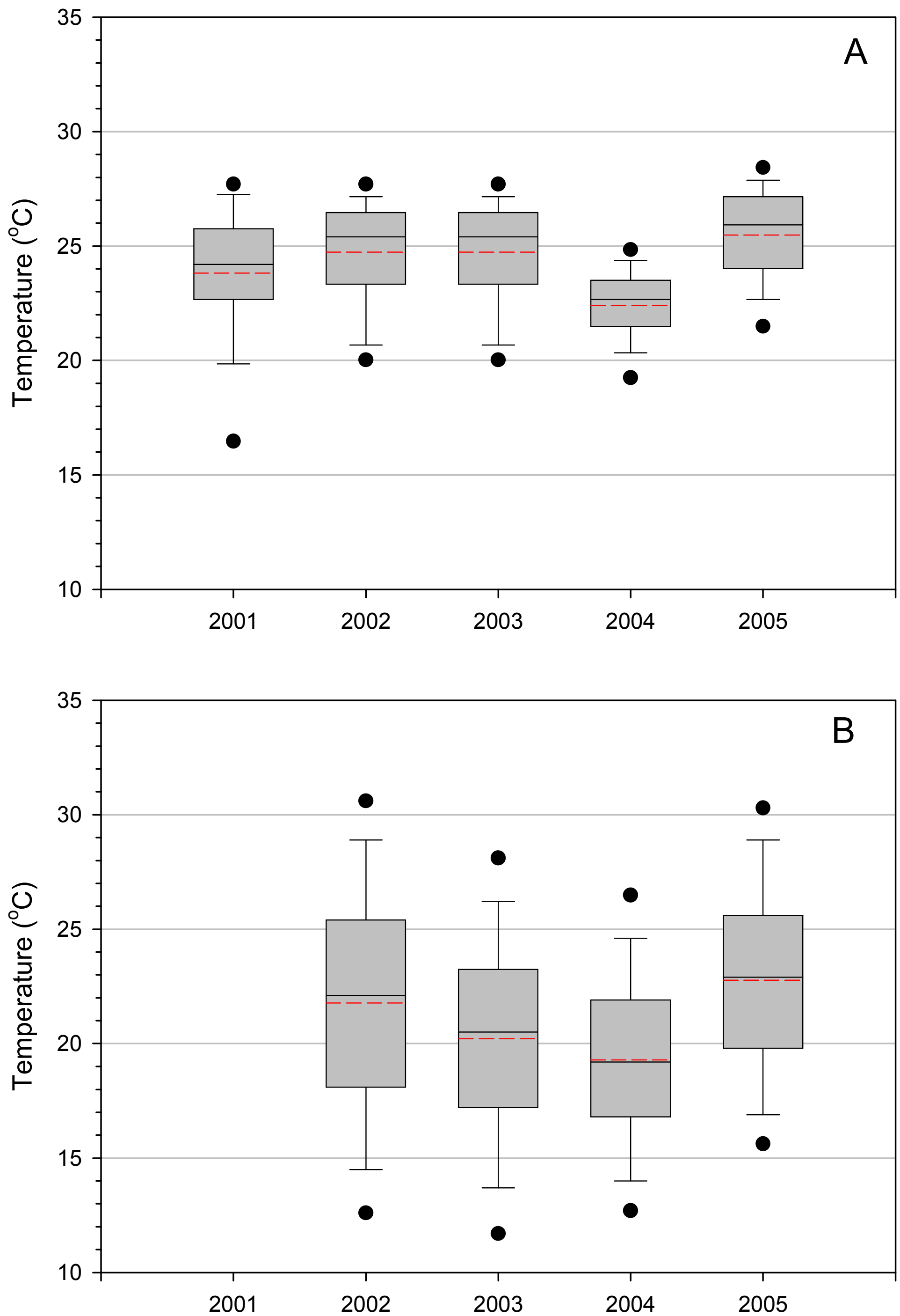
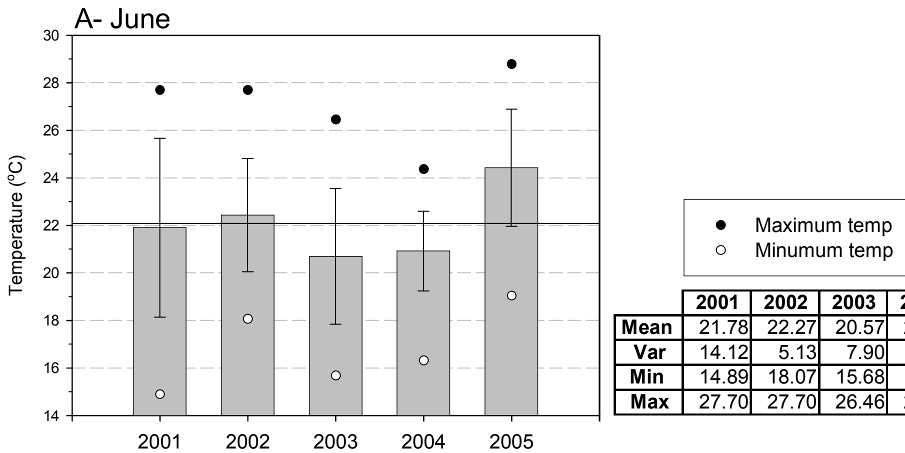
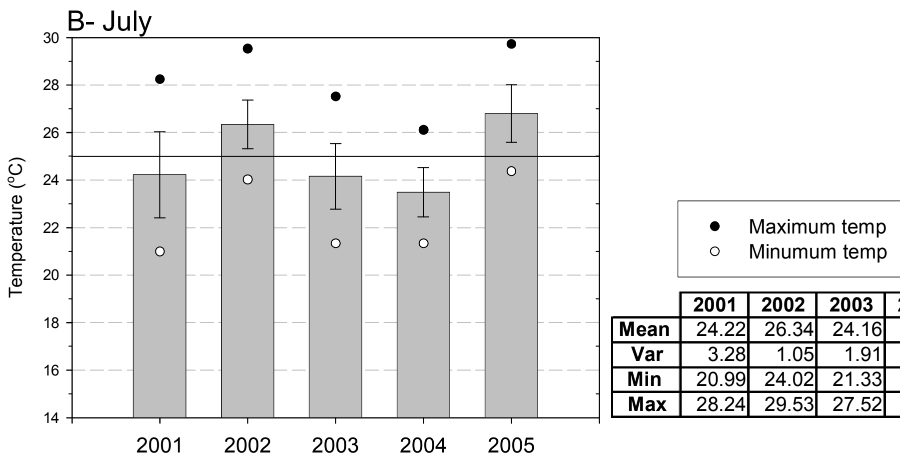


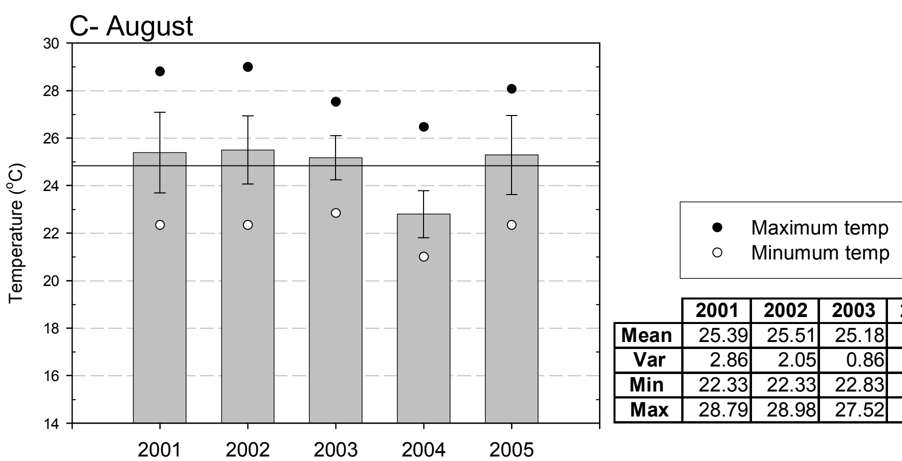
Figure 5.4. Summer (June 1- August 31) temperatures, 2001-2001. A- Water temperatures at logging station TL2. B- Air Temperatures at Environment Canada Climate station, Vineland Ontario. Outer margins of box represent the 25th and 75th percentile; straight black line represents median value; red dotted line represents the mean; 5th and 95th percentile values are indicated with an asterisk.



	2001	2002	2003	2004	2005
Mean	21.78	22.27	20.57	20.87	24.33
Var	14.12	5.13	7.90	2.80	6.00
Min	14.89	18.07	15.68	16.32	19.04
Max	27.70	27.70	26.46	24.37	28.79



	2001	2002	2003	2004	2005
Mean	24.22	26.34	24.16	23.48	26.79
Var	3.28	1.05	1.91	1.08	1.47
Min	20.99	24.02	21.33	21.33	24.37
Max	28.24	29.53	27.52	26.11	29.72



	2001	2002	2003	2004	2005
Mean	25.39	25.51	25.18	22.80	25.30
Var	2.86	2.05	0.86	0.98	2.77
Min	22.33	22.33	22.83	20.99	22.33
Max	28.79	28.98	27.52	26.46	28.06

Figure 5.5. Summer monthly mean temperatures, and related statistics, at temperature logging station TL2, Grand River, 2001-2005.

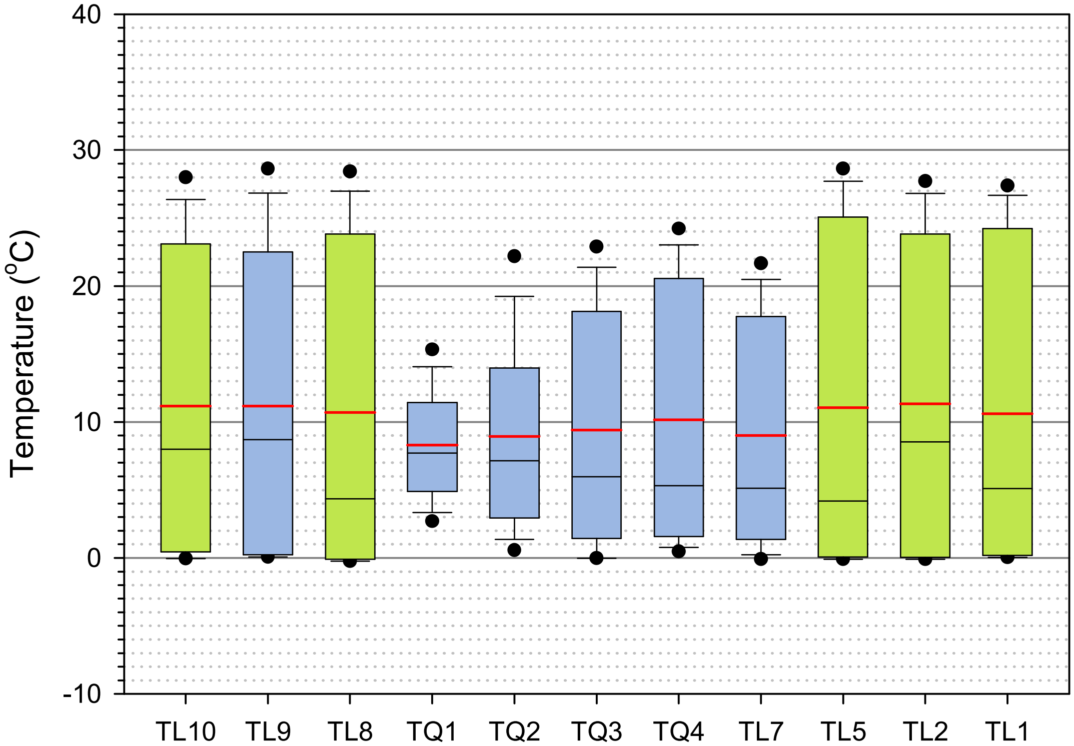


Figure 5.6. Summary of temperatures from 10 logging stations in the Grand River for three seasons (November 26, 2004 to September 1, 2005). Green bars indicate main channel locations while blue bars represent tributary stations. Outer margins of boxes represent the 25th and 75th percentile; straight black line represents median value; red dotted line represents the mean; 5th and 95th percentile values are indicated with an asterisk.

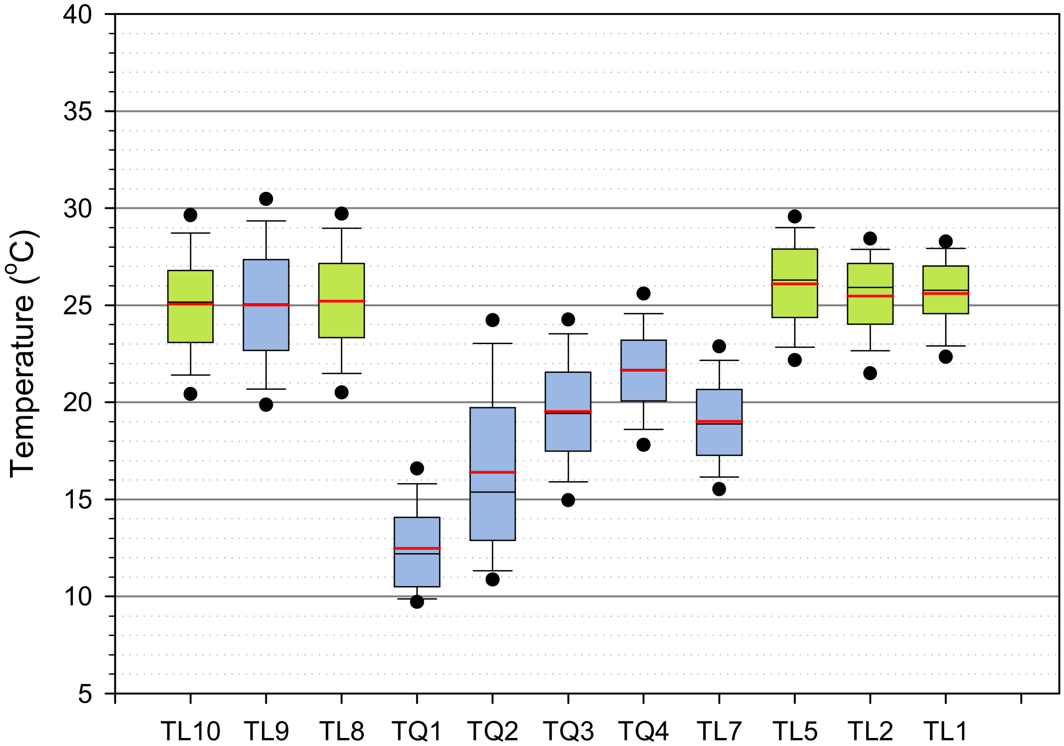


Figure 5.7. Summer (July 1 to August 31, 2005) temperatures at 10 logging stations in the Grand River. Green bars indicate main channel locations while blue bars represent tributary stations. Outer margins of boxes represent the 25th and 75th percentile; straight black line represents median value; red dotted line represents the mean; 5th and 95th percentile values are indicated with an asterisk.

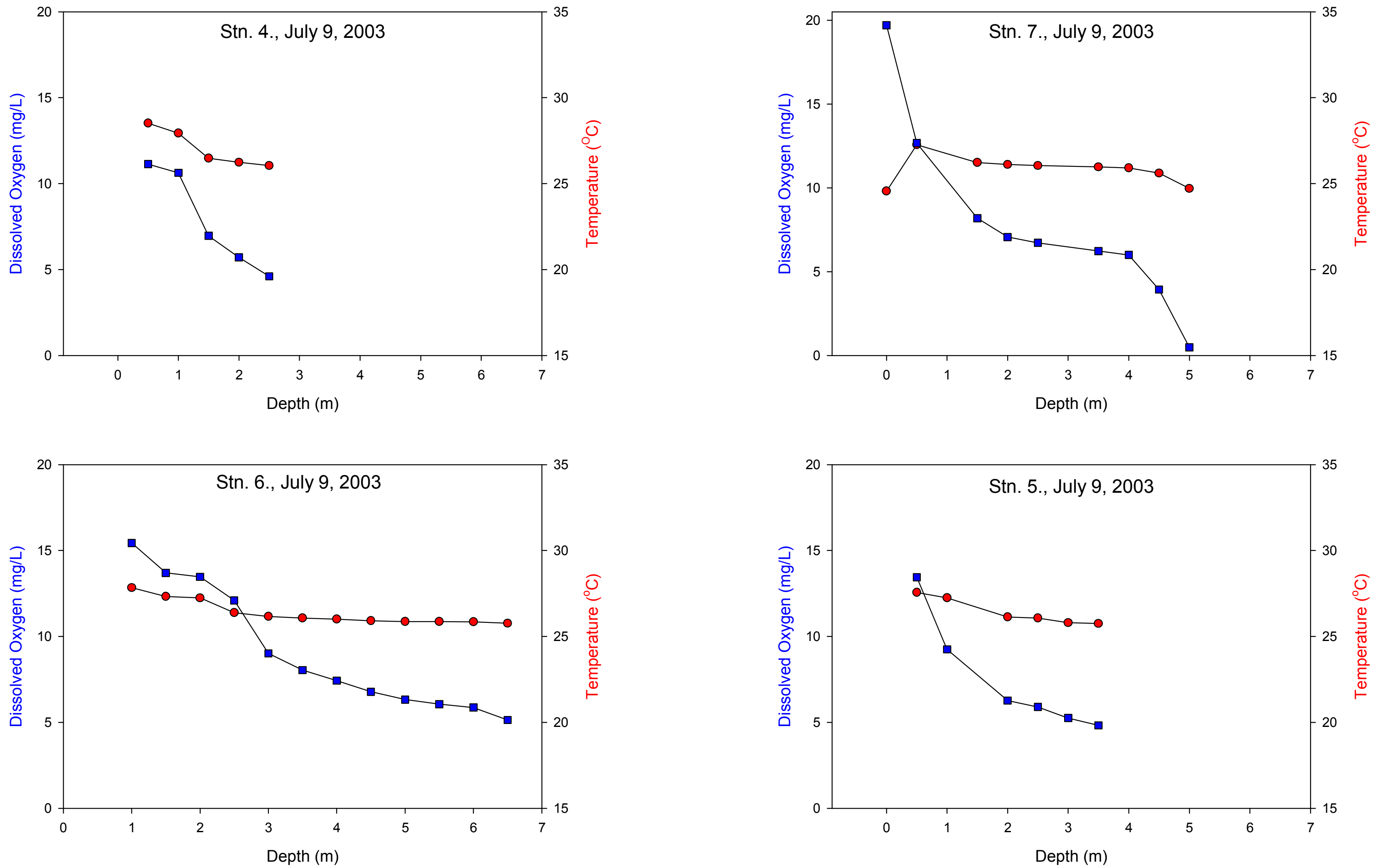
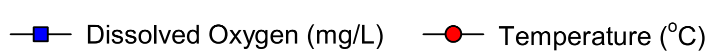


Figure 5.8. Water column profiles of temperature and oxygen at four locations, Grand River, July 9, 2003.



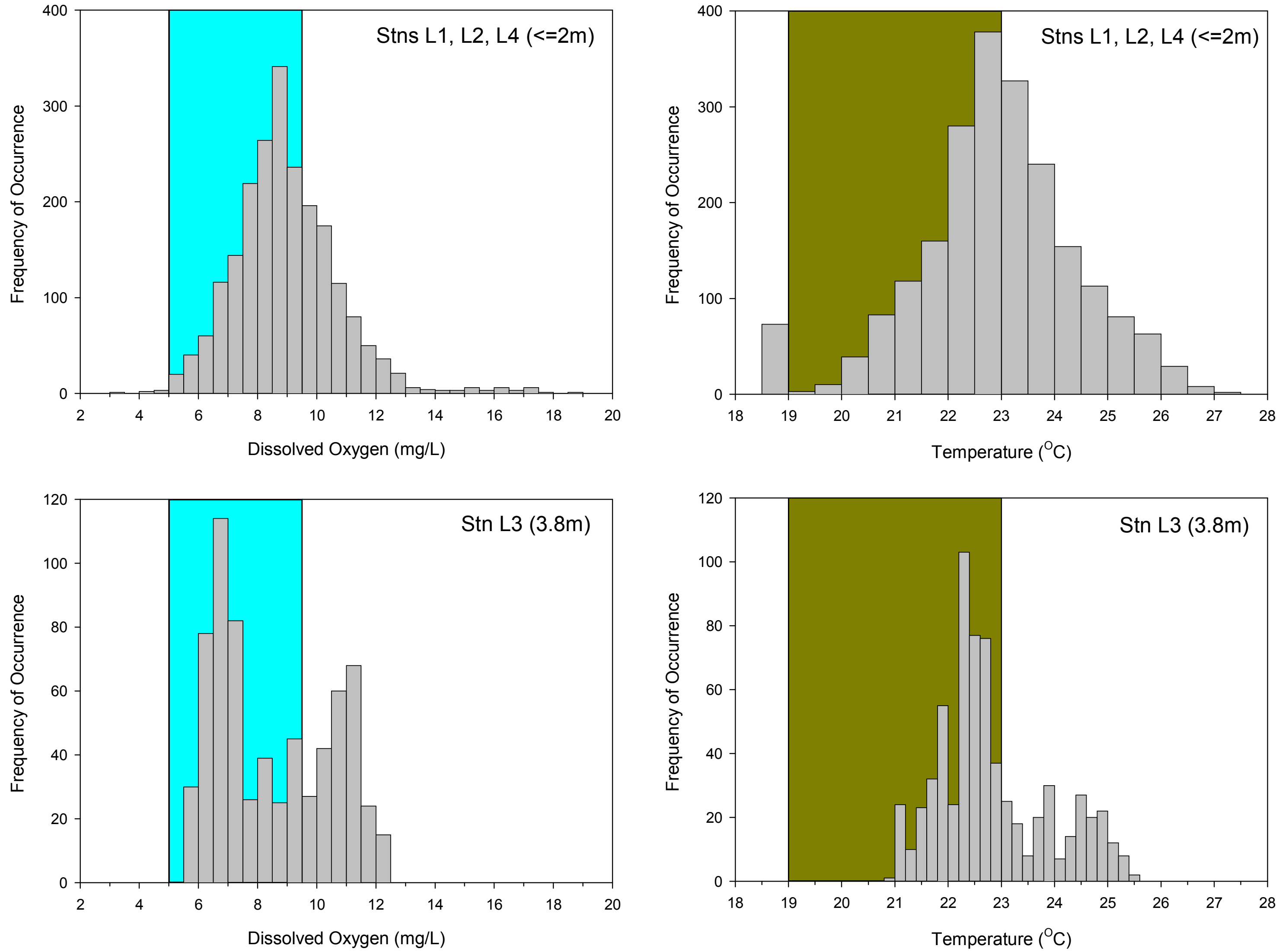


Figure 5.9. Frequency distribution of temperature and oxygen values measured at continuous logging stations in 2004. Target ranges are shown for oxygen (blue) and temperature (green) as outlined in “Methods”.

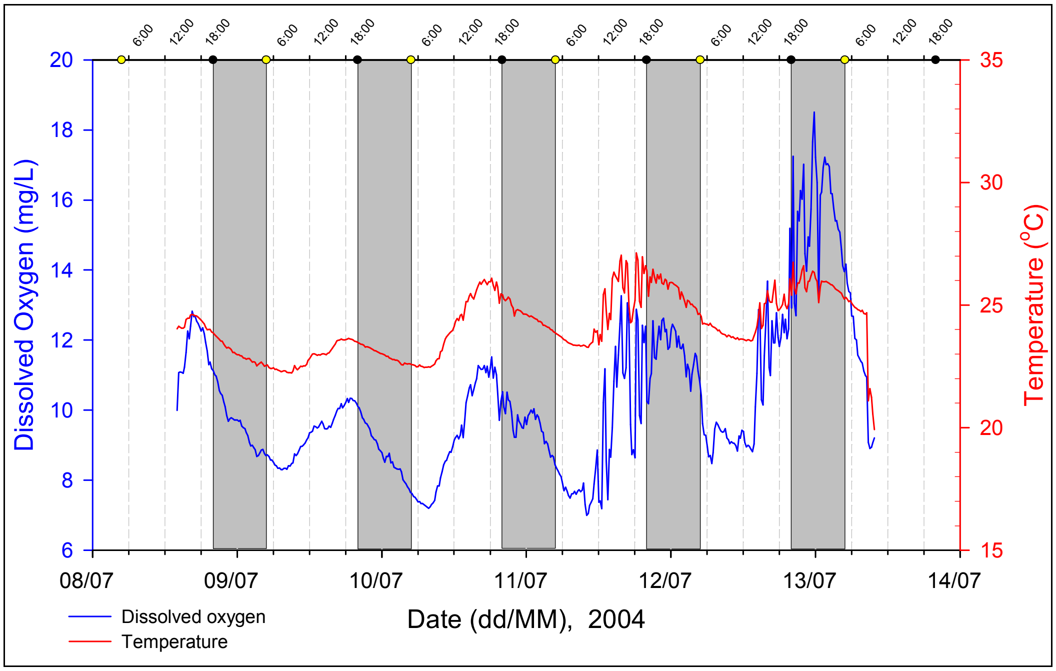


Figure 5.10. Temperature and oxygen measured hourly at 0.75m depth in the lower Grand River (Logger Station L1), between July 8 and July 13, 2004. Time of day (24-hour clock) is shown along the top for reference. Sunrise and sunset are indicated by yellow and black circles; respectively. Periods between sunset and sunrise are shaded grey.

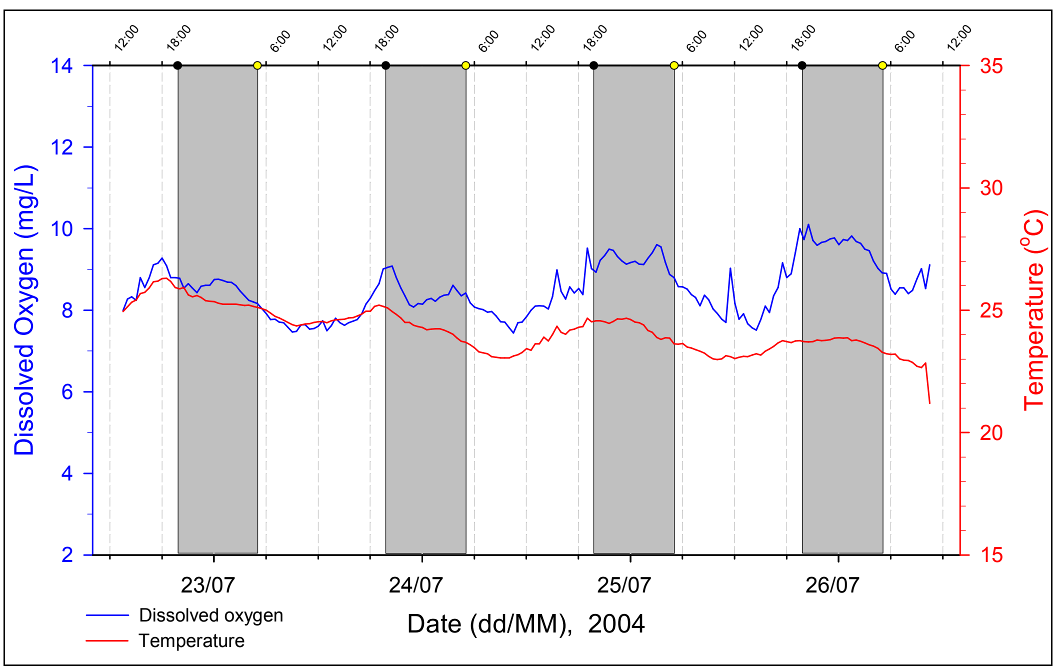


Figure 5.11A. Temperature and oxygen measured hourly at 2.0m depth in the lower Grand River (Logger Station L2), between July 22 and July 26, 2004. Time of day (24-hour clock) is shown along the top for reference. Sunrise and sunset are indicated by yellow and black circles; respectively. Periods between sunset and sunrise are shaded grey.

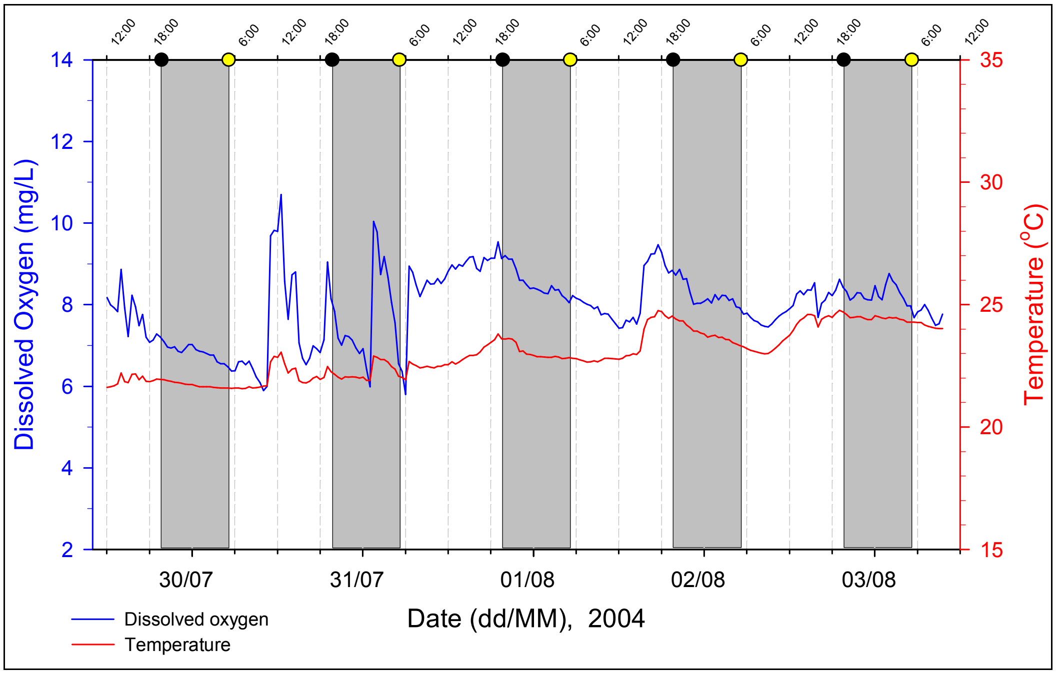


Figure 5.11B. Temperature and oxygen measured hourly at 2.0 m depth in the lower Grand River (Logger Station L2), between July 29 and Aug 3, 2004. Time of day (24-hour clock) is shown along the top for reference. Sunrise and sunset are indicated by yellow and black circles; respectively. Periods between sunset and sunrise are shaded grey.

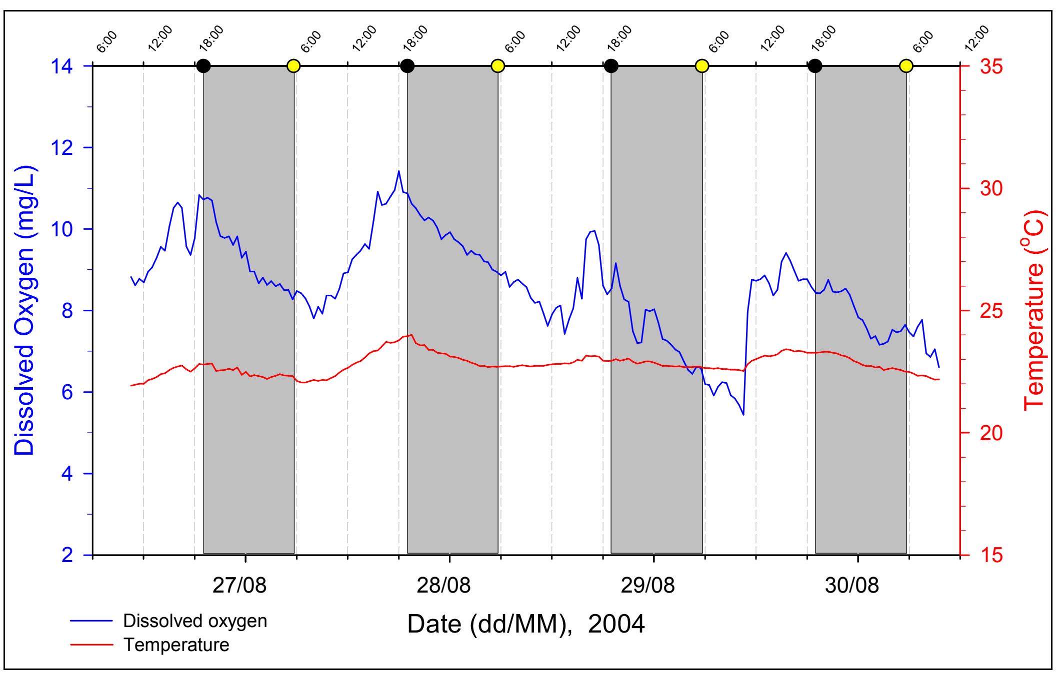


Figure 5.11C. Temperature and oxygen measured hourly at 0.75m depth in the lower Grand River (Logger Station L2), between Aug 26 and Aug 30, 2004. Time of day (24-hour clock) is shown along the top for reference. Sunrise and sunset are indicated by yellow and black circles; respectively. Periods between sunset and sunrise are shaded grey.

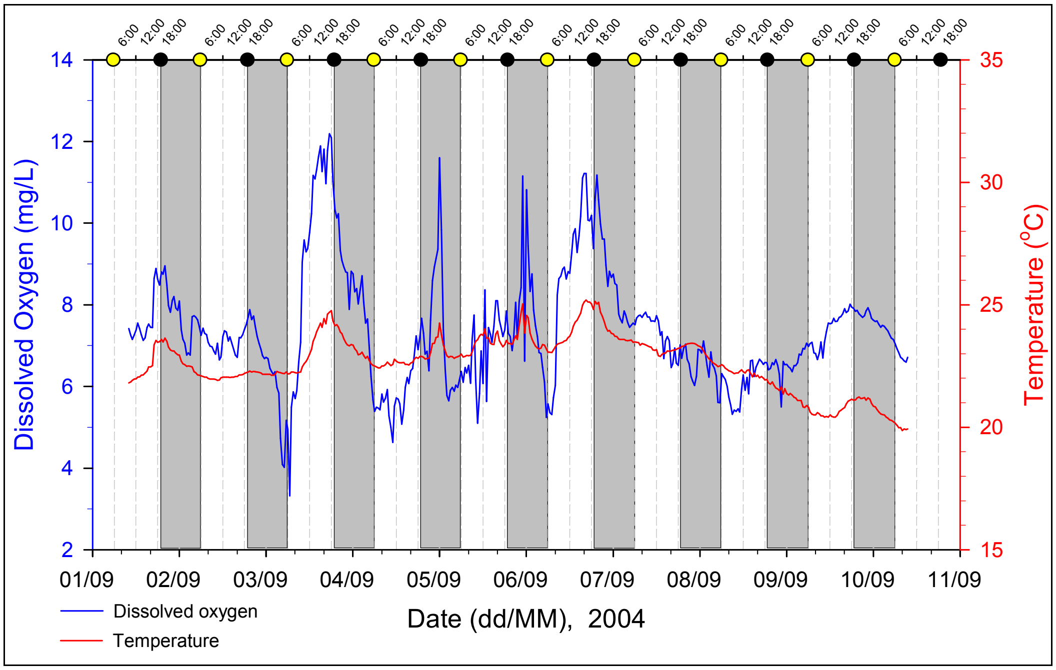


Figure 5.11D. Temperature and oxygen measured hourly at 0.75m depth in the lower Grand River (Logger Station L2), between Sept 1 and Sept 10, 2004. Time of day (24-hour clock) is shown along the top for reference. Sunrise and sunset are indicated by yellow and black circles; respectively. Periods between sunset and sunrise are shaded grey.

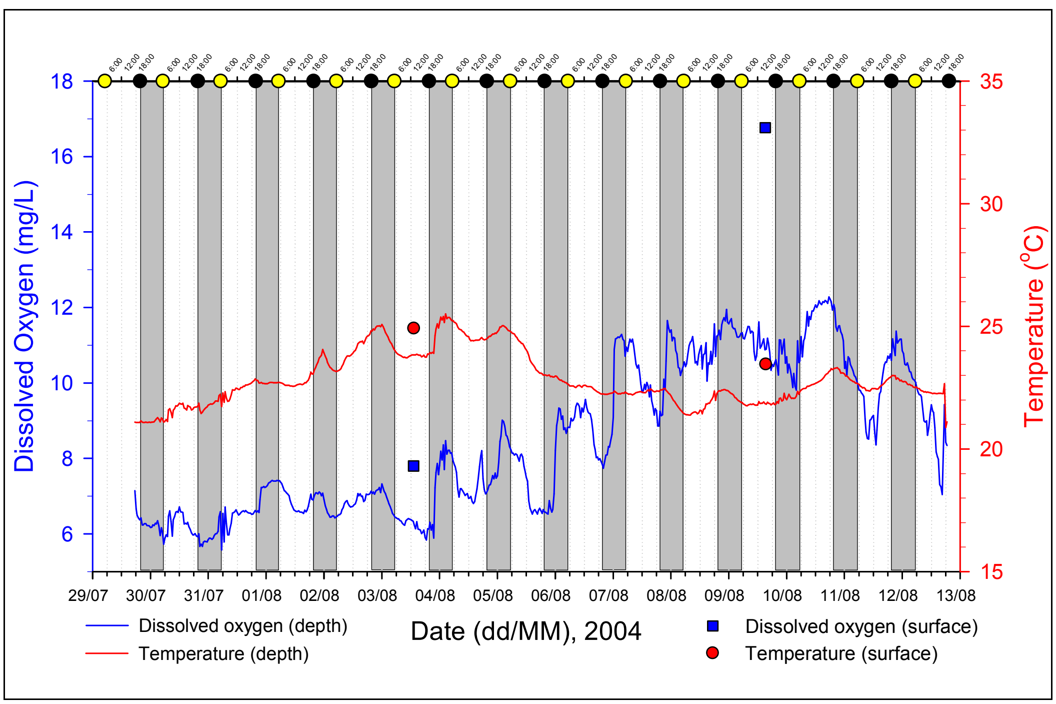


Figure 5.12. Temperature and oxygen measured hourly at 3.8m depth in the lower Grand River (Logger Station L3), between July 29 and August 12, 2004. Surface measurements, taken on August 3rd and 9th are displayed for comparison. Time of day (24-hour clock) is shown along the top for reference. Sunrise and sunset are indicated by yellow and black circles; respectively. Periods between sunset and sunrise are shaded grey.

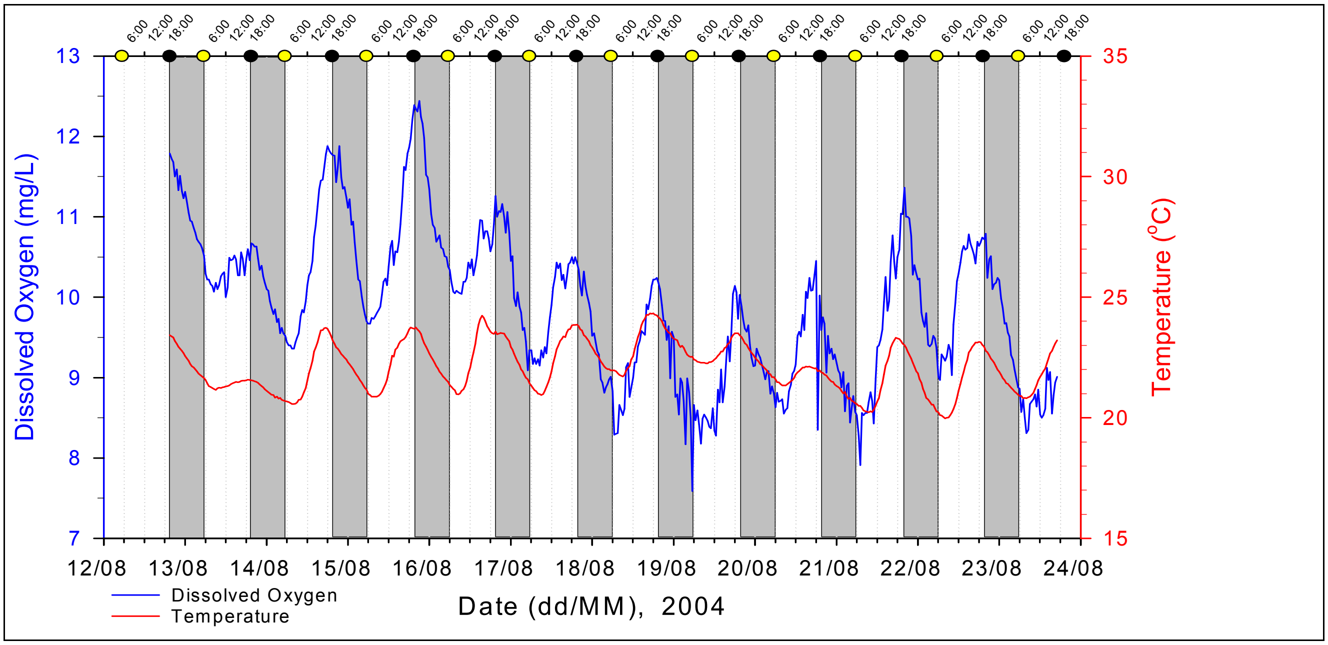


Figure 5.13. Temperature and oxygen measured hourly at 1m depth in Sulphur Ck (Logger Station L4), between August 12 and August 24, 2004. Time of day (24-hour clock) is shown along the top for reference. Sunrise and sunset are indicated by yellow and black circles; respectively. Periods between sunset and sunrise are shaded grey.

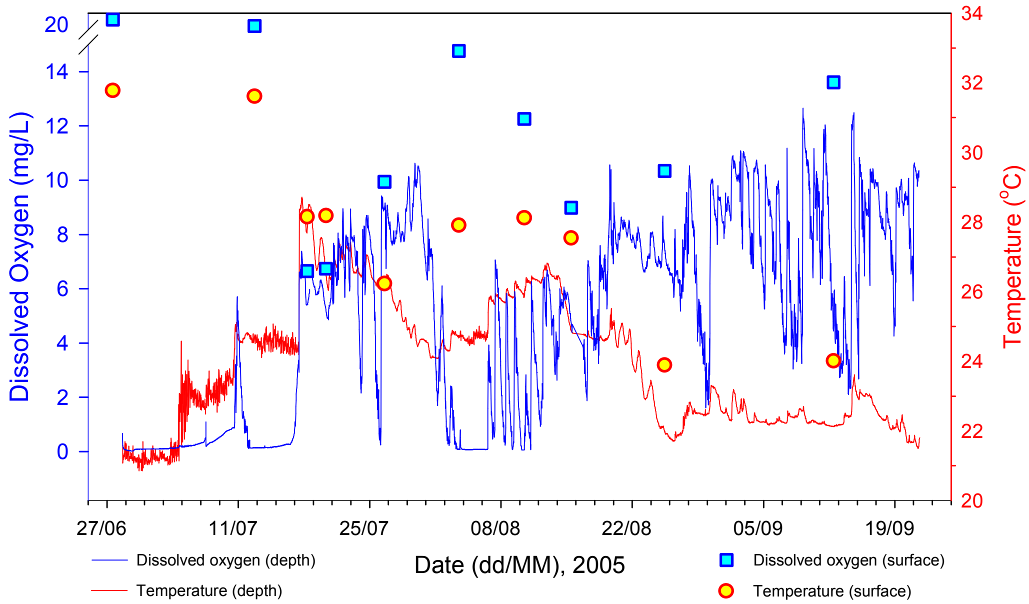


Figure 5.14A. Temperature (red) and oxygen (blue) measured hourly at 5.5m depth in the lower Grand River (Logger Station L5), between June 28 and Sept 21, 2005. Surface values, are provided where available.

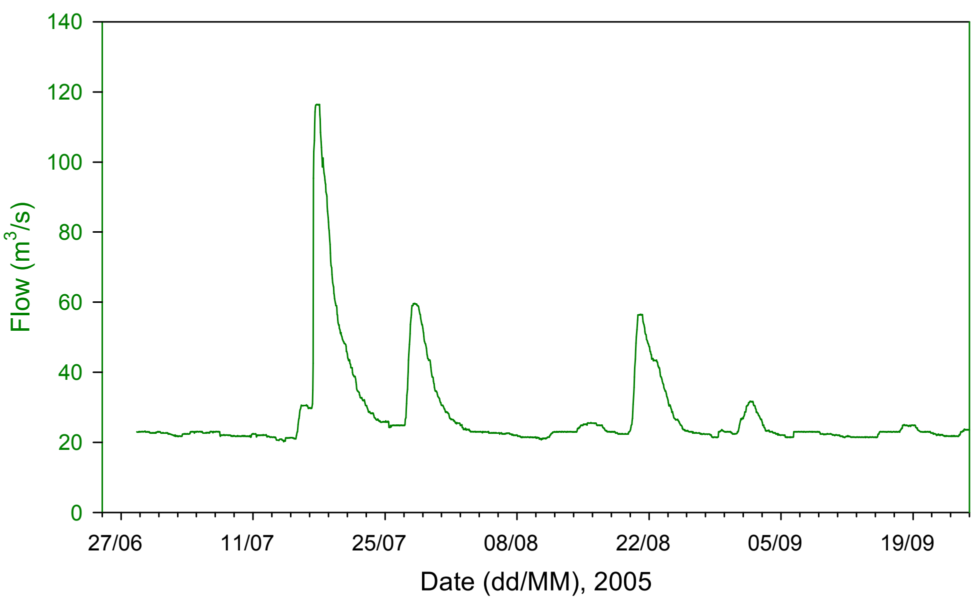


Figure 5.14B. Hourly flow measures (m3/second) measured at York between June 28 and Sept 21, 2005. Courtesy of the Grand River Conservation Authority (GRCA).

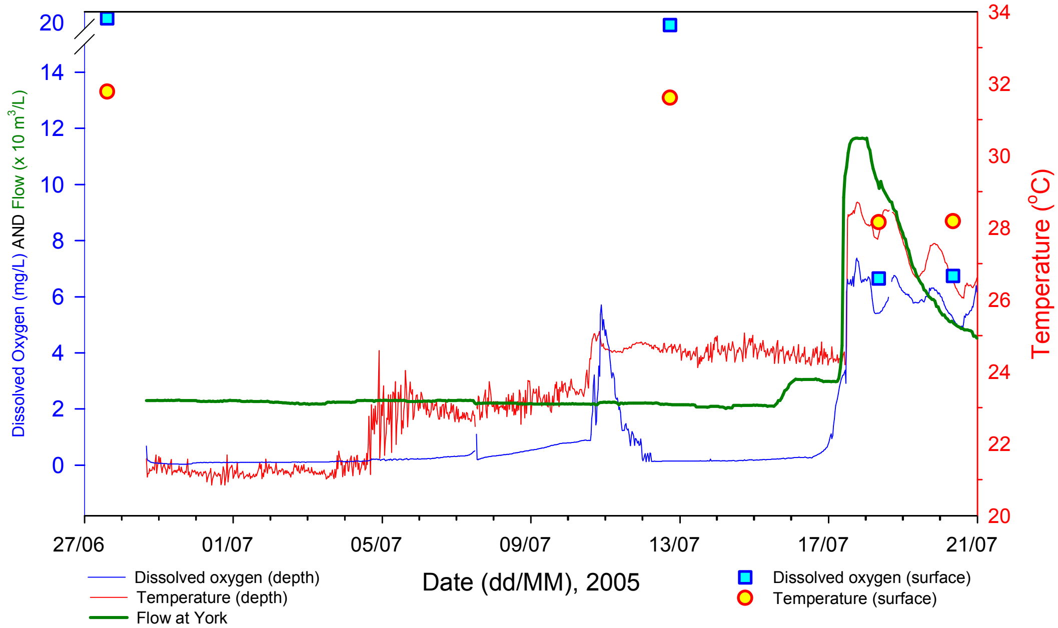


Figure 5.14C. Temperature (red) and oxygen (blue) measured hourly at 5.5m depth in the lower Grand River (Logger Station L5), between June 28 and July 21, 2005. Surface values, are provided where available. The green line indicates river flow measured at York (courtesy of GRCA)

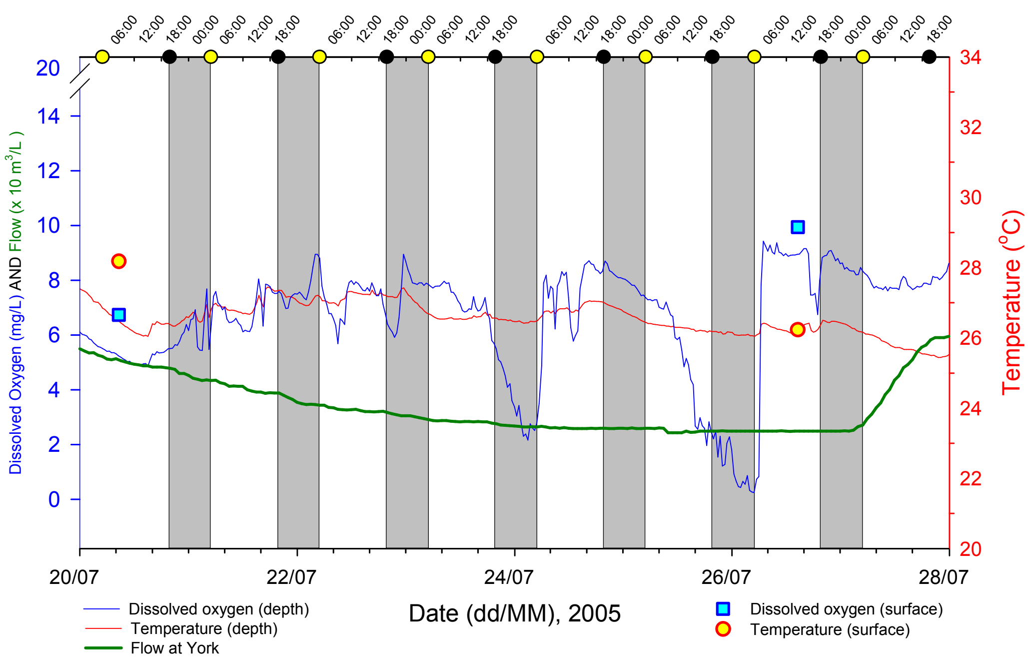


Figure 5.14D. Temperature (red) and oxygen (blue) measured hourly at 5.5m depth in the lower Grand River (Logger Station L5), between July 20 and July 28, 2005. Surface values, are provided where available. The green line indicates river flow measured at York (courtesy of GRCA)

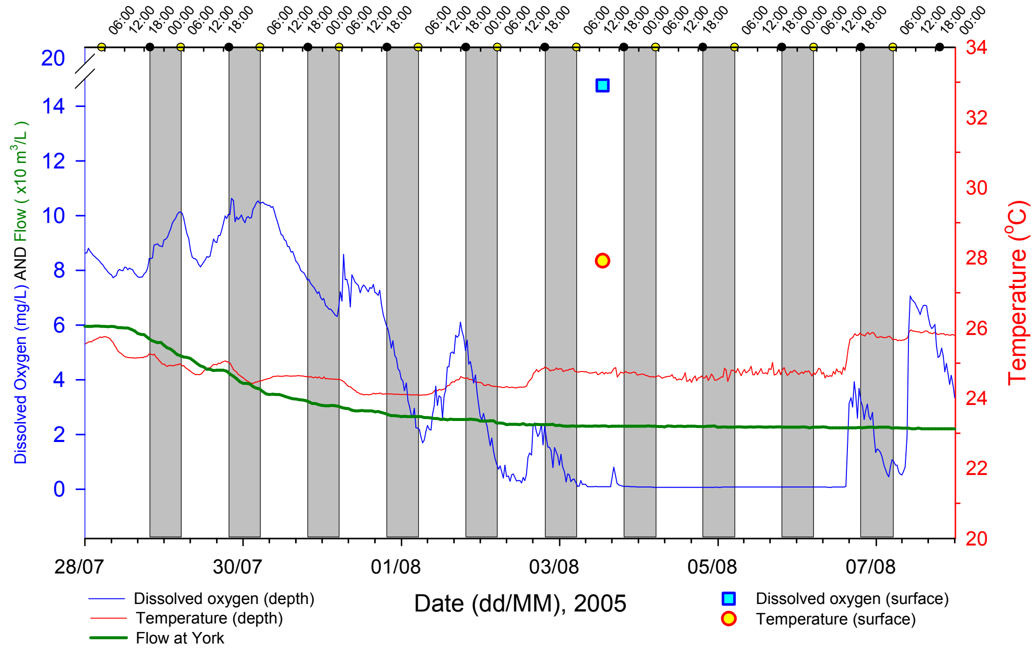


Figure 5.14E. Temperature (red) and oxygen (blue) measured hourly at 5.5m depth in the lower Grand River (Logger Station L5), between July 28 and Aug 8, 2005. Surface values, are provided where available. The green line indicates river flow measured at York (courtesy of GRCA)

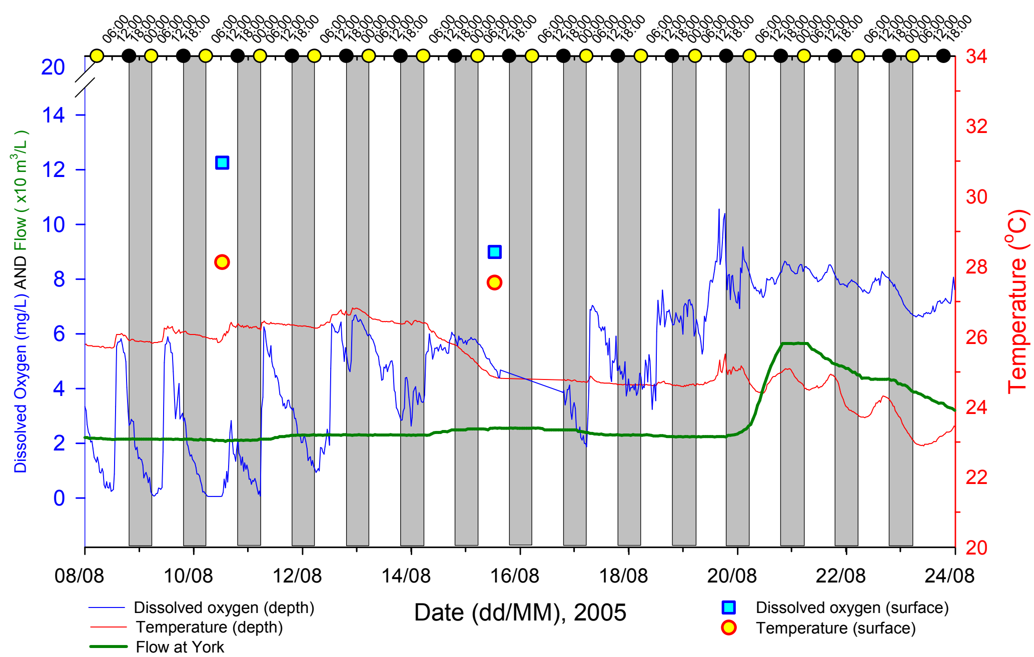


Figure 5.14F. Temperature (red) and oxygen (blue) measured hourly at 5.5m depth in the lower Grand River (Logger Station L5), between Aug 8 and Aug 25, 2005. Surface values, are provided where available. The green line indicates river flow measured at York (courtesy of GRCA)

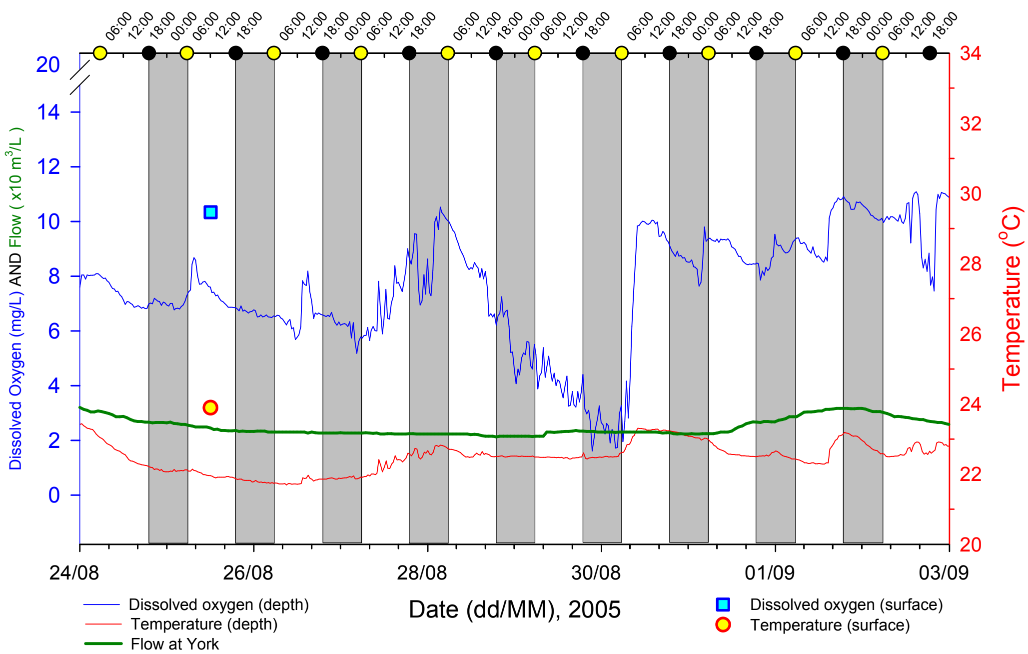


Figure 5.14G. Temperature (red) and oxygen (blue) measured hourly at 5.5m depth in the lower Grand River (Logger Station L5), between Aug 24 and Sep 04, 2005. Surface values, are provided where available. The green line indicates river flow measured at York (courtesy of GRCA)

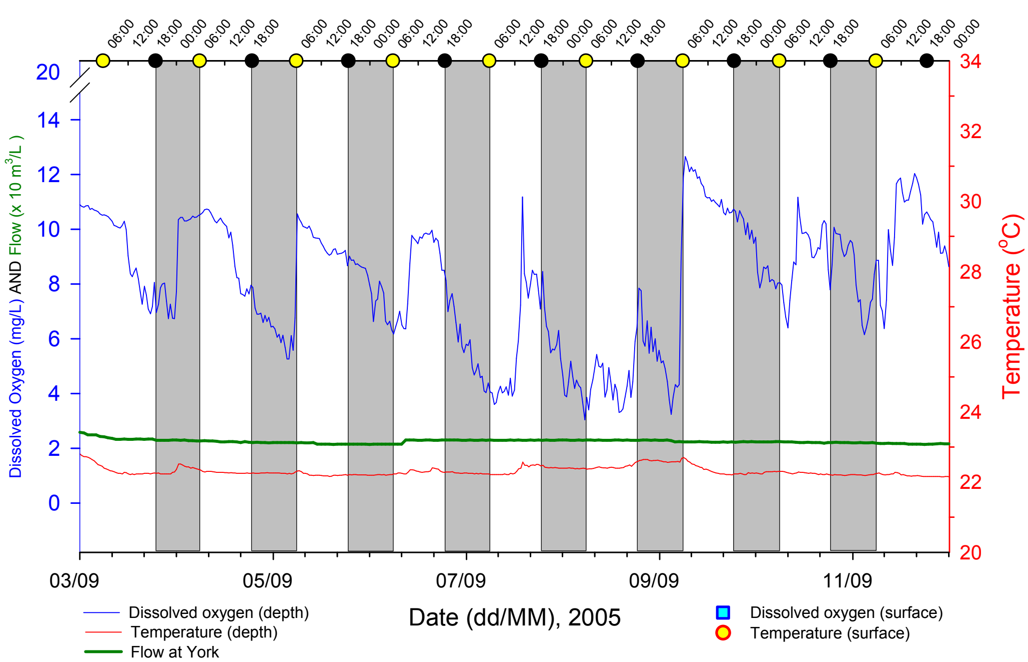


Figure 5.14H. Temperature (red) and oxygen (blue) measured hourly at 5.5m depth in the lower Grand River (Logger Station L5), between Sept 03 and Sept 12, 2005. Surface values, are provided where available. The green line indicates river flow measured at York (courtesy of GRCA)

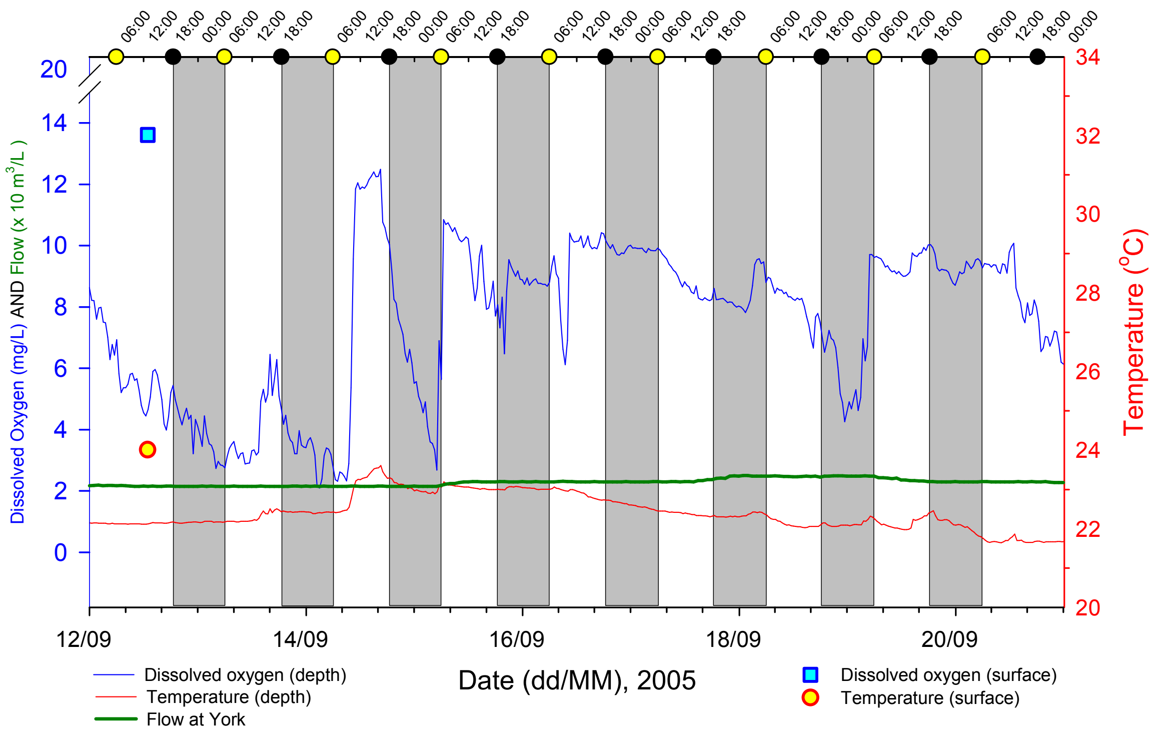


Figure 5.14I. Temperature (red) and oxygen (blue) measured hourly at 5.5m depth in the lower Grand River (Logger Station L5), between Sept 12 and Sept 28, 2005. Surface values, are provided where available. The green line indicates river flow measured at York (courtesy of GRCA)

5.7 Tables

Table 5.1. Temperature logging station details, Grand River, 2001-2005

Station ID	Relative to Dunnville Dam	Relative to Main channel	Depth (m)	Longitude (decimal degrees)	Longitude (decimal degrees)	General Description
T1	Below	Main	1.6	42.8620	-79.5760	Port Maitland
T2	Below	Main	1.5	42.8997	-79.6157	Riverside Marina; Dunnville (below dam)
T3	Below	Main	1.2	42.8970	-79.6291	Fishway; Dunnville (below dam)
T4	Above	Main	1.0	42.8974	-79.6287	Fishway; Dunnville (above dam)
T5	Above	Main	1.0	42.9152	-79.6541	R.C. residence; Dunnville (approx 1km above dam))
T6w	Above	Main	0.5	42.9385	-79.8534	Cayuga (fall, winter, spring)
T6s	Above	Main	1.2	42.9456	-79.8611	Cayuga (summer)
T7	Above	Tributary	1.5	42.9765	-79.8846	Rogers Ck (just upstream of confluence with GR main channel)
T8	Above	Main	0.5	43.0106	-79.8798	York
T9	Above	Tributary	0.3	43.0190	-79.8975	Boston-MacKenzie Ck (just upstream of concluence with GR main channel)
T10	Above	Main	0.5	43.0577	-79.9187	Caledonia
TQ1	Above	Tributary	0.3	42.9461	-79.9147	Mill Creek at Decewsville Rd.(above old Taquanya resevoir)
TQ2	Above	Tributary	0.5	42.9558	-79.9131	Mill Creek at Townline Rd.(below old Taquanya resevoir)
TQ3	Above	Tributary	0.2	42.9703	-79.8987	Mill Creek at R. Fox property
TQ4	Above	Tributary	1.0	42.9785	-79.8975	Rogers Creek at Indianna Rd. (upstream of confluence with Mill Ck.)

Table 5.2. Duration of temperature logging and frequency of measurements (1-2 /hr) at 10 stations, Grand River, 2001-2005.

		TL1 Port M.	TL2 Riverside	TL3 Downstream	TL4 Upstream	TL5 Culps	TL6 Cayuga	TL7 Rogers C.	TL8 York	TL9 Boston M.	TL10 Caledonia
	Jan										
	Feb										
	Mar										
	Apr										
	May										
2001	Jun										
	Jul										
	Aug										
	Sep										
	Oct										
	Nov										
	Dec	2 hr	2 hr								
	Jan										
	Feb										
	Mar										
	Apr										
	May										
2002	Jun										
	Jul										
	Aug										
	Sep										
	Oct										
	Nov										
	Dec										
	Jan										
	Feb	2 hr				2 hr					
	Mar										
	Apr										
	May			1 hr	1 hr						
2003	Jun										
	Jul										
	Aug										
	Sep						1 hr	1 hr	1 hr	1 hr	1 hr
	Oct										
	Nov										
	Dec										
	Jan										
	Feb										
	Mar										
	Apr			1 hr	1 hr		2 hr	2 hr	2 hr	2 hr	2 hr
	May										
2004	Jun	2 hr	2 hr								
	Jul										
	Aug										
	Sep										
	Oct			2 hr		2 hr					
	Nov										
	Dec										
	Jan										
	Feb								2 hr		
	Mar										
	Apr										
	May			1 hr	1 hr						
2005	Jun										
	Jul						2 hr	2 hr	2 hr	2 hr	2 hr
	Aug	2 hr		2 hr							
	Sep										
	Oct										
	Nov										
	Dec										

Table 5.3. Temperature and oxygen profiling: frequency of sampling events at 10 stations within the Grand River between 2003 and 2005.

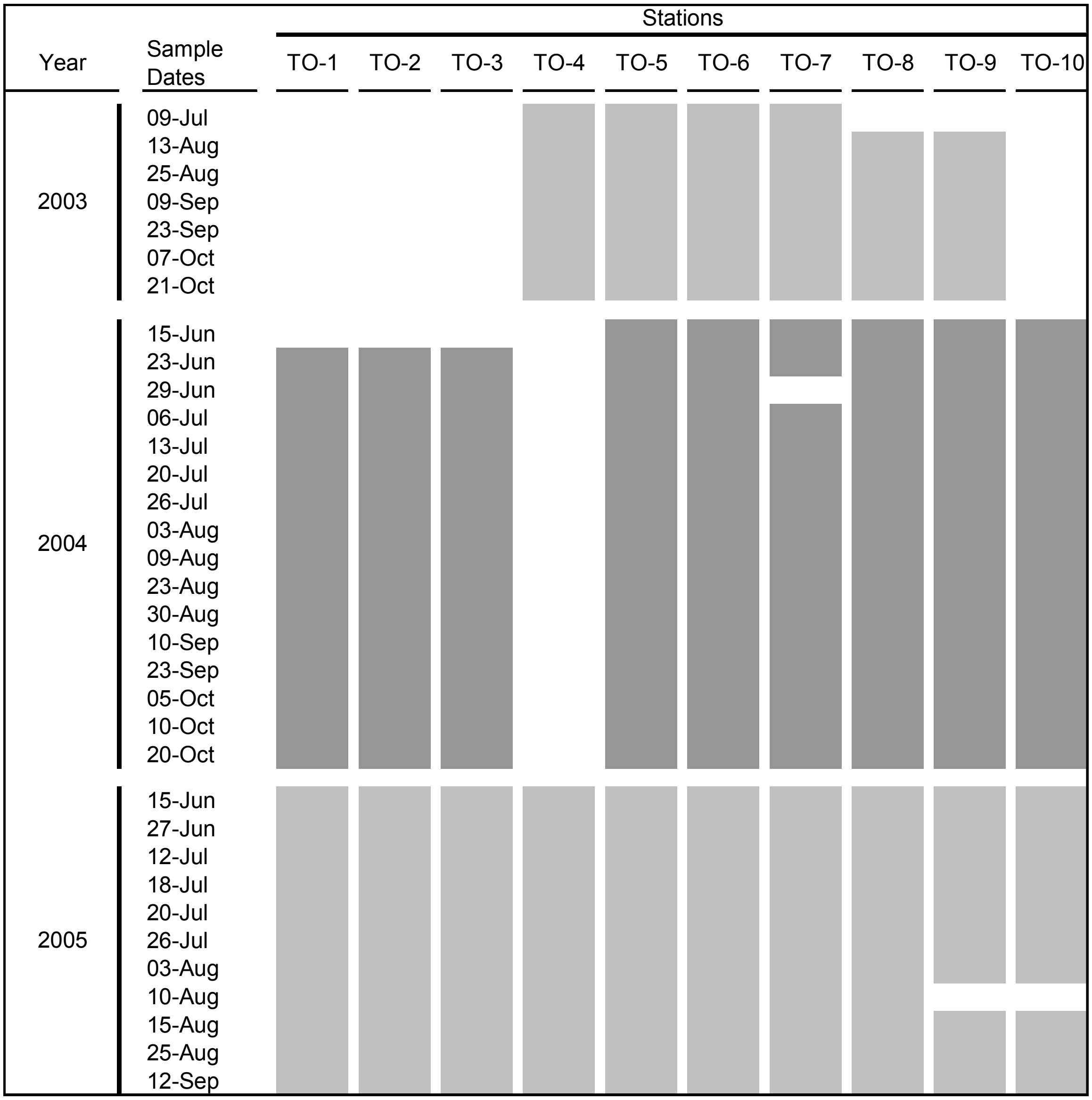


Table 5.4. Continuous logging of temperature and oxygen at depth: station locations, descriptions and duration of logging events.

Year	Station ID	DEPTH	LAT	LON	Description	START	STOP	Duration
		(m)	(north)	(east)				(days_hour:min)
2004	L1	0.75	42.91511	-79.65406	RC residence	08-Jul-04	13-Jul-04	04 19:45
2004	L2	2.0	42.90092	-79.62115	Above Dam (1)	22-Jul-04	26-Jul-04	03 21:00
					Above Dam (2)	29-Jul-04	30-Jul-04	04 22:30
					Above Dam (3)	26-Aug-04	30-Aug-04	03 23:00
					Above Dam (4)	01-Sep-04	10-Sep-04	08 23:30
2004	L3	3.8	42.91724	-79.74079	RV resort	29-Jul-04	12-Aug-04	14 1:00
2004	L4	1.0	42.89585	-79.62913	Sulphur Ck.	12-Aug-04	23-Aug-04	10 21:30
2005	L5	6.5	42.92720	-79.68040	Breakwall (profile stn6)	28-Jun-05	21-Sep-05	85 00:00

Table 5.5. Summary of temperature and oxygen profile data, Grand River, 2003

Station ID	Date	Depth		Temperature (oC)			Dissolved Oxygen					
							DO - % Saturation			DO (mg/L)		
	yy-mm-dd	Max	ΔD	Max	Min	ΔT	Max	Min	Δ %	Max	Min	ΔDO
4	03-07-09	2.5	2.0	28.52	26.05	-2.47	144.0	57.0	-87.0	11.14	4.61	-6.53
5	03-07-09	3.5	3.0	27.56	25.75	-1.81	170.7	59.4	-111.3	13.45	4.83	-8.62
6	03-07-09	6.5	5.5	27.84	25.77	-2.07	196.3	63.2	-133.1	15.44	5.14	-10.30
7	03-07-09	5.0	5.0	27.27	24.57	-2.70	236.4	5.9	-230.5	19.69	0.49	-19.20
4	03-08-13	1.5	1.0	27.04	25.29	-1.75	139.6	98.9	-40.7	11.22	8.21	-3.01
5	03-08-13	3.5	3.5	25.05	24.86	-0.19	100.3	87.7	-12.6	8.23	7.37	-0.86
6	03-08-13	6.0	5.5	25.61	24.86	-0.75	136.6	94.5	-42.1	11.33	7.91	-3.42
7	03-08-13	5.0	4.0	24.57	24.46	-0.11	96.0	85.3	-10.7	8.08	7.19	-0.89
8	03-08-13	4.0	4.0	28.09	25.45	-2.64	165.2	110.7	-54.5	13.03	9.09	-3.94
9	03-08-13	4.0	3.0	25.52	24.27	-1.25	100.6	83.4	-17.2	8.32	7.05	-1.27
4	03-08-25	2.0	1.5	24.57	24.15	-0.42	110.8	99.2	-11.6	9.19	8.30	-0.89
5	03-08-25	2.5	2.5	25.20	24.17	-1.03	131.5	97.1	-34.4	10.79	8.11	-2.68
6	03-08-25	6.0	6.0	25.54	24.43	-1.11	142.4	88.0	-54.4	11.61	7.32	-4.29
7	03-08-25	5.0	5.0	26.59	24.58	-2.01	141.9	81.0	-61.0	11.45	6.72	-4.73
8	03-08-25	3.0	3.0	24.99	23.74	-1.25	143.2	103.0	-40.2	11.79	8.68	-3.11
9	03-08-25	4.0	4.0	24.17	22.97	-1.20	139.2	91.9	-47.3	11.63	7.85	-3.78
4	03-09-09	1.5	1.0	22.78	21.78	-1.00				9.15	8.15	-1.00
5	03-09-09	3.0	3.0	22.36	20.63	-1.73				8.95	5.99	-2.96
6	03-09-09	5.5	5.5	22.11	21.23	-0.88				8.71	6.53	-2.18
7	03-09-09	5.0	5.0	22.00	21.01	-0.99				9.48	6.98	-2.50
8	03-09-09	3.5	3.5	22.83	21.85	-0.98				10.76	8.22	-2.54
9	03-09-09	4.0	4.0	23.64	21.51	-2.13				11.38	7.41	-3.97
4	03-09-23	2.0	1.5	18.52	18.40	-0.12	68.8	65.2	-3.6	6.38	6.07	-0.31
5	03-09-23	3.5	3.5	18.56	10.81	-7.75	84.7	62.6	-22.1	9.43	5.84	-3.59
6	03-09-23	4.5	4.5	18.66	18.62	-0.04	75.7	72.7	-3.0	7.01	6.73	-0.28
7	03-09-23	3.5	3.5	18.75	18.71	-0.04	68.7	65.6	-3.1	6.35	6.06	-0.29
8	03-09-23	2.0	2.0	18.77	18.75	-0.02	68.7	67.7	-1.0	6.35	6.25	-0.10
9	03-09-23	4.0	4.0	17.93	17.89	-0.04	66.1	63.6	-2.5	6.21	5.98	-0.23
4	03-10-07	2.0	1.5	11.71	11.61	-0.10	96.2	94.1	-2.1	10.49	10.28	-0.21
5	03-10-07	3.0	3.0	11.68	10.78	-0.90	94.8	83.3	-11.5	10.27	9.27	-1.00
6	03-10-07	6.0	6.0	11.87	10.82	-1.05	93.5	84.6	-8.9	10.15	9.43	-0.72
7	03-10-07	5.0	5.0	11.56	10.50	-1.06	97.1	87.8	-9.3	10.62	9.84	-0.78
8	03-10-07	3.0	3.0	11.60	10.89	-0.71	101.7	96.1	-5.7	11.12	10.67	-0.45
9	03-10-07	4.0	4.0	11.29	10.81	-0.48	90.6	86.8	-3.8	9.98	9.66	-0.32
4	03-10-21	1.5	1.0	10.82	10.81	-0.01	77.6	75.3	-2.3	8.45	8.20	-0.25
5	03-10-21	3.0	3.0	10.37	10.36	-0.01	71.3	68.7	-2.6	8.12	7.56	-0.56
6	03-10-21	6.5	6.5	10.28	10.27	-0.01	77.3	71.5	-5.8	8.53	7.89	-0.64
7	03-10-21	6.0	6.0	10.84	10.12	-0.72	84.8	78.8	-6.0	9.44	8.72	-0.72
8	03-10-21	4.0	4.0	10.77	10.76	-0.01	94.7	91.2	-3.5	10.33	9.94	-0.39
9	03-10-21	5.0	5.0	11.32	11.29	-0.03	87.5	84.7	-2.8	9.42	9.12	-0.30

Table 5.6. Summary of temperature and oxygen profile data, Grand River, 2004

Station ID	Date yy-mm-dd	Depth Max	Depth Min	ΔD	Temperature (oC) Max	Temperature (oC) Min	ΔT	DO - % Saturation Max	DO - % Saturation Min	Δ %	DO (mg/L) Max	DO (mg/L) Min	ΔDO
5	04-06-15	3.3	0.2	**3.2**	24.43	21.73	**-2.70**	155.4	102.1	**-53.3**	12.95	8.95	**-4.00**
6	04-06-15	5.7	0.2	**5.5**	24.19	21.90	**-2.29**	173.4	103.3	**-70.1**	14.63	9.02	**-5.61**
7	04-06-15	4.3	0.2	**4.2**	25.49	21.99	**-3.50**	180.1	113.0	**-67.1**	14.79	9.86	**-4.93**
8	04-06-15	3.9	0.2	**3.8**	26.30	22.02	**-4.28**	195.5	98.0	**-97.5**	15.79	8.55	**-7.24**
9	04-06-15	3.4	0.2	**3.2**	24.35	23.10	**-1.25**	145.6	101.3	**-44.3**	12.15	8.65	**-3.50**
10	04-06-15	1.4	0.2	**1.2**	24.86	24.83	**-0.03**	164.1	163.2	**-0.9**	13.57	13.49	**-0.08**
1	04-06-23	6.0	0.2	**5.8**	21.56	18.28	**-3.28**	100.6	81.3	**-19.3**	8.85	7.40	**-1.45**
2	04-06-23	4.5	0.2	**4.4**	22.72	20.65	**-2.07**	126.2	83.8	**-42.4**	10.88	7.51	**-3.37**
3	04-06-23	4.0	0.2	**3.8**	22.06	20.63	**-1.43**	109.9	87.9	**-22.0**	9.58	7.88	**-1.70**
5	04-06-23	3.6	0.2	**3.5**	22.30	20.35	**-1.95**	115.7	84.0	**-31.7**	10.04	7.57	**-2.47**
6	04-06-23	6.0	0.2	**5.9**	13.37	21.37	**8.00**	127.9	94.6	**-33.3**	10.88	8.36	**-2.52**
7	04-06-23	5.0	0.2	**4.9**	22.38	20.36	**-2.02**	112.9	77.2	**-35.7**	9.78	6.95	**-2.83**
8	04-06-23	4.0	0.2	**3.9**	22.95	21.42	**-1.53**	118.7	101.8	**-16.9**	10.17	8.98	**-1.19**
9	04-06-23	3.5	0.2	**3.3**	22.13	20.20	**-1.93**	103.8	84.2	**-19.6**	9.03	7.61	**-1.42**
10	04-06-23	2.0	0.2	**1.9**	22.52	22.50	**-0.02**	120.1	118.8	**-1.3**	10.38	10.27	**-0.11**
1	04-06-29	5.8	0.2	**5.6**	20.36	20.19	**-0.17**	93.3	87.5	**-5.8**	8.40	7.91	**-0.49**
2	04-06-29	4.5	0.2	**4.4**	10.39	19.98	**9.59**	96.8	88.9	**-7.9**	8.72	8.07	**-0.65**
3	04-06-29	3.0	0.2	**2.9**	20.07	20.04	**-0.03**	99.5	97.7	**-1.8**	9.02	8.86	**-0.16**
5	04-06-29	3.5	0.2	**3.3**	20.66	20.31	**-0.35**	109.7	107.2	**-2.5**	9.83	9.67	**-0.16**
6	04-06-29	4.7	0.2	**4.5**	21.09	20.53	**-0.56**	103.0	95.5	**-7.5**	9.15	8.58	**-0.57**
8	04-06-29	3.5	0.2	**3.4**	19.98	19.39	**-0.59**	86.5	77.6	**-8.9**	7.85	7.12	**-0.73**
9	04-06-29	3.5	0.2	**3.3**	20.50	19.63	**-0.87**	104.8	96.4	**-8.4**	9.42	8.81	**-0.61**
10	04-06-29	2.0	0.2	**1.9**	20.79	20.75	**-0.04**	105.8	105.1	**-0.7**	9.45	9.39	**-0.06**
1	04-07-06	6.0	0.2	**5.8**	23.58	21.56	**-2.02**	89.9	78.3	**-11.6**	7.61	6.76	**-0.85**
2	04-07-06	4.5	0.2	**4.3**	23.44	23.15	**-0.29**	101.7	83.3	**-18.4**	8.63	7.11	**-1.52**
3	04-07-06	4.0	0.2	**3.9**	23.60	22.94	**-0.66**	104.4	83.2	**-21.2**	8.83	7.13	**-1.70**
5	04-07-06	3.0	0.2	**2.8**	24.61	22.94	**-1.67**	151.3	88.8	**-62.5**	12.59	7.61	**-4.98**
6	04-07-06	6.0	0.2	**5.8**	24.95	23.04	**-1.91**	179.3	86.2	**-93.1**	14.95	7.37	**-7.58**
7	04-07-06	5.0	0.2	**4.9**	25.30	23.00	**-2.30**	182.5	88.3	**-94.2**	15.03	7.56	**-7.47**
8	04-07-06	4.0	0.2	**3.9**	25.83	22.75	**-3.08**	164.5	91.8	**-72.7**	13.85	7.89	**-5.96**
9	04-07-06	3.5	0.1	**3.4**	25.36	22.65	**-2.71**	177.2	99.8	**-77.4**	14.67	8.60	**-6.07**
10	04-07-06	1.5	0.1	**1.3**	24.56	24.49	**-0.07**	113.6	113.1	**-0.5**	9.45	9.41	**-0.04**
1	04-07-13	6.0	0.1	**5.9**	25.19	22.79	**-2.40**	158.4	42.5	**-115.9**	13.01	3.62	**-9.39**
2	04-07-13	4.5	0.1	**4.4**	24.94	24.04	**-0.90**	127.7	69.0	**-58.7**	10.54	5.79	**-4.75**
3	04-07-13	4.0	0.1	**3.9**	24.96	24.24	**-0.72**	150.9	84.5	**-66.4**	12.45	7.06	**-5.39**
5	04-07-13	3.5	0.1	**3.4**	25.58	22.54	**-3.04**	192.8	49.4	**-143.4**	15.73	4.26	**-11.47**
6	04-07-13	6.0	0.1	**5.9**	27.31	22.89	**-4.42**	289.9	60.3	**-229.6**	22.93	5.17	**-17.76**
7	04-07-13	5.0	0.1	**5.0**	26.38	22.40	**-3.98**	155.9	41.6	**-114.3**	12.54	3.61	**-8.93**
8	04-07-13	4.0	0.1	**3.9**	27.00	22.62	**-4.38**	147.8	66.9	**-80.9**	11.79	5.77	**-6.02**
9	04-07-13	4.5	0.1	**4.4**	26.16	22.79	**-3.37**	112.5	67.9	**-44.6**	9.08	5.83	**-3.25**
10	04-07-13	2.1	0.1	**2.0**	25.71	25.68	**-0.03**	109.9	107.0	**-2.9**	8.95	8.71	**-0.24**
1	04-07-20	6.0	0.1	**5.9**	23.39	22.78	**-0.61**	104.4	79.8	**-24.6**	8.87	6.84	**-2.03**
2	04-07-20	4.5	0.1	**4.4**	23.96	22.71	**-1.25**	115.5	50.6	**-64.9**	9.71	4.35	**-5.36**
3	04-07-20	4.0	0.1	**3.9**	23.58	22.93	**-0.65**	109.5	80.1	**-29.4**	9.27	6.86	**-2.41**
5	04-07-20	3.5	0.1	**3.4**	24.55	23.15	**-1.40**	112.6	86.7	**-25.9**	9.37	7.40	**-1.97**
6	04-07-20	6.1	0.1	**5.9**	24.43	23.25	**-1.18**	94.0	76.2	**-17.8**	7.83	6.49	**-1.34**
7	04-07-20	5.0	0.1	**4.9**	24.42	23.23	**-1.19**	92.3	77.9	**-14.4**	7.70	6.64	**-1.06**
8	04-07-20	4.1	0.1	**3.9**	25.20	24.10	**-1.10**	102.0	88.3	**-13.7**	8.38	7.40	**-0.98**
9	04-07-20	4.5	0.1	**4.4**	24.40	23.14	**-1.26**	91.4	74.9	**-16.5**	7.62	6.39	**-1.23**
10	04-07-20	2.0	0.1	**1.9**	25.29	25.23	**-0.06**	102.6	101.0	**-1.6**	8.41	8.29	**-0.12**
1	04-07-26	6.0	0.2	**5.8**	22.81	22.96	**0.15**	96.1	91.5	**-4.6**	8.26	7.86	**-0.40**
2	04-07-26	4.5	0.2	**4.3**	22.91	22.89	**-0.02**	103.4	98.3	**-5.1**	8.87	8.43	**-0.44**
3	04-07-26	4.1	0.2	**3.9**	22.82	22.66	**-0.16**	101.2	90.3	**-10.9**	8.70	7.78	**-0.92**
5	04-07-26	3.5	0.2	**3.3**	23.00	22.95	**-0.05**	103.6	92.0	**-11.6**	8.87	7.88	**-0.99**
6	04-07-26	6.1	0.2	**5.9**	23.01	22.90	**-0.11**	108.5	103.0	**-5.5**	8.29	8.84	**0.55**
7	04-07-26	5.0	0.2	**4.8**	23.18	23.00	**-0.18**	119.5	101.0	**-18.5**	10.20	8.65	**-1.55**
8	04-07-26	4.0	0.2	**3.8**	22.27	22.24	**-0.03**	87.3	87.0	**-0.3**	7.58	7.55	**-0.03**
9	04-07-26	4.5	0.2	**4.3**	23.21	23.18	**-0.03**	103.3	102.7	**-0.6**	8.81	8.75	**-0.06**
10	04-07-26	2.0	0.2	**1.8**	21.95	21.88	**-0.07**	90.3	88.9	**-1.4**	7.90	7.77	**-0.13**

(cont'd)

Table 5.6 (cont'd). Summary of temperature and oxygen profile data, Grand River, 2004

Station	Date	Depth			Temperature (oC)			Dissolved Oxygen					
								DO - % Saturation			DO (mg/L)		
ID	yy-mm-dd	Max	Min	ΔD	Max	Min	ΔT	Max	Min	Δ %	Max	Min	ΔDO
1	04-08-03	6.1	0.1	**6.0**	25.73	24.38	**-1.35**	119.6	86.5	**-33.1**	9.74	7.21	**-2.53**
2	04-08-03	5.0	0.1	**4.9**	26.23	24.42	**-1.81**	139.3	89.1	**-50.2**	11.23	7.43	**-3.80**
3	04-08-03	4.0	0.1	**3.9**	25.75	24.31	**-1.44**	120.6	89.2	**-31.4**	9.81	7.45	**-2.36**
5	04-08-03	3.5	0.1	**3.4**	25.43	24.58	**-0.85**	110.5	90.3	**-20.2**	9.04	7.50	**-1.54**
6	04-08-03	6.5	0.1	**6.4**	26.00	24.68	**-1.32**	117.1	88.4	**-28.7**	7.50	7.33	**-0.17**
7	04-08-03	5.0	0.1	**4.9**	24.95	23.75	**-1.20**	99.3	78.6	**-20.7**	8.20	6.63	**-1.57**
8	04-08-03	4.0	0.1	**3.9**	27.30	25.08	**-2.22**	136.1	96.9	**-39.2**	10.77	7.98	**-2.79**
9	04-08-03	5.0	0.1	**4.9**	26.57	24.99	**-1.58**	117.9	88.4	**-29.5**	9.45	7.30	**-2.15**
10	04-08-03	2.1	0.1	**2.0**	25.69	25.59	**-0.10**	108.0	106.6	**-1.4**	8.82	8.68	**-0.14**
1	04-08-09	6.1	0.2	**5.9**	22.80	22.14	**-0.66**	129.5	101.4	**-28.1**	11.14	8.83	**-2.31**
2	04-08-09	4.5	0.2	**4.3**	23.41	21.88	**-1.53**	149.9	95.3	**-54.6**	12.76	8.34	**-4.42**
3	04-08-09	4.0	0.2	**3.8**	23.35	22.33	**-1.02**	136.7	81.3	**-55.4**	11.64	7.05	**-4.59**
5	04-08-09	3.5	0.2	**3.3**	23.61	21.91	**-1.70**	178.4	118.1	**-60.3**	15.10	10.32	**-4.78**
6	04-08-09	6.5	0.2	**6.3**	24.02	21.85	**-2.17**	208.6	130.7	**-77.9**	17.52	11.44	**-6.08**
7	04-08-09	5.0	0.2	**4.8**	23.47	21.59	**-1.88**	198.3	97.7	**-100.6**	16.83	8.60	**-8.23**
8	04-08-09	3.5	0.2	**3.4**	24.71	21.70	**-3.01**	223.5	122.0	**-101.5**	18.53	10.70	**-7.83**
9	04-08-09	4.5	0.2	**4.3**	24.85	21.50	**-3.35**	190.0	114.6	**-75.4**	15.72	10.10	**-5.62**
10	04-08-09	2.0	0.2	**1.8**	22.71	22.68	**-0.03**	127.1	126.0	**-1.1**	10.94	10.85	**-0.09**
1	04-08-23	6.1	0.2	**5.9**	21.94	21.42	**-0.52**	119.4	103.8	**-15.6**	10.44	9.16	**-1.28**
2	04-08-23	4.5	0.2	**4.4**	22.47	21.08	**-1.39**	139.5	79.0	**-60.5**	72.06	7.02	**-65.04**
3	04-08-23	4.0	0.2	**3.9**	22.42	21.55	**-0.87**	119.3	88.1	**-31.2**	10.33	7.75	**-2.58**
5	04-08-23	3.5	0.1	**3.4**	21.76	21.51	**-0.25**	114.4	105.8	**-8.6**	10.03	9.32	**-0.71**
6	04-08-23	6.1	0.2	**5.9**	21.81	21.44	**-0.37**	117.4	105.3	**-12.1**	10.28	9.29	**-0.99**
7	04-08-23	5.0	0.2	**4.9**	21.29	20.86	**-0.43**	119.6	108.6	**-11.0**	10.60	9.68	**-0.92**
8	04-08-23	3.5	0.1	**3.4**	21.52	21.35	**-0.17**	123.9	120.0	**-3.9**	10.91	10.60	**-0.31**
9	04-08-23	4.5	0.2	**4.4**	21.05	20.10	**-0.95**	116.8	74.3	**-42.5**	10.38	6.72	**-3.66**
10	04-08-23	2.0	0.2	**1.9**	20.80	20.71	**-0.09**	98.0	96.7	**-1.3**	8.75	8.64	**-0.11**
1	04-08-30	6.0	0.2	**5.8**	22.70	22.52	**-0.18**	86.2	79.0	**-7.2**	7.42	6.83	**-0.59**
2	04-08-30	4.5	0.2	**4.3**	22.65	22.31	**-0.34**	90.4	80.3	**-10.1**	7.79	6.96	**-0.83**
3	04-08-30	4.0	0.2	**3.8**	22.59	22.21	**-0.38**	89.7	83.4	**-6.3**	7.78	7.25	**-0.53**
5	04-08-30	3.5	0.2	**3.4**	22.50	22.40	**-0.10**	88.3	83.3	**-5.0**	7.63	7.21	**-0.42**
6	04-08-30	6.5	0.2	**6.3**	22.63	22.59	**-0.04**	84.9	83.4	**-1.5**	7.32	7.19	**-0.13**
7	04-08-30	5.0	0.2	**4.8**	22.46	22.44	**-0.02**	88.7	87.7	**-1.0**	7.67	7.58	**-0.09**
8	04-08-30	4.0	0.2	**3.8**	22.51	22.44	**-0.07**	90.7	89.1	**-1.6**	7.84	7.71	**-0.13**
9	04-08-30	4.5	0.2	**4.3**	22.28	22.26	**-0.02**	79.0	78.0	**-1.0**	6.85	6.77	**-0.08**
10	04-08-30	2.0	0.2	**1.8**	22.04	22.00	**-0.04**	79.6	79.4	**-0.2**	6.94	6.92	**-0.02**
1	04-09-10	6.0	0.2	**5.8**	21.90	19.28	**-2.62**	108.7	68.2	**-40.5**	9.51	6.29	**-3.22**
2	04-09-10	4.5	0.2	**4.3**	22.61	20.19	**-2.42**	130.2	79.7	**-50.5**	11.23	7.21	**-4.02**
3	04-09-10	4.0	0.2	**3.8**	21.74	19.93	**-1.81**	102.7	77.6	**-25.1**	9.01	7.05	**-1.96**
5	04-09-10	3.5	0.2	**3.3**	21.03	20.40	**-0.63**	79.6	72.8	**-6.8**	7.08	6.56	**-0.52**
6	04-09-10	6.5	0.2	**6.3**	21.49	20.29	**-1.20**	85.7	71.9	**-13.8**	7.64	6.48	**-1.16**
7	04-09-10	5.0	0.2	**4.8**	22.07	20.13	**-1.94**	91.6	73.1	**-18.5**	8.01	6.62	**-1.39**
8	04-09-10	3.5	0.2	**3.3**	21.52	19.59	**-1.93**	100.9	82.3	**-18.6**	8.88	7.51	**-1.37**
9	04-09-10	4.5	0.2	**4.3**	22.19	20.58	**-1.61**	108.4	93.1	**-15.3**	9.47	8.35	**-1.12**
10	04-09-10	2.0	0.2	**1.8**	21.35	21.32	**-0.03**	99.2	96.1	**-3.1**	8.77	8.50	**-0.27**
1	04-09-23	6.1	0.3	**5.8**	20.71	19.33	**-1.38**	135.5	62.1	**-73.4**	12.13	5.71	**-6.42**
2	04-09-23	4.5	0.3	**4.3**	20.37	19.14	**-1.23**	113.7	65.4	**-48.3**	10.24	6.03	**-4.21**
3	04-09-23	4.0	0.3	**3.7**	20.97	19.45	**-1.52**	117.7	55.2	**-62.5**	10.48	5.07	**-5.41**
5	04-09-23	3.5	0.3	**3.3**	22.02	18.70	**-3.32**	149.6	89.1	**-60.5**	13.46	8.29	**-5.17**
6	04-09-23	6.0	0.3	**5.8**	21.53	19.10	**-2.43**	154.9	108.2	**-46.7**	13.98	10.00	**-3.98**
7	04-09-23	5.0	0.3	**4.8**	21.93	18.32	**-3.61**	139.1	46.6	**-92.5**	12.25	4.37	**-7.88**
8	04-09-23	3.5	0.2	**3.3**	22.54	18.39	**-4.15**	153.4	89.1	**-64.3**	13.43	8.35	**-5.08**
9	04-09-23	4.5	0.3	**4.3**	23.13	17.84	**-5.29**	169.2	50.6	**-118.6**	14.81	4.80	**-10.01**
10	04-09-23	2.0	0.2	**1.8**	20.55	19.84	**-0.71**	124.0	13.7	**-110.3**	11.28	10.20	**-1.08**
1	04-10-05	5.8	0.3	**5.6**	16.06	15.15	**-0.91**	106.2	81.3	**-24.9**	10.44	8.15	**-2.29**
2	04-10-05	4.5	0.3	**4.3**	16.53	15.14	**-1.39**	115.1	85.4	**-29.7**	11.20	8.57	**-2.63**
3	04-10-05	4.0	0.3	**3.8**	15.72	15.08	**-0.64**	100.0	79.3	**-20.7**	9.91	7.96	**-1.95**
5	04-10-05	3.5	0.3	**3.3**	16.38	15.21	**-1.17**	100.4	80.8	**-19.6**	9.81	8.09	**-1.72**
6	04-10-05	6.5	0.3	**6.2**	16.69	15.73	**-0.96**	96.5	83.0	**-13.5**	9.37	8.21	**-1.16**
7	04-10-05	5.0	0.3	**4.7**	16.57	15.86	**-0.71**	101.6	87.5	**-14.1**	9.91	8.64	**-1.27**
8	04-10-05	3.5	0.3	**3.2**	15.20	14.46	**-0.74**	103.3	91.4	**-11.9**	10.36	9.30	**-1.06**
9	04-10-05	4.5	0.3	**4.2**	15.31	14.77	**-0.54**	89.7	85.8	**-3.9**	9.00	8.67	**-0.33**
10	04-10-05	2.0	0.3	**1.7**	13.03	12.81	**-0.22**	82.5	81.1	**-1.4**	8.67	8.56	**-0.11**
1	04-10-10	6.0	0.2	**5.8**	9.83	9.75	**-0.08**	93.9	91.7	**-2.2**	10.61	10.38	**-0.23**
2	04-10-10	4.5	0.2	**4.3**	10.02	9.98	**-0.04**	94.0	93.0	**-1.0**	10.57	10.47	**-0.10**
3	04-10-10	4.0	0.2	**3.8**	10.05	9.99	**-0.06**	93.6	92.2	**-1.4**	10.52	10.37	**-0.15**
5	04-10-20	3.5	0.2	**3.3**	10.10	10.08	**-0.02**	89.0	88.1	**-0.9**	9.99	9.89	**-0.10**
6	04-10-20	6.5	0.2	**6.3**	9.82	9.73	**-0.09**	88.7	86.6	**-2.1**	10.03	9.81	**-0.22**
7	04-10-20	5.0	0.2	**4.8**	9.67	9.60	**-0.07**	90.9	89.0	**-1.9**	10.32	10.11	**-0.21**
8	04-10-20	4.0	0.2	**3.8**	10.11	10.10	**-0.01**	89.8	89.5	**-0.3**	10.08	10.05	**-0.03**
9	04-10-20	4.0	0.2	**3.8**	9.62	9.59	**-0.03**	87.9	86.6	**-1.3**	9.99	9.83	**-0.16**
10	04-10-20	2.0	0.2	**1.8**	9.53	9.51	**-0.02**	91.7	91.1	**-0.6**	10.44	10.36	**-0.08**

Table 5.7. Summary of temperature and oxygen profile data, Grand River, 2005.

Station	Date	Depth			Temperature (oC)			Dissolved Oxygen: DO - % Saturation			Dissolved Oxygen: DO (mg/L)		
ID	yy-mm-dd	Max	Min	ΔD	Max	Min	ΔT	Max	Min	Δ %	Max	Min	ΔDO
1	05-06-15	6.1	0.0	6.1	26.30	22.05	-4.25	85.9	56.3	-29.6	6.91	4.91	-2.00
2	05-06-15	4.5	0.0	4.5	26.49	21.30	-5.19	84.2	2.9	-81.3	6.76	0.26	-6.50
3	05-06-15	3.9	0.0	3.9	26.38	26.22	-0.16	81.2	78.7	-2.5	6.54	6.33	-0.21
4	05-06-15	0.0	0.0	0.0	26.70	26.70	0.00	90.4	90.4	0.0	7.22	7.22	0.00
5	05-06-15	0.0	0.0	0.0	26.64	26.64	0.00	83.0	82.9	-0.1	6.64	6.64	0.00
6	05-06-15	6.1	0.0	6.1	26.76	19.32	-7.44	87.3	1.6	-85.7	6.97	0.15	-6.82
7	05-06-15	5.0	0.0	5.0	26.77	24.69	-2.08	106.9	84.6	-22.3	8.53	7.01	-1.52
8	05-06-15	4.0	0.0	4.0	26.63	20.19	-6.44	102.0	2.5	-99.5	8.16	0.23	-7.93
9	05-06-15	4.6	0.0	4.6	27.56	17.73	-9.83	111.2	1.6	-109.6	8.76	0.15	-8.61
10	05-06-15	2.0	0.0	2.0	25.99	25.70	-0.29	106.4	101.7	-4.7	8.62	8.27	-0.35
1	05-06-27	6.0	0.2	5.8	27.44	17.88	-9.56	208.8	58.7	-150.1	16.73	5.09	-11.64
2	05-06-27	5.0	0.2	4.8	28.06	19.99	-8.07	220.8	16.5	-204.3	17.45	1.50	-15.95
3	05-06-27	4.0	0.2	3.8	28.85	24.05	-4.80	266.9	12.5	-254.4	20.54	1.05	-19.49
4	05-06-27	0.6	0.2	0.4	29.36	28.18	-1.18	314.4	285.7	-28.7	24.48	21.81	-2.67
5	05-06-27	3.5	0.2	3.3	30.32	23.57	-6.75	343.0	25.1	-317.9	26.07	2.12	-23.95
6	05-06-27	6.0	0.2	5.8	31.78	22.05	-9.73	334.5	1.6	-332.9	25.40	0.14	-25.26
7	05-06-27	5.0	0.2	4.8	29.72	22.33	-7.39	356.2	2.5	-353.7	27.57	0.22	-27.35
8	05-06-27	3.5	0.2	3.3	32.05	23.87	-8.18	262.6	22.7	-239.9	20.51	1.91	-18.60
9	05-06-27	4.5	0.2	4.3	30.96	20.47	-10.49	275.7	3.7	-272.0	20.46	0.33	-20.13
10	05-06-27	2.0	0.2	1.8	28.53	28.37	-0.16	128.3	123.2	-5.1	9.92	9.56	-0.36
1	05-07-12	6.0	0.2	5.8	27.06	22.07	-4.99	167.0	9.4	-157.6	13.26	0.82	-12.44
2	05-07-12	4.5	0.2	4.3	27.37	24.80	-2.57	164.2	46.1	-118.1	12.97	3.82	-9.15
3	05-07-12	4.0	0.2	3.8	27.26	24.51	-2.75	147.4	10.8	-136.6	11.66	0.90	-10.76
4	05-07-12	1.1	0.2	0.9	28.28	26.34	-1.94	217.1	133.0	-84.1	16.97	10.70	-6.27
5	05-07-12	3.5	0.2	3.4	29.14	25.13	-4.01	237.2	14.8	-222.4	18.16	1.22	-16.94
6	05-07-12	6.0	0.2	5.8	31.61	24.93	-6.68	268.0	1.4	-266.6	19.67	0.11	-19.56
7	05-07-12	5.0	0.2	4.8	28.91	25.02	-3.89	208.1	8.8	-199.3	16.48	0.73	-15.75
8	05-07-12	4.1	0.2	3.9	29.54	24.87	-4.67	204.8	50.8	-154.0	15.72	4.20	-11.52
9	05-07-12	4.0	0.2	3.9	29.08	23.94	-5.14	164.6	20.3	-144.3	12.61	1.71	-10.90
10	05-07-12	2.0	0.2	1.8	28.53	27.94	-0.59	104.0	90.1	-13.9	8.13	6.97	-1.16
1	05-07-18	5.6	0.1	5.4	28.16	28.14	-0.02	85.4	82.7	-2.7	6.65	6.44	-0.21
2	05-07-18	4.5	0.1	4.3	28.03	27.96	-0.07	92.9	87.1	-5.8	7.25	6.81	-0.44
3	05-07-18	4.0	0.1	3.8	27.98	27.91	-0.07	97.3	96.7	-0.6	7.60	7.56	-0.04
4	05-07-18	1.5	0.1	1.4	28.13	28.09	-0.04	90.1	89.3	-0.8	7.02	6.97	-0.05
5	05-07-18	3.6	0.1	3.4	27.95	27.87	-0.08	77.2	73.9	-3.3	6.03	5.79	-0.24
6	05-07-18	6.5	0.1	6.4	28.69	28.52	-0.17	79.1	76.3	-2.8	6.10	5.91	-0.19
7	05-07-18	5.1	0.1	4.9	28.06	27.81	-0.25	84.0	77.6	-6.4	6.55	6.08	-0.47
8	05-07-18	4.0	0.1	3.9	27.26	26.76	-0.50	80.7	75.7	-5.0	6.39	6.05	-0.34
9	05-07-18	5.1	0.1	5.0	26.80	26.65	-0.15	81.0	78.3	-2.7	6.47	6.27	-0.20
10	05-07-18	2.8	0.1	2.7	27.21	27.18	-0.03	82.0	81.3	-0.7	6.50	6.45	-0.05
1	05-07-20	5.9	0.2	5.8	28.18	17.99	-10.19	86.6	68.1	-18.5	6.74	5.58	-1.16
2	05-07-20	4.5	0.2	4.3	27.78	27.03	-0.75	90.2	74.5	-15.7	7.07	5.92	-1.15
3	05-07-20	4.0	0.2	3.8	27.97	26.62	-1.35	95.9	81.5	-14.4	7.49	6.53	-0.96
4	05-07-20	1.6	0.2	1.4	28.23	26.51	-1.72	81.6	58.8	-22.8	6.35	4.72	-1.63
5	05-07-20	3.5	0.2	3.3	28.25	26.79	-1.46	84.0	64.7	-19.3	6.54	5.17	-1.37
6	05-07-20	6.5	0.2	6.3	28.00	26.16	-1.84	81.1	60.8	-20.3	6.34	4.91	-1.43
7	05-07-20	5.0	0.2	4.8	27.22	25.52	-1.70	86.2	62.4	-23.8	6.83	5.10	-1.73
8	05-07-20	4.0	0.2	3.8	29.18	27.06	-2.12	118.7	89.9	-28.8	9.09	7.15	-1.94
9	05-07-20	4.5	0.2	4.2	27.69	25.45	-2.24	96.7	69.7	-27.0	7.60	5.70	-1.90
10	05-07-20	2.0	0.2	1.8	27.64	27.46	-0.18	103.1	99.7	-3.4	8.11	7.87	-0.24

(cont'd)

Table 5.7 (cont'd). Summary of temperature and oxygen profile data, Grand River, 2005

Station	Date	Depth			Temperature (oC)			Dissolved Oxygen DO - % Saturation			DO (mg/L)		
ID	yy-mm-dd	Max	Min	ΔD	Max	Min	ΔT	Max	Min	Δ %	Max	Min	ΔDO
1	05-07-26	6.0	0.1	5.9	26.62	26.52	-0.10	93.8	76.5	-17.3	7.52	6.14	-1.38
2	05-07-26	4.5	0.1	4.4	26.38	26.12	-0.26	95.9	59.6	-36.3	7.72	4.82	-2.90
3	05-07-26	4.1	0.1	4.0	26.89	26.47	-0.42	93.8	85.2	-8.6	7.50	6.85	-0.65
4	05-07-26	1.5	0.1	1.4	26.70	26.64	-0.06	109.8	109.3	-0.5	8.78	8.76	-0.02
5	05-07-26	2.5	0.1	2.4	26.59	26.41	-0.18	117.2	106.9	-10.3	9.39	8.60	-0.79
6	05-07-26	5.9	0.1	5.9	26.46	26.14	-0.32	125.9	107.1	-18.8	10.11	8.65	-1.46
7	05-07-26	4.5	0.1	4.4	26.50	26.43	-0.07	123.2	117.4	-5.8	9.89	9.43	-0.46
8	05-07-26	3.5	0.1	3.4	26.19	26.04	-0.15	129.8	121.9	-7.9	10.48	9.86	-0.62
9	05-07-26	4.0	0.1	3.9	27.85	25.87	-1.98	153.2	87.4	-65.8	12.00	7.09	-4.91
10	05-07-26	1.5	0.1	1.4	26.23	26.21	-0.02	123.2	122.4	-0.8	9.94	9.88	-0.06
1	05-08-03	6.0	0.2	5.8	27.65	25.76	-1.89	125.3	33.3	-92.0	9.85	2.71	-7.14
2	05-08-03	4.5	0.2	4.3	27.54	25.54	-2.00	129.2	33.1	-96.1	10.18	2.70	-7.48
3	05-08-03	4.0	0.2	3.8	27.78	25.78	-2.00	131.6	26.2	-105.4	10.33	2.13	-8.20
4	05-08-03	1.5	0.2	1.4	27.67	26.60	-1.07	155.7	118.2	-37.5	12.24	9.47	-2.77
5	05-08-03	3.0	0.2	2.8	27.65	25.34	-2.31	181.2	39.8	-141.4	14.24	3.26	-10.98
6	05-08-03	6.5	0.2	6.4	27.91	24.96	-2.95	188.6	16.9	-171.7	14.76	1.39	-13.37
7	05-08-03	5.0	0.2	4.9	28.27	24.40	-3.87	230.6	28.6	-202.0	17.94	2.39	-15.55
8	05-08-03	4.0	0.2	3.9	28.28	24.87	-3.41	217.1	24.2	-192.9	16.88	2.00	-14.88
9	05-08-03	4.0	0.2	3.9	29.59	24.34	-5.25	225.4	41.7	-183.7	17.13	3.48	-13.65
10	05-08-03	2.0	0.2	1.8	27.88	27.79	-0.09	161.0	158.0	-3.0	12.63	12.39	-0.24
1	05-08-10	5.0	0.1	4.8	27.57	27.25	-0.32	103.3	80.0	-23.3	8.13	6.33	-1.80
2	05-08-10	4.6	0.2	4.4	27.57	26.26	-1.31	106.5	24.4	-82.1	8.38	1.97	-6.41
3	05-08-10	4.0	0.1	3.9	27.47	26.43	-1.04	92.4	31.2	-61.2	7.29	2.50	-4.79
4	05-08-10	1.0	0.2	0.8	27.55	27.54	-0.01	111.0	110.2	-0.8	8.74	8.68	-0.06
5	05-08-10	3.5	0.1	3.4	27.86	26.24	-1.62	118.3	22.0	-96.3	9.30	1.78	-7.52
6	05-08-10	6.0	0.2	5.8	28.16	26.78	-1.38	158.3	94.0	-64.3	12.33	7.50	-4.83
7	05-08-10	4.5	0.1	4.4	27.60	27.02	-0.58	133.5	105.6	-27.9	10.51	8.39	-2.12
8	05-08-10	3.5	0.1	3.4	28.48	27.70	-0.78	141.3	121.7	-19.6	10.94	9.56	-1.38
1	05-08-15	6.0	0.2	5.8	25.69	24.95	-0.74	74.9	52.9	-22.0	6.10	4.37	-1.73
2	05-08-15	4.5	0.2	4.3	25.47	24.79	-0.68	96.6	70.9	-25.7	7.90	5.87	-2.03
3	05-08-15	4.0	0.2	3.8	25.82	24.40	-1.42	108.8	74.0	-34.8	8.90	6.16	-2.74
4	05-08-15	1.5	0.2	1.3	26.35	24.17	-2.18	94.3	62.4	-31.9	7.58	5.23	-2.35
5	05-08-15	3.0	0.2	2.8	27.54	24.85	-2.69	115.8	60.3	-55.5	9.12	4.99	-4.13
6	05-08-15	6.5	0.2	6.3	27.54	24.82	-2.72	117.5	68.0	-49.5	9.46	5.62	-3.84
7	05-08-15	5.0	0.2	4.8	27.92	24.37	-3.55	119.8	71.8	-48.0	9.47	5.99	-3.48
8	05-08-15	3.5	0.2	3.3	27.14	24.71	-2.43	107.1	74.4	-32.7	8.50	6.17	-2.33
9	05-08-15	4.5	0.2	4.3	26.40	23.46	-2.94	121.9	82.8	-39.1	9.86	7.03	-2.83
10	05-08-15	2.0	0.2	1.8	25.60	25.41	-0.19	130.3	127.7	-2.6	10.62	10.45	-0.17
1	05-08-25	5.5	0.3	5.2	22.63	22.44	-0.19	100.0	78.9	-21.1	8.62	6.82	-1.80
2	05-08-25	4.6	0.3	4.3	22.86	22.55	-0.31	104.8	74.8	-30.0	8.99	6.45	-2.54
3	05-08-25	3.5	0.3	3.3	23.38	22.98	-0.40	105.4	85.2	-20.2	8.96	7.29	-1.67
4	05-08-25	1.5	0.3	1.2	22.99	22.49	-0.50	96.5	79.2	-17.3	8.26	6.84	-1.42
5	05-08-25	3.5	0.3	3.2	23.04	22.19	-0.85	107.1	85.4	-21.7	9.16	7.42	-1.74
6	05-08-25	6.0	0.2	5.7	23.89	21.93	-1.96	122.9	83.2	-39.7	10.34	7.26	-3.08
7	05-08-25	5.0	0.2	4.8	23.33	21.30	-2.03	135.3	67.1	-68.2	11.56	5.93	-5.63
8	05-08-25	4.0	0.2	3.7	23.05	21.51	-1.54	106.3	81.9	-24.4	9.10	7.22	-1.88
9	05-08-25	4.0	0.2	3.8	23.66	22.24	-1.42	139.3	104.9	-34.4	11.78	9.12	-2.66
10	05-08-25	2.0	0.2	1.7	22.47	22.38	-0.09	117.6	109.2	-8.4	10.18	9.44	-0.74
1	05-09-12	5.5	0.2	5.3	23.43	22.63	-0.80	126.2	61.2	-65.0	10.72	5.27	-5.45
2	05-09-12	4.5	0.2	4.3	23.45	22.44	-1.01	138.0	69.4	-68.6	11.71	6.01	-5.70
3	05-09-12	4.0	0.2	3.8	23.30	22.06	-1.24	116.4	60.6	-55.8	9.91	5.28	-4.63
4	05-09-12	1.5	0.2	1.3	23.14	23.10	-0.04	123.5	120.2	-3.3	10.55	10.27	-0.28
5	05-09-12	3.5	0.2	3.3	24.08	22.23	-1.85	143.9	75.3	-68.6	12.09	6.54	-5.55
6	05-09-12	6.0	0.2	5.8	24.01	22.47	-1.54	162.1	116.9	-45.2	13.61	10.11	-3.50
7	05-09-12	5.0	0.2	4.8	24.03	22.14	-1.89	166.8	33.8	-133.0	14.00	2.94	-11.06
8	05-09-12	4.0	0.2	3.8	24.42	22.04	-2.38	160.6	86.6	-74.0	13.39	7.55	-5.84
9	05-09-12	4.5	0.2	4.3	24.64	21.44	-3.20	149.5	63.7	-85.8	12.40	5.61	-6.79
10	05-09-12	1.5	0.2	1.3	23.83	23.32	-0.51	125.5	115.4	-10.1	10.67	9.72	-0.95

Table 5.8. Summary of low oxygen (<5.5 mg/L) events measured at depth (5.5m) at Grand River logging station L5 during continuous logging June-September, 2005

Date (yyyy/mm/dd)	Duration (hours)	Duration (days)	Dissolved Oxygen (mg/L) Mean	Minimum	Max	Median	Mode
2005/06/26	292.00	12.17	0.30	0.03	3.53	0.18	0.10
2005/07/10	156.00	6.50	0.65	0.12	4.93	0.20	0.14
2005/07/21	3.50	0.15	4.93	4.86	4.96	4.93	4.96
2005/07/23	9.00	0.38	3.41	2.16	5.01	3.38	N/A
2005/07/25	15.50	0.65	1.82	0.25	4.91	1.89	N/A
2005/07/31	17.00	0.71	3.21	1.70	4.97	3.06	3.41
2005/08/01	132.50	5.52	0.68	0.07	4.66	0.09	0.08
2005/08/07	17.00	0.71	1.95	0.24	4.87	1.49	0.94
2005/08/08	17.00	0.71	1.49	0.07	4.98	1.20	0.10
2005/08/09	39.50	1.65	1.28	0.06	4.62	0.99	0.06
2005/08/11	26.00	1.08	2.65	0.93	4.98	2.31	3.29
2005/08/13	14.50	0.60	3.92	2.63	5.01	3.87	4.88
2005/08/15	17.00	0.71	3.52	1.87	4.93	3.62	3.97
2005/08/17	12.00	0.50	4.25	3.73	4.98	4.10	4.04
2005/08/18	2.00	0.08	3.79	3.24	4.16	3.99	N/A
2005/08/29	1.50	0.06	4.41	4.07	4.61	4.47	N/A
2005/08/29	1.00	0.04	4.25	3.89	4.49	4.36	N/A
2005/08/29	23.50	0.98	3.26	1.62	5.08	3.26	3.79
2005/09/07	1.00	0.04	4.82	4.68	4.95	4.84	N/A
2005/09/07	9.00	0.38	4.19	4.08	4.04	3.60	5.29
2005/09/08	8.00	0.33	4.21	3.04	5.18	4.21	N/A
2005/09/08	7.00	0.29	4.07	3.31	4.95	4.12	N/A
2005/09/09	3.50	0.15	4.14	3.24	4.91	4.29	4.33
2005/09/10	0.50	0.02	4.68	4.61	4.74	4.68	N/A
2005/09/12	1.50	0.06	4.61	4.45	4.79	4.61	N/A
2005/09/12	1.50	0.06	4.40	3.99	4.98	4.31	N/A
2005/09/12	19.00	0.79	3.62	2.73	4.98	3.39	3.22
2005/09/13	15.50	0.65	3.21	2.10	4.69	3.21	3.21
2005/09/15	3.50	0.15	3.95	2.68	4.91	3.85	N/A

Table 5.9. Example habitat volume constraints calculated for adult and young-of-year walleye, from select water column profile samples collected in the Grand River between Dunnville and Cayuga. (Temperature and oxygen depth equations in Appendix E-8).

Date of sampling	Depth below which temperature is acceptable (m)	Depth above which oxygen is acceptable (m)	Volume lost to high surface temperature (m^2)	volumen lost to low oxygen at depth (m^2)	Proportion of total river section volume lost days	Potential duration of conditions days
	Adult walleye (temperature <=25 °C and Oxygen >=2mg/L)					
27-Jun-05	2.8	4.0	9872025.09	395659.62	0.90	12.1
12-Jul-05	4.0	4.6	11076010.06	167980.27	0.98	6.5
03-Aug-05	4.2	4.7	11076010.06	167980.27	0.98	5.5
						24.1
	YOY walleye (temperatue <=28°C and Oxygen >=4mg/L)					
27-Jun-05	1.1	3.6	4523947.54	881030.36	0.47	12.1
12-Jul-05	0.5	4.0	2530485.55	395659.62	0.26	6.5
03-Aug-05	0.4	4.1	2530485.55	395659.62	0.26	5.5
						24.1

6.0 Habitat Quality – Summary and Conclusions

The preceding sections detail the results of a multi-year assessment program that sought to characterize the aquatic habitat quality of the lower reaches of the Grand River watershed, termed the southern Grand River (SGR). This involved both measurements of physical habitat (e.g. water chemistry, temperature, oxygen) as well as quantification of the biota (algae, benthic invertebrates and fish). The physical measures were used to describe the environment while measures derived from the biota were used as an index of what the current habitat was capable of supporting. The results were interpreted relative to: i) values deemed necessary for a healthy aquatic ecosystem (e.g. CCME guidelines for TP); ii) expectations based on historic records (e.g. fish species presence in fisheries) and iii) biotic indices scaled to permit interpretation of habitat state (e.g. Lake Erie Tributary Index of Biotic Integrity). The overall conclusion drawn from this assessment is that the aquatic habitat downstream of Brantford is degraded and cannot currently support much of the historically present or desired, flora and fauna. Further the full range of access to acceptable habitat within the SGR is prevented or limited for some species.

While observations were made of conditions that would prove lethal to particular species and life stages (e.g. $NO_3 > 2.93$ mg/L, toxic to amphibian eggs), many tolerable but sub-optimal conditions were also documented. Newcombe and Jensen (1996) highlight the ability of total suspended solids, at sub-lethal concentrations described here, to affect the behaviour and compromise the reproductive capacity of some fish species. Over the short term this might reduce the abundance or range of a particular species while over the long term it could contribute to the extirpation of that species from the community. Whereas some pelagic fish species may find their total habitat volume periodically restricted by lethal bottom anoxia, benthivorous species may be more frequently and permanently affected if the anoxia reduces benthic invertebrate diversity over time. It is the chronic exposure to all variables, including infrequently occurring less-than-lethal stressors, that shapes the habitat and determines the composition of the biota over the long term. This long term selection pressure in the SGR is reflected in biotic communities dominated by species tolerant of adverse conditions.

Measurements at all levels indicate that much of the Grand River's main channel downstream of Caledonia (and for some measures, downstream of Brantford) can be considered a eutrophic to hyper-eutrophic environment. This condition is undoubtedly human influenced and is chronic. Many of the factors implicated in reduced aquatic habitat quality are interconnected and likely contribute through more than one pathway, sometimes feeding back to previous stages or compounding other impairments. This interconnectedness complicates attempts to address the problem. A generalized picture was developed which links many of the observations described in the previous sections (Figure 6.1).

The observed high nutrient loads that in part define the eutrophic environment foster extremely high standing crops of planktonic algae and emergent cattail, particularly in the reservoir and lake-effect waters. Submerged macrophytes were noted as being rare to non-existent, a characteristic described during previous assessments of the area (Knapton 1993, Gilbert and Ryan 2007) and observed to characterize highly eutrophic reservoirs under experimental conditions (Kilgore et al. 1993). In addition to actual measures of water column chlorophyll, observed diurnal oxygen cycles are further evidence of the large planktonic biomass present. In theory, planktonic algae have the ability to reinforce their predominance in the plant community both directly and indirectly. They contribute to light extinction in the water column and subsequently "shade out" submerged aquatic plants and, by increasing oxygen demand, they indirectly structure the fish community; non-specialist, bottom scavenger fish species typical of eutrophic and low oxygen environments (e.g. common carp) tend to uproot any submerged macrophytes present. Submerged macrophytes themselves play an important habitat structuring function and their rarity itself, negatively influences the make-up of the fish community as well as the benthic invertebrate community. The high concentrations of total suspended solids observed similarly impede the establishment of submerged macrophyte communities through shading and smothering in depositional areas. Using a water quality index designed to capture much of this complexity Chow-Fraser (2006) described the wetlands downstream of Dunnville as "very degraded" and ranked them as among the worst of 110 Great Lakes coastal wetlands examined.

While this generalist picture probably applies to some degree in most of the lower river reach, gradients in measures suggest that the habitat is not uniform throughout. Patterns in water quality parameters along the longitudinal axis of the river point to differential loading, utilization, and possibly re-suspension of nutrients. While nitrates decline from Brantford to Port Maitland, organic nitrogen steadily increases. Total phosphorus, nitrite, and ammonia all decline from Brantford downstream to the area around Cayuga and then begin to climb as one moves further downstream. It is these latter measures which suggest Cayuga as an interface between some aspects of upstream and downstream habitat. Algal biomass is for the most part higher below than above Cayuga. Some benthic invertebrate observations point to improvements at in an upstream fashion. Indexes of fish health (only measured at Caledonia and downstream) similarly improve in an upstream fashion. As Cayuga represents the theoretical upstream limit of the backwater influence of the Dunnville dam, many of these changes in production and habitat health are undoubtedly linked to the change in hydrology (reduced flow energy, increased retention time) imposed by the structural change. The transition from a lotic to a lentic environment downstream of Cayuga alters the *effect* of the eutrophic conditions (high nutrients) and possibly the nutrient conditions themselves. The proposed ecological relationships (Figure 6.1) recognize the likelihood that under anoxic conditions, phosphorus can be released in a soluble reactive form (SRP) that is readily useable by algae. In effect, low flow, high temperature and high algae biomass conditions in the reservoir, may create a feedback loop (anoxia>SRP>algae) that exacerbates conditions. The predominance of uniform mud, muck and hard-pack substrate downstream of Cayuga, in contrast to the areas of exposed bedrock and riffle from Cayuga upstream to Caledonia, is another likely consequence of the altered hydrology and depositional zone imposed by the dam at Dunnville.

Subwatershed inputs to the main channel also offer exceptions to the generalized habitat picture presented above. They introduce important habitat diversity by way of offering altered environments (e.g. increased canopy in the McKenzie Ck. system) and potential refuge from such things as suspended solid loads (Boston Creek) or extreme temperatures (groundwater in the Rogers Creek system). In addition to protection from summer high temperatures, Peterson and Rabeni (1996) emphasize the important winter refuge role played by groundwater-fed streams that are tributary to large warmwater rivers. The decommissioning of a dam and draining of an impoundment on the Rogers Creek system by the GRCA in 2005 has undoubtedly enhanced its ability to offer thermal refuge. The influence of subwatershed inputs on the main channel also includes a general increase in fish diversity in the immediate vicinity of the tributary mouth, a condition noted by Kiffney et al. (2006). Statzner and Higler (1985) describe the ability of subwatersheds to partially "reset" a river channel to a previous (upstream) condition as characterized by the River Continuum Concept (RCC; Vannote et al. 1980).
It should be noted that most large subwatersheds in the lower river reach empty to the main channel well above Cayuga, the theoretical upstream limit to the reservoir influence of the Dunnville dam (Figure 6.2). Historically, wetland areas adjacent to the main river channel would have provided additional habitat diversity however these areas are currently degraded and unable

to sufficiently provide habitat function. Unfortunately but understandably, the healthiest adjacent wetland in the Cayuga to Dunnville corridor is the one most hydrologically separated from the waters of the main channel (Gilbert and Ryan, 2007).

Addressing habitat quality issues.

Tackling water quality issues begins with sourcing inputs. While it is important to recognize that the underlying geology and geomorphology of the lower river reaches will place bounds on the type of aquatic ecosystem that can exist, it is apparent that anthropomorphic stressors, particularly high phosphorus and nitrogen inputs, are currently impairing the lower reach of the Grand River. The lower reaches of large river systems have inherent characteristics that differentiate them from middle and upper reaches as described by the RCC. According to this theory, as stream order increases, there is a natural progression of the ecosystem from an allochthanous to an autochthanous food chain. Particulate organic input from periphyton gives way to inputs from phytoplankton, macrophytes decline from highs that occur mid-order and sediment burrowers increase over benthic filter feeders (Vannote et al. 1980, Minshall et al. 1985). These characteristics are magnified in the lower Grand, and taken to extremes below Cayuga; planktonic algae essentially exclude macrophytes and periphyton and organic pollution-tolerant sediment burrowers dominate.

While recognizing the significance of upstream loading of pollutants, contributions from both point and non-point sources within the lower river reach should not be discounted. Lack of information on subwatershed and overland flows complicate attempts to estimate loading however differences in individual water quality measures may be helpful in identifying types of pollution sources. For instance Fairchild creek has a stronger urban anthropogenic signature (Cl^-) than Boston and McKenzie Creeks which consistently have higher summer concentrations of TP. Similarly, McKenzie Creek can be differentiated from Boston and Fairchild by its relatively high concentrations of organic nitrogen.

In the main channel, the longitudinal increase in organic nitrogen with distance downstream from Brantford can not be solely attributed to increasing algal biomass. The more rural landscape may be providing increased input from such sources as increased livestock production coupled with flashy overland flows and un-vegetated river banks. In this less populated part of the watershed, contributions of organic nitrogen from overcapacity septic systems and water pollution control plants should not be discounted.

Many of the consequences of high nutrient loading and poor water quality are exacerbated in the zone of river immediately in the backwater of the Dunnville dam. This affected area represents a considerable portion of the lower river reach (Figure 6.2). Removing this impediment would return the hydrology of this section of river to a more natural state. The RCC emphasises that the longitudinal axis of a river system represents a continuum of continuously integrating series of physical gradients and associated biotic adjustments (Vannote et al. 1980). Reservoirs and ponding alter this dynamic. Under a dam removal scenario, the slowing of the river and deposition / re-suspension of particles would become a dynamic process, influenced by seiche effects of Lake Erie rather than imposed at a fixed point. Sediment transport would increase.

The resulting decrease in fragmentation of the river would improve habitat on a number of fronts, additional to those associated with water quality. Gilbert and Ryan (2007) note the changes that such an action would have on wetland coverage, location, and associated plant communities. It is conceivable that more diverse bottom substrate would be uncovered downstream of Cayuga following the flushing of accumulated sediment. Unimpeded two way access would benefit not only the fish community but the ecosystem as a whole. The negative effects of river ecosystem fragmentation have been well documented (Lingnon et al. 1995, Metcalfe-Smith et al. 2000, Noakes et al. 2000, Petts 1984, Porto et al. 1999, Vaugh and Taylor 1999). With the understanding that improvements in water quality may take a long time to accomplish, a more dynamic, lake-seiche affected lower river may prove less prone to bottom anoxia. Where low oxygen conditions persist, fish would have freer access to move and avoid sub-optimal or lethal locations. The same would hold true for high summer temperatures which may become more extreme and more prevalent under climate change scenarios. As noted by the Instream Flow Council (2002), water temperature in most North American rivers increases toward the mouth, such that the mean channel is at or near mean monthly air temperature.

Integral to any efforts at habitat rehabilitation, is the need for continued monitoring over time. The development of a program for monitoring is essential if adaptive management is to be practiced. and must occur concurrent with restoration strategy development (Roni et al. 2005, Williams et al. 1997). Necessary are measurements that are sensitive to targeted changes. In this assessment we considered both individual habitat measures as well as integrators of the effects of those measures (i.e. biota). Both have limitations but elements of each are likely required in order to determine if broad ecosystem change is occurring over time.

Although the known range of some water quality parameters was expanded through the current assessment, the increased sampling frequency did not greatly alter any overall characterization of water quality beyond what could be concluded based on long term provincial water quality monitoring. The increased spatial sampling did help elucidate the overall nutrient dynamics of the system however it did not indicate obvious points of loading. This may be due to a lack of corresponding flow information over the same spatial scale or to a predominance of non-point sources. High variability of water quality parameters might preclude attempts to show incremental improvements. Previously established objectives should continue to be targeted (e.g. 0.03 mg/L total phosphorus).

As an integrator of nutrients, algal biomass (as indicated by Ch-*a* concentration) may be a more suitable parameter with which to monitor change, especially if movement toward mesotrophy is a goal. Seasonal variability would dictate that multiple samples be collected from spring through fall. Similarly, knowledge of the frequency, and extent of low oxygen events (one significant outcome of eutrophication) would be useful. As noted previously, oxygen depletion can be hard to capture even with frequent “snapshot” monitoring. Close-to-substrate continuous monitoring at key locations and appropriate summaries would be required if improved oxygen regime were to be chosen as an objective. Current stations for continuous dissolved oxygen monitoring in the Grand River watershed (GRCA) are located based on the functional needs of monitoring oxygen recovery downstream of point source inputs (particularly municipal WPCP inputs) and so do not necessarily describe oxygen in areas susceptible to anoxia from other oxygen demands (e.g. organic sediment).

Benthic invertebrate indices, another habitat integrator approach, especially those based on identification to species, are time consuming and potentially costly. More rapid approaches (requiring identification to family) might not be sensitive to change. Developing a benthic invertebrate monitoring tool could be done within the context of the Ontario Benthic Biomonitoring Protocol (Jones et al. 2004) but with modifications as necessary to acknowledge the river lake interface environment and with careful recognition of seasonal sensitivities. Fish indices, particularly a well developed IBI, would probably be sensitive to many aspects of change in habitat quality. As an integrator of health at more than one trophic level, parsing out contributing factors may be problematic however it would well serve the purpose of describing overall ecosystem improvements. A program to develop a fish IBI sensitive to the Grand River environment and goals would be desirable.

Regardless of which monitoring tools are ultimately chosen, the data presented in this report should prove useful as a baseline from which to develop those tools and to which comparisons future habitat conditions can be made.

6.2 References

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6.3 Figures

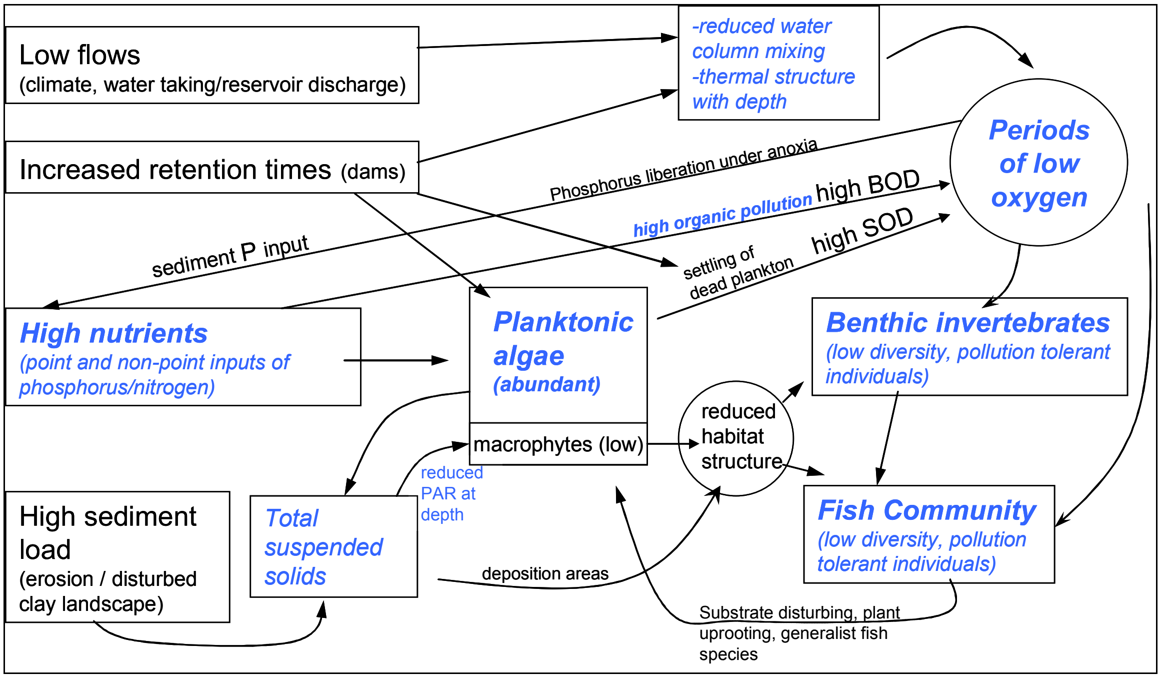

Figure 6.1. Theoretical interactions between ecosystem components in the highly eutrophic waters of the lower reach of the Grand River. Components highlighted in blue were documented in the current study while those in black are derived from previous studies and trophic theory.

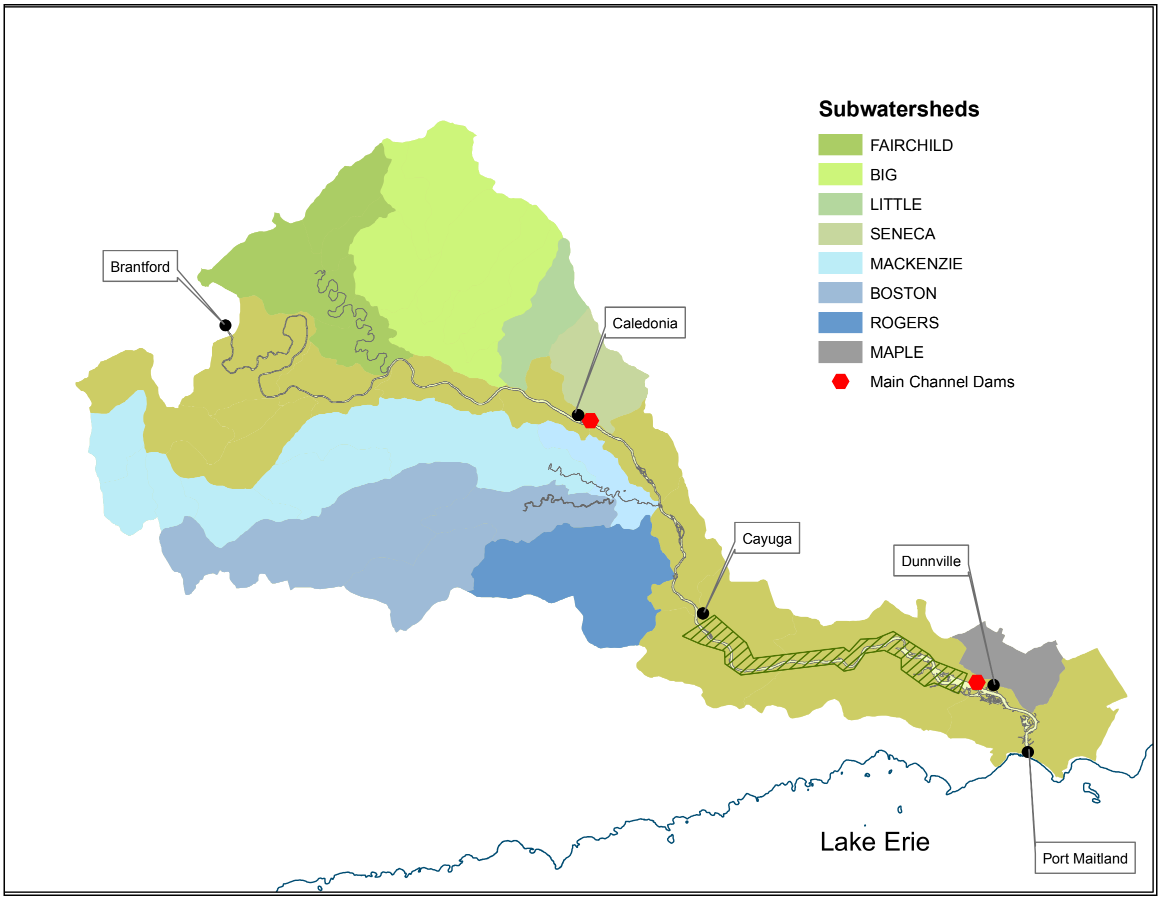

Figure 6.2. Grand River watershed downstream of Brantford showing subwatershed inputs to the main channel and major dams. The theoretical extent of the reservoir behind the Dunnville dam is indicated with green hatch marks.

Appendices

Appendix A-1. Details of laboratory specifications used for analysis of water quality parameters collected during Grand River sampling 2003-2004.

Parameter	Unit reported	Minimum detectable limit (MDL)	Method
Ammonia (NH_3-N)	mg/L	0.03	APHA 4500
Nitrite (NO_2)	mg/L	0.002	APHA 4500 / HACH 8503m
Nitrate (NO_3)	mg/L	0.007	APHA 4500 / HACH 8171m
Total Kjehldahl Nitrogen (TKN)	mg/L	0.04	APHA 4500
Chloride (Cl)	mg/L	0.4	APHA 4500 / HACH 8113
Total Phosphorus (TP)	mg/L	0.02	APHA 4500
Total Suspended solids (TSS)	mg/L	4	APHA 2540 D
pH	SU	0.03	APHA 4500 A,B MOD
[1]E. coli	CFU/100mL	0	APHA 9215, 9222

1. Only sampled on one date, August 31, 2004

Appendix A-2. Objectives and targets proposed by provincial and federal agencies

Parameter	Objective	Value	Agency	Purpose
[1]Ammonia (un-ionized; NH_3)	0.02 mg/L	concentration	MOE/ PWQO	Protection of aquatic life
[2]Nitrite (NO_2)	0.06 mg/L	concentration	CCME (federal) / CEQG	Protection of aquatic life
[3]Nitrate nitrogen (NO_3-N)	<2.93 mg/L	concentration	CCME (federal) / CEQG	Protection of aquatic life
Chloride (Cl)	250 mg/L	concentration	Env. Canada	Protection of drinking water
	8 mg/L	concentration		Background reference: areas free from anthropogenic influence
Total Phosphorus (TP)	<0.03 mg/L	concentration	MOE/ PWQO	Eliminate excessive plant growth in **streams and rivers**
	0.02 mg/L	Average concentrations for the ice free period	MOE/ PWQO	Avoid nuisance algae in **lakes**
[4]Total Suspended solids (TSS)	25 mg/L or 10% of background	concentration	CCME (federal) / CEQG	Protection of fish
pH	6.5-8.5 SU	concentration	MOE/ PWQO	Protection of aquatic life
[5]E. coli	100 CFU/100mL	concentration	MOE	Protection of human health/ beach closings

1. Free (un-ionized) ammonia (dependant on pH and temperature; calculated from formula provided by Emerson et al., 1975)
2. based on RT toxicity tests; many warmwater fish have higher tolerances (e.g. largemouth bass-)
3. protection from direct toxic effects; not related to eutrophication
4. This objective is narrative and has a number of species specific caveats with re: “natural” levels, and duration of exposure (DFO
5. This criteria is based on a specific sampling protocol (geometric mean of 5 samples per site) not followed here. This value is used as a starting point for general discussion.

Appendix A-3. Designation of trophic boundaries based on mean and range concentrations of total nitrogen and total phosphorus.

	Trophic State			
Parameter (mg/L)	Oligotrophic	Mesotrophic	Eutrophic	Hypereutrophic
Total Nitrogen[1]	< 0.4 mg/L	0.4-0.6 mg/L	0.6-1.5 mg/L	> 1.5 mg/L
Total Nitrogen[2]	**Mean 0.661** Range 0.307-1.630	**Mean 0.753** Range 0.361-1.387	**Mean 1.875** Range 0.393-6.100	-
Total Nitrogen[3]	< 0.300	0.300 – 0.650	0.650 – 1.500	> 1.500
Total Phosphorus[1]	< 0.015 mg/L	0.015-0.025 mg/L	0.025-0.1 mg/L	> 0.1 mg/L
Total Phosphorus[2]	**Mean 0.008** Range 0.003-0.0177	**Mean 0.0267** Range 0.0109-0.0956	**Mean 0.0844** Range 0.016-0.386	Range 0.750-1.20
Total Phosphorus[3]	< 0.009	0.009 – 0.018	0.018 - 0.050	> 0.050

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Appendix B-1. Chlorophyll-a (Chl-a) concentrations from surface waters at seven locations (C1-C7) within the lower reaches of the Grand River, 2003 and 2004. Values are provided for analysis that corrects for the presence of phaeopigments (COR) and that which does not (UC; sometimes referred to as “total chlorophyll”). Numbers represent the mean of two separate water filtrations and spectrophotometric readings.

Date (dd/MM/YY)	C1 (Port Maitland)		C2 (Betamik harbour)		C3 (Dun-above dam)		C4 (mid Dun- Cayuga)		C5 (Cayuga)		C6 (York)		C7 (Brantford)	
2003	UC	COR	UC	COR	UC	COR	UC	COR	UC	COR	UC	COR	UC	COR
23/07/03			50.60	26.80			31.18	19.07					4.21	2.51
06/08/03	26.54	16.77			40.93	29.40	27.93	23.19	6.46	1.74	7.64	3.74	5.63	2.41
13/08/03					41.85	28.20	43.95	30.61	21.53	6.15				
25/08/03					61.73	36.95	55.90	30.20	32.18	21.92				
02/09/03	43.13	42.92			55.83	28.69	52.66	38.39	14.73	7.15	18.45	9.58	4.52	1.94
09/09/03					64.53	34.35	54.46	40.70	19.58	13.34				
15/09/03	19.47	9.49			54.52	19.18	31.16	20.11	24.81	13.16	20.70	12.83	3.90	0.74
23/09/03					23.76	13.83	24.20	16.10	6.41	0.80				
29/09/03					17.30	9.02	9.32	6.55	6.85	3.74				
07/10/03					31.58	18.78	12.95	4.74	2.93	1.20				
16/10/03	36.49	29.00			24.77	16.97	13.55	6.82	8.42	5.35	12.46	8.22	10.90	5.61
21/10/03					7.80	4.28	9.92	4.21	8.02	3.47				
27/10/03	11.47	5.88			7.54	4.41	6.91	3.34	5.39	2.74	4.72	2.27	8.14	2.81
2004														
15/06/04					40.12	30.27	57.21	46.24	27.22	21.72				
23/06/04	24.30	16.97	29.36	22.19	31.14	25.86	36.97	31.07	14.06	11.09				
29/06/04	34.74	30.20	41.82	31.47	56.64	45.24	25.40	18.78	11.55	8.22				
06/07/04	34.84	23.66	72.73	56.67	42.10	33.61	36.91	29.00	11.50	9.16				
13/07/04	60.58	48.51	48.74	39.23	49.16	40.43	33.51	28.47	8.41	6.42				
20/07/04	32.10	22.45	31.44	21.18	27.95	19.18	15.42	11.23	8.74	6.55				
26/07/04	37.81	28.47	46.06	36.49	33.26	24.46	30.30	22.85	10.95	7.89				
03/08/04	37.25	29.34	44.21	37.36	24.02	19.45	23.52	20.18	13.76	11.03				
09/08/04	58.25	44.97	61.58	47.58	68.21	53.66	60.68	47.71	25.32	20.31				
23/08/04	45.73	32.34	53.62	41.23	41.99	30.07	33.24	26.66	13.96	10.76				
30/08/04	30.73	21.45	25.68	16.64	23.47	14.17	22.62	16.57	12.29	8.15				
23/09/04	39.39	31.88	75.72	65.22	18.03	14.37	21.96	17.91	14.31	11.43				
20/10/04	19.52	14.50	20.42	16.77	13.44	10.22	5.92	4.48	3.43	2.34				

Appendix C-1A. Benthic invertebrate counts from replicate sampling at 5 stations located in the lower reach of the Grand River, 2002.

			Station B1					Station B2					Station B3					Station B5			
GROUP	FAMILY	TAXON	R1	R2	R3	R4	Total	R1	R2	R3	R4	Total	R1	R2	R3	R4	Total	R1	R2	R3	Total
							0					0					0				0
OLIGOCHAETA	Lumbricidae	*Lumbricidae incomplete*					0					0	1	2		1	4			1	1
	Tubificidae	*Immatures with hair chaetae*					0	1				1	2	2	1		5				0
		Immatures without hair chaetae	4	11	13	10	38	17	4			21	2		2	2	6	8	15	5	28
		Branchiura sowerbyi				1	1	1	2			3		1	6	1	8	2	7	1	10
		Limnodrilus cervix					0		1			1	5	3		1	9	1		1	2
		Limnodrilus hoffmeisteri	1	3	1		5					0					0	2			2
ACARI	Hygrobatidae	*Hygrobates sp*					0					0					0		1		1
	Krendowskiidae	*nr Geayia sp*					0					0					0	1			1
	Limnesiidae	*Limnesia sp*			1	91	92					0					0	1			1
	Unionicolidae	*Unionicola sp*					0					0		1			1				0
COLEOPTERA	Elmidae	*Dubiraphia sp larvae*					0					0		1			1				0
DIPTERA	Ceratopogonidae	*Ceratopogonidae type III*		1			1	1				1				1	1		1	3	4
	Chironomidae						0					0					0				0
	Chironominae	*Chironomus sp*					0	18	4	11	1	34	4	7	7	3	21	1	3		4
		Cladopelma sp					0					0		1	1		2				0
		Cryptochironomus sp	7	8	4	1	20	3	2	1		6	2	2		1	5	2	7	2	11
		Dicrotendipes sp					0					0					0			1	1
		Glyptotendipes sp gp "A"	1			73	74					0					0				0
		Microchironomus sp	1				1		2			2	3	2	2	4	11		1		1
		Parachironomus sp				2	2					0					0				0
		Polypedilum sg Tripodura sp	63	60	45	1	169	10	3			13					0			3	3
		Cladotanytarsus sp	1		1		2		1			1					0				0
	Orthocladiinae	*Orthocladius sp*				7	7					0					0			1	1
	Tanypodinae	*Ablabesmyia annulatum gp*					0					0					0	1		1	2
		Coelotanypus sp					0	1				1		1		1	2		3	2	5
		Procladius sp		1	1		2	9	3			12		10	5	17	32	6	7	15	28
		Tanypus "concavus"					0					0	1	1	3	1	6	1		1	2
		Tanypus neopunctipennis					0					0	1				1				0
		Tanypus stellatus					0					0					0		1		1
EPHEMEROPTERA	Caenidae	*Caenis sp*	2			1	3					0					0				0
	Ephemeridae	*Hexagenia sp juv*					0	1		2		3					0				0
HEMIPTERA	Corixidae	*Palmacorixa nana*					0					0		1			1	3			3
GASTROPODA	Hydrobiidae	*Amnicola limosa*					0					0					0		1		1
BIVALVIA	Sphaeriidae	*Musculium sp juv*					0					0					0		2		2
		Musculium transversum					0					0					0		2		2
NEMATODA		Unidentified	1	1		1	3	1	1			2					0				0
		Total	81	85	66	188	**420**	63	23	14	1	**101**	21	35	27	33	**116**	29	51	37	**117**
		Species Count	9	7	7	**10**		**11**	9	3	1		9	**14**	8	11		12	**13**	**13**	

Appendix C-1B. Benthic invertebrate counts from replicate sampling at 5 stations located in the lower reach of the Grand River, 2003

			Station B1					Station B2					Station B3					Station B4				Station B5				
GROUP	**FAMILY**	**TAXON**	R1	R2	R3	R4	Total	R1	R2	R3	R4	Total	R1	R2	R3	R4	Total	R1	R2	R3	Total	R1	R2	R3	R4	Total
							0					0					0				0					0
HIRUDINEA	Glossiphoniidae	*Helobdella stagnalis*					0					0					0				0				1	1
OLIGOCHAETA	Lumbricidae	*Sparganophilus sp*					0					0					0	2			2					0
	Tubificidae	*Immatures with hair chaetae*				2	2		3			3	5	9	7		21		1		1					0
		Immatures without hair chaetae	41	35	134	394	604	3	27	78	7	115	87	47	21	2	157		2	5	7	1	1	4	5	11
		Branchiura sowerbyi			3	2	5		4	7		11	8	12	7	1	28	1			1	3	1	2	4	10
		Limnodrilus cervix	2			1	3					0	5		3		8				0					0
		Limnodrilus hoffmeisteri	1	1	7	3	12					0	1				1				0					0
ACARI	Limnesiidae	*Limnesia sp*	2				2					0					0				0					0
							0					0					0				0					0
COLEOPTERA	Elmidae	*Dubiraphia sp larvae*					0					0		1			1				0	1	2	2	1	6
		Stenelmis sp larval casts only					0					0					0				0			1	1	2
DIPTERA	Ceratopogonidae	*Ceratopogonidae type III*	1	2	7	1	11		3	4		7	1	1			2		1		1				1	1
	Chironomidae						0					0					0				0					0
	Chironominae	*Chironomus sp*	3	41	12	88	144		9	4		13	4		2	2	8		1	3	4		9	10	2	21
		Cryptochironomus sp	11		2		13			2	1	3					0	1			1				1	1
		Microchironomus sp		1			1					0					0	1			1					0
		Tribelos sp					0					0					0				0		1			1
		Cladotanytarsus sp	1				1					0					0				0					0
	Tanypodinae	*Ablabesmyia annulatum gp*			5		5		1			1					0	3			3					0
		Clinotanypus sp			1		1			3		3	5	6	3		14	8			8	15		8	89	112
		Procladius sp	1		2		3			6		6					0	1			1					0
EPHEMEROPTERA	Ephemeridae	*Hexagenia sp juv*					0					0					0	2			2	1	1	2	2	6
MEGALOPTERA	Sialidae	*Sialis sp*					0					0					0	2			2				1	1
GASTROPODA	Viviparidae	*Campeloma decisum*					0					0					0				0				1	1
BIVALVIA	Sphaeriidae	*Musculium sp*					0					0					0	4			4					0
		Pisidium sp	1				1					0					0	1			1	1			1	2
TURBELLARIA	Plagiostomidae	*Hydrolimax sp*		3		1	4					0					0				0					0
NEMATODA		Unidentified		1			1					0					0				0					0
		Total	64	84	173	492	**813**	3	47	104	8	**162**	116	76	43	5	**240**	26	5	8	**39**	22	15	29	110	**176**
		Species Count	**10**	7	9	8		1	6	**7**	2		**8**	6	6	3		**11**	4	2		6	6	7	**13**	

Appendix D-1. Metrics used to calculate index of biotic integrity (IBI) values for Grand River fish communities downstream of Caledonia 2003 and 2004; from Thoma (1999) and Karr (1981)

 # Species – number of native species. List compiled using Cudmore and Crossman (2000)

 # Sunfish species – a modification of Karr's sunfish metric; expanded to include Pomoxis and Micropterus recognizing that, for Lake Erie watersheds, not all sites have the potential to harbor all species of sunfish potentially found in the basin.

 # Cyprinid species – this metric replaces Karr's sucker species metric; which can be naturallry low in abundance and numbers in L. Erie drowned river mouth systems. Whereas cyprinid species were traditionally a prominent component of these systems.

 # Benthic species – modification of Karr's darter metric. It provides a good range and environmental responsiveness within L. Erie and lower watersheds. It responds primarily to environmental disturbance from sedimentation and low oxygen levels. List attempts to maintain Karr's original sensitivity and so tolerant benthic species such as bullheads and suckers were excluded.

% Phytophillic individuals – modified from Karr's % insectivorous cyprinids.

% Top carnivores - follows metric from Karr

 # Intolerant species – variation from Karr; utilizes Ohio EPA listings (Ohio EPA 1988). Includes: mooneye, black redhorse, greater redhorse, river redhorse, redside dace, hornyhead chub, river chub, pugnose shiner, blackchin shiner, blacknose shiner, rosyface shiner, mimic shiner, pugnose minnow, longnose dace, silver shiner, stonecat, brindled madtom, northern madtom, eastern sand darter, channel darter

% Omnivore individuals - follows metric from Karr; included gizzard shad

% Nonindigenous individuals – utilizes Cudmore and Crossman (2000)

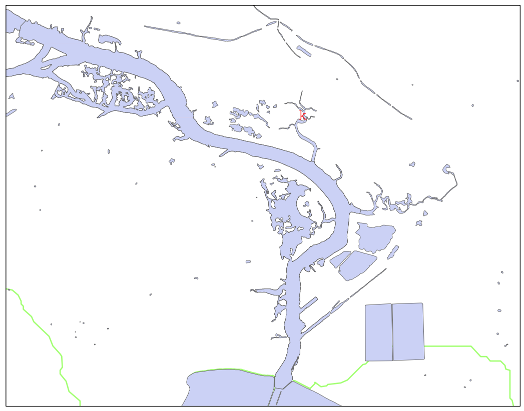
% Tolerant individuals - utilizes Ohio EPA listings (Ohio EPA 1988). Includes:
central mudminnow, white sucker, goldfish, carp, golden shiner, bluntnose minnow, fathead minnow, blacknose dace, creek chub, yellow bullhead, brown bullhead, banded killifish, green sunfish, goldfish x carp, Ictaluridae hybrids: black x brown bullhead, yellow x brown bullhead, mirror carp

% DELT (observable deformities, eroded fins, lesions, tumours) follows Ohio EPA methods for classifiying external deformities; note: not used in this case because of concern over inconsistent record keeping.

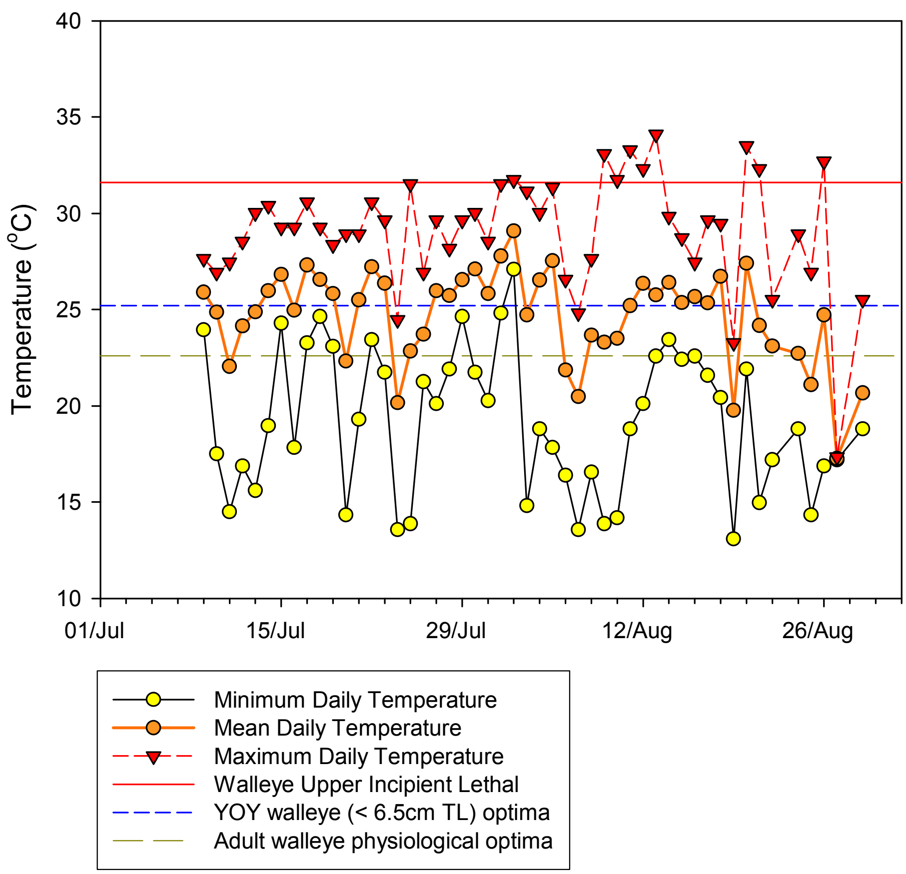
Relative numbers – standardized by fishing time (electroseconds)

Appendix E-1. Dunnville Marsh Water Temperatures Summer, 2002

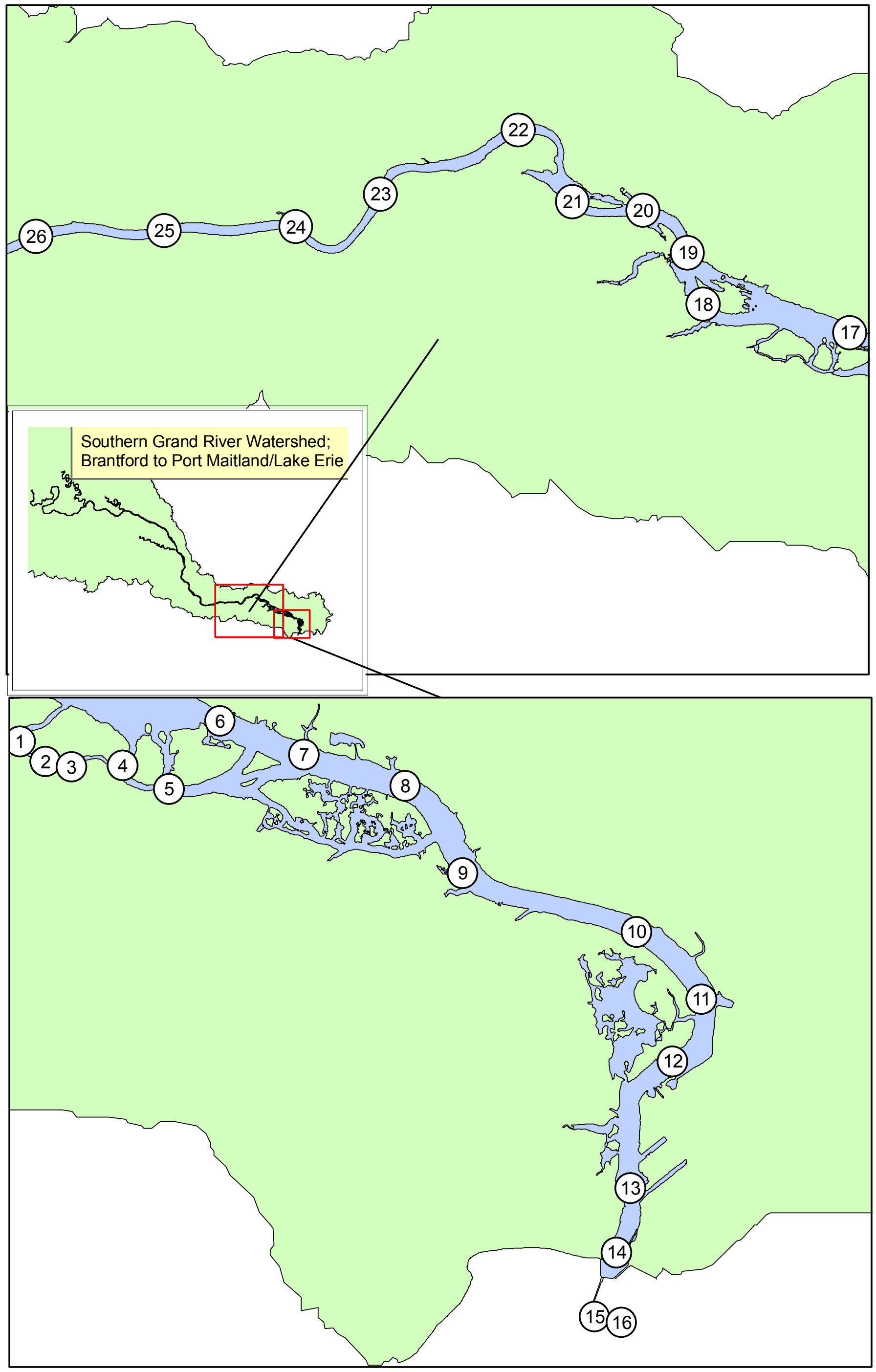
A temperature logger (Optic StowAway Temp; Onset Computer Corp, MA) set to record hourly temperatures was deployed in the Dunnville Marshes, downstream of Dunnville ON, in association with the Maple Ck. drainage, from July 9 to August 31, 2002. Mean, minimum and maximum daily temperatures are displayed relative to walleye thermal reference points from Hokanson (1977).



Logger location



APPENDIX E-2A. Locations of sampling sites where water column temperature and oxygen profiles were collected in August and September, 2002.



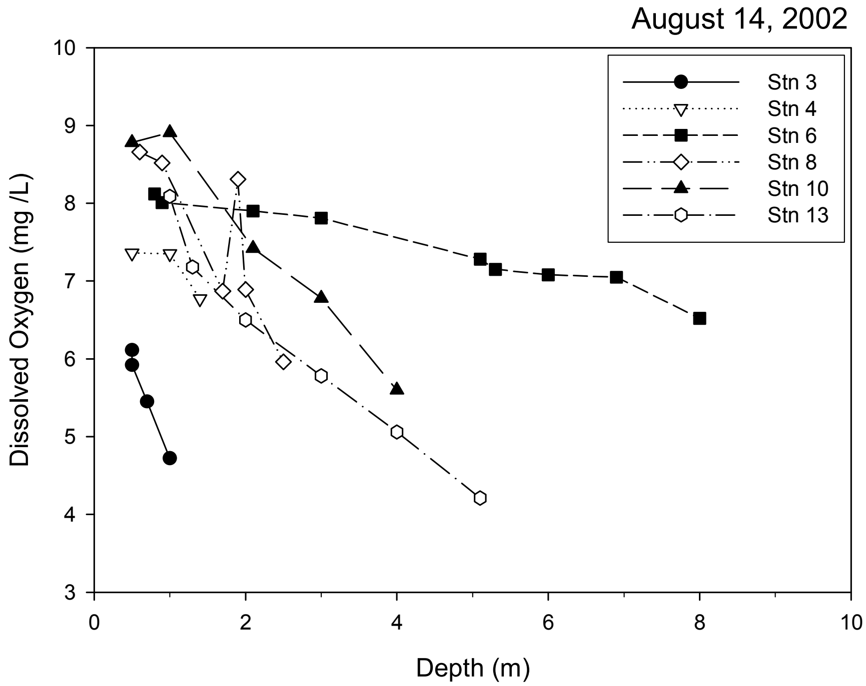
Appendix E-2B. Description of 2002 water column temperature and oxygen profile sample site locations.

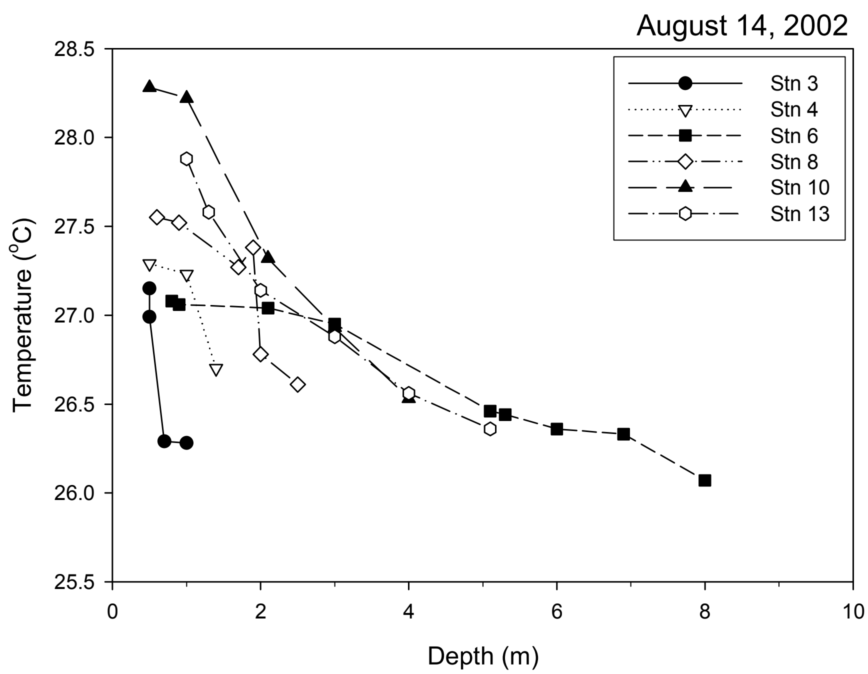
2002 Temp/DO Profile Stations	Sample Dates			Description	Co-ordinates		Regular site in 2003 - 2005 profiling
Stn ID	14-Aug-02	09-Sep-02	10-Sep-02		Latitude	Longitude	
1		+		Sulphur Ck Weir 4	42.899	-79.640	
2		+		Sulphur Ck Channel 3-4	42.897	-79.638	
3	+	+		Sulphur Ck. Campsites	42.896	-79.635	
4	+	+		Sulphur Ck. Fishway	42.896	-79.629	
5		+		Sulphur Ck. Weir 2	42.895	-79.624	
6	+	+		Dunnville dam plungepool	42.900	-79.619	
7		+		Main (near sunfish ck mouth)	42.897	-79.610	
8	+	+		Main channel near Betamik harbour	42.895	-79.599	TO-3
9		+		Main channel btwn Betamik & P_shipyard	42.888	-79.593	
10	+	+		Main channel near maple ck.	42.883	-79.574	TO-2
11		+		Main channel near maple ck. "outlet"	42.877	-79.567	
12		+		Main channel near Broad ck	42.872	-79.570	
13	+	+		Main channel near shipyard	42.862	-79.575	TO-1 (close)
14		+		Main channel btwn piers	42.857	-79.577	
15		+		Lake directly out from west pier	42.852	-79.579	
16		+		Lake nearshore in plume	42.852	-79.576	
17			+	Main directly above dam	42.901	-79.621	TO-4
18			+	Byng park upstream boat launch	42.905	-79.651	
19			+	Main channel- Evergreen Point	42.913	-79.654	TO-5
20			+	Upstream end of first embayment	42.919	-79.663	
21			+	Private camp shoreline	42.921	-79.678	TO-6 (close)
22			+	Fish Community station #63	42.932	-79.689	
23			+	just downstream of private RV resort	42.923	-79.717	TO-7
24			+	private RV resort	42.918	-79.735	
25			+	Main channel near power lines	42.918	-79.762	TO-8
26			+	Fish Community station #64	42.917	-79.788	

Appendix E-2C. Summary of temperature and oxygen profile data, Grand River, August and September, 2002

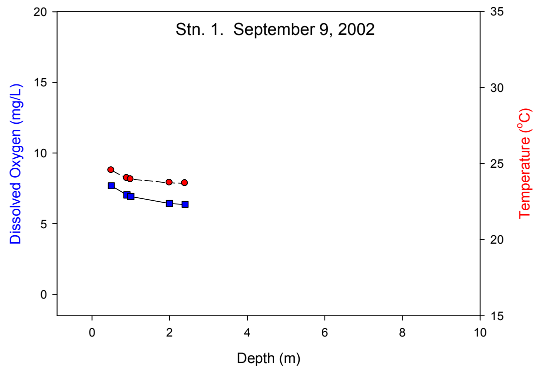
Station ID / Date	Depth		Temperature (oC)			Dissolved Oxygen: DO - % Saturation			Dissolved Oxygen: DO (mg/L)		
	Max	ΔD	Max	Min	ΔT	Max	Min	Δ %	Max	Min	ΔDO
Aug/14											
3	1.0	0.5	27.2	26.3	-0.9	76.8	58.5	-18.3	6.1	4.7	-1.4
4	1.4	0.5	27.3	26.7	-0.6	92.8	83.4	-9.4	7.4	6.8	-0.6
6	8.0	7.2	27.1	26.1	-1.0	102.1	80.5	-21.6	8.1	6.5	-1.6
8	2.5	1.9	27.6	26.6	-0.9	110.1	74.3	-35.8	8.7	6.0	-2.7
10	4.0	3.5	28.3	26.5	-1.8	114.3	69.7	-44.6	8.9	5.6	-3.3
13	5.1	4.1	27.9	26.4	-1.5	103.1	52.2	-50.9	8.1	4.2	-3.9
Sep/09											
1	2.4	1.9	24.5	23.7	-0.8	91.8	74.9	-16.9	7.7	6.4	-1.3
2	1.4	0.9	23.8	23.5	-0.3	86.2	78.8	-7.4	7.3	6.7	-0.6
3	1.0	0.4	23.7	23.5	-0.2	84.3	68.8	-15.5	7.2	5.9	-1.3
4	2.1	1.6	24.1	23.9	-0.2	91.5	87.3	-4.2	7.8	7.4	-0.4
5	1.7	1.2	24.4	23.5	-0.9	88.5	71.8	-16.7	7.4	6.1	-1.3
6	9.8	9.3	24.8	24.1	-0.7	99.6	82.7	-16.9	8.3	7.0	-1.3
7	3.0	2.4	27.1	24.1	-3.0	125.9	77.5	-48.4	10.1	6.6	-3.5
8	2.6	2.1	27.1	24.2	-2.9	128.1	44.3	-83.8	10.3	3.7	-6.5
9	3.3	2.8	26.9	24.4	-2.5	124.2	64.8	-59.4	10.0	5.4	-4.5
10	4.0	3.5	26.8	23.8	-3.0	116.8	36.2	-80.6	9.4	3.1	-6.3
11	3.4	2.9	26.0	24.4	-1.5	109.8	63.3	-46.5	9.0	5.3	-3.7
12	2.9	2.4	26.1	24.3	-1.8	117.1	63.4	-53.7	9.5	5.3	-4.2
13	4.3	3.8	25.6	23.5	-2.0	112.0	32.5	-79.5	9.2	2.8	-6.5
14	6.6	6.0	24.9	23.7	-1.2	103.8	42.0	-61.8	8.7	3.6	-5.1
15	7.1	6.6	24.8	23.4	-1.4	105.6	48.6	-57.0	8.9	4.1	-4.7
16	3.9	3.4	24.7	23.2	-1.5	104.3	27.8	-76.5	8.7	2.4	-6.4
17	2.0	1.5	24.4	24.0	-0.4	91.5	63.9	-27.6	7.7	5.4	-2.3
18	1.7	1.6	24.9	23.6	-1.3	103.2	28.5	-74.7	8.6	2.4	-6.2
19	2.9	2.3	25.3	23.5	-1.8	125.2	41.8	-83.4	10.3	3.6	-6.8
20	3.1	2.6	25.2	23.5	-1.8	127.3	46.5	-80.8	10.5	4.0	-6.6
21	2.5	1.9	24.6	23.6	-1.0	127.6	65.5	-62.1	10.7	5.6	-5.1
22	2.9	2.4	25.0	23.4	-1.6	127.8	45.9	-81.9	10.6	3.9	-6.7
23	2.9	2.4	25.3	23.1	-2.2	139.9	38.6	-101.3	11.6	3.3	-8.3
24	4.0	3.5	24.8	22.7	-2.0	137.6	8.0	-129.6	11.5	0.7	-10.8
25	2.3	2.1	24.3	23.5	-0.8	115.0	80.8	-34.2	9.7	6.9	-2.8
26	3.5	3.5	25.0	22.3	-2.7	118.8	7.2	-111.6	9.9	0.6	-9.2

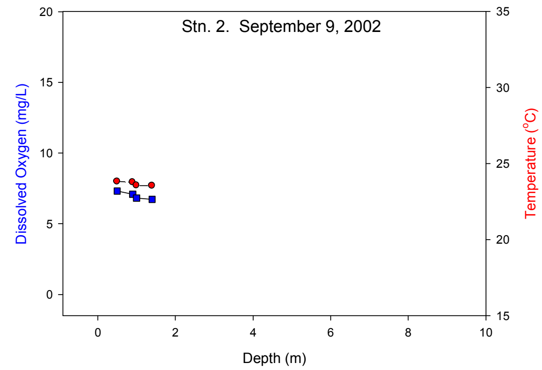
Appendix E-2D. Water column profiles of temperature and oxygen, Grand River, August and September, 2002.

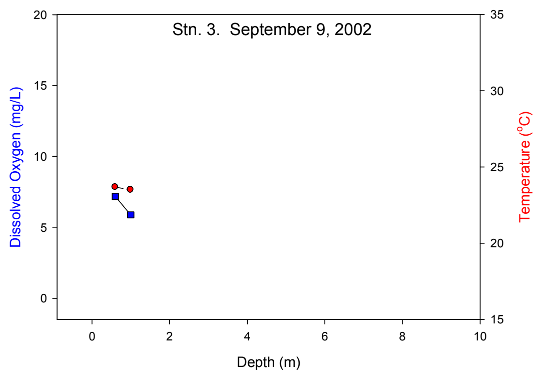


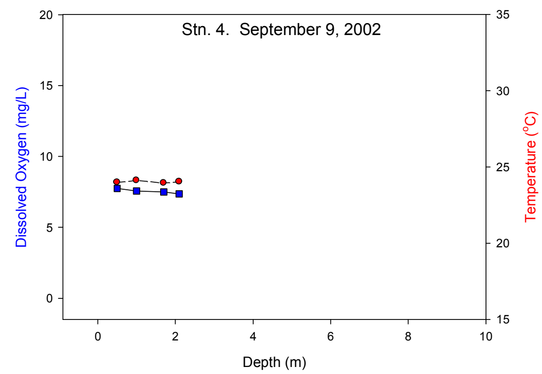


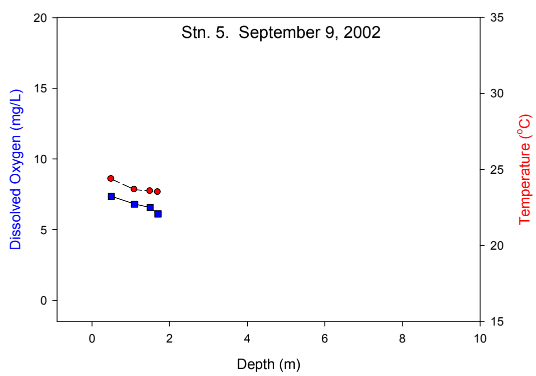
Appendix E-2D cont'd

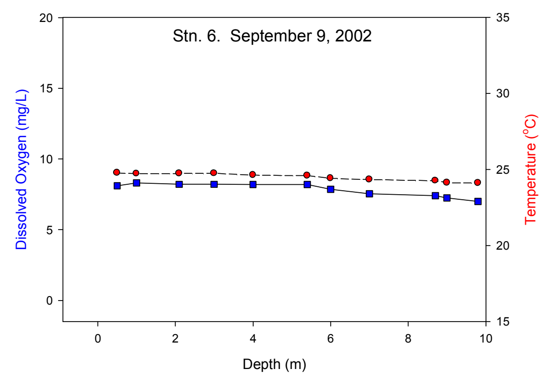


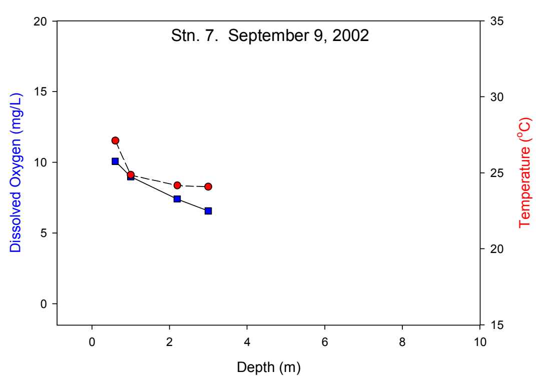


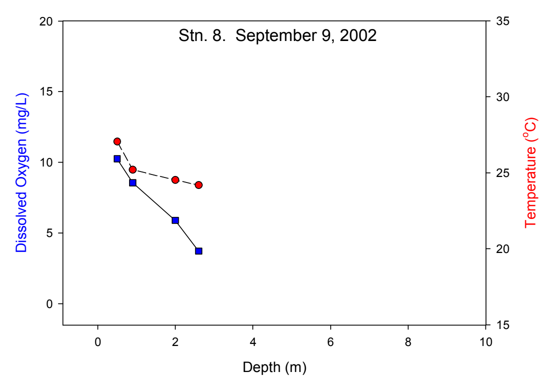






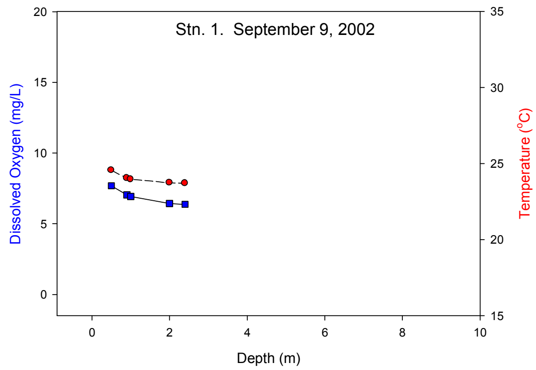


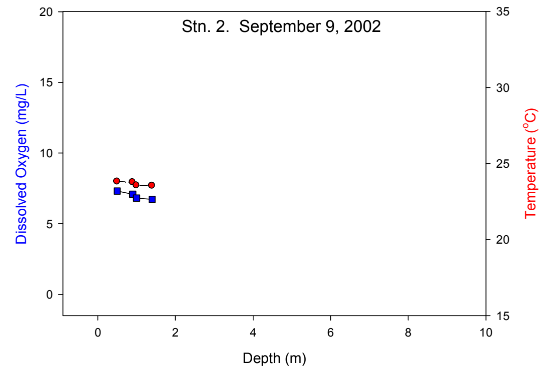


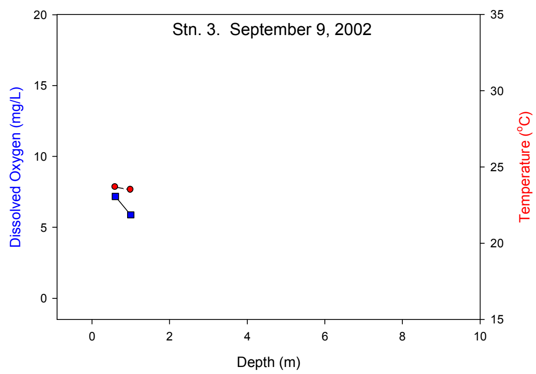


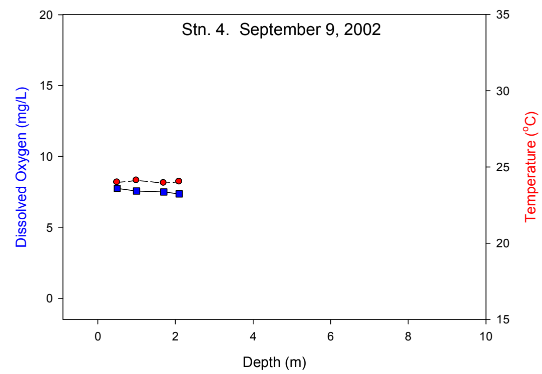
Dissolved Oxygen (mg/L)   Temperature (°C)

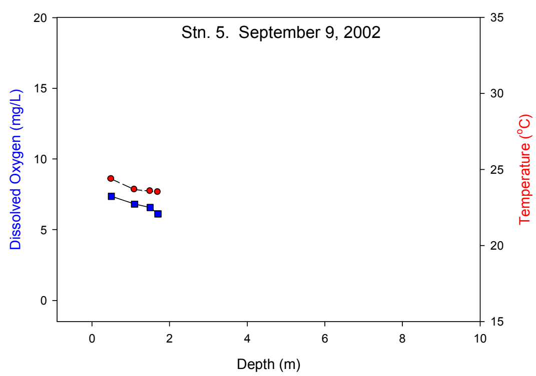
Appendix E-2D cont'd

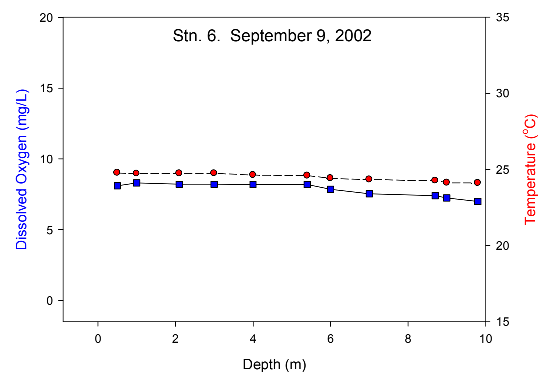


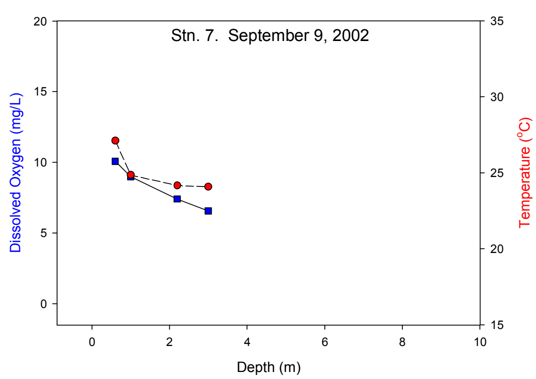


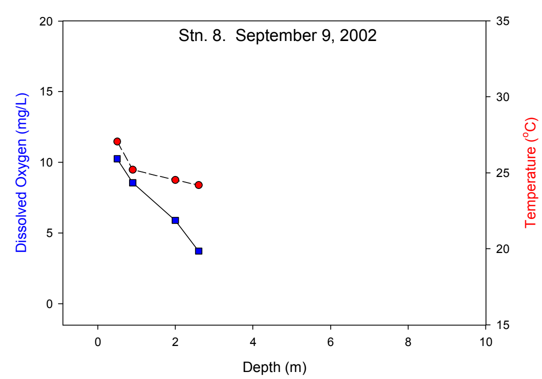






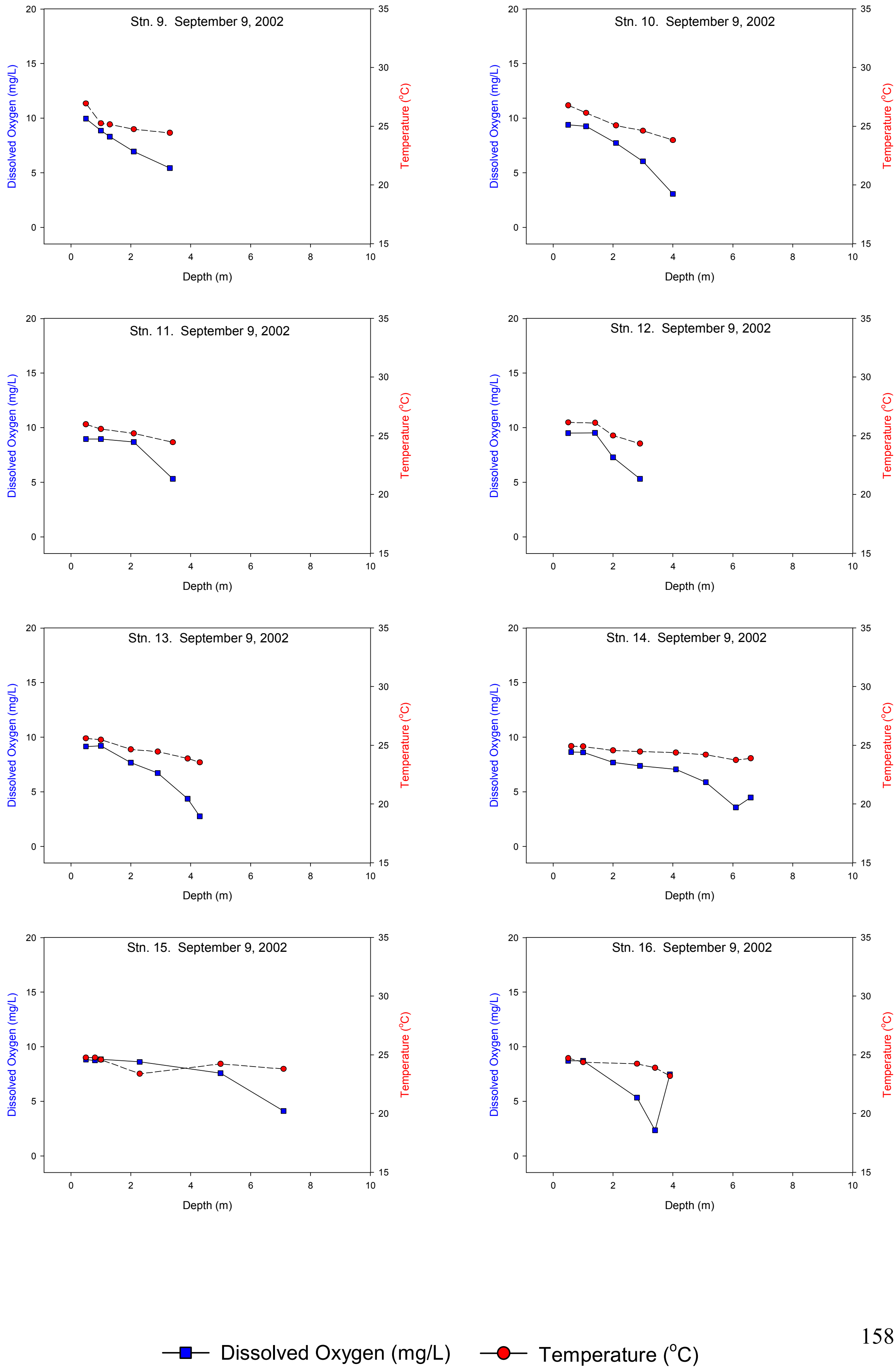




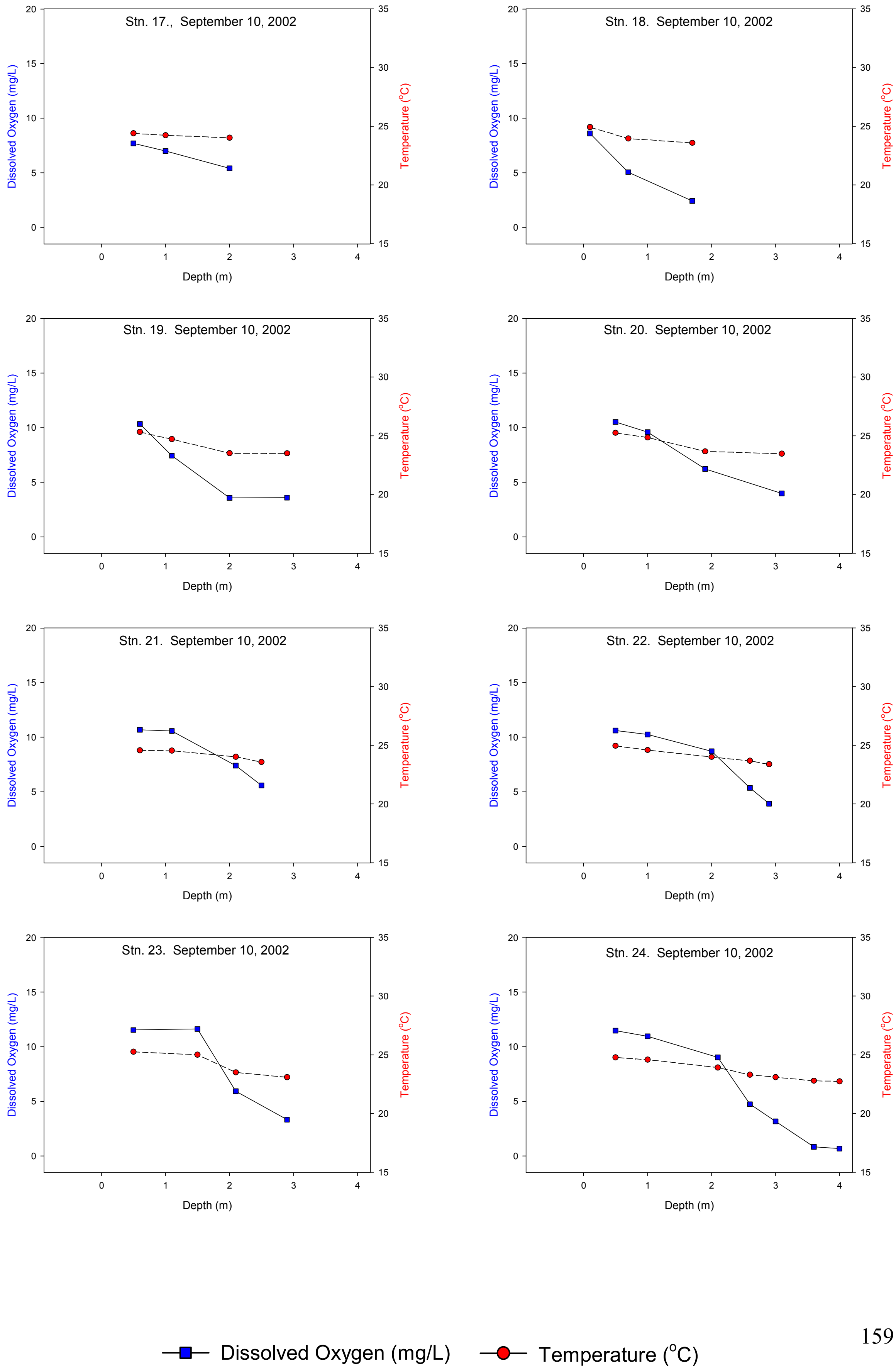


Dissolved Oxygen (mg/L)   Temperature (°C)

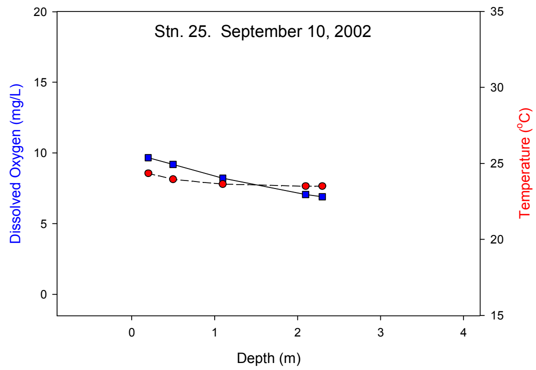
Appendix E-2D cont'd

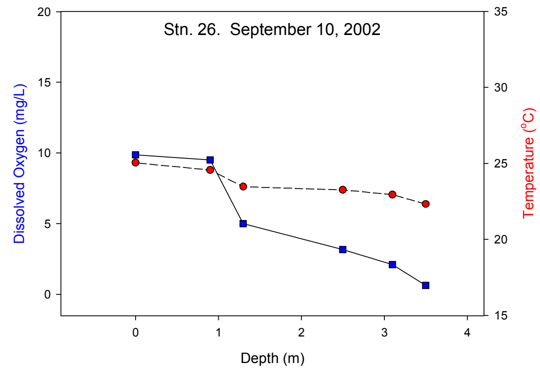


Appendix E-2D cont'd



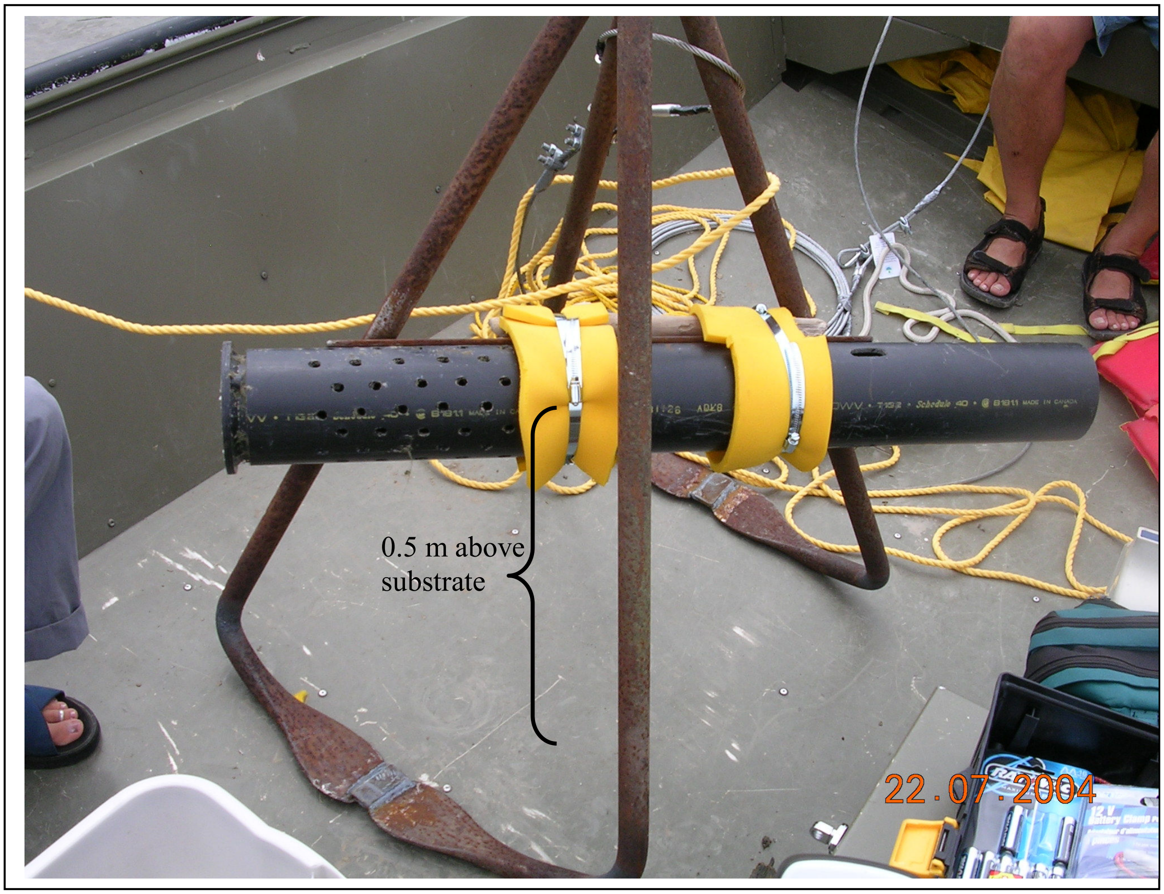
Appendix E-2D cont'd





Dissolved Oxygen (mg/L) Temperature (°C)

Appendix E-3. Temperature and oxygen: continuous logging at depth. Picture of bracket for holding and protecting logging equipment.



Appendix E-4. Descriptive Statistics of temperatures collected at logging stations (TL1-TL10) within the southern Grand River, 2001-2005.

TL1		Minimum	Mean	Maximum	St. Dev.
2001	April	5.42	9.51	14.27	2.43
	May	6.51	11.58	18.73	3.90
	June	10.54	15.93	22.01	2.08
	July	12.56	20.25	25.61	2.85
	August	17.60	23.21	25.61	1.31
	September	14.58	20.16	23.87	2.56
	October	7.44	12.60	17.44	2.71
	November	6.20	8.12	9.92	0.94
	December	0.04	3.91	7.60	2.35
2002	January	0.04	0.31	1.48	0.32
	February	-0.11	0.86	3.07	0.84
	March	0.04	2.74	6.20	1.62
	April	3.23	9.74	17.76	3.97
	May	8.83	12.64	20.52	2.22
	June	10.08	19.16	25.44	2.69
	July	19.39	23.49	28.10	1.57
	August	23.02	25.56	28.47	1.32
	September	18.24	22.37	25.61	1.84
	October	7.13	13.96	20.68	3.97
	November	1.80	5.55	9.30	1.88
	December	-0.11	0.48	1.64	0.36
2003	January	-0.11	0.17	0.52	0.11
	February	0.04	0.15	0.68	0.14
	March	-0.11	1.18	6.82	2.12
	April	0.52	7.64	15.06	4.32
	May	12.09	14.98	19.06	1.64
	June	15.22	20.26	25.44	2.60
	July	21.01	23.81	26.67	1.05
	August	23.19	25.26	27.56	0.90
	September	14.58	20.49	23.53	2.18
	October	8.22	12.00	16.01	1.92
	November	3.23	6.51	10.54	2.04
	December	-0.11	1.08	3.70	0.86
2004	January	-0.28	0.49	3.70	1.09
	February]	-0.11	0.07	0.36	0.09
	March	-0.11	2.18	8.99	2.41
	April	4.01	9.41	14.42	3.06
	May	11.01	16.51	21.68	3.10
	June	16.96	20.75	24.04	1.52
	July	21.51	23.46	25.61	0.96
	August	21.01	22.71	25.78	0.91
	September	18.73	21.55	25.26	1.57
	October	9.30	13.35	19.87	2.87
	November	4.32	7.00	11.47	1.86
	December	-0.11	1.52	7.29	1.70
2005	January	-0.11	0.31	2.59	0.53
	February	0.04	0.10	0.20	0.08
	March	0.04	0.52	4.32	1.08
	April	2.28	8.35	12.72	2.83
	May	8.83	12.98	16.33	2.65
	June	20.68	24.65	28.10	2.12
	July	23.87	26.54	29.94	1.27
	August	22.34	25.36	28.28	1.57
	September	21.84	22.82	23.70	0.43

Appendix E-4. Descriptive Statistics of temperatures collected at logging stations (TL1-TL10) within the southern Grand River, 2001-2005.

TL2		Minimum	Mean	Maximum	St. Dev.
2001	April	5.27	9.96	17.27	2.94
	May	14.11	17.92	20.67	1.30
	June	14.89	21.78	27.70	3.76
	July	20.99	24.22	28.24	1.81
	August	22.33	25.39	28.79	1.69
	September	14.73	20.30	25.06	2.71
	October	7.14	12.59	18.07	2.75
	November	5.58	8.11	10.39	0.99
	December	0.05	3.82	7.76	2.37
2002	January	-0.10	0.28	1.81	0.36
	February	-0.10	0.89	3.39	0.89
	March	-0.10	2.80	6.67	1.69
	April	2.92	9.81	18.56	4.06
	May	8.84	13.15	21.33	2.83
	June	18.07	22.27	27.70	2.26
	July	24.02	26.34	29.53	1.02
	August	22.33	25.51	28.98	1.43
	September	18.07	22.37	25.93	1.88
	October	6.21	13.35	20.83	4.27
	November	1.18	5.38	9.77	2.04
	December	-0.10	0.50	1.97	0.37
2003	January	0.05	0.18	0.37	0.12
	February	0.05	0.09	0.37	0.07
	March	-0.10	1.17	7.14	2.19
	April	0.37	7.82	15.53	4.45
	May	12.09	15.00	19.69	1.70
	June	15.68	20.57	26.46	2.81
	July	21.33	24.16	27.52	1.38
	August	22.83	25.18	27.52	0.93
	September	14.26	20.36	23.51	2.21
	October	7.61	11.45	15.21	1.89
	November	3.24	6.52	10.39	2.03
	December	-0.10	1.14	3.71	0.88
2004	January	-0.10	0.49	3.71	1.13
	February	-0.10	0.03	0.21	0.06
	March	-0.10	2.32	8.38	2.41
	April	4.18	9.69	14.57	3.06
	May	10.55	16.65	22.33	3.08
	June	16.32	20.87	24.37	1.67
	July	21.33	23.48	26.11	1.04
	August	20.99	22.80	26.46	0.99
	September	18.39	21.39	25.06	1.61
	October	9.46	13.14	19.37	2.81
	November	4.18	6.98	11.32	1.85
	December	-0.10	1.48	5.12	1.61
2005	January	-0.10	0.23	3.39	0.66
	February	-0.10	-0.04	0.21	0.07
	March	-0.10	0.53	5.12	1.35
	April	1.81	8.91	14.73	3.13
	May	8.53	14.85	20.50	3.10
	June	19.04	24.33	28.79	2.45
	July	24.37	26.79	29.72	1.21
	August	22.33	25.30	28.06	1.66
	September	21.66	22.84	24.19	0.66

Appendix E-4. Descriptive Statistics of temperatures collected at logging stations (TL1-TL10) within the southern Grand River, 2001-2005.

TL3		Minimum	Mean	Maximum	St. Dev.
2003	April	-0.59	6.94	15.51	4.42
	May	11.14	14.14	18.05	1.60
	June	13.93	19.59	26.26	2.89
	July	21.80	24.53	26.78	1.18
2004	March	-0.08	2.46	8.39	2.43
	April	3.73	9.59	15.22	3.09
	May	10.40	16.56	22.49	3.12
	June	16.17	20.72	24.88	1.72
	July	20.67	23.44	26.45	1.23
	August	20.02	22.70	26.10	1.19
	September	17.59	21.31	25.92	1.93
	October	8.85	12.97	20.18	2.73
	November	4.04	6.78	11.95	1.95
	December	-0.24	1.30	4.98	1.59
2005	January	-0.24	-0.01	2.63	0.54
	February	-0.24	-0.22	0.08	0.05
	March	-0.24	0.17	4.19	0.97
	April	1.52	8.65	15.85	3.05
	May	7.93	14.40	20.67	2.99
	June	17.59	23.95	29.52	2.62
	July	22.49	26.30	30.83	1.63
	August	20.99	24.77	28.61	1.90
	September	19.86	22.33	24.54	1.19

TL4		Minimum	Mean	Maximum	St. Dev.
2003	April	7.75	7.75	16.71	4.44
	May	14.92	14.92	19.62	1.80
	June	20.48	20.48	28.17	3.09
	July	25.66	25.66	29.09	1.43
2004	March	2.52	2.52	9.93	2.55
	April	9.57	9.57	15.53	3.19
	May	16.58	16.58	22.82	3.24
2005	March	3.00	3.00	3.72	0.39
	April	8.75	8.75	16.47	3.12
	May	14.63	14.63	20.83	3.15

Appendix E-4. Descriptive Statistics of temperatures collected at logging stations (TL1-TL10) within the southern Grand River, 2001-2005.

TL5		Minimum	Mean	Maximum	St. Dev.
2002	July	24.04	26.62	29.74	1.01
	August	22.68	25.98	30.68	1.55
	September	17.92	22.83	27.90	2.12
	October	6.22	13.51	21.67	4.28
	November	0.56	5.35	10.72	2.18
	December	-0.08	0.46	1.03	0.28
2003	January	-0.08	0.26	0.88	0.31
	February	-0.08	0.12	0.56	0.18
	March	-0.08	1.20	7.31	2.16
	April	-0.08	8.02	17.12	4.48
	May	11.79	14.97	19.22	1.72
	June	15.38	21.02	27.90	3.20
	July	21.84	24.78	29.00	1.62
	August	23.01	25.58	28.63	1.05
	September	14.27	20.60	24.91	2.43
	October	7.00	11.37	16.17	2.06
	November	3.10	6.39	10.72	2.08
	December	-0.24	1.10	3.57	0.87
2004	January	-0.24	0.54	4.19	1.09
	February	-0.08	0.09	0.56	0.17
	March	-0.08	2.30	7.93	2.39
	April	4.04	9.62	14.90	3.10
	May	9.94	16.59	22.84	3.14
	June	16.48	21.02	25.77	1.90
	July	21.51	23.84	27.36	1.25
	August	21.01	23.13	27.18	1.16
	September	18.73	21.83	27.01	1.73
	October	9.01	13.17	20.35	3.01
	November	3.10	6.81	11.64	1.92
	December	-0.24	1.48	5.13	1.53
2005	January	-0.24	0.13	3.26	0.62
	February	-0.24	-0.07	0.07	0.07
	March	-0.08	0.51	4.66	1.21
	April	1.36	8.89	17.28	3.29
	May	8.23	15.10	21.67	3.39
	June	18.89	25.12	31.44	2.82
	July	24.38	27.31	33.19	1.59
	August	22.01	25.69	29.93	1.94
	September	21.67	23.24	25.60	0.98

Appendix E-4. Descriptive Statistics of temperatures collected at logging stations (TL1-TL10) within the southern Grand River, 2001-2005.

TL6		Minimum	Mean	Maximum	St. Dev.
2003	August	21.49	24.95	27.33	1.34
	September	12.88	19.94	23.67	2.46
	October	7.77	11.03	15.53	1.98
	November	3.56	6.48	10.71	1.94
	December	0.22	1.41	3.71	0.90
2004	January	0.06	0.59	4.03	1.13
	February	0.06	0.10	0.38	0.07
	March	0.06	2.38	6.52	1.92
	April	5.12	8.96	12.88	2.57
	May	11.02	14.99	18.39	2.36
	June	15.21	20.50	25.57	2.27
	July	20.50	23.36	27.15	1.45
	August	19.53	22.51	26.97	1.33
	September	17.11	20.91	25.23	1.91
	October	11.63	15.34	18.72	1.70
2005	June	19.21	25.49	29.39	2.70
	July	22.17	26.63	30.14	1.65
	August	20.35	25.01	29.02	2.05

Appendix E-4. Descriptive Statistics of temperatures collected at logging stations (TL1-TL10) within the southern Grand River, 2001-2005.

TL7		Minimum	Mean	Maximum	St. Dev.
2003	August	14.73	19.54	23.84	1.92
	September	9.92	15.50	18.39	1.57
	October	5.74	9.37	15.37	1.81
	November	1.35	6.24	12.09	2.59
	December	0.23	1.88	4.66	1.10
2004	January	-0.09	1.20	7.92	1.50
	February	-0.09	1.73	6.06	1.09
	March	-0.09	3.62	12.09	3.14
	April	1.51	9.89	16.47	3.27
	May	7.15	16.05	25.23	3.63
	June	12.87	18.46	24.71	2.36
	July	16.16	19.52	25.06	1.81
	August	13.33	17.92	23.67	1.94
	September	11.02	16.43	21.16	2.18
	October	7.15	10.49	14.89	1.71
	November	2.14	6.45	10.71	2.08
	December	-0.09	2.14	5.43	1.67
2005	January	-0.09	0.76	5.28	0.96
	February	-0.09	1.62	4.97	1.30
	March	-0.09	2.32	8.07	1.85
	April	-0.09	8.91	17.43	3.58
	May	4.66	6.96	9.15	1.25
	June	12.72	19.35	24.88	2.60
	July	15.21	19.66	24.71	2.04
	August	13.64	18.04	22.66	1.81

Appendix E-4. Descriptive Statistics of temperatures collected at logging stations (TL1-TL10) within the southern Grand River, 2001-2005.

TL8		Minimum	Mean	Maximum	St. Dev.
2003	August	19.83	24.02	27.31	1.59
	September	12.54	19.10	23.82	2.58
	October	7.13	10.21	16.13	2.11
	November	2.60	5.52	9.91	1.92
	December	-0.92	0.49	2.76	0.97
2004	January	-0.75	-0.25	3.38	1.11
	February	-0.75	-0.75	-0.75	0.00
	March	-0.92	1.56	7.13	2.24
	April	3.86	8.79	14.71	3.09
	May	9.29	15.24	20.97	2.97
	October	9.62	11.22	13.18	0.77
	November	3.58	6.55	11.79	1.95
	December	-0.24	1.18	4.82	1.60
2005	January	-0.24	0.20	3.11	0.69
	February	-0.24	-0.13	0.72	0.13
	March	-0.24	1.06	4.67	1.55
	April	1.36	8.53	16.48	3.24
	May	8.08	14.55	20.99	3.38
	June	18.56	24.48	31.22	3.15
	July	21.82	26.37	31.99	2.11
	August	20.02	24.76	30.27	2.42

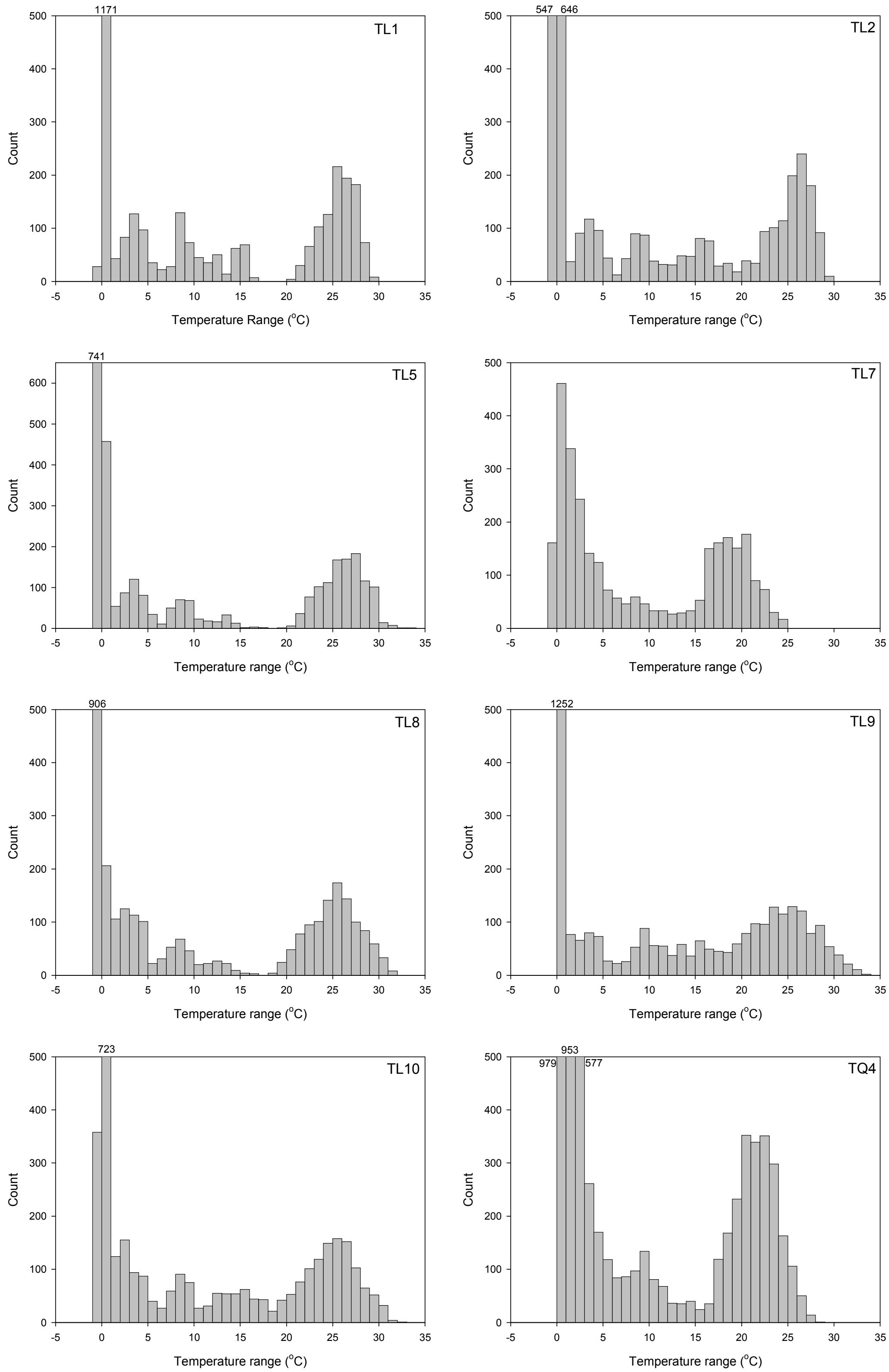
Appendix E-4. Descriptive Statistics of temperatures collected at logging stations (TL1-TL10) within the southern Grand River, 2001-2005.

TL9		Minimum	Mean	Maximum	St. Dev.
2003	August	18.57	23.87	28.80	2.13
	September	11.49	18.99	25.42	3.09
	October	6.38	10.02	17.77	2.19
	November	2.14	6.21	11.81	2.38
	December	-0.08	0.97	3.42	0.94
2004	January	0.07	0.62	5.76	1.30
	February	0.07	0.07	0.23	0.01
	March	0.07	2.77	10.26	3.01
	April	4.19	10.10	16.02	3.07
	May	8.39	16.57	23.86	3.40
	June	14.43	20.62	28.07	2.68
	July	18.90	22.84	29.35	2.35
	August	16.49	21.85	28.43	2.32
	September	13.35	20.02	27.35	2.91
	October	7.16	11.86	19.38	2.62
	November	1.19	6.12	12.42	2.26
	December	0.07	1.36	4.82	1.54
2005	January	0.07	0.30	3.26	0.41
	February	0.07	0.11	0.23	0.07
	March	0.07	0.37	4.35	0.71
	April	0.07	9.16	17.77	3.63
	May	7.78	15.19	23.52	3.53
	June	17.12	24.74	32.19	3.71
	July	19.87	26.27	33.96	2.68
	August	17.77	23.99	31.03	2.81

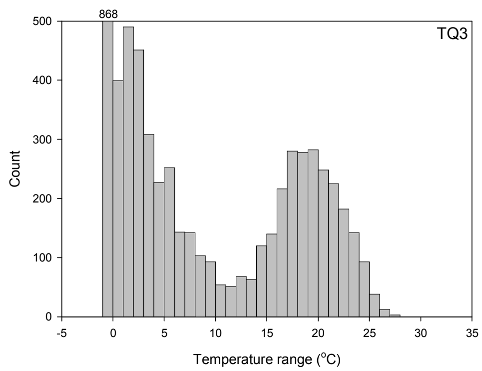
Appendix E-4. Descriptive Statistics of temperatures collected at logging stations (TL1-TL10) within the southern Grand River, 2001-2005.

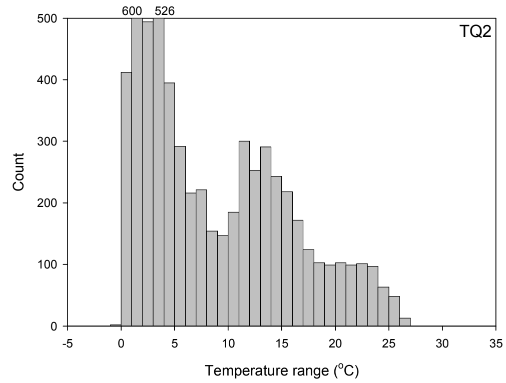
TL10		Minimum	Mean	Maximum	St. Dev.
2003	August	20.43	24.56	28.36	1.58
	September	13.25	19.87	26.03	2.78
	October	7.98	10.91	17.67	2.07
	November	3.14	6.33	10.62	1.96
	December	-0.04	1.28	3.46	0.95
2004	January	-0.04	0.49	4.39	1.18
	February	-0.04	0.02	0.59	0.12
	March	-0.04	2.48	8.13	2.33
	April	4.71	9.61	15.12	3.01
	May	10.15	15.78	21.41	2.92
	June	14.97	20.04	25.16	1.98
	July	19.62	22.77	26.74	1.45
	August	18.64	22.12	26.21	1.51
	September	16.71	20.66	26.03	2.10
	October	8.13	12.61	21.41	2.77
	November	3.93	6.79	12.16	1.92
	December	-0.21	1.38	5.02	1.57
2005	January	-0.04	0.60	2.83	0.57
	February	-0.04	0.18	1.24	0.19
	March	-0.04	1.09	4.55	1.26
	April	1.24	8.53	16.08	3.20
	May	8.29	14.32	20.43	3.18
	June	18.31	24.21	31.53	3.10
	July	21.91	26.25	32.12	2.08
	August	20.11	24.68	30.96	2.41

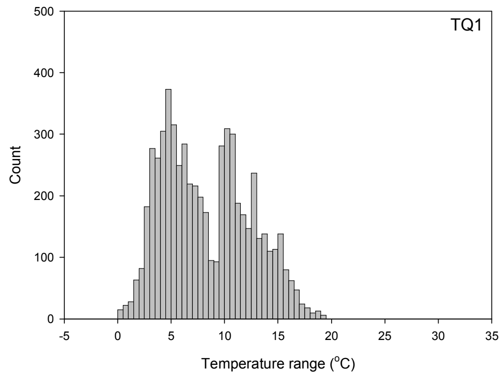
Appendix E-5. Distribution of hourly temperatures measured between November 26, 2004 and September 1, 2006 at 11 stations in the Grand River



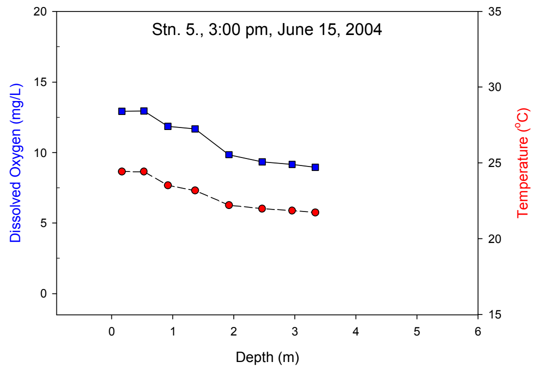
Appendix E-5. Distribution of hourly temperatures measured between November 26, 2004 and September 1, 2006 at 11 stations in the Grand River

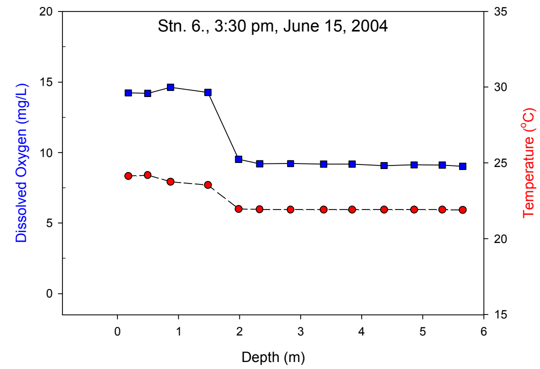


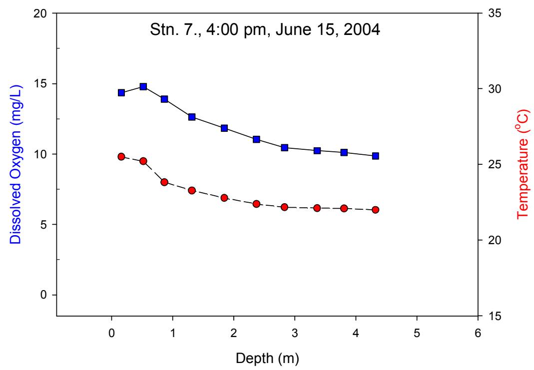


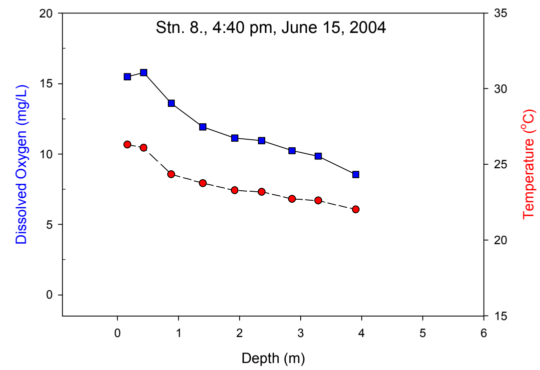


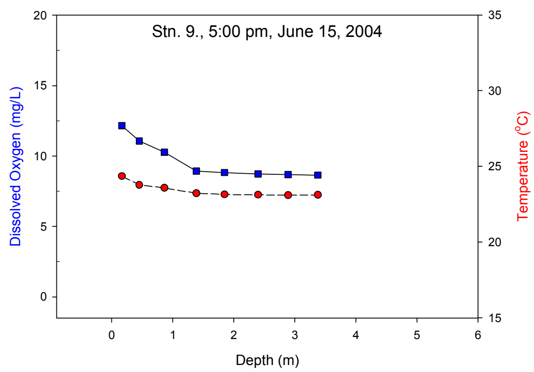
Appendix E6: Temperature and oxygen profiles, Grand River, 2004.

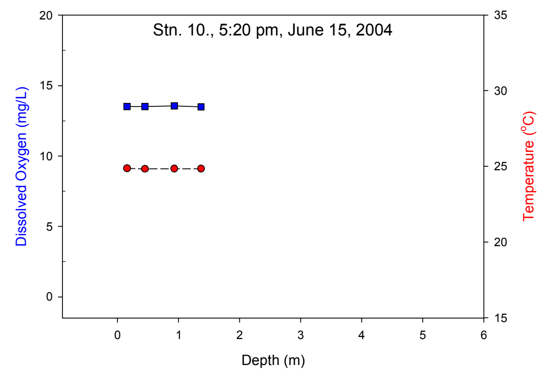


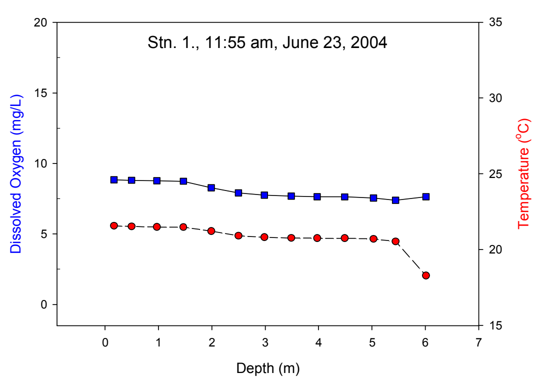


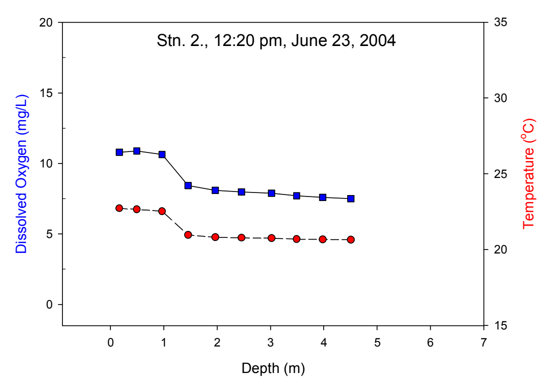






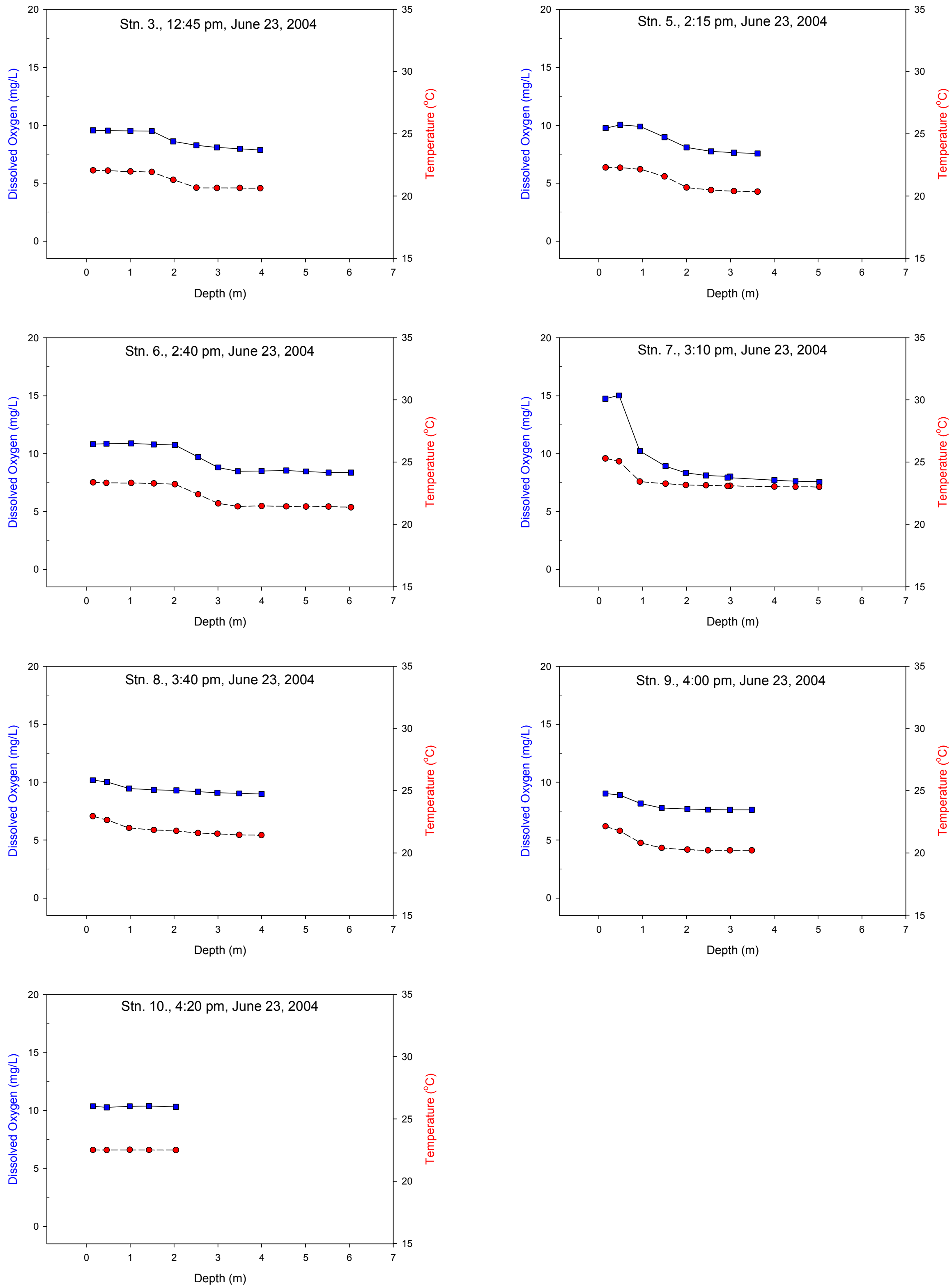


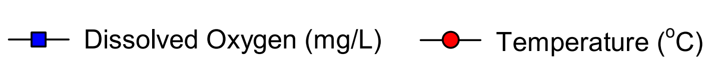




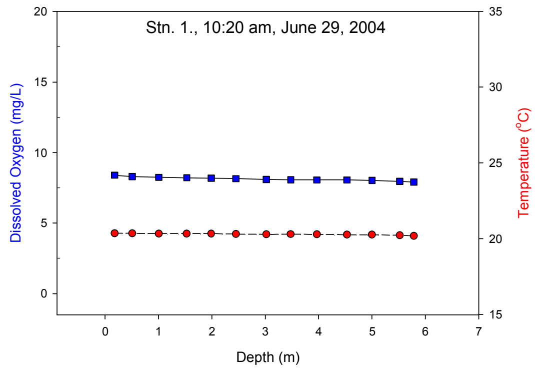
Dissolved Oxygen (mg/L)   Temperature (°C)

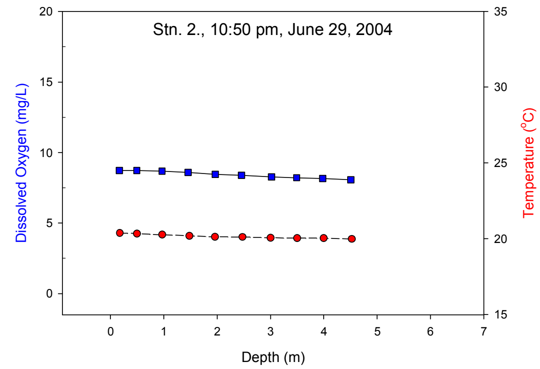
Appendix E6: Temperature and oxygen profiles, Grand River, 2004.

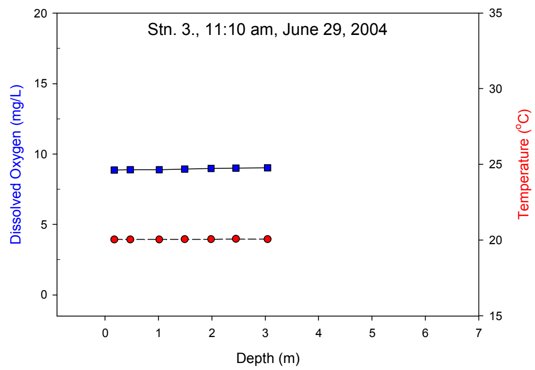


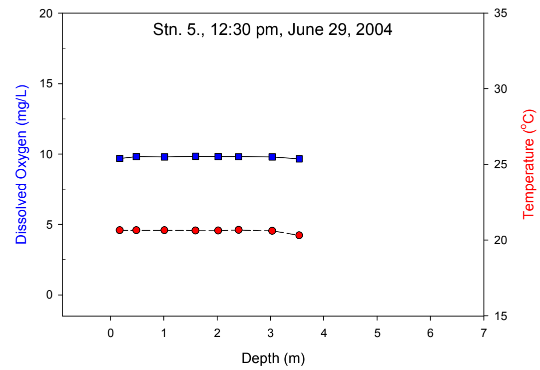


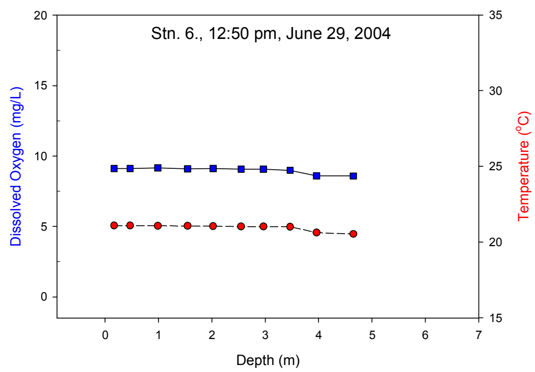
Appendix E6: Temperature and oxygen profiles, Grand River, 2004.

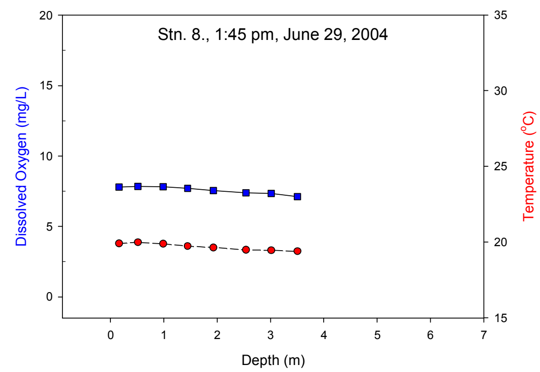


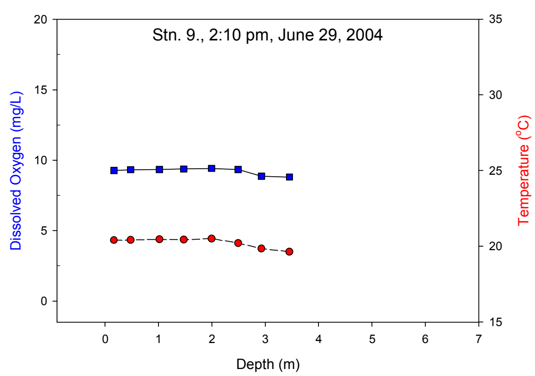


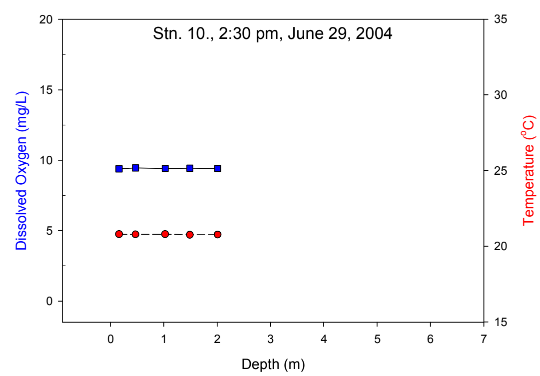






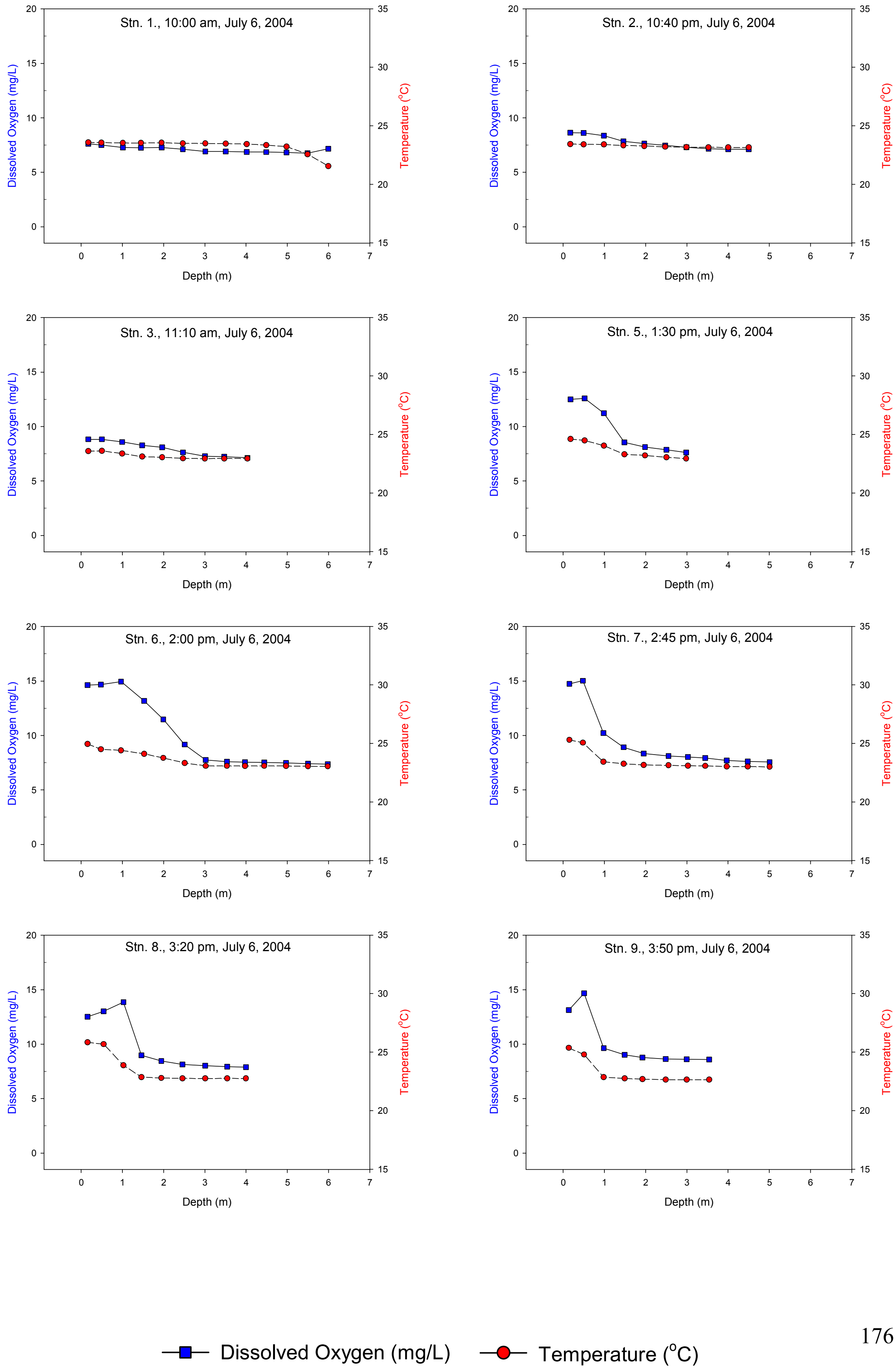




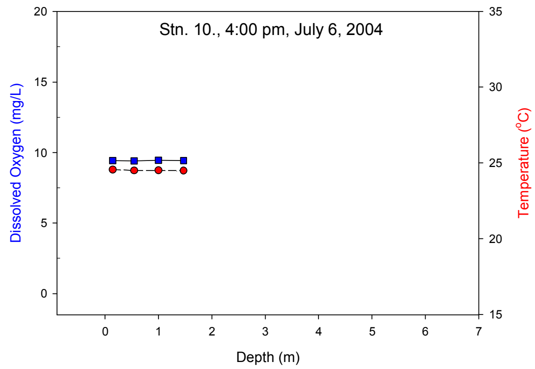


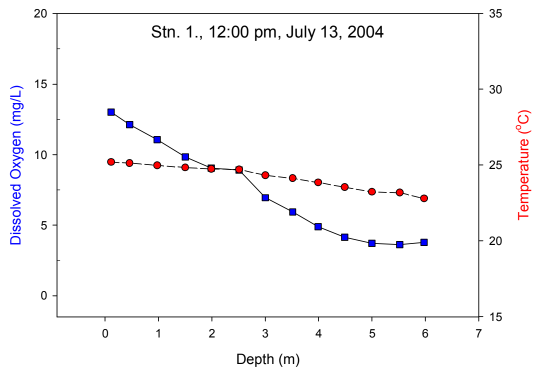
Dissolved Oxygen (mg/L) Temperature (°C)

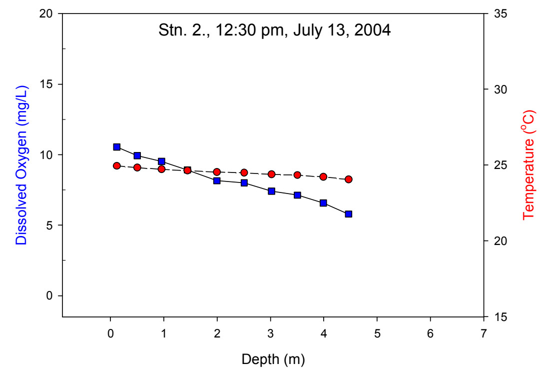
Appendix E6: Temperature and oxygen profiles, Grand River, 2004.

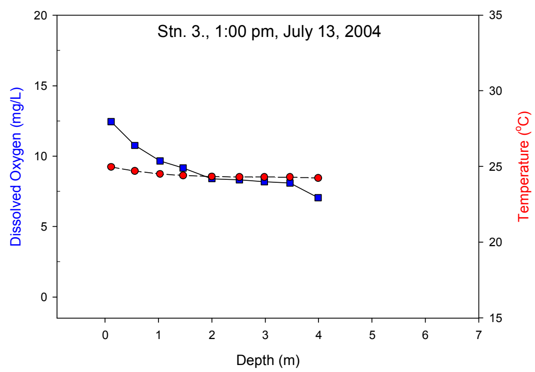


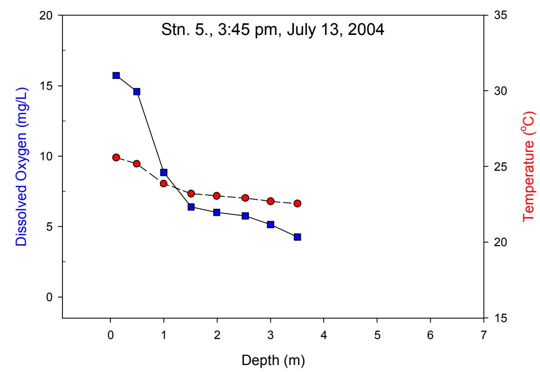
Appendix E6: Temperature and oxygen profiles, Grand River, 2004.

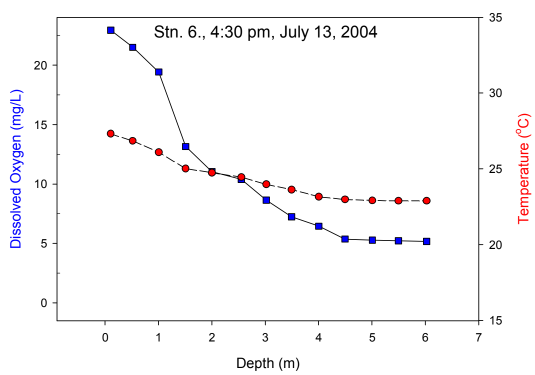


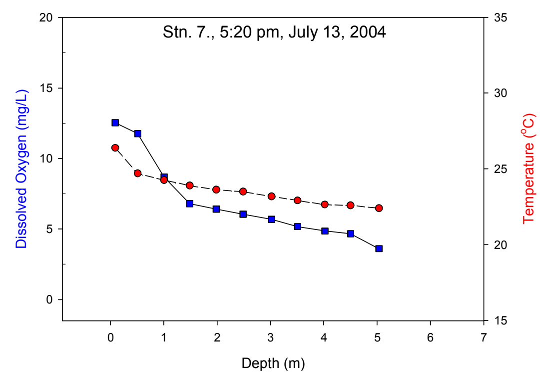


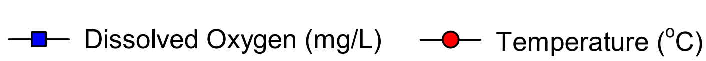




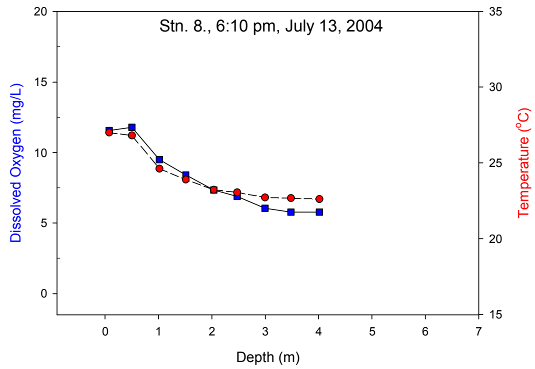


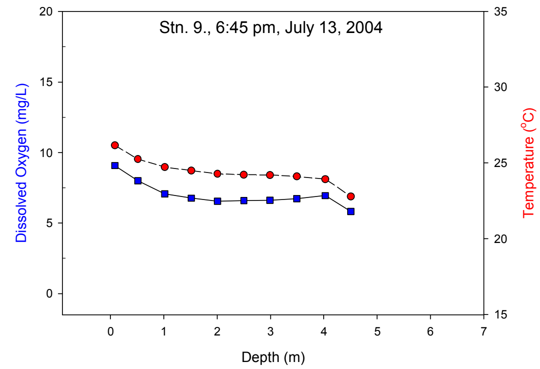


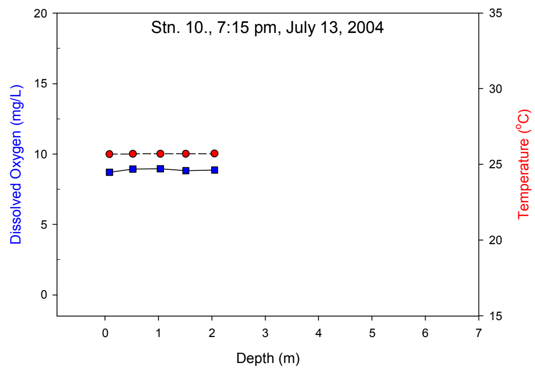


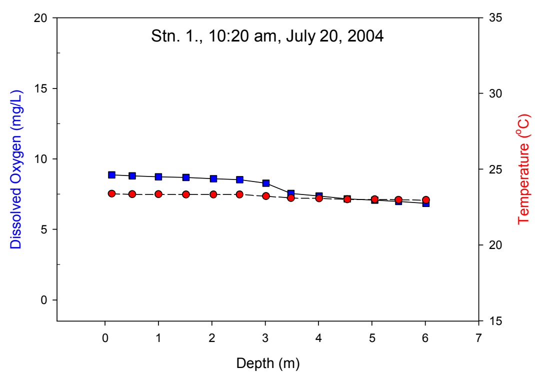


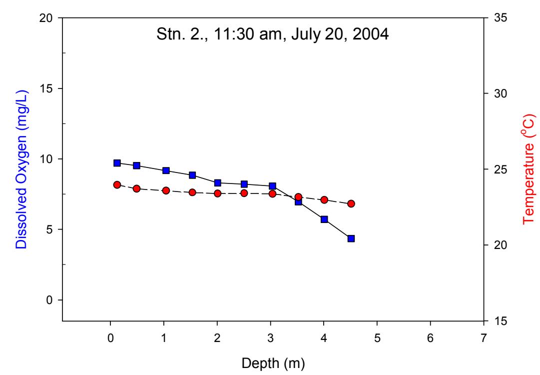
Appendix E6: Temperature and oxygen profiles, Grand River, 2004.

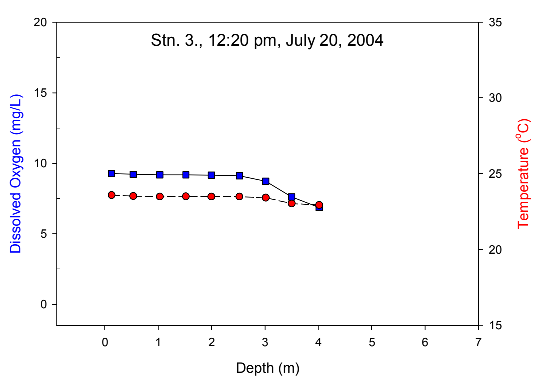


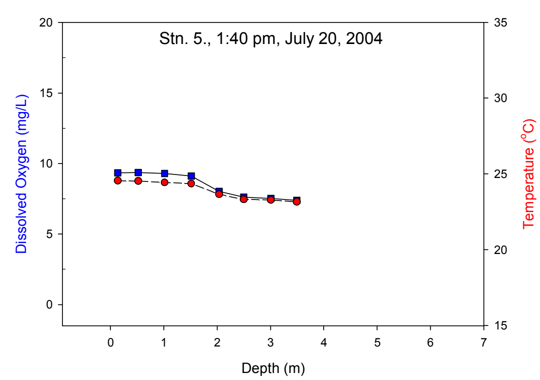






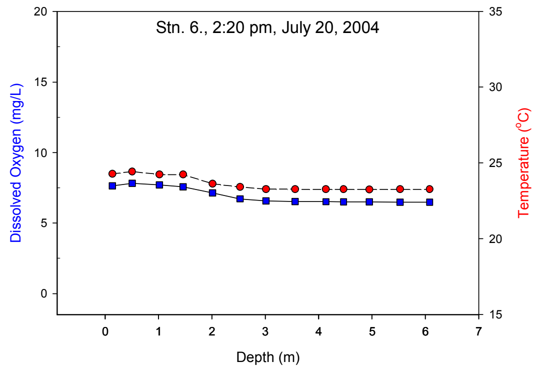


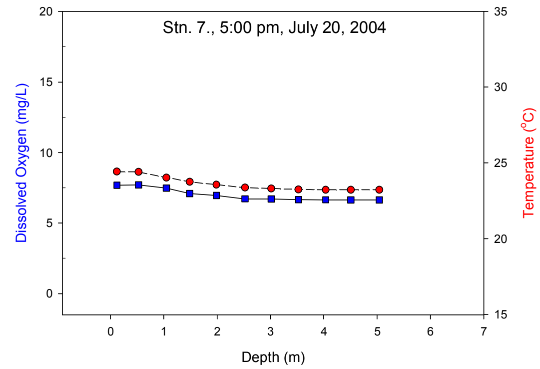


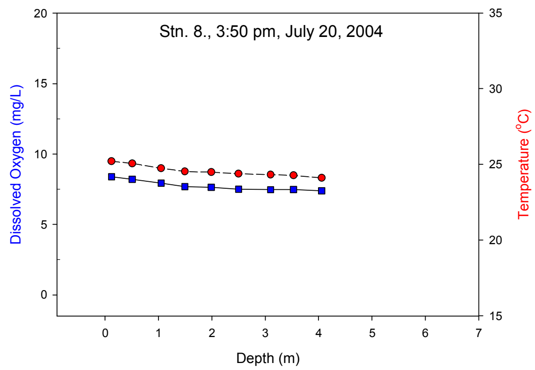


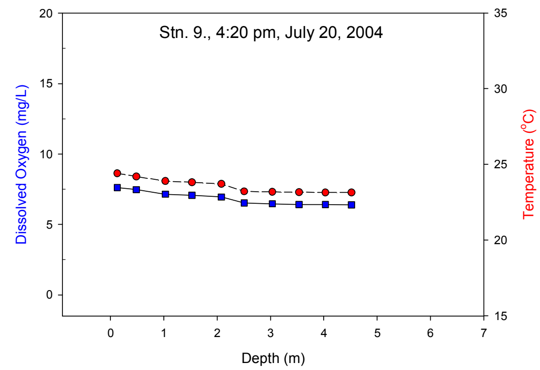
Dissolved Oxygen (mg/L) Temperature (°C)

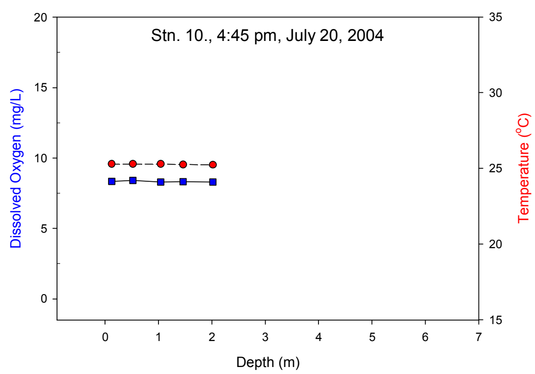
Appendix E6: Temperature and oxygen profiles, Grand River, 2004.

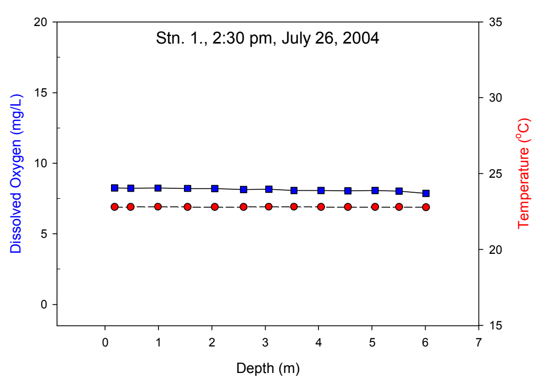


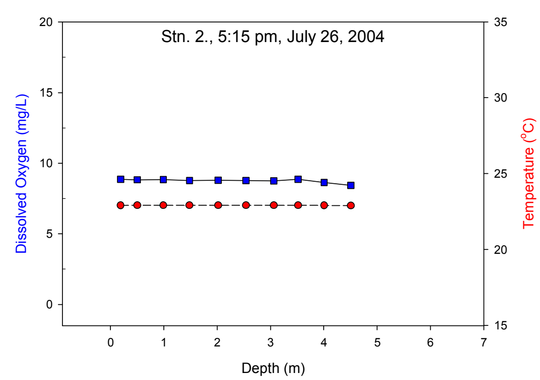






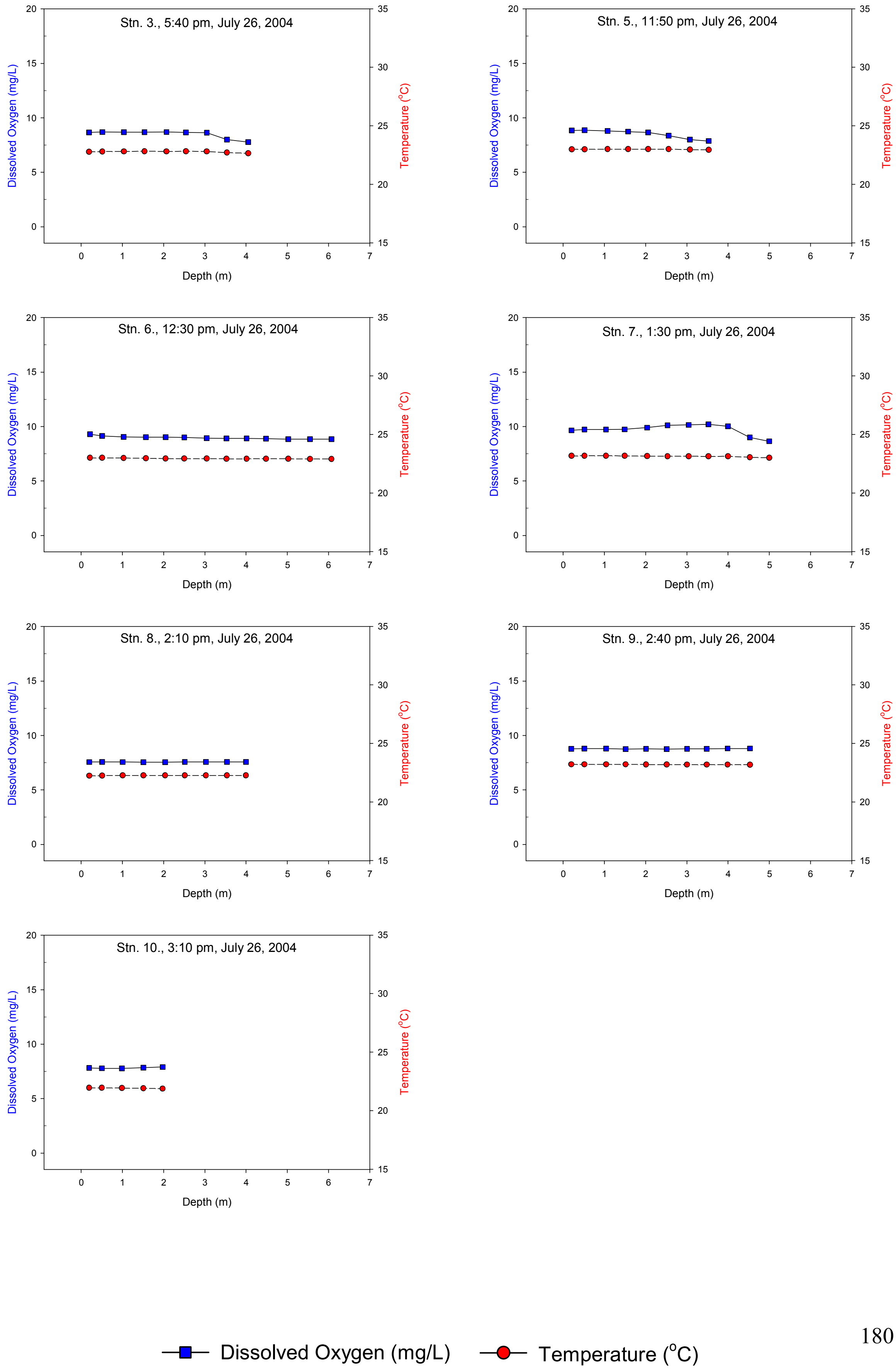




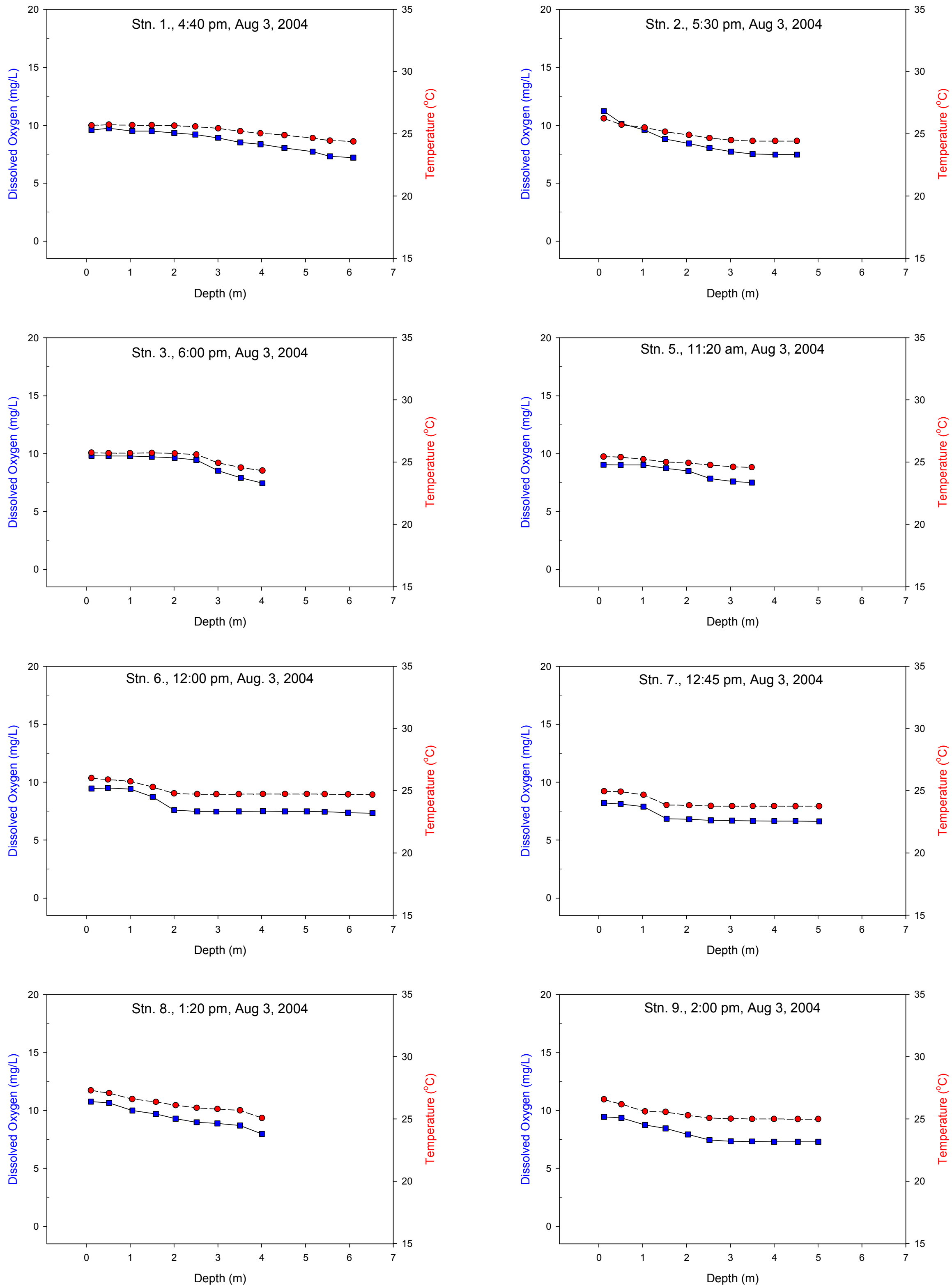


Dissolved Oxygen (mg/L)   Temperature (°C)

Appendix E6: Temperature and oxygen profiles, Grand River, 2004.

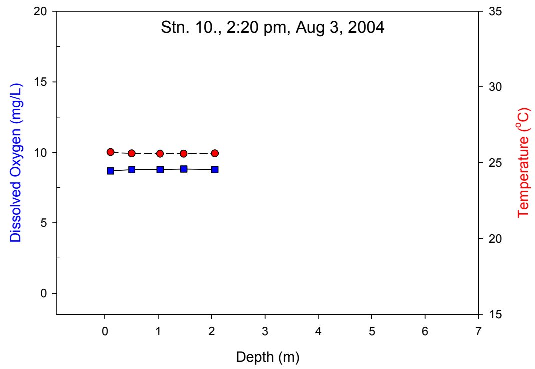


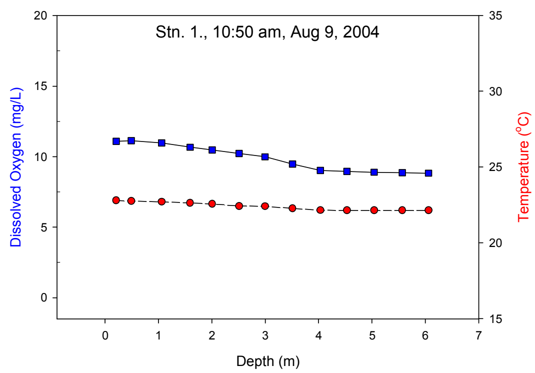
Appendix E6: Temperature and oxygen profiles, Grand River, 2004.

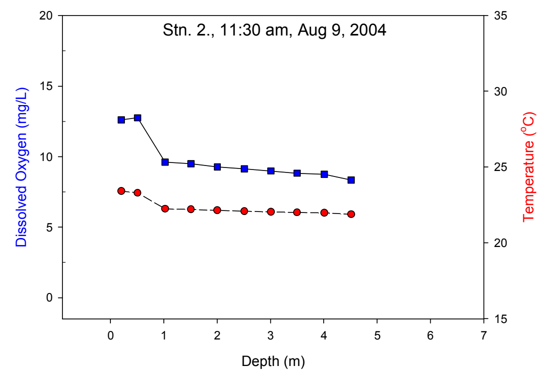


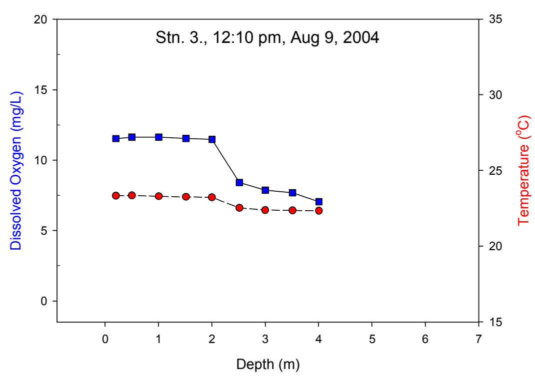
Dissolved Oxygen (mg/L) Temperature (°C)

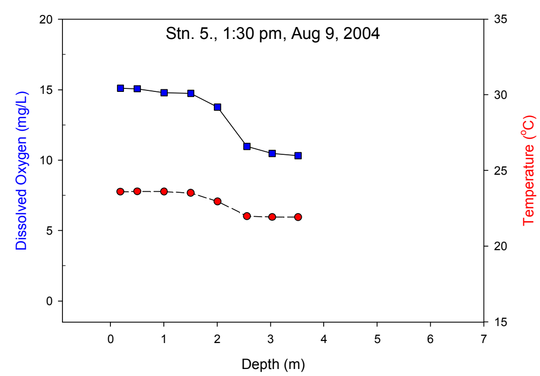
Appendix E6: Temperature and oxygen profiles, Grand River, 2004.

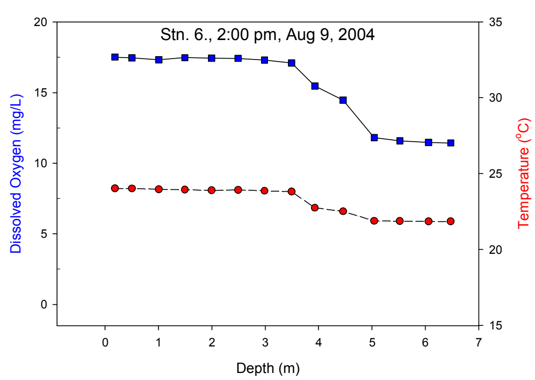


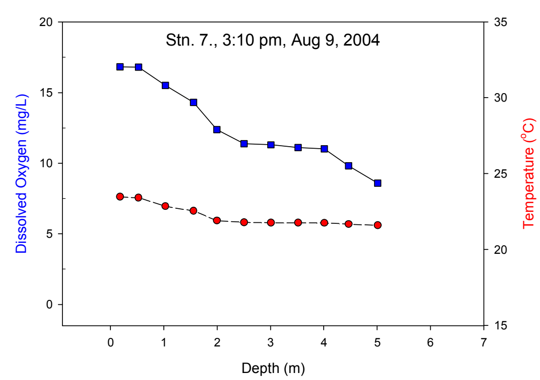






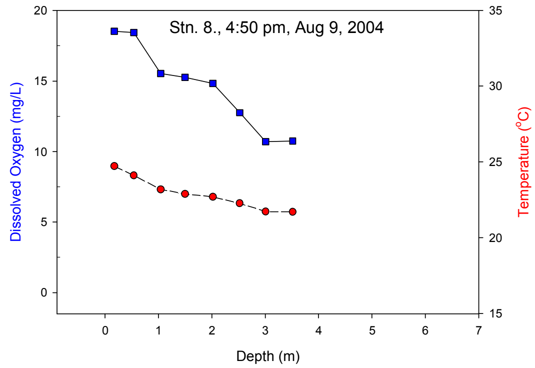


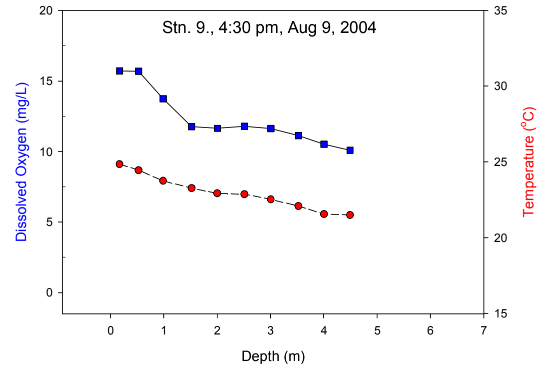


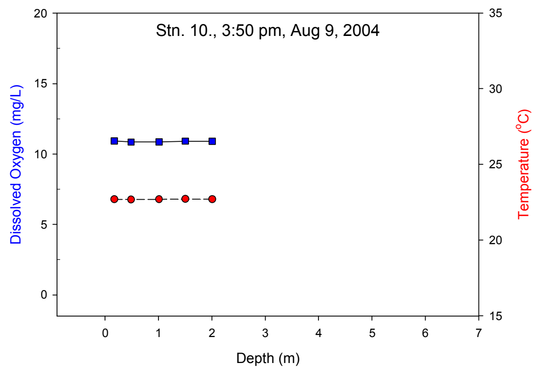


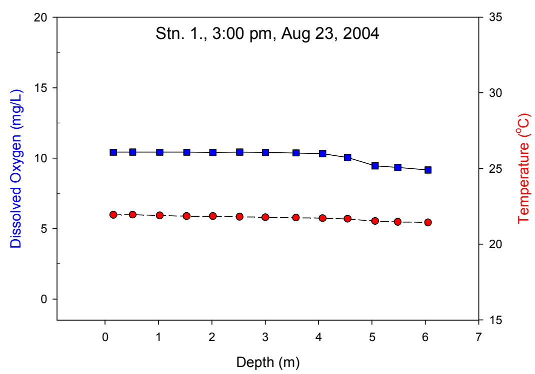
Dissolved Oxygen (mg/L) Temperature (°C)

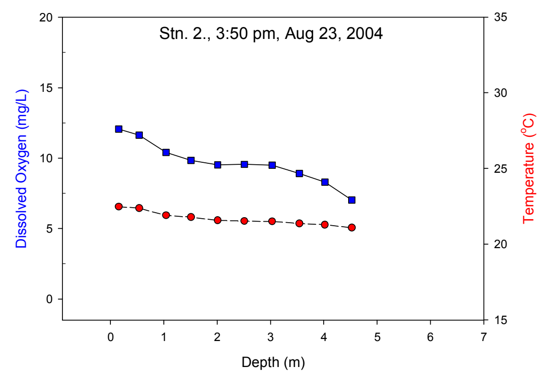
Appendix E6: Temperature and oxygen profiles, Grand River, 2004.

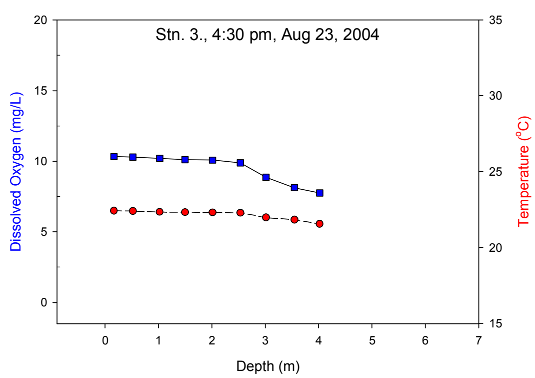


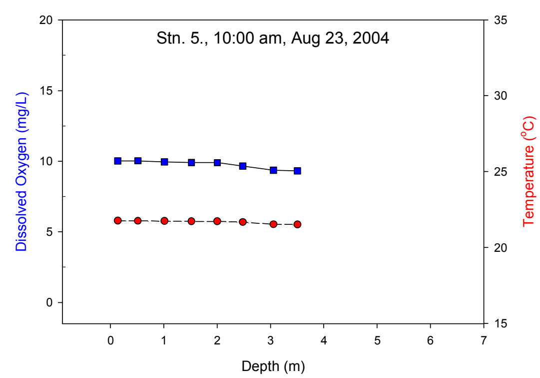






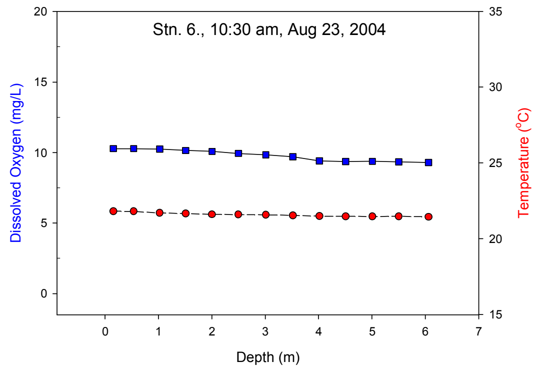


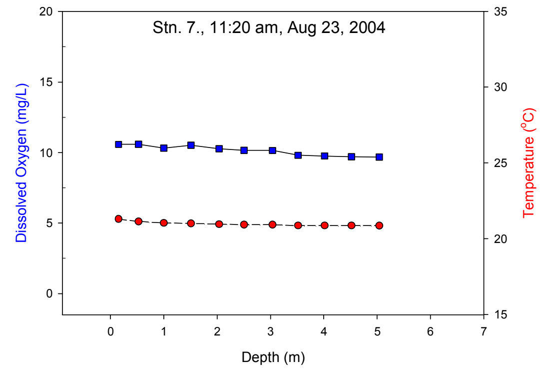


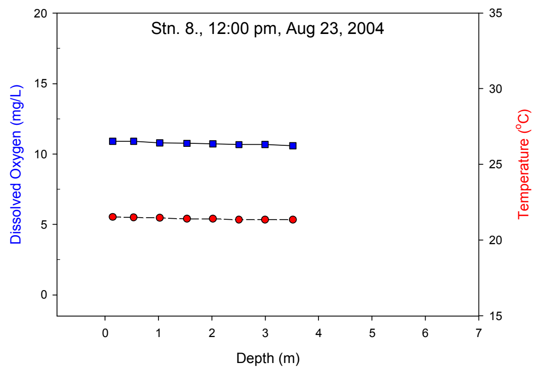


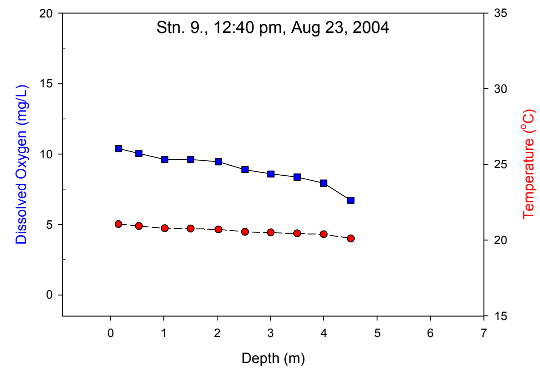
Dissolved Oxygen (mg/L) Temperature (°C)

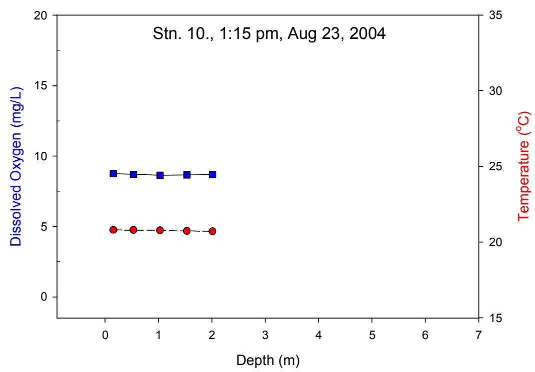
Appendix E6: Temperature and oxygen profiles, Grand River, 2004.

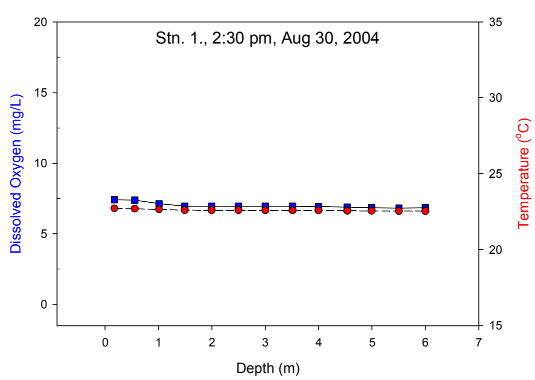


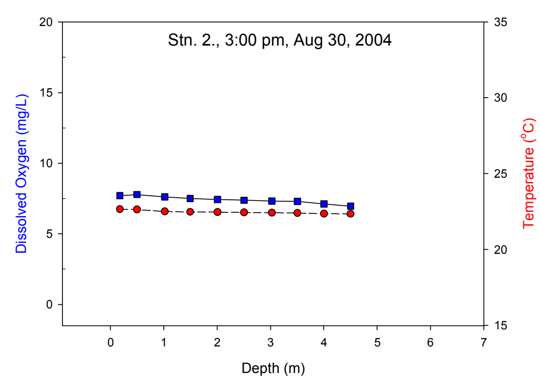






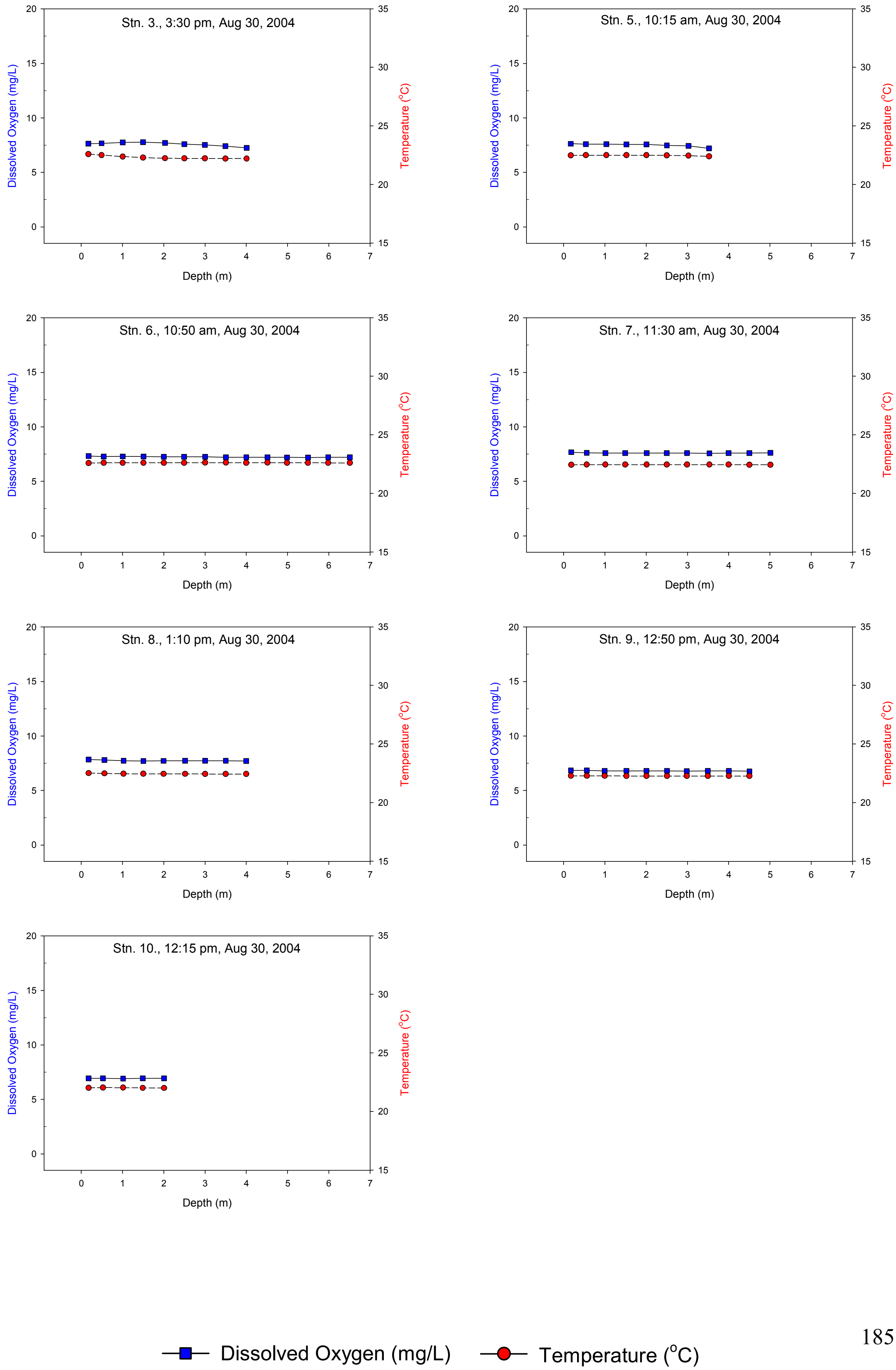




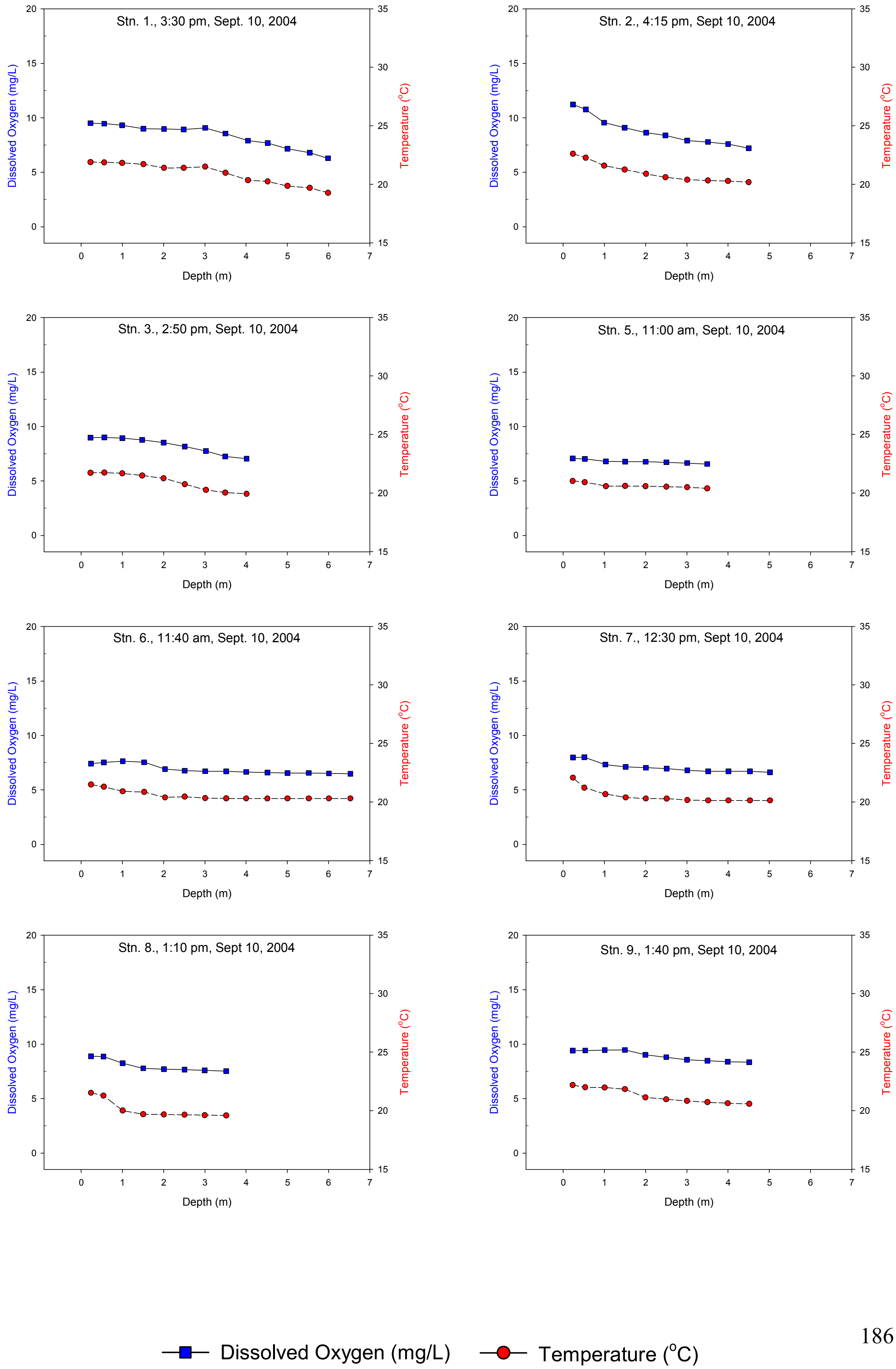


Dissolved Oxygen (mg/L)   Temperature (°C)

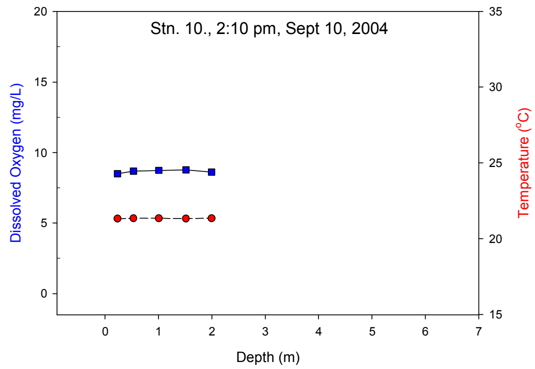
Appendix E6: Temperature and oxygen profiles, Grand River, 2004.

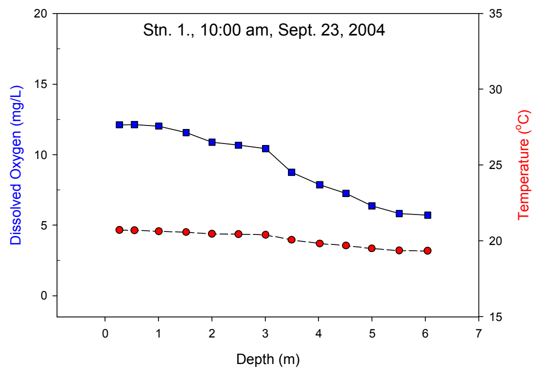


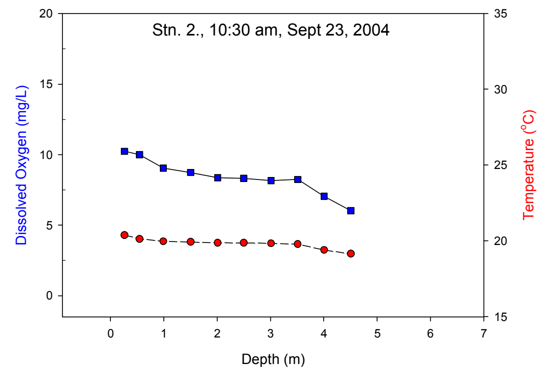
Appendix E6: Temperature and oxygen profiles, Grand River, 2004.

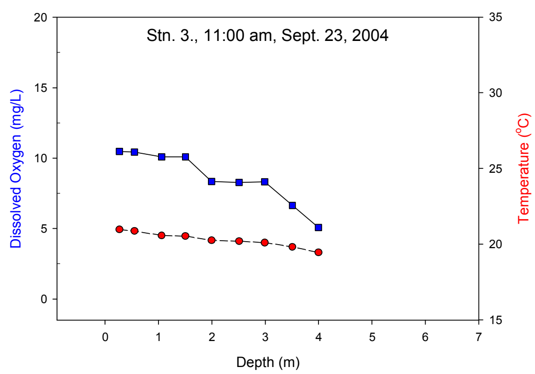


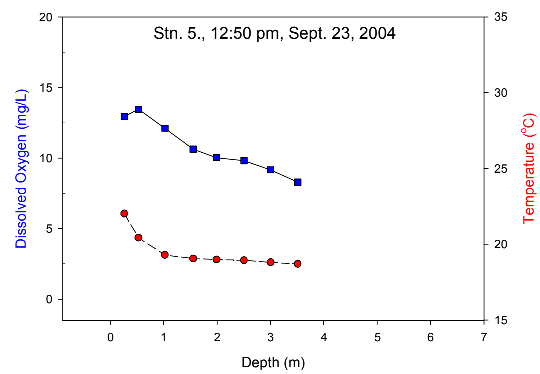
Appendix E6: Temperature and oxygen profiles, Grand River, 2004.

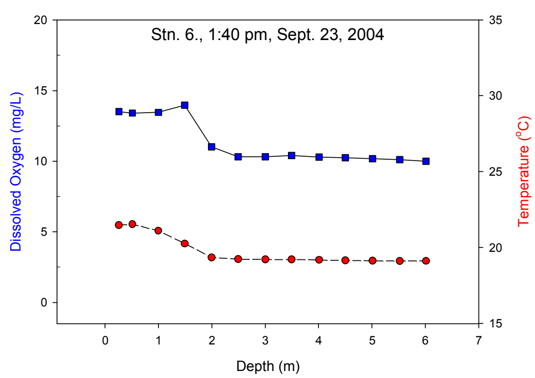


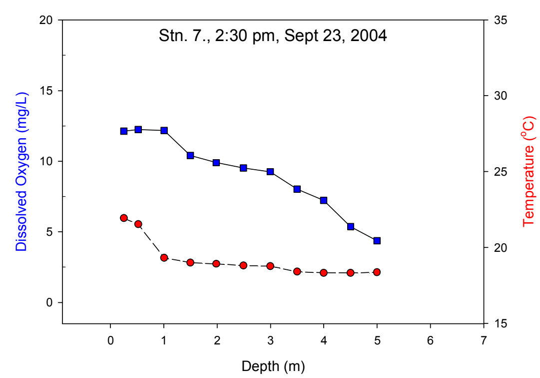


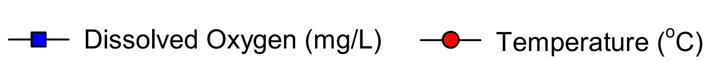




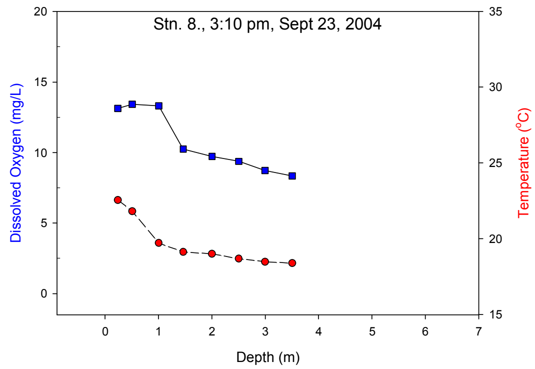


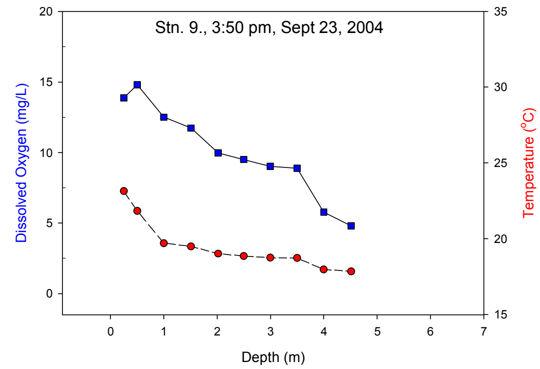


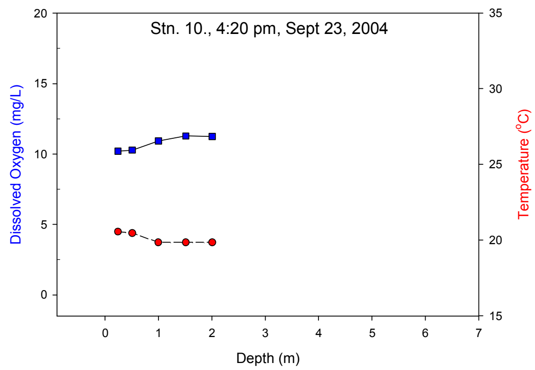


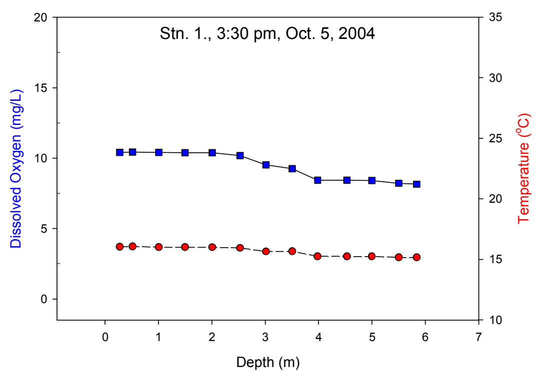


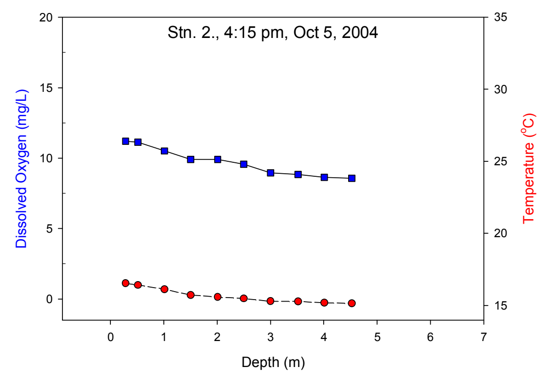
Appendix E6: Temperature and oxygen profiles, Grand River, 2004.

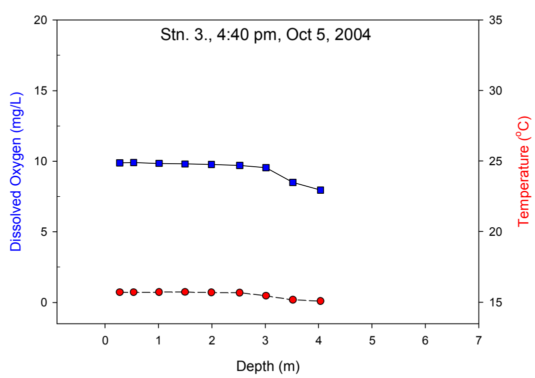


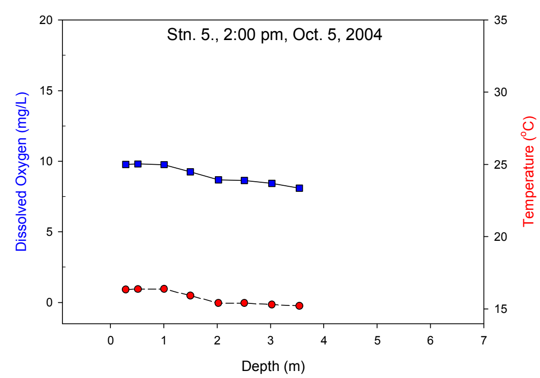


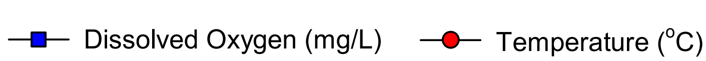




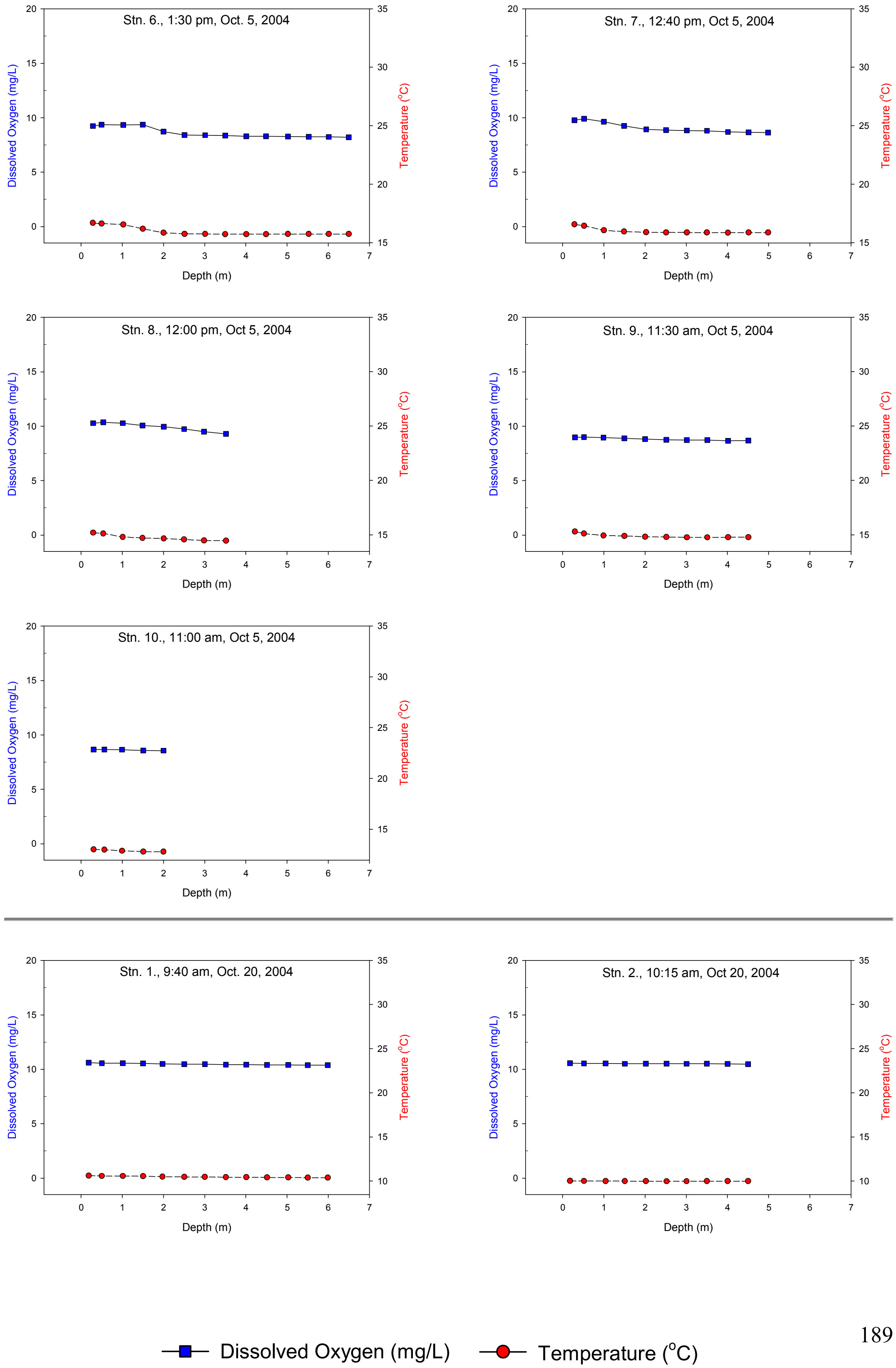




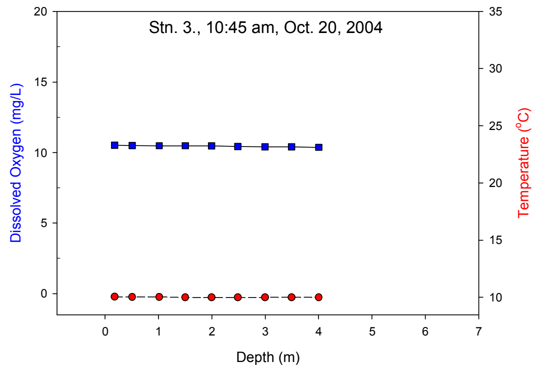


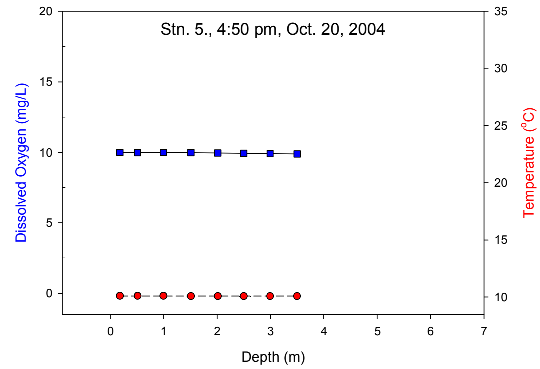


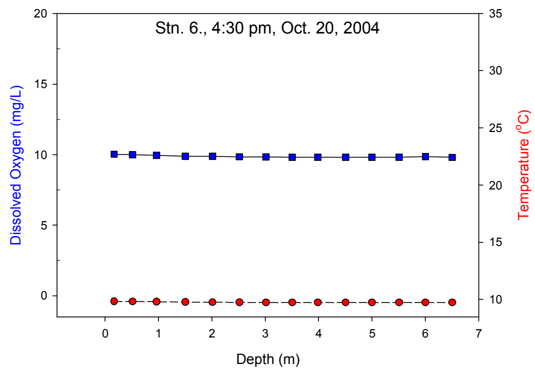
Appendix E6: Temperature and oxygen profiles, Grand River, 2004.

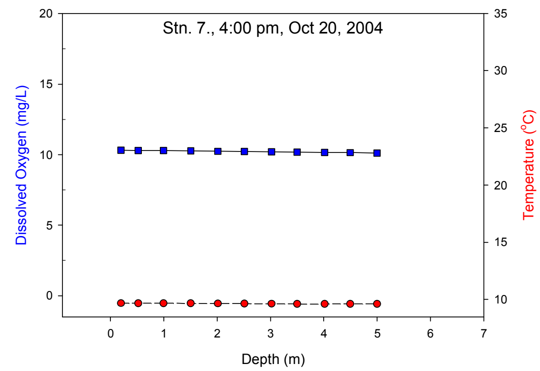


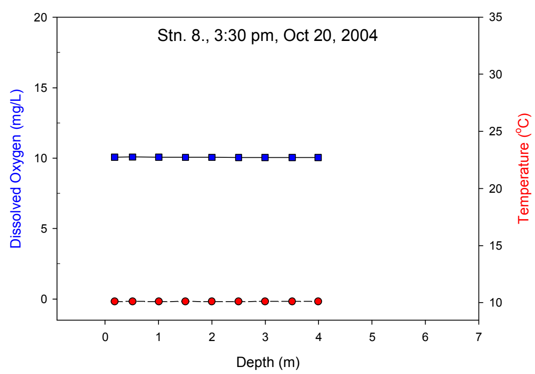
Appendix E6: Temperature and oxygen profiles, Grand River, 2004.

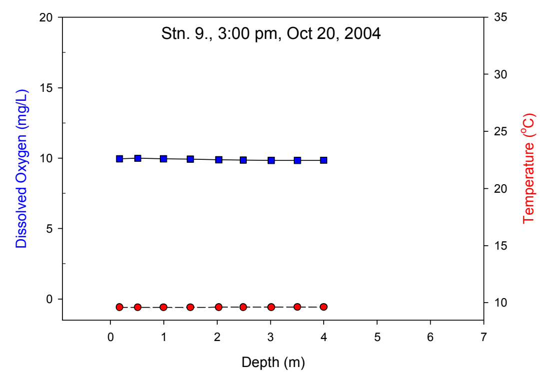


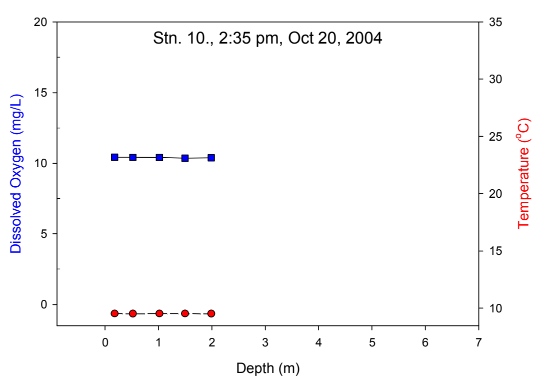






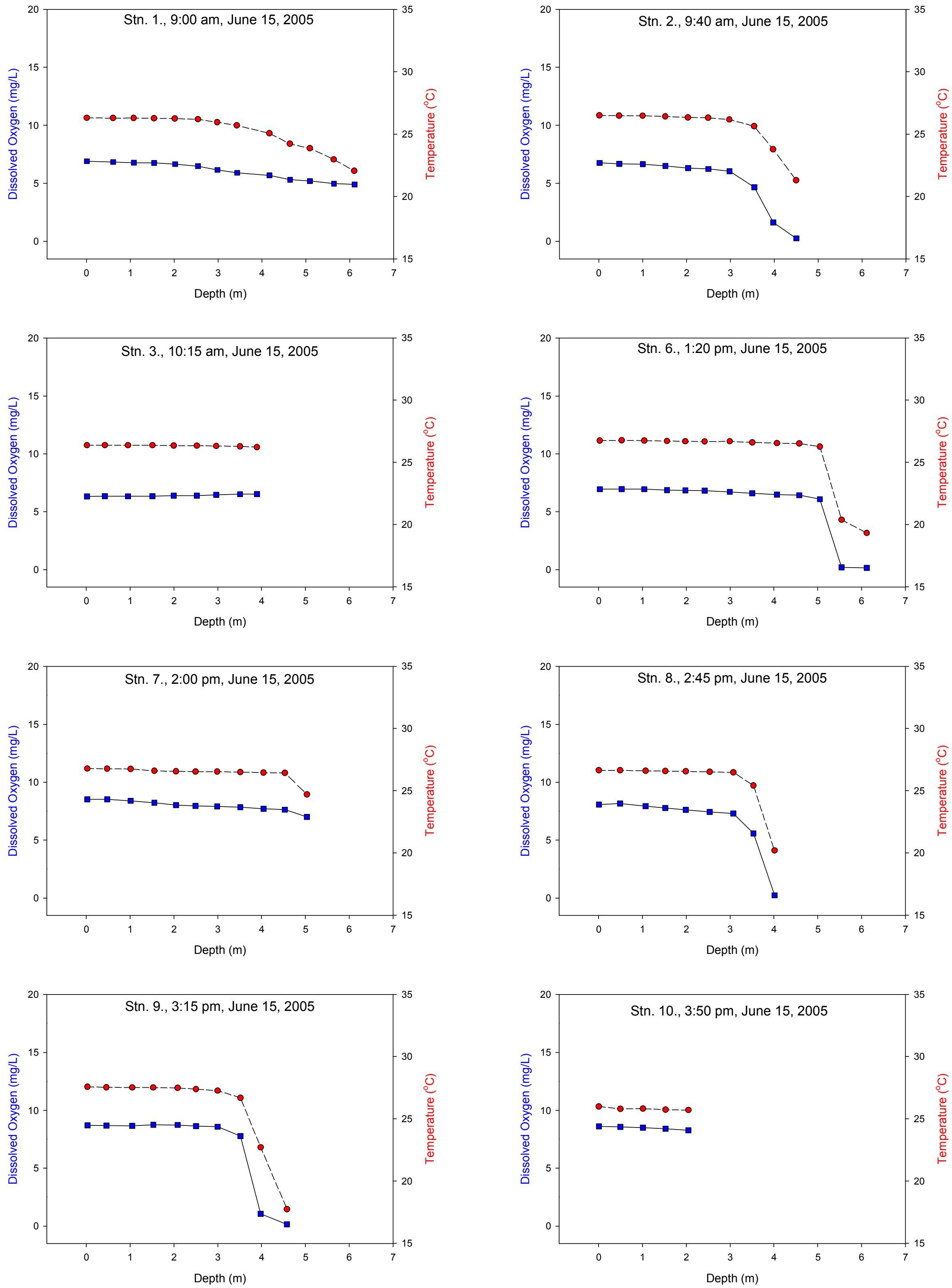


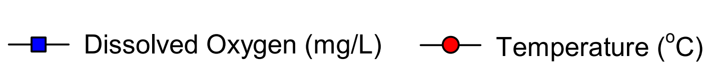




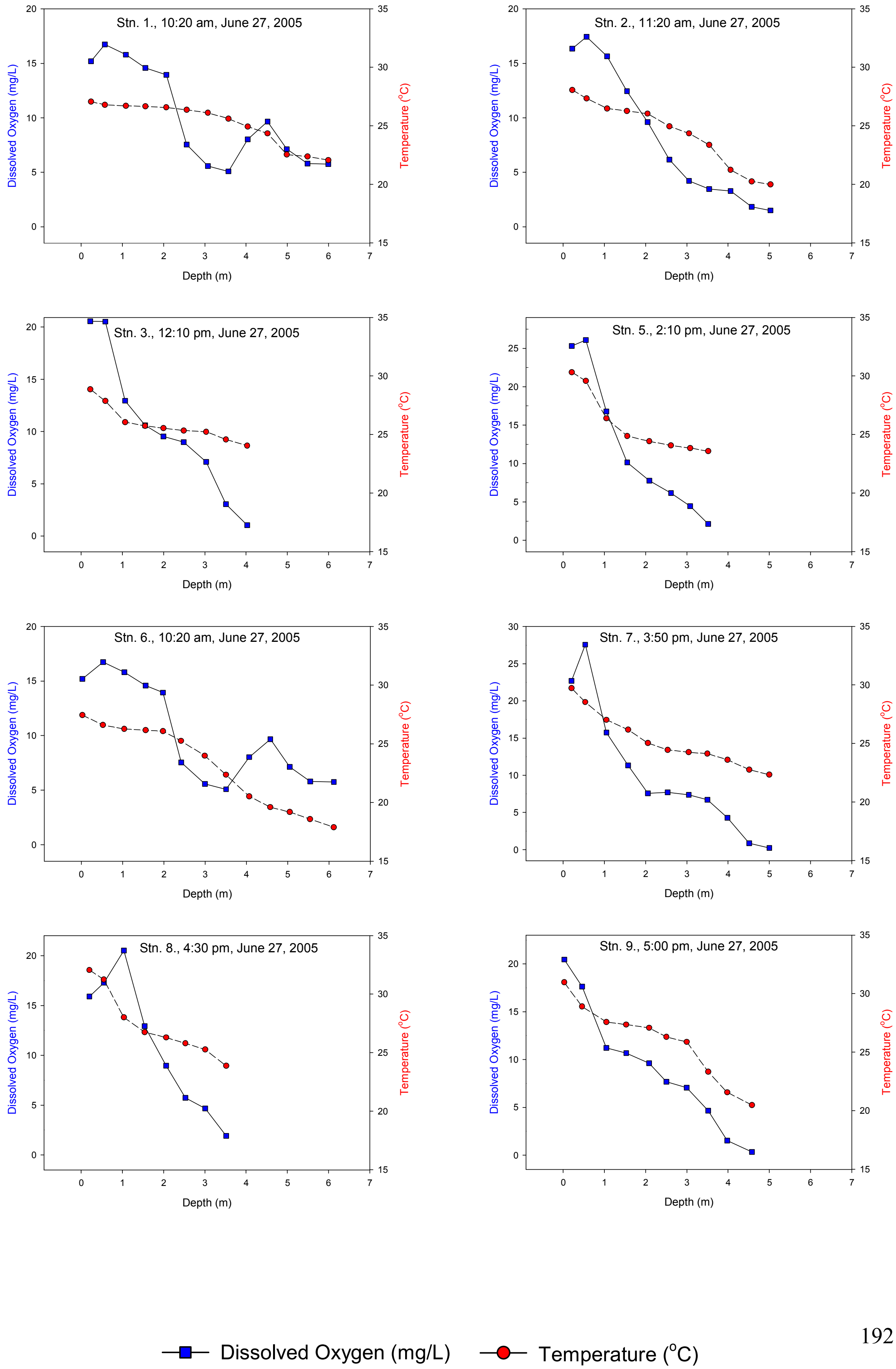
Dissolved Oxygen (mg/L) Temperature (°C)

Appendix E7: Temperature and oxygen profiles, Grand River, 2005.

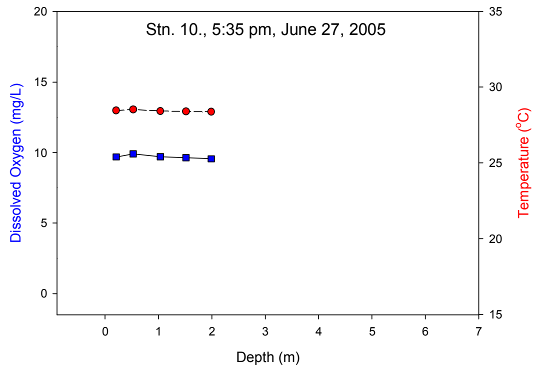


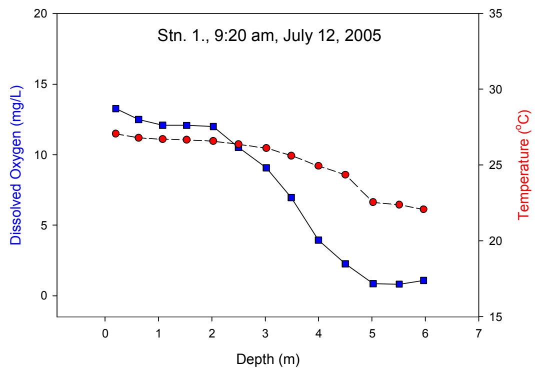


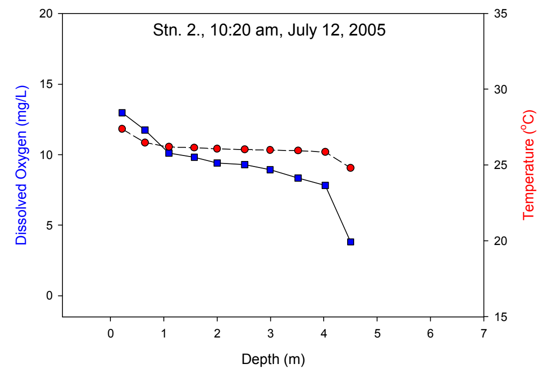
Appendix E7: Temperature and oxygen profiles, Grand River, 2005.

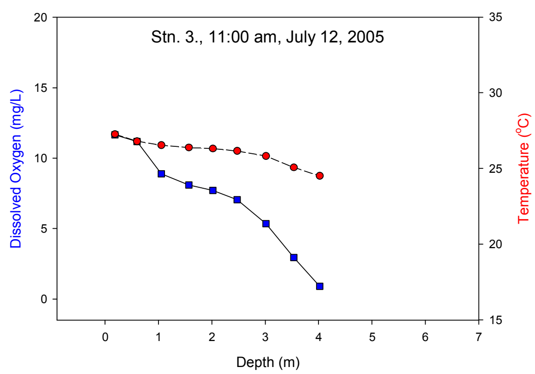


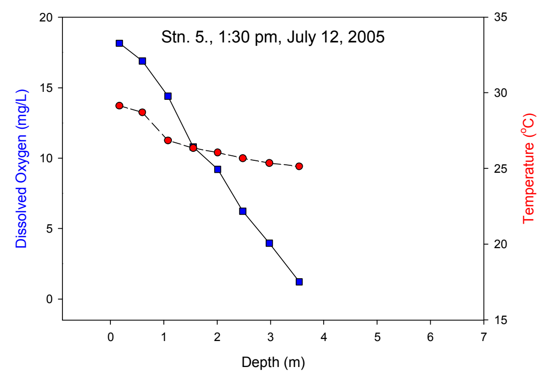
Appendix E7: Temperature and oxygen profiles, Grand River, 2005.

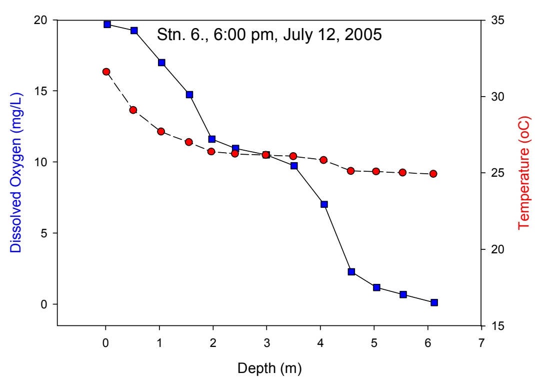


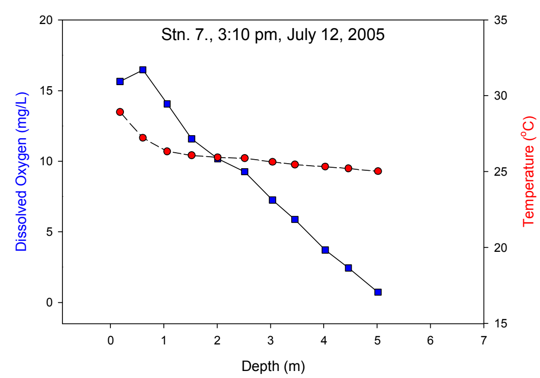






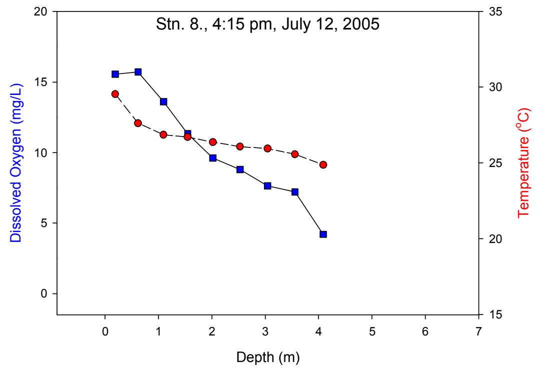


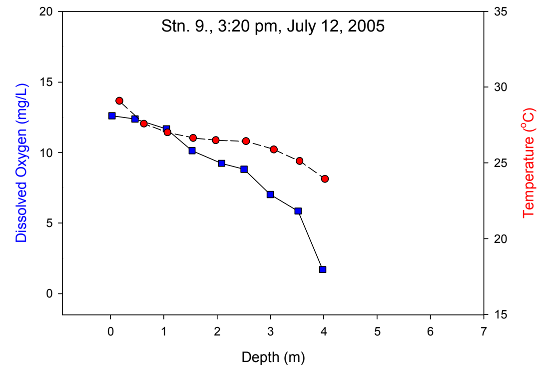


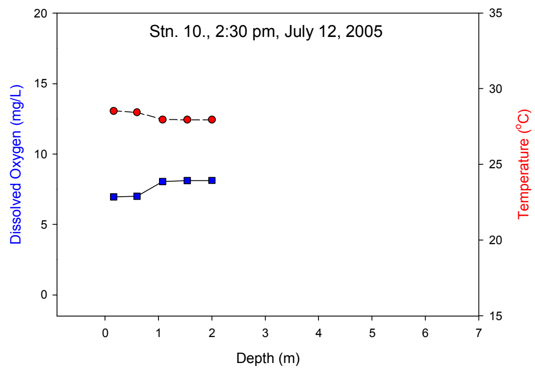


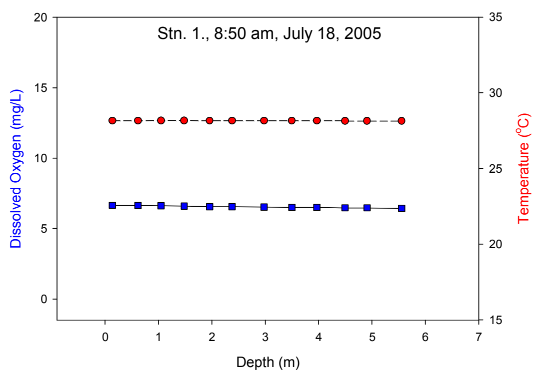
Dissolved Oxygen (mg/L) Temperature (^{o}C)

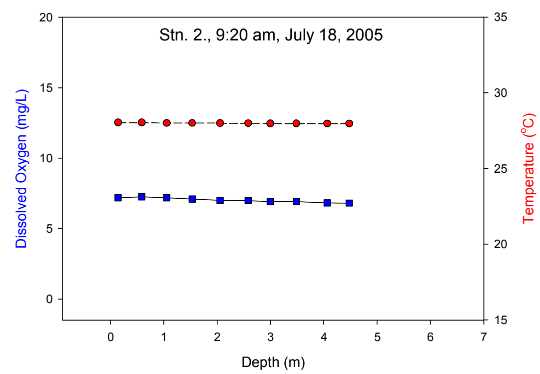
Appendix E7: Temperature and oxygen profiles, Grand River, 2005.

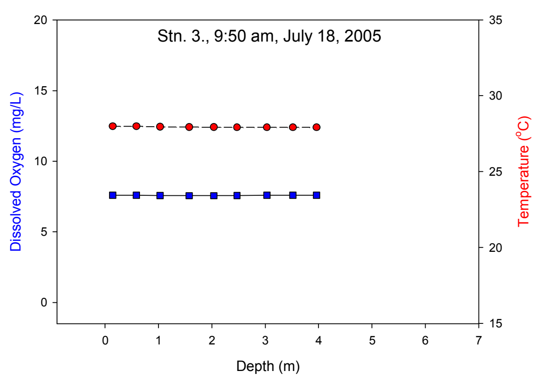


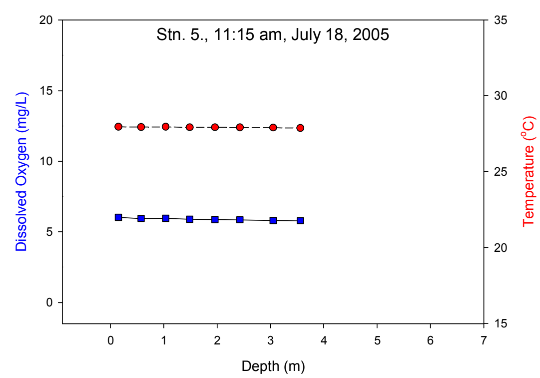


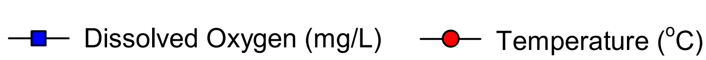




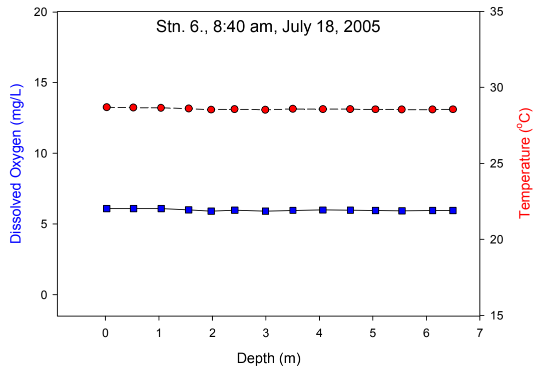


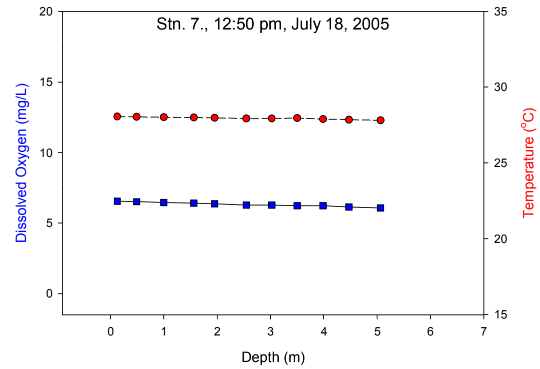


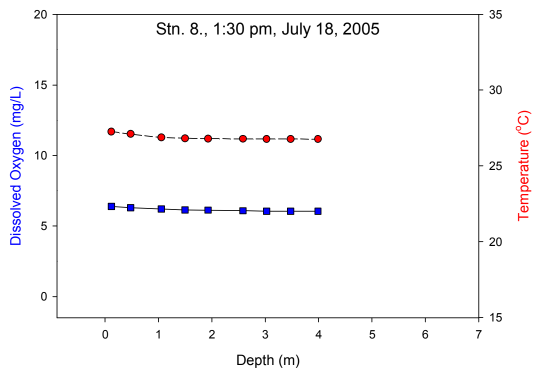


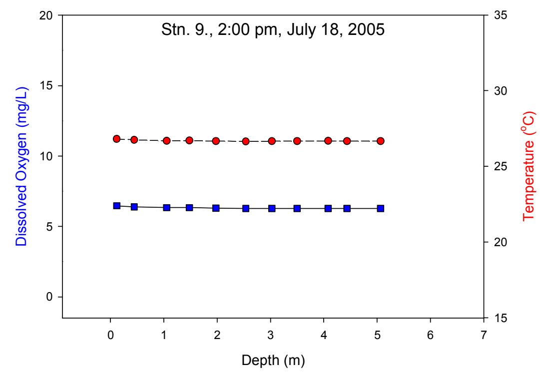


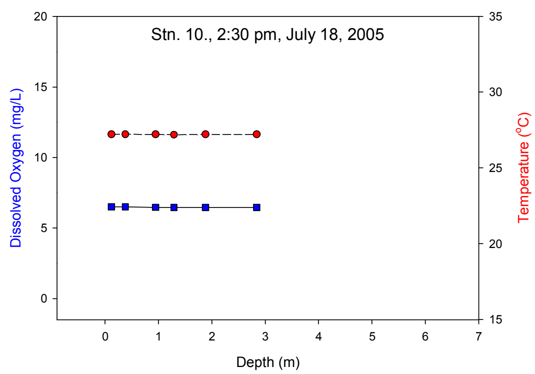
Appendix E7: Temperature and oxygen profiles, Grand River, 2005.

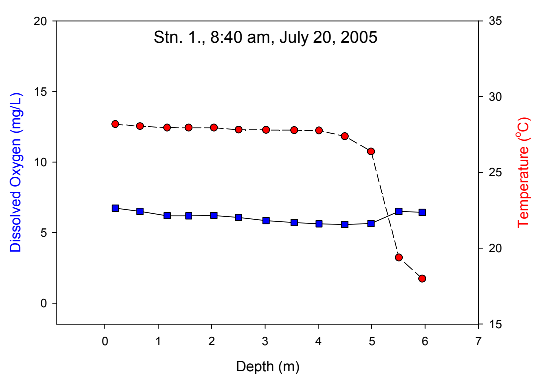


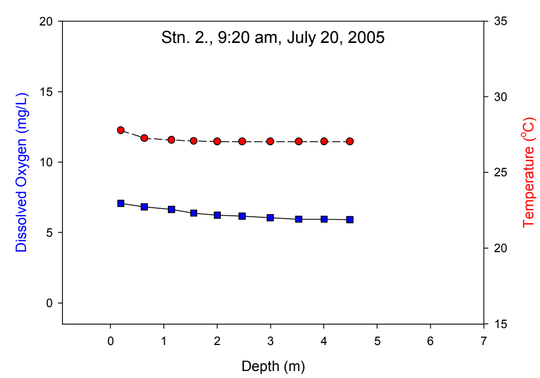


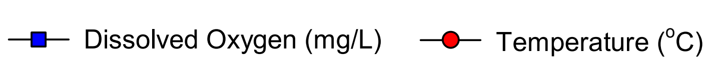




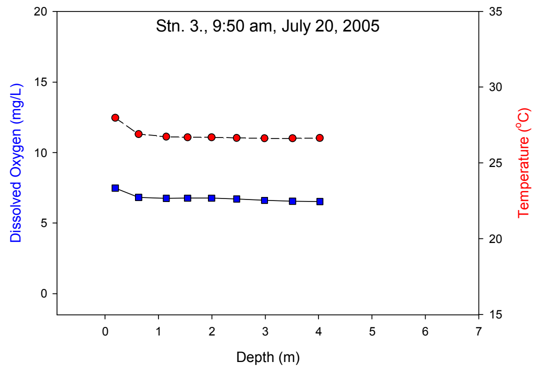


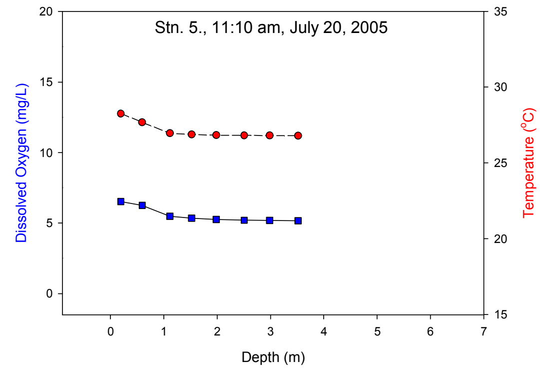


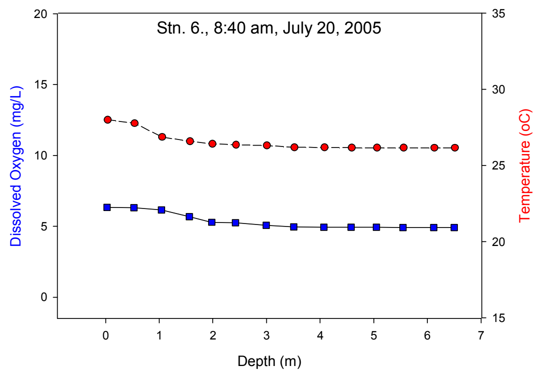


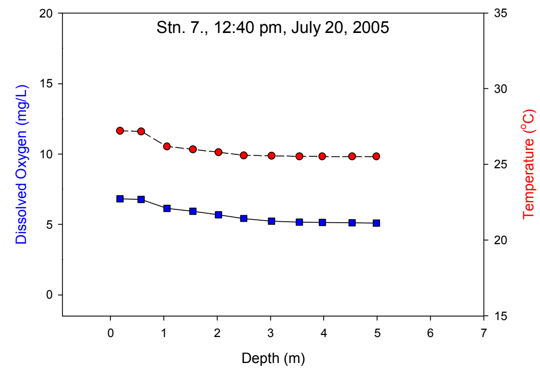


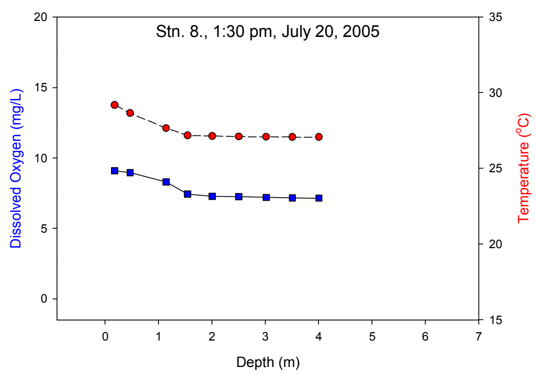
Appendix E7: Temperature and oxygen profiles, Grand River, 2005.

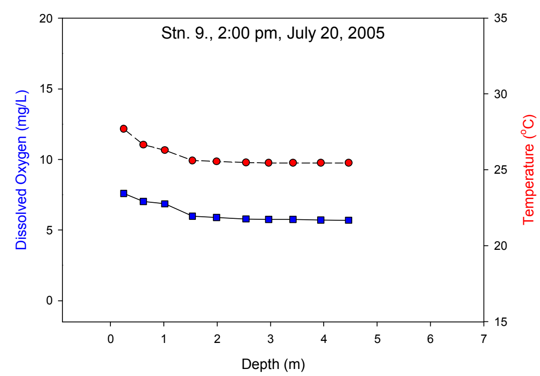


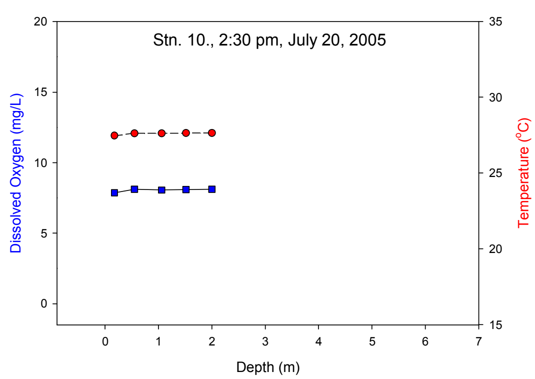






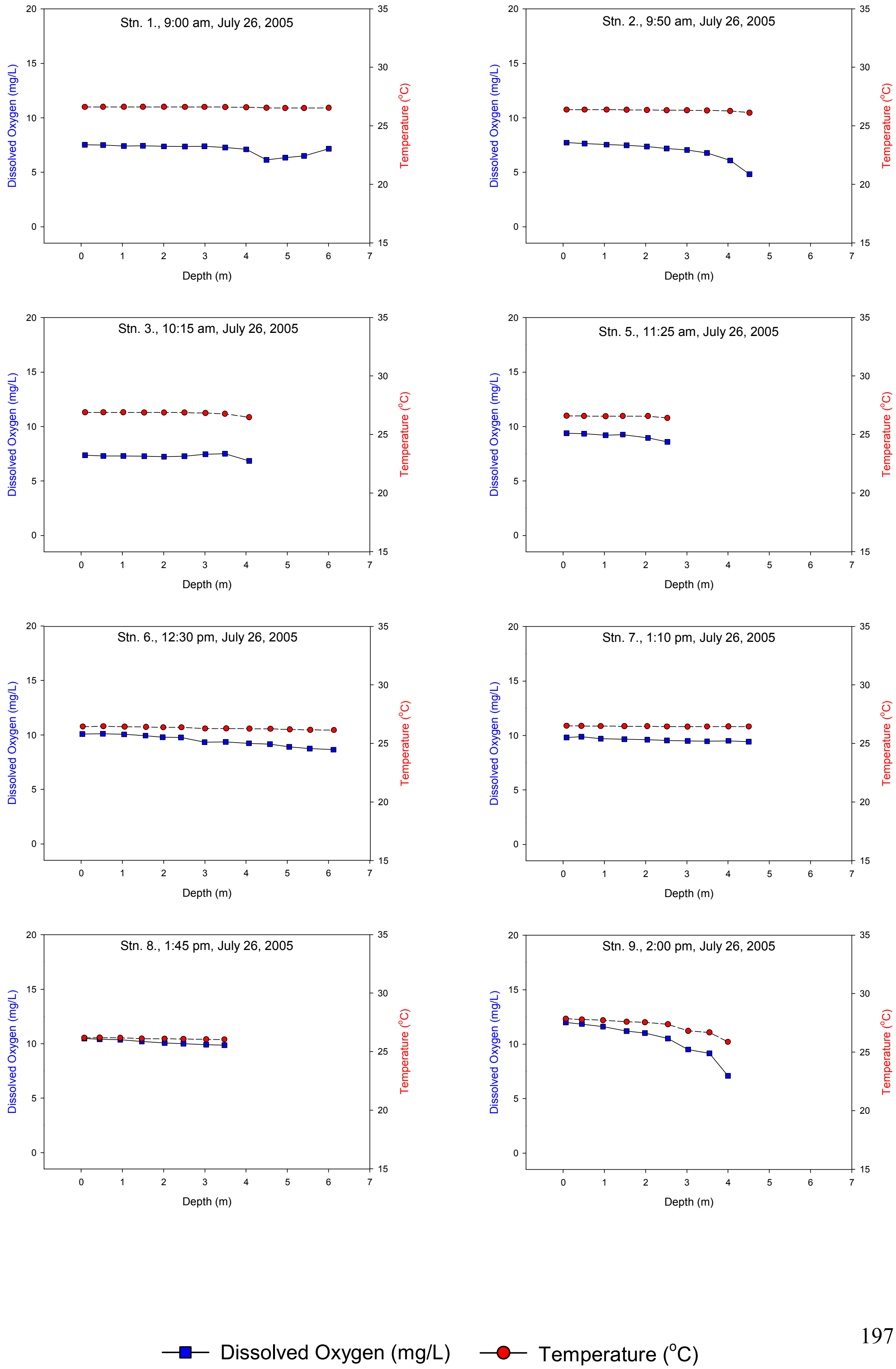




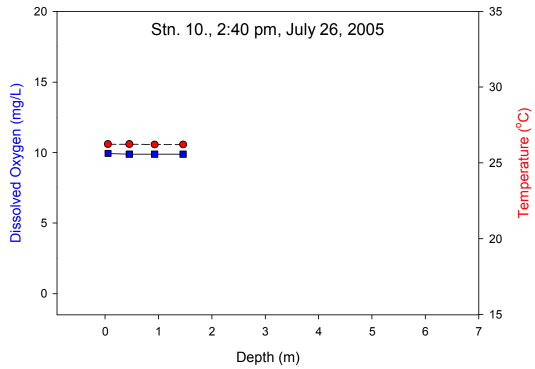


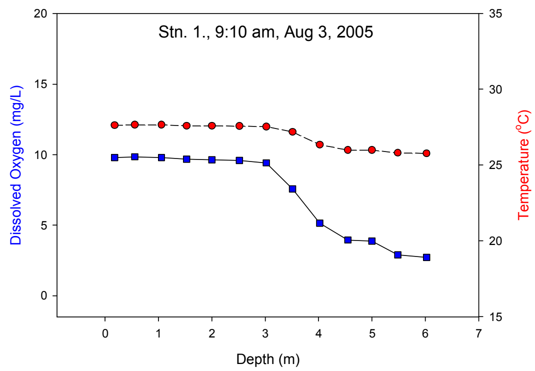
Dissolved Oxygen (mg/L)   Temperature (°C)

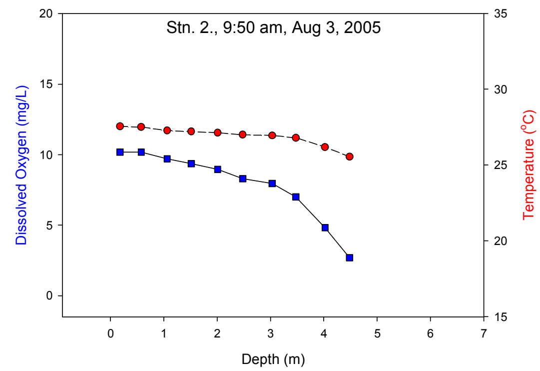
Appendix E7: Temperature and oxygen profiles, Grand River, 2005.

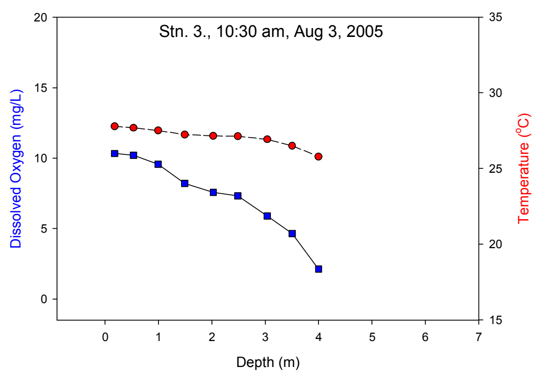


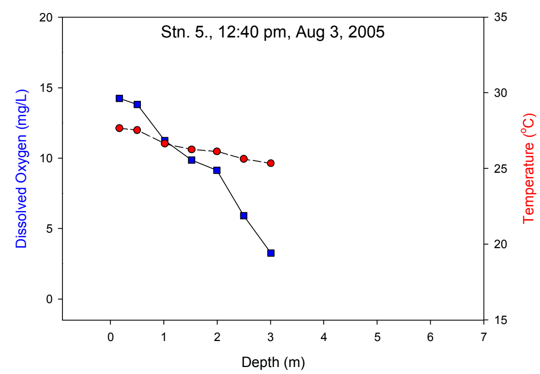
Appendix E7: Temperature and oxygen profiles, Grand River, 2005.

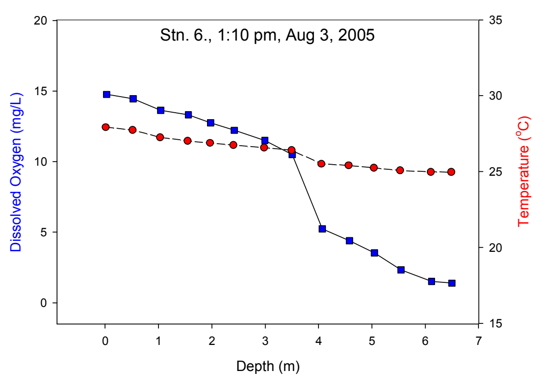


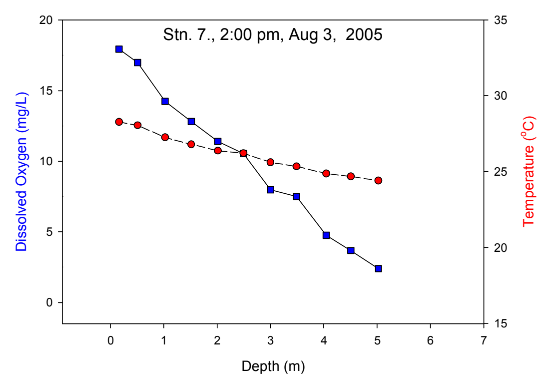






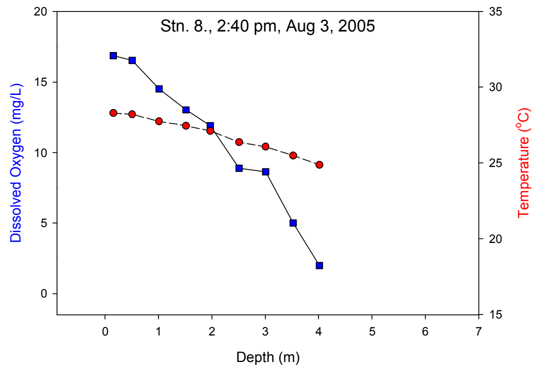


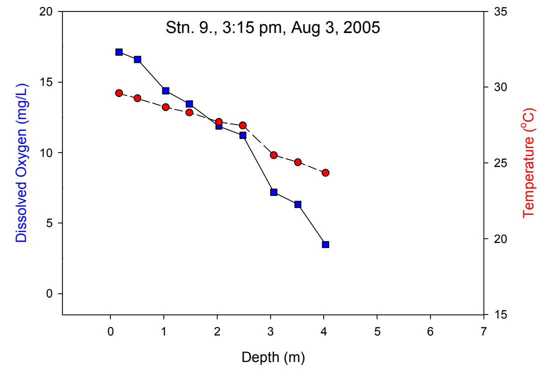


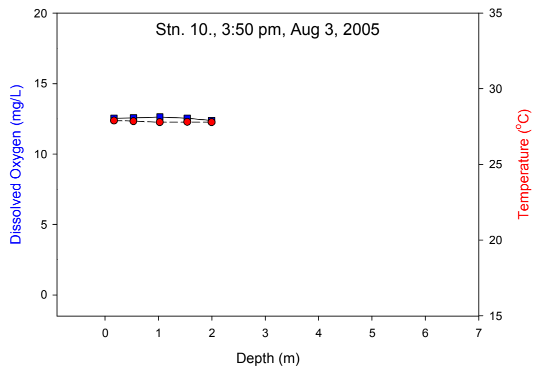


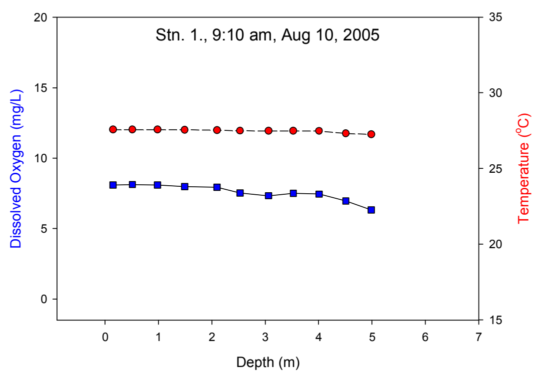
Dissolved Oxygen (mg/L)   Temperature (°C)

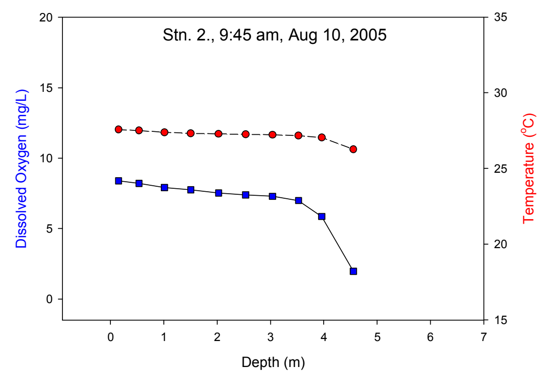
Appendix E7: Temperature and oxygen profiles, Grand River, 2005.

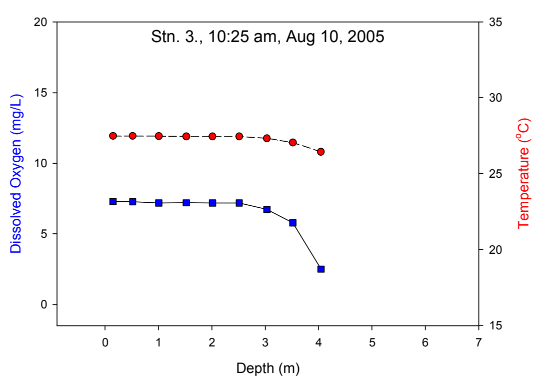


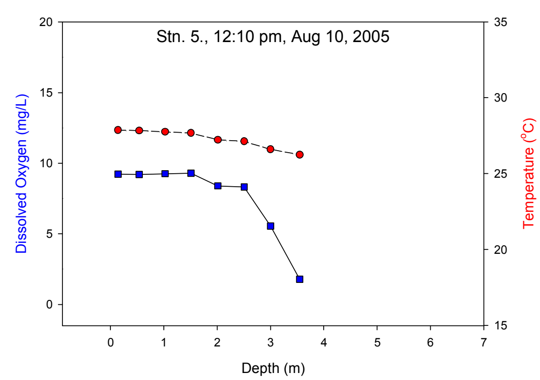






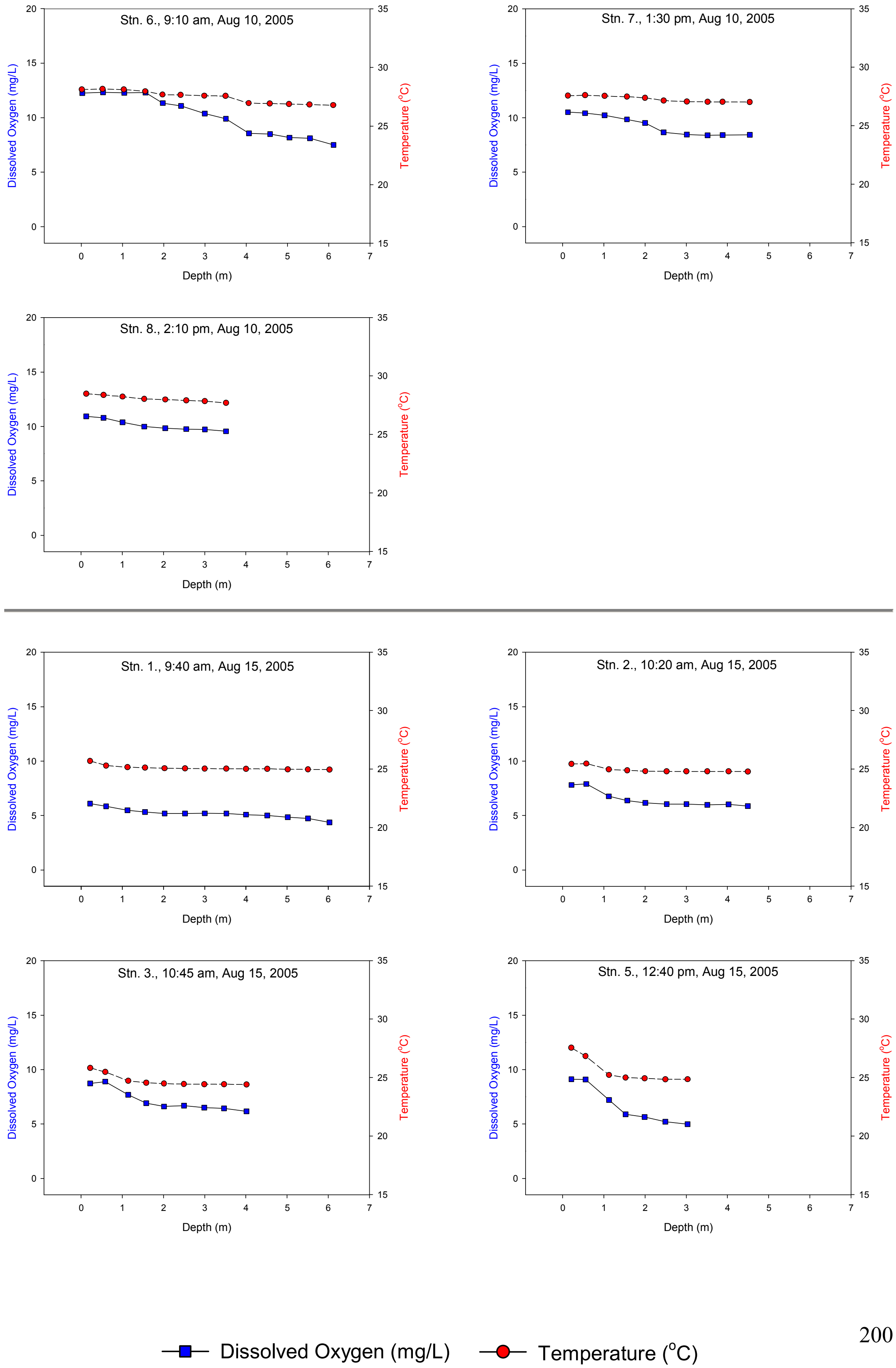




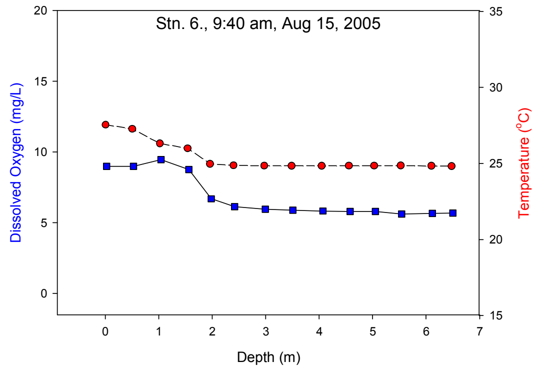


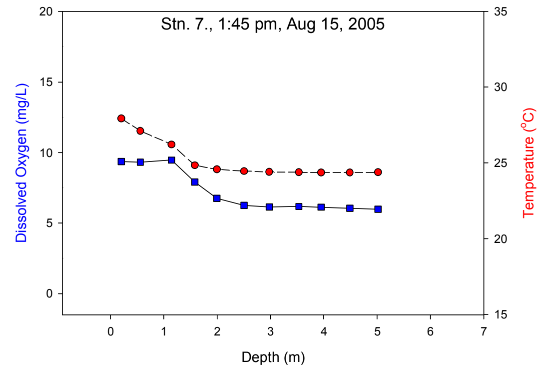
Dissolved Oxygen (mg/L) Temperature (°C)

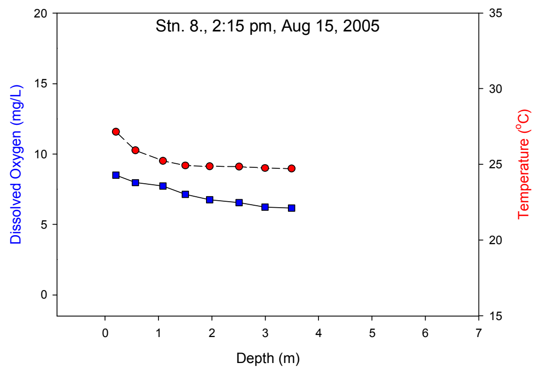
Appendix E7: Temperature and oxygen profiles, Grand River, 2005.

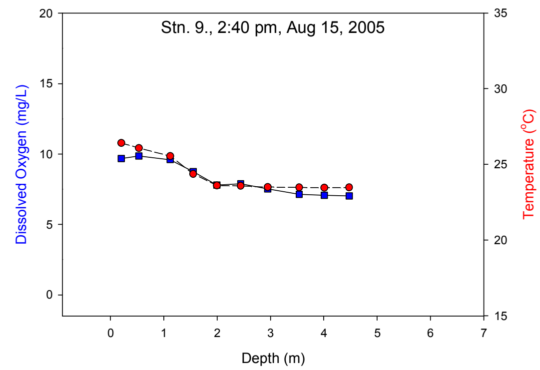


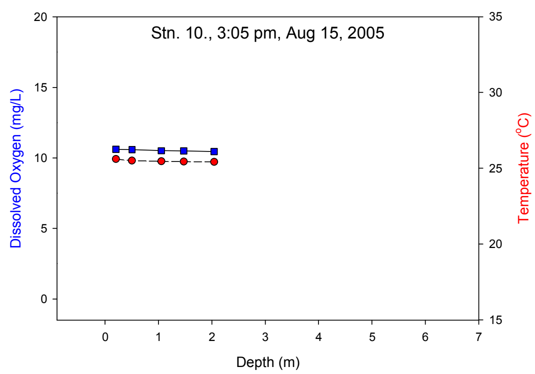
Appendix E7: Temperature and oxygen profiles, Grand River, 2005.

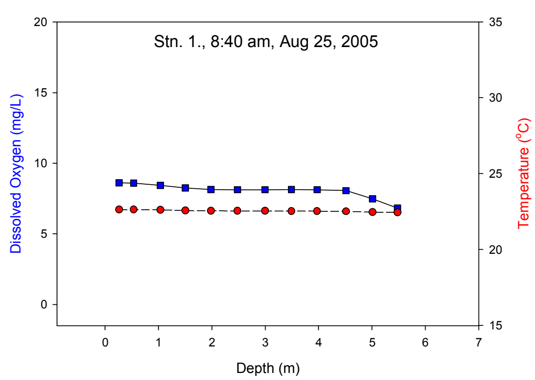


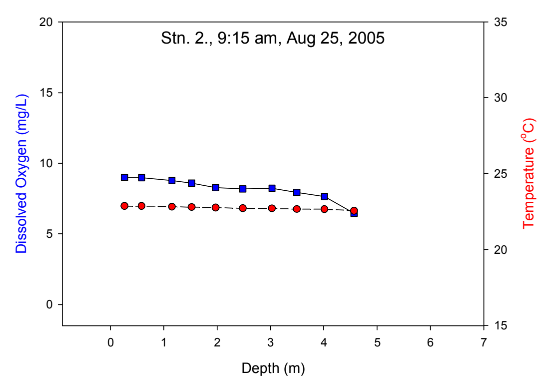




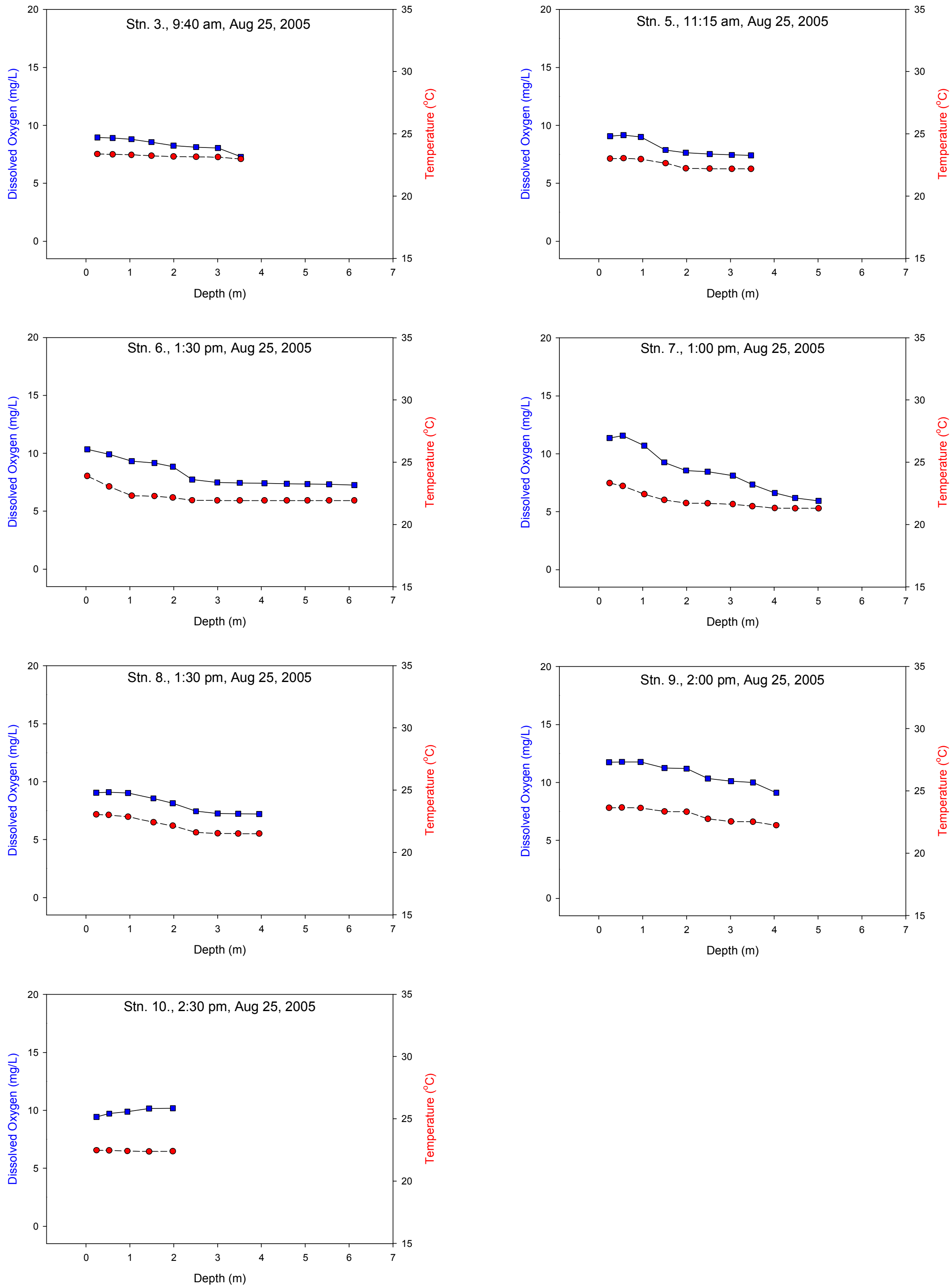


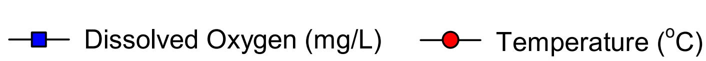


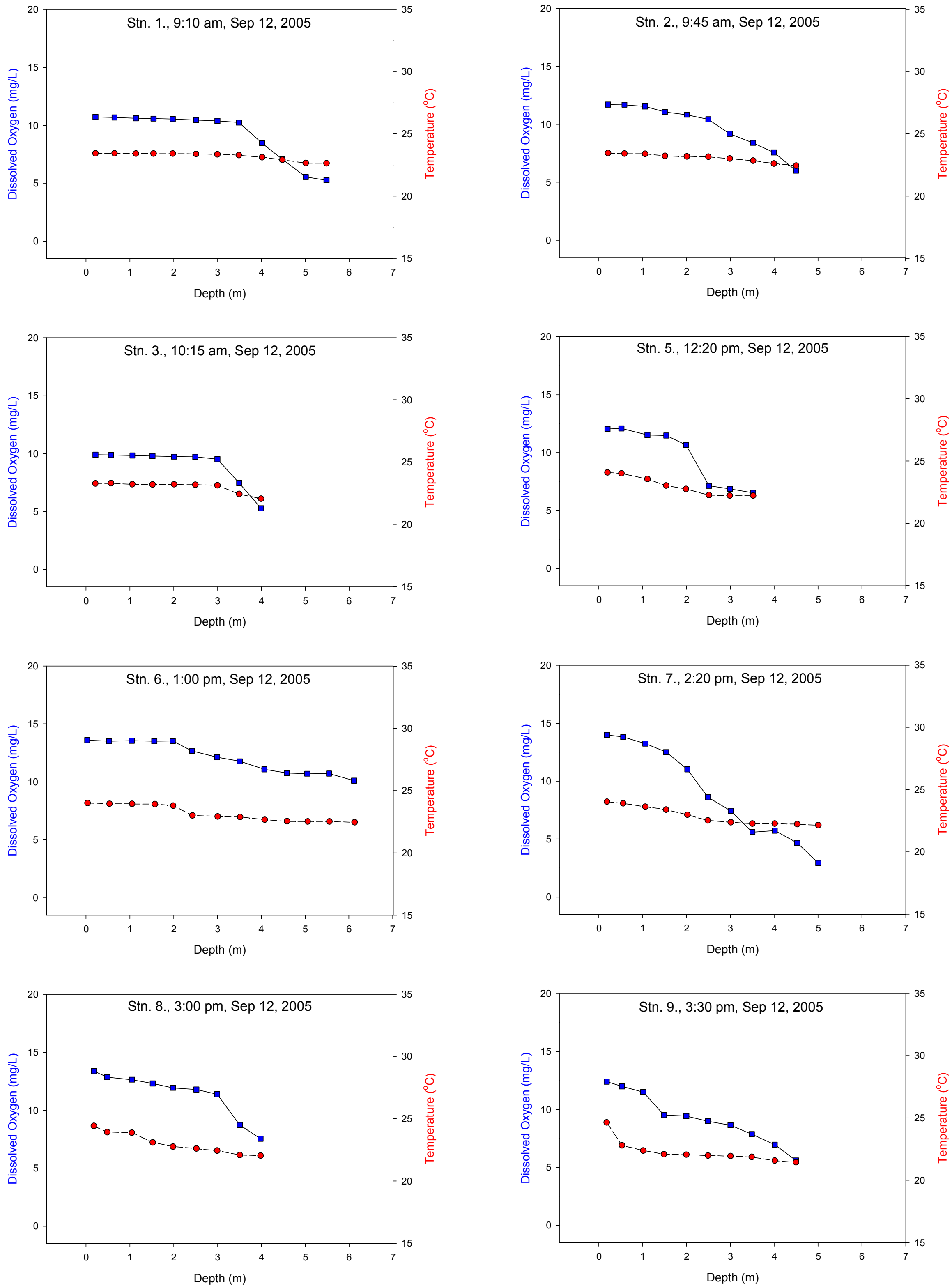




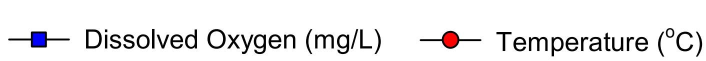
Dissolved Oxygen (mg/L) Temperature (°C)


Stn. 3., 9:40 am, Aug 25, 2005
Stn. 5., 11:15 am, Aug 25, 2005
Stn. 6., 1:30 pm, Aug 25, 2005
Stn. 7., 1:00 pm, Aug 25, 2005
Stn. 8., 1:30 pm, Aug 25, 2005
Stn. 9., 2:00 pm, Aug 25, 2005
Stn. 10., 2:30 pm, Aug 25, 2005
Dissolved Oxygen (mg/L)
Temperature (°C)
Depth (m)
0
5
10
15
20
25
30
35
1
2
3
4
6
7

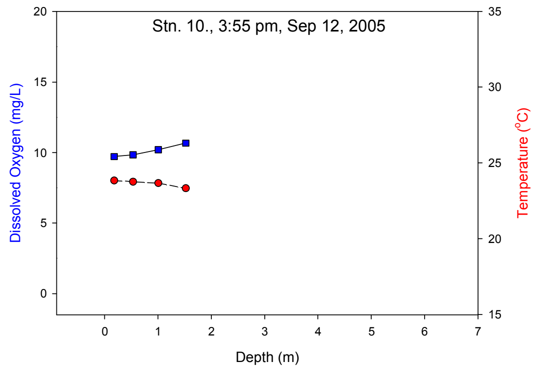

Dissolved Oxygen (mg/L)
Temperature (°C)

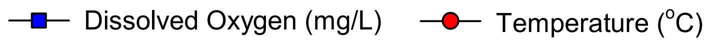


Stn. 1., 9:10 am, Sep 12, 2005
Stn. 2., 9:45 am, Sep 12, 2005
Stn. 3., 10:15 am, Sep 12, 2005
Stn. 5., 12:20 pm, Sep 12, 2005
Stn. 6., 1:00 pm, Sep 12, 2005
Stn. 7., 2:20 pm, Sep 12, 2005
Stn. 8., 3:00 pm, Sep 12, 2005
Stn. 9., 3:30 pm, Sep 12, 2005
Dissolved Oxygen (mg/L)
Temperature (°C)
Depth (m)



Dissolved Oxygen (mg/L)
Temperature (°C)


Stn. 10., 3:55 pm, Sep 12, 2005
Dissolved Oxygen (mg/L)
Temperature (°C)
Depth (m)
20
15
10
5
0
35
30
25
20
15
0
1
2
3
4
5
6
7


Dissolved Oxygen (mg/L)
Temperature (°C)

Appendix E8: Equations describing the relationship between temperature and depth; and oxygen and depth, during water column profiling on three days, summer, 2005.

Temperature at Depth

Station	June 27 Temperature		slope (m)	constant (b)	Target Temperature (y) 24	25	27	28
1	y = -1.7999x + 28.572	R^2 = 0.9512	-1.800	28.572	2.540	1.985	0.873	0.318
2	y = -1.7026x + 28.772	R2 = 0.9573	-1.703	28.772	2.803	2.215	1.041	0.453
3	y = -1.0654x + 28.101	R2 = 0.8451	-1.065	28.101	3.849	2.911	1.033	0.095
5	y = -2.018x + 29.577	R2 = 0.8267	-2.018	29.577	2.764	2.268	1.277	0.781
6	y = -1.312x + 29.403	R2 = 0.8333	-1.312	29.403	4.118	3.356	1.832	1.069
7	y = -1.3987x + 28.831	R2 = 0.9269	-1.399	28.831	3.454	2.739	1.309	0.594
8	y = -2.3135x + 31.579	R2 = 0.9037	-2.314	31.579	3.276	2.844	1.979	1.547
9	y = -2.1627x + 30.829	R2 = 0.9368	-2.163	30.829	3.158	2.695	1.770	1.308
	Average 1-9				3.245	2.627	1.389	0.771
	Average 5-9				3.354	2.780	1.633	1.060
ALL Stns	y = -1.6702x + 29.387	R2 = 0.8209	-1.670	29.387	3.225	2.627	1.429	0.830
	July 12 Temperature		**m**	**b**	**24**	**25**	**27**	**28**
1	y = -0.9034x + 27.984	R2 = 0.8765	-0.903	27.984	4.410	3.303	1.089	-0.018
2	y = -0.3962x + 27.026	R2 = 0.7653	-0.396	27.026	7.638	5.114	0.066	-2.458
3	y = -0.6178x + 27.358	R2 = 0.9204	-0.618	27.358	5.435	3.817	0.579	-1.039
5	y = -1.2023x + 28.818	R2 = 0.8773	-1.202	28.818	4.007	3.176	1.512	0.680
6	y = -0.8655x + 29.274	R2 = 0.7457	-0.866	29.274	6.094	4.938	2.627	1.472
7	y = -0.5926x + 27.59	R2 = 0.7295	-0.593	27.590	6.058	4.371	0.996	-0.692
8	y = -0.9223x + 28.531	R2 = 0.8361	-0.922	28.531	4.913	3.828	1.660	0.576
9	y = -0.9304x + 28.47	R2 = 0.8739	-0.930	28.470	4.804	3.730	1.580	0.505
	Average 1-9				5.420	4.034	1.264	-0.122
	Average 5-9				5.175	4.008	1.675	0.508
ALL Stns	y = -0.7669x + 28.059	R2 = 0.6992	-0.767	28.059	5.293	3.989	1.381	0.077
	August 3 Temperature		**m**	**b**	**24**	**25**	**27**	**28**
1	y = -0.3901x + 28.122	R2 = 0.8403	-0.390	28.122	10.567	8.003	2.876	0.313
2	y = -0.3838x + 27.784	R2 = 0.8313	-0.384	27.784	9.859	7.254	2.043	-0.563
3	y = -0.4386x + 27.962	R2 = 0.8846	-0.439	27.962	9.033	6.753	2.193	-0.087
5	y = -0.8343x + 27.725	R2 = 0.9632	-0.834	27.725	4.465	3.266	0.869	-0.330
6	y = -0.2463x + 28.109	R2 = 0.9651	-0.495	27.880	7.845	5.823	1.779	-0.243
7	y = -0.8011x + 28.19	R2 = 0.9824	-0.801	28.190	5.230	3.982	1.485	0.237
8	y = -0.8932x + 28.647	R2 = 0.9851	-0.893	28.647	5.203	4.083	1.844	0.724
9	y = -1.3864x + 30.139	R2 = 0.96	-1.386	30.139	4.428	3.707	2.264	1.543
	Average 1-9				7.079	5.359	1.919	0.199
	Average 5-9				5.434	4.172	1.648	0.386
ALL Stns	y = -0.5708x + 28.138	R2 = 0.6897	-0.571	28.138	7.249	5.498	1.994	0.242

Appendix E8: Equations describing the relationship between temperature and depth; and oxygen and depth, during water column profiling on three days, summer, 2005.

Oxygen at Depth

					Target Oxygen Concentration (y)		
Station	June 27 Oxygen		slope (m)	constant (b)	5.5	4	2
1	y = -1.9834x + 16.133	R2 = 0.7079	-1.983	16.133	5.361	6.117	7.126
2	y = -3.6524x + 17.753	R2 = 0.9348	-3.652	17.753	3.355	3.765	4.313
3	y = -4.9609x + 20.664	R2 = 0.9332	-4.961	20.664	3.057	3.359	3.762
5	y = -7.4229x + 25.953	R2 = 0.9126	-7.423	25.953	2.755	2.957	3.227
6	y = -4.1527x + 23.572	R2 = 0.9558	-4.153	23.572	4.352	4.713	5.195
7	y = -4.9228x + 22.718	R2 = 0.8485	-4.923	22.718	3.498	3.802	4.209
8	y = -5.2208x + 20.407	R2 = 0.8545	-5.221	20.407	2.855	3.143	3.526
9	y = -4.2499x + 18.698	R2 = 0.9383	-4.250	18.698	3.105	3.458	3.929
	Average 1-9				3.542	3.914	4.411
	Average 5-9				3.313	3.615	4.017
ALL Stns	y = -3.8325x + 19.879	R2 = 0.753	-3.835	19.879	3.749	4.140	4.662
	July 12 Oxygen		**m**	**b**	5.5	4	2
1	y = -2.5543x + 15.25	R2 = 0.9319	-2.554	15.250	3.817	4.404	5.187
2	y = -1.4645x + 12.55	R2 = 0.8396	-1.465	12.550	4.814	5.838	7.204
3	y = -2.6261x + 12.476	R2 = 0.9597	-2.626	12.476	2.656	3.228	3.989
5	y = -5.2076x + 19.486	R2 = 0.9951	-5.208	19.486	2.686	2.974	3.358
6	y = -3.61x + 20.581	R2 = 0.9718	-3.610	20.581	4.178	4.593	5.147
7	y = -3.2997x + 17.21	R2 = 0.9881	-3.300	17.210	3.549	4.003	4.610
8	y = -2.9124x + 16.456	R2 = 0.9672	-2.912	16.456	3.762	4.277	4.964
9	y = -2.5352x + 14.057	R2 = 0.9153	-2.535	14.057	3.375	3.967	4.756
	Average 1-9				3.605	4.161	4.902
	Average 5-9				3.510	3.963	4.567
ALL Stns	y = -2.7409x + 15.545	R2 = 0.806	-2.741	15.545	3.665	4.212	4.942
	August 3 Oxygen		**m**	**b**	**24**	**25**	**27**
1	y = -0.3901x + 28.122	R2 = 0.8403	-0.390	28.122	10.567	8.003	2.876
2	y = -0.3838x + 27.784	R2 = 0.8313	-0.384	27.784	9.859	7.254	2.043
3	y = -0.4386x + 27.962	R2 = 0.8846	-0.439	27.962	9.033	6.753	2.193
5	y = -0.8343x + 27.725	R2 = 0.9632	-0.834	27.725	4.465	3.266	0.869
6	y = -0.2463x + 28.109	R2 = 0.9651	-0.495	27.880	7.845	5.823	1.779
7	y = -0.8011x + 28.19	R2 = 0.9824	-0.801	28.190	5.230	3.982	1.485
8	y = -0.8932x + 28.647	R2 = 0.9851	-0.893	28.647	5.203	4.083	1.844
9	y = -1.3864x + 30.139	R2 = 0.96	-1.386	30.139	4.428	3.707	2.264
	Average 1-9				7.079	5.359	1.919
	Average 5-9				5.434	4.172	1.648
ALL Stns	y = -0.5708x + 28.138	R2 = 0.6897	-0.571	28.138	7.249	5.498	1.994