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The Limnology of Williston Reservoir: Results From the 1999 Monitoring Program

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ABSTRACT

Studies were conducted in 1999, the first year of a 2 year intensive limnological monitor whose purpose was to establish a uniform, consistent and reliable physico-chemical and biological database to enable proper assessment of future change and the provision of new data to forecast system productive capacity. This interim report summarises results of data gathered during the first year of the monitor of Williston Reservoir. The reservoir has shown remarkably little variance among variables and basins, despite the biogeoclimatic complexity and diversity of landscapes inundated, and the immense size of the system's drainage basin. Average concentrations of dissolved phosphorus and nitrogen (TDP and NO_3-N) and values of their ratio (TDP:NO_3-N) suggest no serious nutrient limitation of phytoplankton growth except in the Finlay Reach where in August, values of NO_3-N were depleted. Phytoplankton and zooplankton communities were similar to those found in other large, oligotrophic BC lakes, with the small picoplankters, nanoflagellates and small diatoms predominant in the phytoplankton community; and zooplankton dominated by copepods and in late-summer by cladocerans. Using mean values of total phosphorus (TP) and chlorophyll from the 1999 monitor has enabled a valid comparison with earlier estimates has indicated that Williston Reservoir since impoundment in 1968 has been a moderately productive ecosystem, but that it has slowly lost nutrients (P) through sedimentation and outflow, and has progressively become less productive. The system in the 1970s, after land inundation and nutrient liberation, was much more productive (boom cycle), but currently, based on 1999 information lies within the low production **oligotrophic** range.

INTRODUCTION

Background & Scope

The Williston monitoring program was developed to gather salient limnological information that is required for the determination of the current trophic status and productive capacity of the reservoir. Numerous past limnological studies (BC Research 1976, 1977; Barrett and Halsey 1985; Fleming et. al. 1991 unpublished data; G3 report Vol. 1 1996) have collected data and reported on water quality and status of biotic resources. Frequent inconsistencies in such factors as; locations of sample stations, depths and times sampled, physico-chemical variables examined, sampling methods and with using differing analytical chemistry laboratories, has created considerable variance in reported results, that has strained the validity of comparisons among and between years with past data.

The 1999 Williston Reservoir Monitor (WRM) program has established permanent sampling stations, and has registered them with the Environmental Monitoring System (EMS) database, that is administered by the Water Management Branch (Ministry of Environment, Lands and Parks - MELP). Limnological data gathered from these WRM stations will be available to all researchers wishing to the access the EMS database. Establishment of 5 permanent sampling locations, will foster the need for consistency in all future studies, enabling more meaningful comparisons to be made in future without the uncertainties of station location and methodological differences. It is the WRM program's intent that the longer-term Williston Reservoir monitor that will follow in year's 2002-5 will replicate sampling station locations, methods and analytical protocols used here. The replication will enable a more reliable means of assessment of changes in Williston's productive capacity, and what the implications of any change might mean to food chains and fisheries resources.

Study purpose

This interim report presents limnological results obtained during the open-water (growing season) of year 1 of the 2 year Williston Reservoir intensive monitor program. The current trophic status of the reservoir will be determined from synthesis of 'key' physico-chemical and biological variables. This report is intended to be a 'status' report with a reduced interpretation of results and discussion section. A more comprehensive analysis of the limnological data together with comparisons with other large BC lakes and reservoirs will be presented in the final monitor report, scheduled for completion by March 31, 2001.

Description of study area.

Williston Reservoir (56° N latitude, 124° W longitude) is located approximately 140 km north of Prince George in northeast British Columbia, Canada (Figure 1). Williston Reservoir was created in 1968 by damming (W.A.C. Bennett Dam) the Peace River near Hudson's Hope, B.C. for hydroelectric generation. Approximately 22 km downstream of the W.A.C. Bennett Dam a second dam (Peace Canyon Dam) impounds water to the base of the W.A.C. Bennett

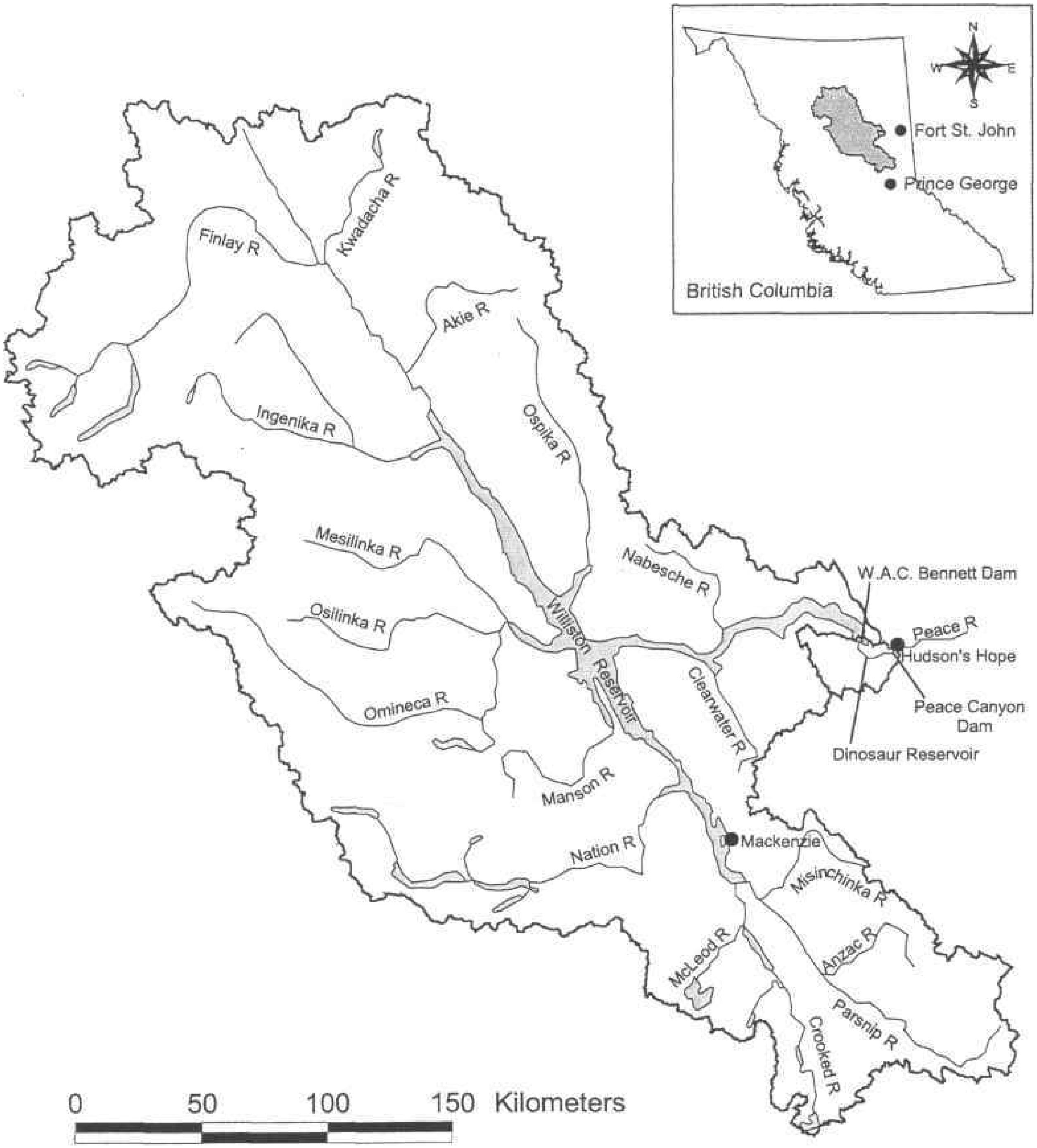

Figure 1. Williston Reservoir Watershed.

Dam creating Dinosaur Reservoir. Dinosaur Reservoir is operated as "run of the river" hydroelectric project with minimal (1-2 m) water level fluctuations. The Peace River flows east to Lake Athabasca that lies within the MacKenzie River drainage system, which flows north and discharges into the Arctic Ocean.

The W.A.C. Bennett Dam inundated the upper Peace River canyon creating the Peace Reach that extends westward approximately 120 km to 'junction' with the confluence of the Parsnip and Finlay Reaches. From the Junction the Finlay Reach (previous Finlay River basin) extends in a northwest direction about 120 km, and to the south the Parsnip Reach (previous Parsnip River basin) extends in a southeast direction for approximately 110 km (Figure 1).

The Williston Reservoir drainage basin encompasses five biogeoclimatic sub-zones: sub-boreal spruce, sub-alpine Engleman Spruce, sub-alpine fir, boreal white and black spruce, and spruce-willow-birch and alpine tundra (BC Hydro 1988). The Omineca Mountains to the west, and Rocky Mountains to the east contain the generally north to south lying Finlay and Parsnip reaches within the Rocky Mountain Trench. The two reaches are contained within a wide, flat-bottomed valley. Glacial deposition, moraines and lacustrine deposits are common (Fleming et al. 1991, unpublished data). Glacial till is the most abundant surficial deposit found within the drainage (Ministry of Environment 1983). The Peace Reach has a "V" shaped bottom and is much narrower and deeper than either the Finlay or Parsnip reaches. Steep-sloped sedimentary rock is predominant in the entrenched western half of the Peace Reach where the Peace River originally (prior to impoundment) cascaded eastward breaking through the Rocky Mountains. The eastern half of the Peace Reach extends into the Rocky Mountain Foothills, and contains lower gradient topography and geological features quite similar to those of Finlay and Parsnip reaches.

Williston watershed is subject to a continental climate with long, cold winters. Temperatures of low as -30° C can occur anytime after October, with sub zero temperatures often extending into April. Frost may occur at any time of the year (McLean 1988), and ice formation on the reservoir can begin as early as November, though complete coverage does not usually occur until January. Ice cover can be delayed, as occurred winter of 1999 - 2000, or even incomplete in uncommonly warm winters. The area in front of the Dam (forebay) is generally the last area to freeze. Ice cover normally extends to approximately the first week of May, and the Finlay Reach is generally the last area be completely "ice free". The summer average air temperatures range from 16° C to 18° C, with maximum temperatures reaching 30° C (G3 report, 1994). Annual precipitation averages 40 - 50 cm in most of the watershed, with the exception of 75 - 100 cm precipitation in the Rocky mountains east of the Finlay Reach (BC Hydro 1988). Snowfall accounts for 35 to 45% of the annual precipitation.

Because Williston Reservoir experiences a harsh continental climate, the system exhibits a dimictic circulation pattern, characterized by 2 distinct periods of deep-mixing, one in spring and the other in autumn, i.e. sometimes termed 'transition' periods. If winds are sufficiently strong and sustained, periods of isothermal temperatures accompany spring and fall transition periods. Thermal stratification with a discernable epilimnion, metalimnion and hypolimnion usually is well established by late May and lasts up to mid- to late October with the commencement of winter storms. Stratification is weakest and shortest in duration in the shallower Finlay and Parsnip reaches and strongest and longest in the much deeper Peace Reach. In winter under ice conditions the reservoir shows 'inverse' stratification extending to 10-15 m beginning in late February and lasting until ice-out in early May.

The reservoir has a mean depth of 44 m and a maximum depth of 166 m (Fleming et al. 1991, unpublished data). The shoreline of Williston Reservoir is of a dendritic shape, encompassing about 1,770 km (BC Research 1977). With a surface area (SA) of 1,779 km^2 at a maximum, normal operating level of 672.1 m (BC Hydro 1988), Williston Reservoir is the largest lentic fresh water system in British Columbia. The catchment area (CA) of the Williston drainage basin is 69,930 km , equal in size to the province of New Brunswick (BC Hydro 1996), and the catchment to surface area ratio (CA/SA) for Williston reservoir is very large - 39:1. The average water residence time of the reservoir is 19 months (Hirst 1991), and with a storage capacity of 74,257 x 10 m^3 of water, Williston by volume is ranked the ninth largest reservoir in the world (MacLean 1998). The reservoir receives and stores most of its hydrologic input from a large spring run-off that peaks in May and June.

The reservoir cycles between maximum and minimum levels once per year. The reservoir stores inflows from spring snow melt and summer precipitation, typically reaching a maximum level in August and September of approximately 672.1 m (Maximum Normal Level or MNL) above sea level. Power generation in response to electricity demand is highest in the winter months resulting in increased discharges from the dam. There are ten intakes at the face of W.A.C. Bennett Dam. The 3 deepest intakes (units #1 - #3) withdraw water, and nutrients, from the deep-water hypolimnetic zone of the reservoir (594.4 m above sea level, or 77.6 m below MNL. The shallower intakes (units #4 - #10) are situated at 627.89 m above sea level or 44.2 m below MNL. Shallower water from the epilimnion can be drawn into these intakes. Small whirlpools are often seen at the surface in front of the shallower intakes indicating water withdrawl from the entire water column. Summer discharges from Williston Reservoir into Dinosaur Reservoir fluctuate between 9 and 15 C., and winter discharges have been recorded as low as 1.5 C. (Bob Westcott, BC Hydro, Pers. Comm.). The discharge temperatures indicate a mix of hypolimnion and epilimnion water withdrawl. Increased discharges and low winter inflows result in dramatic winter draw down. Average draw down from 1984 to 1987 was approximately 1l m per year (Hirst 1991). Minimum reservoir levels are typically reached by the end of April.

Present state of the reservoir.

The impoundment of the Peace River created BC's largest lake/reservoir where only large rivers existed previously. The inundation of approximately 1,700 km^2 of previously forested land, created a sudden and major release of nutrients to the new reservoir resulting in artificially high production levels over the first 5-10 years i.e. 'boom' period. But this source of nutrients from flooded landscapes is finite, and after 10-15 years the reservoir gradually loses nutrients, notably phosphorus (P), by sedimentation and by adsorption to Fe-P and Al-P in surficial sediments. The reservoir also loses potential C production from an impaired littoral zone, and from deep hypolimnetic discharges at the dam. Collectively, these losses outweigh nutrient inputs from natural sources and a process of gradually declining biogenic production begins i.e. oligotrophication ('bust' period) (Stockner et al. 2000). This type of 'boom' and 'bust' cycle is particularly evident in newly created 'riverine' reservoirs such as Williston. Aging of 'new' reservoir to the point of equilibrium with nutrient input/output usually requires 20 to 30 years (Stockner 1998). Based on an analysis of nutrient data from 1975 and 1988 Stockner (1998) considered the present trophic status of Williston Reservoir to be oligotrophic, but whether the system had reached equilibrium with nutrient supplies in each of the 3 major reaches and biotic production stabilised after 30yrs remained conjectural.

METHODS

Stations and Sampling.

To enable future repeatable sampling, five permanent stations (GPS co-ordinates recorded) have been established. Site selection criterion included proximity to past research sampling locations, positioning over the original inundated river channels to achieve maximum depth, and distancing the location from any major turbidity input sources (river mouths, eroding alluvial shorelines, etc.). Five stations were selected, 3 located within the lacustrine zone of each major basin (reach) of the reservoir - Finlay Reach, Parsnip Reach, and Peace Reach (Clearwater) stations; and 2 stations in zones of special interest - the "Junction" and the "Forebay" stations. The Junction station is situated near the old confluence of the Finlay and Parsnip rivers and the origin of the Peace Reach and represents a transition/mixing zone where Finlay and Parsnip waters are mixed and begin flowing eastward. The first Peace reach station is located at 'Clearwater' about 50km east of Junction and the second, the "Forebay" station is located approximately 2 km west of the W.A.C. Bennett Dam in one of the deepest basins of the reservoir. A sixth, nutrient sampling only station is located on the Peace River (left or north bank) 500 m downstream of the Peace Canyon Dam. Locations of the Williston Monitor sampling stations are given in Fig. 2. The data collected at these sites has been entered into the Environmental Monitoring System (EMS) database, and is available to future researchers wishing access to the database. The EMS designation and co-ordinates (NAD 27 datum) for the sites are:

- Parsnip Reach (EMS 234185), UTM co-ordinates 10.458200.6175500
- Finlay Reach (EMS 234184), UTM co-ordinates 10.410111.6252000
- Junction Station (EMS 234187), UTM co-ordinates 10.452000.6211550
- Peace Reach (EMS 234186), UTM co-ordinates 10.486000.6204000
- Forebay Station (EMS 234188), UTM co-ordinates 10.550204.6210540

Sampling trips were conducted at the beginning of each month beginning in May and continuing to November of 1999. One additional sampling trip was done in March, 1999 through the ice at the "Forebay" station. All Williston Reservoir stations were accessed by boat. The Peace River station below the Bennett Dam was accessed by vehicle. The Finlay Reach station was not accessible in May due to extensive ice cover. The Finlay and Parsnip reach stations were also not accessible in November due to high winds and unsafe water conditions.

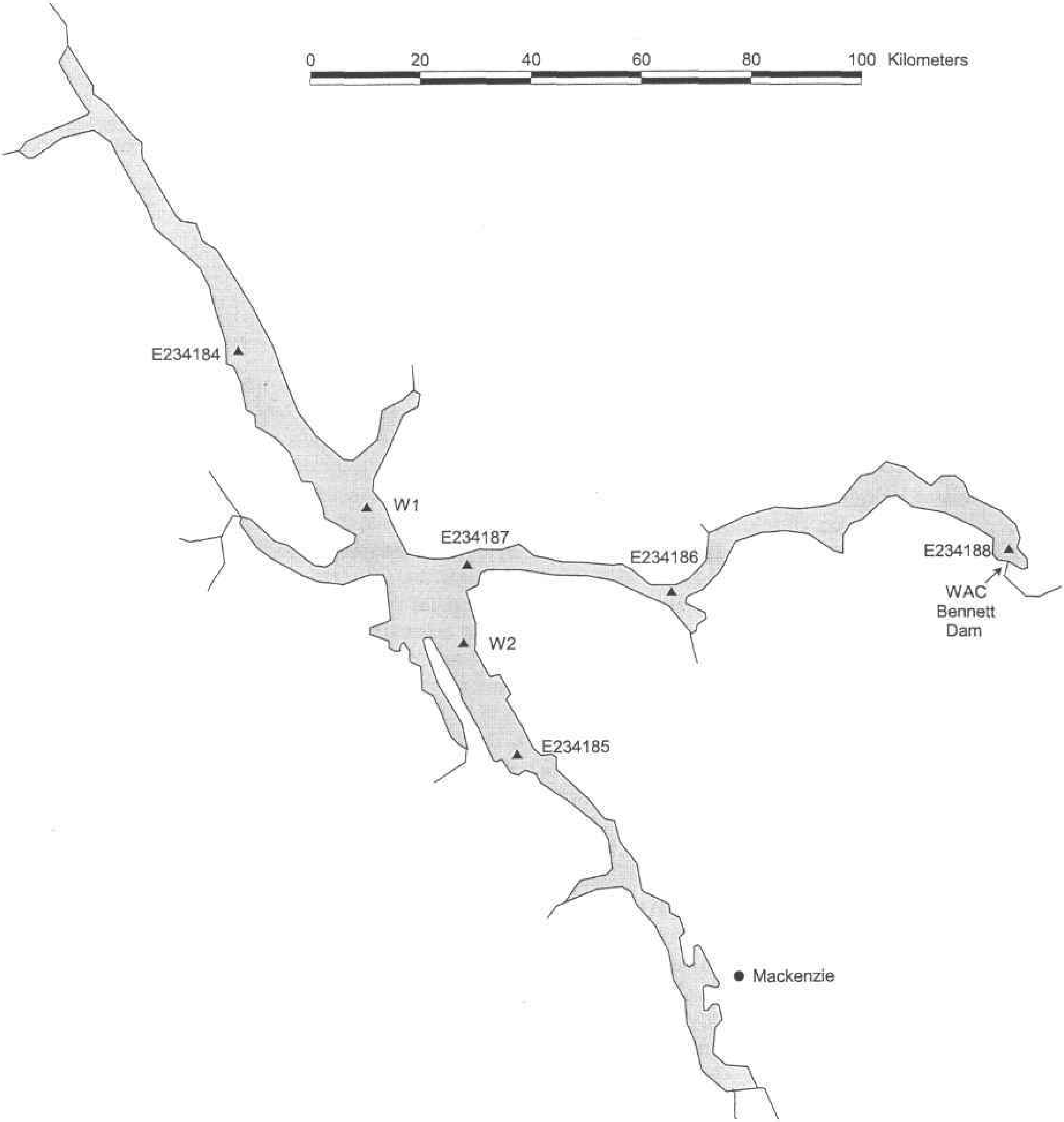

Figure 2. Location of sampling stations.

Physico-chemical.

A YSI model 58 oxygen/ temperature meter was used to collect dissolved oxygen (PPM or mg/L) and temperature (°C) at depth (m). A 20 cm standard freshwater Secchi disc (without viewing chamber) vertically cast from the shaded side of the boat was used to determine Secchi disc depth (i.e. water transparency). Water depth was measured with a digital Hummingbird depth sounder and recorded to the nearest metre. Cloud cover was estimated and recorded to the nearest 10 percent. Reservoir elevation data was provided to the nearest 0.1 m by BC Hydro W.A.C. Bennett Dam operational staff.

Water samples were collected with a vertical Alpha water bottle (Van Dorn, 4.2 1) from 1, 3, and 5m depths. An additional sample was collected from just below the thermocline. Samples were shipped in dark, ice filled containers, and analysed within 72 hours of collection. Analyses of most water samples were conducted at Environment Canada's laboratories at the Pacific Environmental Science Centre (PESC) in North Vancouver, B.C. Laboratory methods employed at PESC are available, if requested, in the form of "individual method summaries" (Stewart Yee, PESC, North Vancouver, personal communication). The methodology follows guidelines published in ***British Columbia environmental laboratory manual for the analysis of water, wastewater, sediment and biological materials*** (McQuaker 1994). Water samples to determine alkalinity for C^{14} production analysis were conducted on two occasions only. Those samples were analysed at a University of British Columbia, Environmental Engineering Laboratory.

A pHep model 3 digital hand-held pH meter provided "field" pH measurements. Water samples collected for chlorophyll-a content were field filtered through a 0.45 µm cellulose acetate filter at a maximum vacuum pressure of 18 cm Hg. The filter was then frozen, stored and submitted for lab analysis at the end of each sampling trip. Water samples collected for low level phosphorus determination were field filtered with a 0.45 µm filter cartridge at low vacuum pressure and the filtered water (TDP) submitted for analysis. Quality control/assurance of laboratory analysis was provided by the Pacific Environmental Science Centre's internal quality assurance program. Additionally, 10% of water samples collected for nutrient level analysis and approximately 50% of samples collected for chlorophyll-a analysis were replicated for comparison of analytical lab results.

Phytoplankton.

When conditions permitted, a 250 ml sample of water from 1, 3, 5 m depths was obtained monthly from May to November from each of the 5 monitoring stations. Each phytoplankton sample was preserved in acid Lugol's iodine preservative and stored in a cool location until analysis. Prior to quantitative enumeration the samples were gently shaken for 60 seconds, carefully poured into 25 mL settling chambers and allowed to settle for a minimum of 24 hr. Counts were done using a Carl Zeiss inverted phase-contrast plankton microscope. Counting followed a 2-step process: 1.] random fields (5 -10) were examined at 250X magnification (16X objective) and large micro-phytoplankton (20-200 µm), e.g. diatoms, dinoflagellates, filamentous blue-greens, were enumerated, and 2.] all cells within a random transect (ranging from 10 to 15 mm) were counted at 1562X magnification (100X objective). This high magnification permitted quantitative enumeration of minute (<2 µm) autotrophic picoplankton cells (0.2-2.0 µm) [Class Cyanophyceae], and also of small auto-, mixo- and heterotrophic nano-flagellates (2.0-20.0 µm) [Classes Chrysophyceae and Cryptophyceae]. In total between 250-300 cells were consistently enumerated in each sample to assure statistical accuracy (Lund et al. 1958). The compendium of Canter-Lund & Lund (1995) was used as the taxonomic reference. The phytoplankton species and biovolume list used for the computation of population and class biovolume estimates for Williston Reservoir in 1999 are presented in Table 1 of Appendix 1.

Zooplankton.

Samples were collected at each monthly site visit using a *Wildco* plankton net. The net mouth opening was 50 cm, length was 1.5 m, Nitex aperture size was 80 µm, and the aperture size on the bucket was 74 µm. The net was towed vertically from 30 m depth to the surface at a speed of 0.5 m/sec. Each tow was replicated. Captured zooplankton were anaesthetised, to prevent egg release, with a solution of 4% sodium bicarbonate, and then preserved in a 70% ethanol, 30% water solution. Zooplankton samples were analysed for species composition, density and biomass using standard zooplankton counting protocol (see Pieters et al. 1998.)

Primary Productivity.

Production experiments to estimate phytoplankton photosynthetic rates (carbon production) for Williston were undertaken in July and September. Samples in July were collected at the Forebay and Junction stations, but due to high winds neither the Parsnip nor Finlay stations could be reached. Instead water was collected at locations several km within each reach, and production only stations were arbitrarily identified as W2 and W1 respectively (see Figure 2). However in September water for primary production estimates was gathered from 4 of the 5 EMS stations, the exception being the Peace Reach station (EMS E234186).

Primary productivity was estimated by using the $^{14}CHCO_3$ (carbon labelled bicarbonate) method (Strickland 1960). Water samples were collected from 1, 3, and 5 m depths and transferred to three, 300 mL BOD (Biological Oxygen Demand) bottles. Two of the bottles were clear, to allow light to penetrate and photosynthesis to occur, and one was covered with black plastic to measure dark uptake and respiration. Each of the sample bottles received addition of one millilitre of 3.7 µCi/ml $^{14}C\text{-}HCO_3$. After inoculation sample bottles were lowered to their respective collection depths and "incubated" for two hours. Incubation was initiated no sooner than 1000 hrs. and no later than 1300 hrs.

The water samples were retrieved after the 2 hour incubation period and stored in a metal box preventing further exposure to light. Within 3 hours the samples were filtered through a 0.45 µm, 47 mm diameter cellulose nitrate membrane filter. The filters were transferred to scintillation vials and 4 drops of 6 N HCL were added to each filter. The vials were shipped to the Radiation Laboratory, University of British Columbia, for analysis by scintillation counter protocol.

RESULTS

Physico-chemical

Temperature. (Appendix 2) The Williston Reservoir is a dimictic system, with two periods of deep mixing in early May (spring) and November (fall) separated by 2 periods of stratification, one in summer (June-October) the other under ice in early spring (February to April). Open-water stratification commences in June at all stations and lasts to late October and early November. The epilimnion depth is variable, depending on duration and strength of wind episodes, but on average ranges from only 15-20 m in the Parsnip Reach to > 35-40 m in the Peace reach. The epilimnion at Junction and Finlay Reach stations is intermediary and ranges between 20-30 m. Maximum temperatures are attained in July/August and range from a low of 13° in the Peace Reach and a high of 19°C, and there is an inverse relationship between average epilimnion depth, maximum temperature and wind strength (not measured). Hypolimnetic temperatures were fairly constant throughout the reservoir, ranging from 4-6°C.

Oxygen. **(Appendix 2)** Dissolved oxygen profiles showed no major trends of significant variations with depth at all stations. Values at most depths were near saturation with respect to temperature and pressure. There were no discernible zones of reduction or super-saturation in the region of the metalimnion or in the hypolimnion, except at the dam forebay station

Light transparency (Secchi depth). **(Table 1; Appendix 3)** Secchi depth readings provide a quick and reliable measure of water transparency, with high values (>10 m) depicting good water clarity (high transparency) and lower readings (<5 m) signifying varying degrees of turbidity and light scattering imparted by particulate or dissolved organic matter (low transparency). Water transparency at all Williston Reservoir stations was generally poor with mean Secchi readings of between 3-4 m. There was a trend prevalent at most station for transparency to increase seasonally with lowest Secchi values in June and July during the peak of 'freshet' and progressively higher values through the summer and into early fall, e.g. September and October. The highest Secchi reading - 7.0 m was measured in October in Finlay Reach, while the two lowest occurred at the dam forebay in September - 1.7m and at the Finlay Reach station in July - 1.9 m. Seasonally, the Peace Reach Clearwater station was the least turbid and dam forebay station the most turbid.

Total Dissolved Solids (TDS) **(Table 1; Appendix 3)** Total dissolved solids reflect weathering (geological and hydrological) characteristics of the drainage basin. Highest seasonal average TDS values occurred in the Finlay Reach (118 mg/m^3) followed closely by Peach Reach stations (109 mg/m^3 [Clearwater] and 111 mg/m^3 [Forebay]). The lowest TDS was in the Parsnip Reach (85 mg/m^3).

Phosphorus. **(Table 1; Appendix 3)** Only two values of phosphorus were measured in 1999, total (TP), which includes the particulate organic and inorganic fractions, and total dissolved (TDP). Concentrations of TP averaged 6.2 mg/m^3 for the reservoir and seasonally ranged between highs of 11 mg/m^3 to lows of 2-3 mg/m^3. The only discernible spatiotemporal pattern was higher values in the growing season, particularly in July/August when particulate organic (phytoplankton) and inorganic particles from freshets elevated concentrations. TDP values were less than TP and averaged 3.6 mg/m^3 for the system and ranged between 2.0 - 8.0 mg/m^3. Concentrations were highest in the Parsnip Reach - 5 mg/m^3 and were lowest in Finlay and Peace Reaches - 3 mg/m^3. Like TP, TDP concentrations were very similar among stations.

Table 1. Mean annual values for selected physico-chemical and biological variables from April - November, 1999. (Units are *mg/m^3* unless otherwise given)

Variables	Finlay Reach	Parsnip Reach	Junction Station	Peace (Clearwater)	Peace (Forebay)	Mean Williston Reservoir
Ave. Epilimnion depth (m)	30	15	20	35	40	28
Maximum Epi-Temp (C°)	17	19	15	13	15	16
Secchi depth (m)	4.3	3.2	3.4	4.0	2.8	
TDS	119	88	100	111	111	106
TP	6.5	6.0	6.5	6.0	6.0	6.2
TN	130	240	190	160	160	176
NO_3	14	80	68	63	60	57
TDP	3.0	5.0	4.0	3.0	3.0	3.6
TDN	90	200	170	150	140	150
NO_3:TDP	4.7	16.0	17.0	21.0	20.0	15.7
Chlorophyll a	1.4	1.6	1.4	1.4	1.3	1.4
Phyto density (cells/mL)	5520	4498	5782	3780	4067	4729
Phyto BioV. (mm^3/L)	0.42	0.50	0.31	0.23	0.18	0.33
Primary Production (mgC/m^3/hr)	34.5	24.5	31	nd	17.5	26.8

Nitrogen (N). **(Table 1; Appendix 3)** Of the 2 directly utilizable forms of N, ammonium is the most readily assimilated, but concentrations in Williston are so low as to be generally undetectable, so by default, nitrate (NO_3-N) becomes the most important form of N supporting algal growth. Both total N (TN) and total dissolved N (TDN) were also measured, but these fractions include particulate (TN) and dissolved (TDN) forms of organic-N that are not readily assimilated and very slowly broken down by bacteria or algal enzymes (refractory). Nitrate concentrations in Williston averaged 57 mg/m^3 and were always well above detection limits at all stations *except* in the Finlay Reach, where epilimnetic values fell to 13 mg/m^3 in June and to depletion in August, i.e. below detection limits. Highest concentrations of epilimnetic nitrate occurred in the Parsnip Reach, exceeding 130 mg/m^3 in June. Nitrate values in at Junction and Peace reach averaged about 64 mg/m^3, and never declined to values considered limiting for algal growth. TN, TDN, values were consistently high and remarkably constant throughout the system, except for moderate declines in Finlay Reach in June and August.

'N:P' ratio. **(Table 1; Appendix 3)** Because there are large components of refractory organics and inorganic particulates included in both TN and TP measurements, a TN:TP ratio has little meaning when looking for limiting nutrients to phototrophic production. A more meaningful assessment of sources of nutrient limitation for phytoplankton can be obtained from a ratio based on nutrients that can be readily assimilated by the algae, namely nitrate + ammonia/phosphate. Since NH_3 was below detection limits at all station and PO_4 was not measured (concentrations too low to measure), a NO_3-N:TDP was used as the best surrogate 'nutrient' ratio to assess possible N or P limitation in the reservoir. Values of NO_3-N:TDP ratio averaged 15.7 for the whole system, and were lowest in the Finlay Reach - 4.7, increased to 16 and 17 in the Parsnip Reach and Junction stations, and increased again to about 20 in the Peace Reach due mainly to lower TDP values.

Phytoplankton.

Density, biovolume, and seasonal trends. **(Table 1; Figs. 3, 4)** In 1999 average phytoplankton population densities ranged from a high of about 5700 cells/mL at the Junction to a low of just over 3700 cells/mL in the Peace Reach at Clearwater, with an average cell density for the reservoir of 4729/mL. Average biovolume ranged from a high in the Finlay Reach of 0.50 mm^3/L to a low at of 0.18 at the dam Forebay station. The average phytoplankton biovolume (biomass) for the reservoir was 0.33 mm^3/L. The small picoplankter *Synechococcus* (Class Cyanophyceae) was numerically predominant at all stations, attaining greatest abundance at the Junction station in July. Diatoms (Bacillariophytes) were the next most abundant group followed by the nano-flagellates (Chryso- and Cryptophytes), Dinophycea and Chlorophytes or green algae. There were no major peaks (blooms), and surprisingly little seasonal variation in either phytoplankton abundance or biomass in Williston in 1999, and the largest population increase that was noted was only a 2-3 fold increase in *Synechococcus* in early July at the Junction station. Lowest phytoplankton population densities occurred in May and peaks in total numbers and biomass occurred at most all stations in August, largely attributable to increases of diatoms and nano-flagellates. Seasonally, among all stations, the Finlay Reach had the highest density and biomass of diatoms and lowest of picoplankton, while Parsnip Reach had the highest density and biomass of nanoflagellates and second lowest abundance of nano-flagellates. Phytoplankton densities and biomass in the Peace Reach were the lowest in the system. The frequently noted bimodal diatom peaks that occur in large lakes in spring and fall, concurrent with deep mixing episodes, were not seen in Williston, only a single, somewhat protracted mid-summer diatom increase.

Vertical distribution. **(Fig. 4)** For most of the growing season there was little variation in phytoplankton population density or biomass among depths sampled - 1, 3, 5m. But there we 2 exceptions, the first in Parsnip Reach where populations at 1m depth in June and July were 2-3 fold higher than those at deeper depths, and the second at the Junction station where there was a picoplankton population peak at 5m in early July.

Species. Species assemblages were very similar among the 5 stations and were numerically dominated by the small cyanobacteria - *Synechococcus.* The most common diatoms found at all stations in the reservoir and listed in order of abundance were- *Cyclotella* spp., *Asterionella formosa, Fragilaria* spp, *Aulicoseira* and *Stephanodiscus.* There was also a great diversity of nano-flagellate (size range 2-20µ) species the most common being *Chromulina, Chroomonas, Chrysochromulina, Cryptomonas, Rhodomonas,* and *Dinobryon.* The dinoflagellates *Peridinium* and *Gymnodinium* were present but not common and never attained large populations in the reservoir.

Chlorophyll

Values of chlorophyll together with biovolume provide estimates of autotrophic (plant) 'biomass'. Concentrations of phytoplankton chlorophyll in the reservoir were remarkably uniform, varying from a low of 0.4 to a high of 2.4 mg/m^3 (Table 1). The average concentration for whole reservoir was 1.4 mg/m^3. By station, the highest average concentrations occurred in the Parsnip Reach - 1.6 mg./m^3, and lowest value was observed at the dam Forebay station - 1.3 mg/m^3.

Primary Production.

Spatial and vertical trends. **(Table 1; Fig. 5)** Measurements of photosynthetic rates (PR) were done only twice (July, September), and thus results must be considered preliminary and interpreted with caution. Nonetheless there were some interesting trends. The first was that the highest average PR rates occurred on both dates within the Finlay Reach (34.5 mgC/m^3/hr) and the lowest on both dates at the dam Forebay station - Peace Reach (17.5 mgC/m^3/hr). After Finlay, the next highest rates were measured at the Junction station (31.0 mgC/m^3/hr) which was only marginally higher than values in the Parsnip Reach (24.5 mgC/m^3/hr). Highest PR rates at all stations in July occurred at 1m depth but in September maximum rates were noted at 3 m at all stations.

Zooplankton.

Spatial and seasonal trends of abundance, biomass. Detailed zooplankton data and analysis is available in *"Williston Reservoir zooplankton analysis program 1999" (*Wilson G.A. et al. 2000). There was a preponderance of copepods at all stations in Williston with greatest densities occurring in August and September the dam Forebay station >45 copepods/L. Single peaks of 11 copepods/L occurred at Clearwater (Peace Reach) in early August and in Finlay Reach in early July, but at the Junction two smaller peaks of 6/L occurred in both June and again in October. The lowest copepod abundance was in the Parsnip Reach which had a single peak of 4/L. The predominant copepod species were *Diaptomus denticornus, D. sicilis, Epischura* sp. and *Cyclops scutifer.* There were 3 predominant genera of cladocerans in Williston - *Daphnia, Holopedium,* and *Eubosmina* and the most abundant was *Daphnia.* Of the 3 species of *Daphnia* enumerated *(D. longiremis, D. pulex* and *D. galeata mendotae),* only *galeata mendotae* was common, with small population peaks in August in the Finlay (2/L) and Parsnip reaches (1/L), October at Junction (1/L), and the largest peak (4/L) at the dam Forebay. *Daphnia* were rarely seen at the Clearwater Station. The only significant density of *Eubosmia* occurred in the Finlay Reach in August - 1/L, at all other stations they were rarely seen.

The greatest zooplankton biomass was at the dam Forebay, where biomass greatly exceeded values seen at remaining stations, especially Parsnip Reach, which had extremely low densities of both Cladocerans and Copepods.

DISCUSSION

General.

Williston Reservoir, by virtue of its inception 30 years by the impoundment of 3 major river systems (Peace, Finlay and Parsnip rivers), is a complex and very large '**T**' shaped lacustrine system with 2 major western basins (Finlay and Parsnip reaches) converging at the junction and flowing eastward within the old Peace River canyon to create the 3rd basin - the Peace Reach. In a recent summary report, Stockner (1998) considered the zone of convergence Finlay and Parsnip reaches at the 'Junction', as the ***'mixing'*** zone for north and south moving Parsnip and Finlay catchment basin inflow waters, and the narrower, deeper, and more wind stressed Peace Reach as the reservoir's zone of ***'integration'***, where chemical and biological features could potentially be different than either of the parent systems - Parsnip and Finlay river basins. The discussion to follow will discuss each major basin separately, presenting the major limnological features of each reach and Junction region of the reservoir, with an emphasis on 'new' results obtained from the 1999 Williston Monitor Program. Albeit short, this discourse will hopefully provide the reader with a better understanding of system function and present productive potentials.

Parsnip Reach. The Parsnip Reach is the most southerly of the reservoir's basins, and throughout the growing season exhibits the smallest average epilimnetic depth (15m), highest maximum temperatures, and lowest water clarity, i.e. transparency. It receives input chiefly from the Parsnip and Pack (Crooked) river drainages from the south and west of the basin. These rivers input the lowest alkalinity (TDS), but highest nitrogen and TDP loadings among all Williston basins. Biologically, with a NO_3:TDP ratio of 16, and values of both nitrate and TDP remaining well above detection levels throughout the summer, phytoplankton and photosynthetic rates are likely seldom limited by nutrient concentration, but because of high turbidity in surface water, light is likely a major limiting factor. Estimates of both phytoplankton biomass (biovolume) and chlorophyll in the Parsnip Reach were the highest of all Williston basins, but primary production (2 dates only) was slightly lower than either the Finlay of Junction stations, again suggesting light limitation. It is quite likely that the large nitrogen loading and high concentrations noted here may emanate from the pulp and paper mill and other anthropogenic discharges to the southern portion of the basin from the community of Mackenzie, BC.

Finlay Reach. The Finlay Reach or north basin is the largest of Williston's 3 major basins, and receives the greatest volume of inflow water, >2-fold higher than average inflow to the Parsnip Reach. This reach is the least turbid and most alkaline, and has an average epilimnion depth of 30 m, which suggests higher wind velocities and fetch in this basin than in Parsnip reach where epilimnetic depths are shallower. The maximum epilimnetic temperature is 17°, slightly cooler than the Parsnip, but the next warmest in the Williston system. One of the most striking features of Finlay Reach is the low quantity of available nitrogen, the lowest by far of any of Williston's basins. All forms of N were low but especially concentrations of NO_3-N that are just above detection limits in June and depleted from the epilimnion in August. Values of TDP are also the low and the NO_3:TDP ratio of 4.7 is about 3-4-fold lower than seen elsewhere in Williston, indicating a strong potential for N limitation of phytoplankton growth during much of growing season. Not surprisingly, the phytoplankton biomass in the Finlay Reach was lower than in Parsnip, but average primary production was higher, likely a result of lower turbidity, better transparency and more available light.

Junction. Waters at the 'Junction' station are a blend of Parsnip and Finlay reach input and strong summer winds blowing out of the Peace canyon from east to west create a well-mixed epilimnion that ranges between 20-25 m in depth. That this station is well situated within the 'zone of mixing' of both Finlay and Parsnip reaches is apparent when one compares the average seasonal values of conservative variables like TDS at Junction -100 mg/m^3 with the average for Parsnip (88) and Finlay (119) reaches - 103mg/m^3, and the average TN at Junction - 190 mg/m^3, which was very similar to the average values for Parsnip (240) and Finlay (130) reaches - 185 mg/m^3 waters. The average epilimnetic depth (20m) at Junction station is greater than Parsnip but less than Finlay with the same trend evident for Secchi depth, i.e. transparency. Phytoplankton biomass was slightly lower than either Parsnip or Finlay reaches, but abundance was higher due to a large sub-surface bloom of small pico-cyanobacteria. Primary production at the Junction was similar to the average of the Parsnip and Finlay mean values, lower than Finlay but higher than Parsnip. There was no indication of any severe nutrient limitation, i.e. NO_3:TDP ratio of 16, but NO_3-N values did decline to low levels <25 mg/m^3 in October. As was noted for the Parsnip Reach, higher turbidity with greater sub-surface light attenuation is likely one of the more significant factors limiting photosynthesis, i.e. carbon production at Junction.

Peace Reach. The east basin or Peace Reach is much deeper, narrower and more wind mixed than either Parsnip or Finlay basins. Two stations sampled conditions in the Reach: the first at 'Riverside' some 35-40 km east of Junction sampled mid-basin waters, while the Forebay station sampled waters at the most eastern portion and deepest (>190 m) of the basin adjacent to the Bennett dam. There was a striking similarity among the 2 stations in nearly all of measured variables, the only notable departures being a greater epilimnetic depth >40 m, a higher maximum temperature, and a higher turbidity (lower average Secchi depth) at the Forebay station. There appeared to be an east-west gradient in biological production within the

Peace Reach, i.e. from the Junction to Forebay stations, with Riverside values of phytoplankton abundance and biomass lower than Junction but slightly higher than seen at the Forebay, which had the lowest average values in the entire reservoir. Shoreline instability and wind and wave erosion of fine alluvial soils at the extreme eastern region of the Peace Reach apparently increases turbidity in the pelagic at Forebay station, which resulted in an average Secchi depth of <3 m. The lowest primary production estimates were also measured at the Forebay, which is likely attributable to light rather than nutrient limitation, since the NO_3:TDP ratio of 20 was just slightly less than Clearwater (21) the highest in the Williston system.

Nutrients and trophic state.

Perhaps the most obvious elements of analysis missing in past limnological assessments of Williston reservoir are those related to nutrient loading and seasonal primary production (carbon budgets). Stockner (1998) assembled autumn TP and TN data from earlier (1975, 1988) surveys to demonstrate that the reservoir over the 13 year period from 1975 to 1988 showed rather striking declines in concentrations of both N and P. The 1999 monitor has provided current TP and TN values to compare with these earlier values, and these data suggest that there has been no major changes in autumnal TN or TP concentrations since 1988 (Table 2). Based on the premise that ambient TN and TP concentrations are well correlated with system productivity, then it appears that production in Williston has now stabilized, and has likely reached a new equilibrium with annual N & P input supply.

Table 2. TN and TP from Nov. 1975, Oct. 1988 and Oct/Nov. 1999 at selected stations (1975 and 1988 values from *G3* EEM report, 1993).

Station	Variable	1975	1988	1999
Finlay (N8)	TN	128-134	80-110	100-140
	TP	11.0	4.0	6.0
Parsnip (S3)	TN	196-315	170-180	170-220
	TP	5.0	4.5	7.3
Junction (J4)	TN	155-166	110-160	120-160
	TP	5	3.5	6.5
Clearwater (E4)	TN	139-171	80-150	130-140
	TP	5	3.5	3.5
Dam Forebay (E 13)	TN	142-228	120-180	140-180
	TP	5	3.5	4.6

Using Williston 1999 values of average TP (6.2 mg/m^3) and chlorophyll (1.4 mg/m^3) provides another assessment of current trophic state and of rate of change since impoundment some 30 years ago (Figs. 6 and 7). The picture emerging from both presentations (one using mean depth vs. areal loading rate, the other chlorophyll vs. loading rate) is that Williston Reservoir for the first decade after impoundment was doubtless a much more productive ecosystem with abundant nutrients from land inundation and decomposition of flooded vegetation (boom cycle), but after 2 decades has slowly lost nutrients (P) through outflow and sedimentation, and has now become less productive. Williston on the basis of most variables measured in 1999 is clearly within the oligotrophic condition. Because of its location and climatic setting it will likely retain in perpetuity its oligotrophic characteristics. But this prognosis **does not** take into account possible changes in productivity that could occur because of global warming, intensive resource extractions (e.g. clear-cut logging), or from catastrophic events like forest fires, earthquakes, etc, all of which could potentially increase N and P inputs and affect system productivity (Stockner et al. 2000).

It is of interest to compare Williston Reservoir 1999 limnological results with other lakes and reservoirs in BC, with large lakes of the Yukon River drainage basin, and with northern Alberta prairie lakes. When one examines where Williston lies within the relationship between TP and chlorophyll for coastal BC lakes (MacIsaac and Stockner 1985), it is clear that Williston has higher TP but lower chlorophyll than many BC coastal and interior lakes (Fig. 8). But the relationship is spurious because up to 50% of the TP in Williston is inorganic particle bound and unavailable for biogenic production. The relationship is much improved by using the average Williston 1999 **TDP** value, which brings Williston directly in line with most BC oligotrophic lakes (Fig. 8).

In a log/log presentation of the TP/chlorophyll using data from Yukon River basin and Alberta prairie lakes, Williston's 1999 values cluster in the centre of the Yukon lake data, which is not surprising considering the similarities of biogeoclimatic settings of both systems (Fig. 9). Further, Yukon lakes support a far greater abundance of large macrozooplankton than coastal BC lakes because they lack significant populations of predaceous planktivorous fishes, e.g. juvenile sockeye. Hence the low chlorophyll in these northern systems is related more to grazing or 'top-down' control than to nutrient supply - 'bottom-up' (Shortreed and Stockner 1986).

SUMMARY

Williston Reservoir, BC's largest lake/ reservoir, is a physically complex and dynamic system, strongly influenced by the diverse geological, physiographic and climatic settings of the 3 major drainage basins - Peace, Finlay, and Parsnip. Despite such inherent complexity there was a remarkable similarity of among physico-chemical and biological variables assessed. Since it is operated as a hydroelectric reservoir it experiences abnormally large (11m) water level fluctuations which create shoreline instabilities and result in the annual re-suspension and re-deposition of fine silt and clay, that increase turbidity, decrease light attenuation and lower biogenic production within the pelagic and littoral zones. Estimates of primary production in 1999 are moderately high compared to other large, interior reservoirs e.g. Arrow, but based on TP and Chlorophyll values from the 1999 monitor program the current trophic state of Williston is positioned well within the oligotrophic range.

ACKNOWLEDGEMENTS

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Figure Legends

Fig. (1) Williston Reservoir watershed (presented in text of the report).

Fig. (2) Location of sampling locations (presented in text of the report).

Fig. (3) Seasonal (May - November) abundance and biomass of the major phytoplankton classes in Williston Reservoir in 1999.

Fig. (4) Seasonal (May - November) epilimnetic phytoplankton average abundance and biomass, and abundance at three depths in Williston Reservoir in 1999.

Fig. (5) Williston reservoir 1999 primary production.

Fig. (6) Relation between annual TP load and mean depth (m) (after Vollenweider 1976)

Fig. (7) Relation between annual TP load and average chlorophyll a (mg/m^3).

Fig. (8) Relation between average TP concentration and average chlorophyll for Vancouver Island lakes, (modified from MacIsaac and Stockner 1985).

Fig. (9) Relation between average TP concentration and average chlorophyll for Vancouver Island, Yukon Territory and prairie lakes, (modified from MacIsaac and Stockner 1985).

Figures 3 - 10

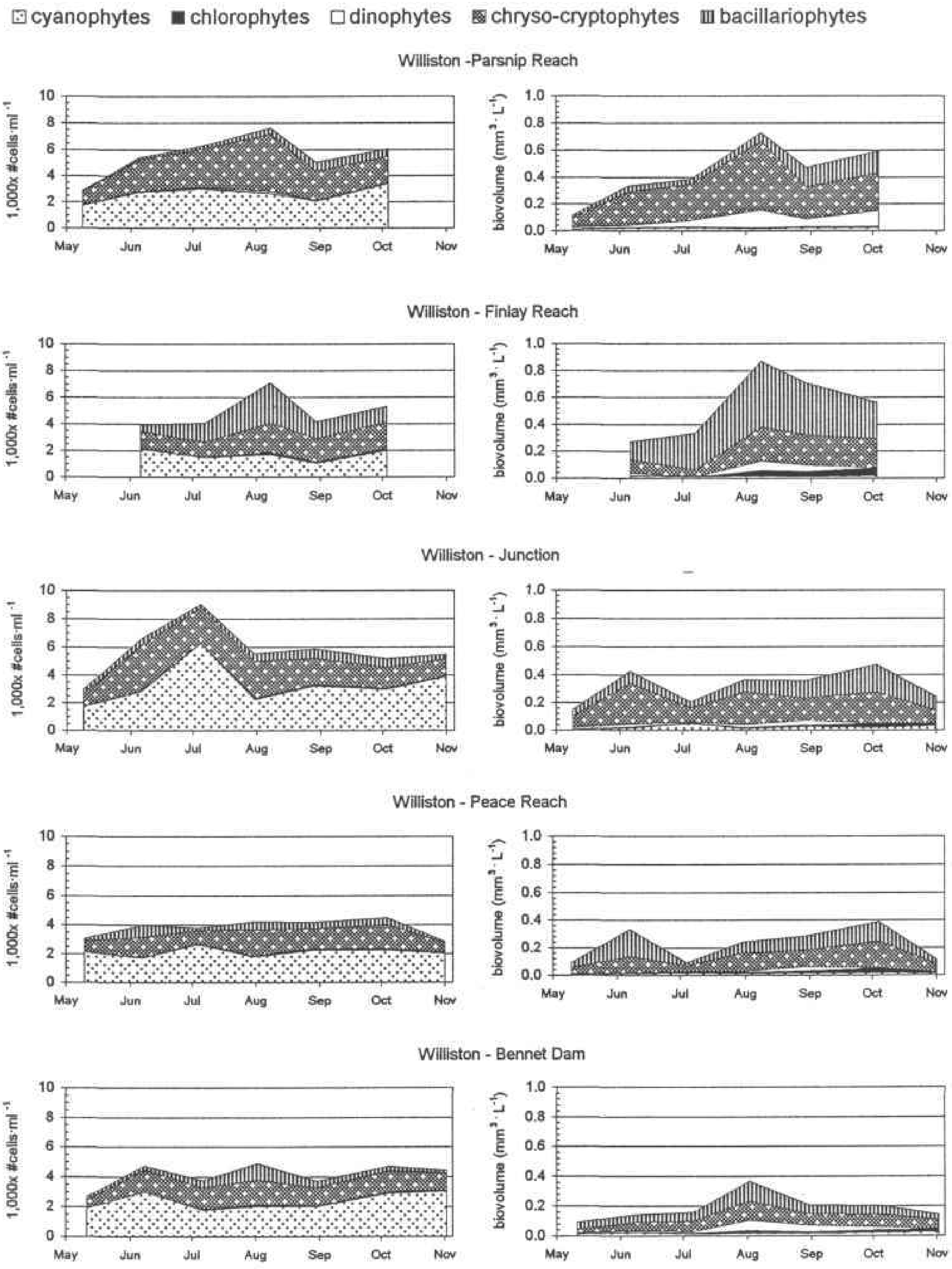


Figure 3. Seasonal (May-Nov.) abundance and biomass of the major phytoplankton classes in Williston Reservoir in 1999.

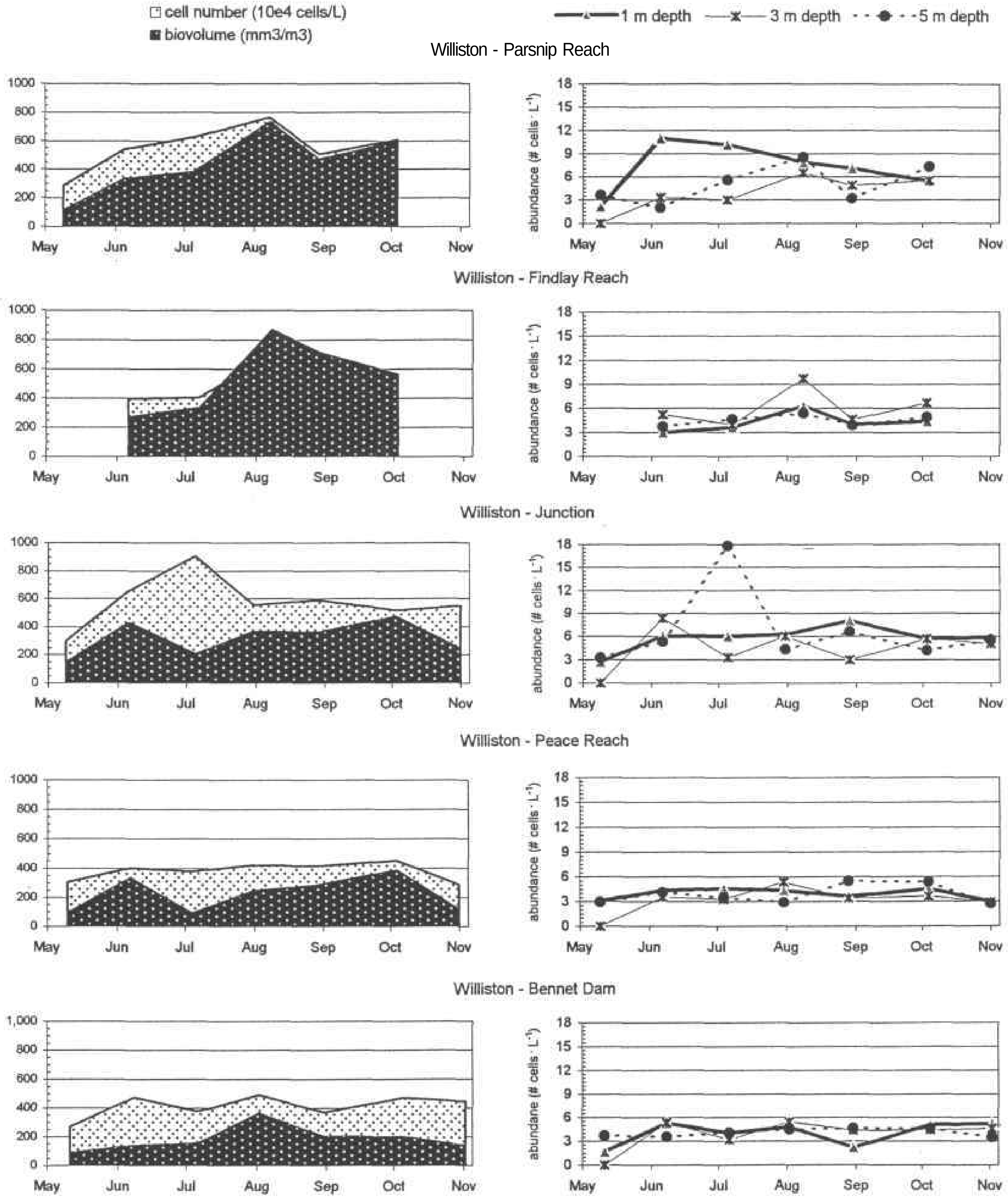


Figure 4. Seasonal (May-Nov) epilimnetic phytoplankton average abundance and biomass, and abundance at three depths in Williston Reservoir in 1999.

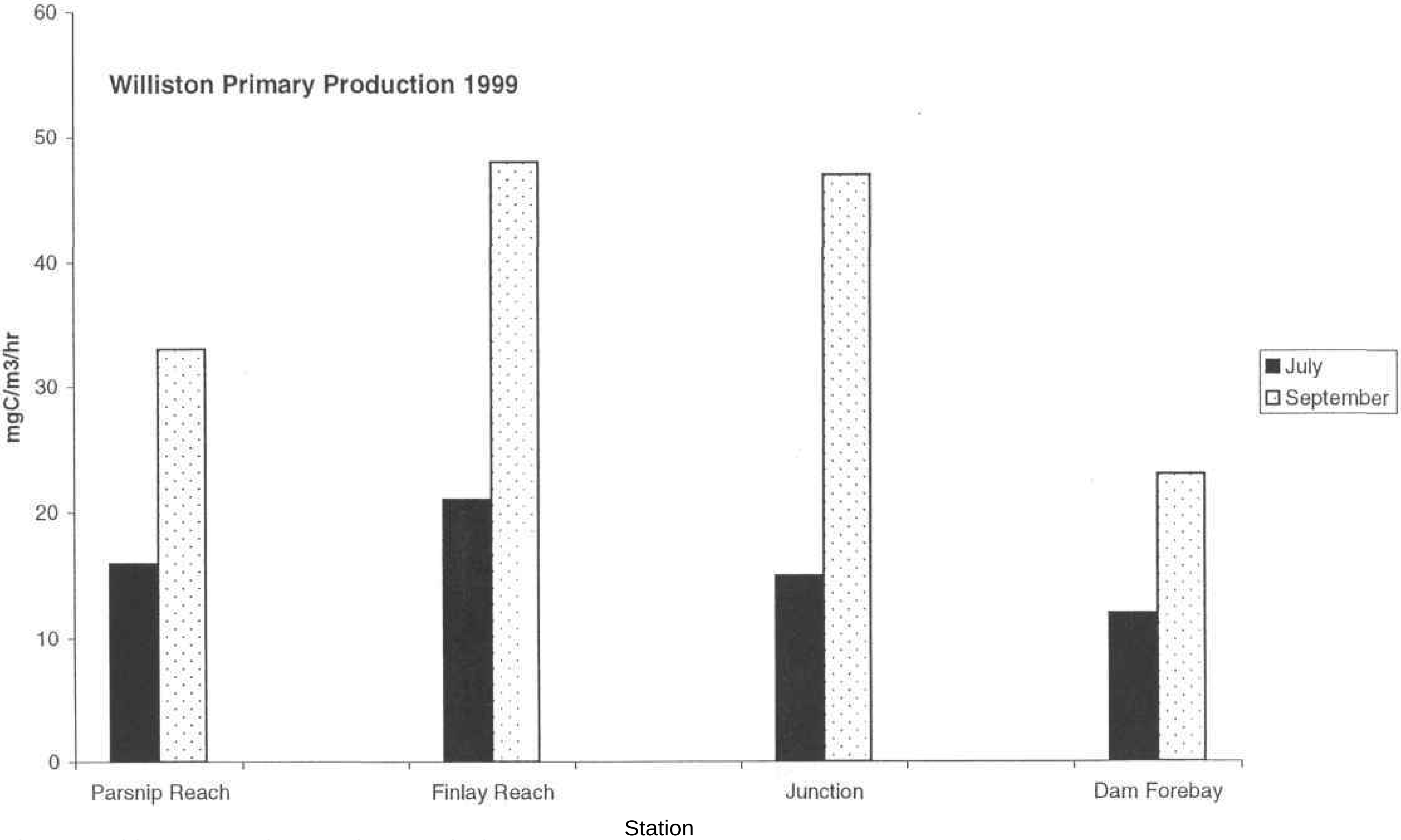


Figure 5. Williston Reservoir 1999 primary production.

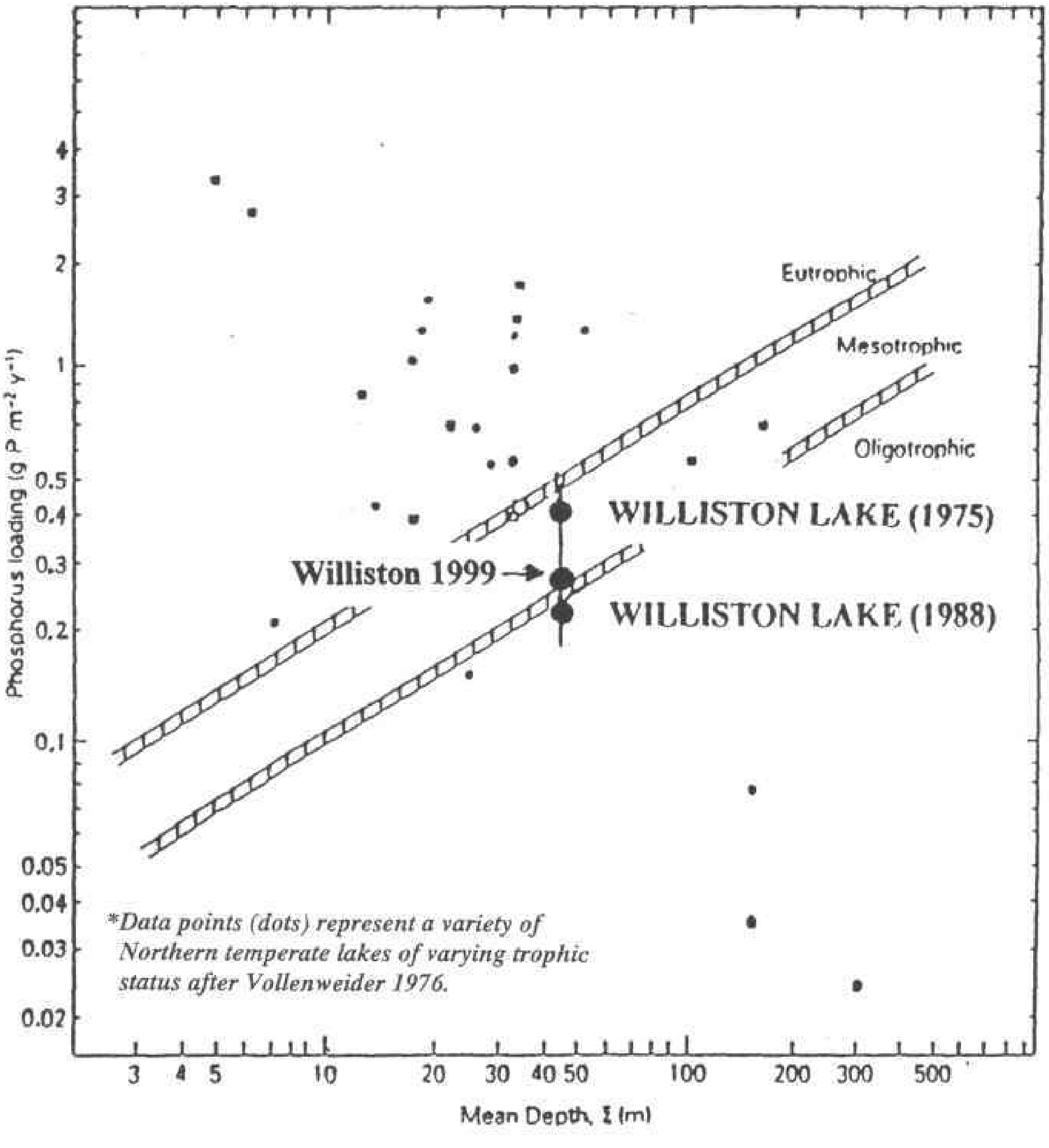


Figure 6. Relation between annual TP load and mean depth (m) (after Vollenweider 1976)

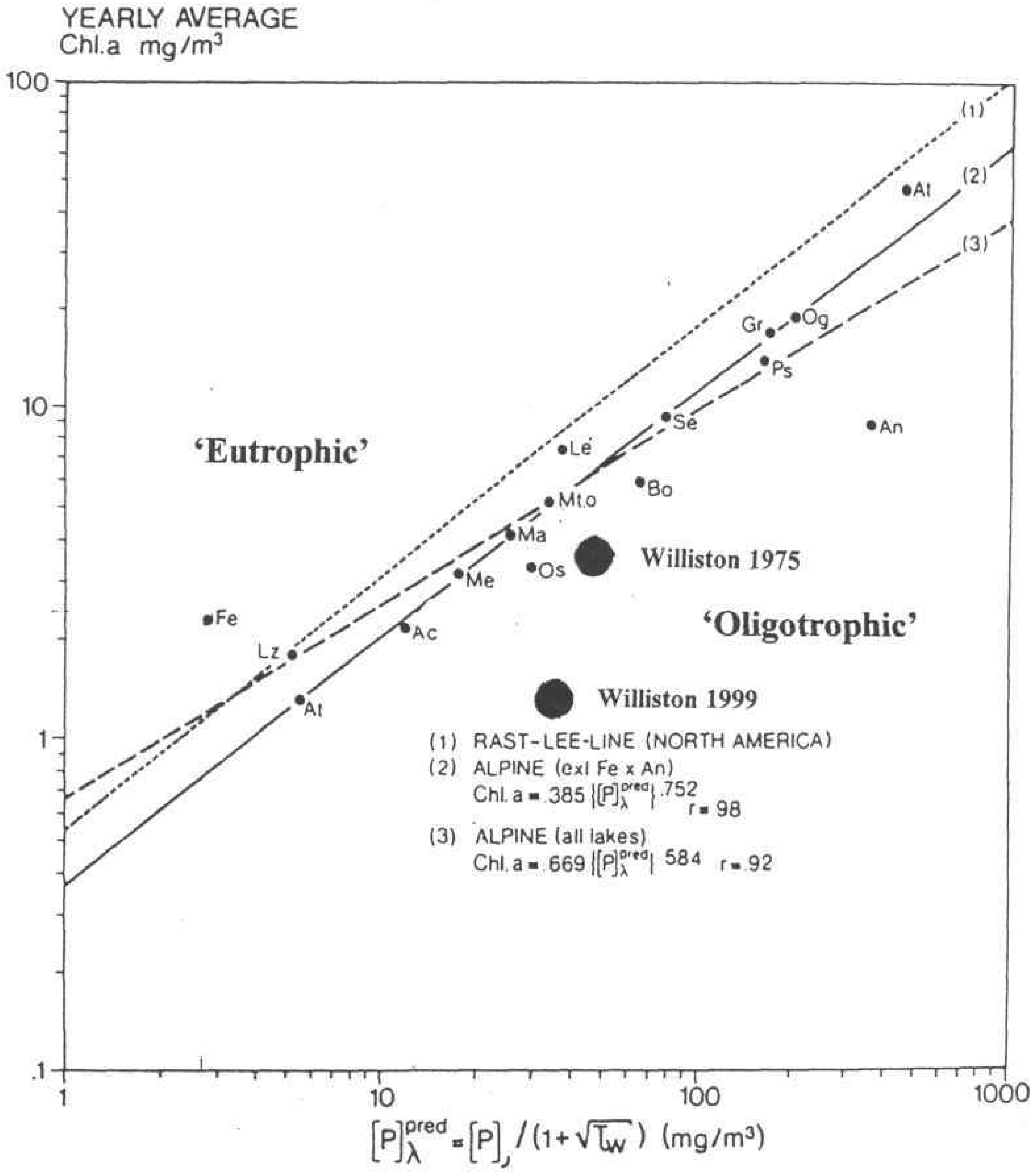


Figure 7. Relation between annual TP load and average chlorophyll a (mg/m).

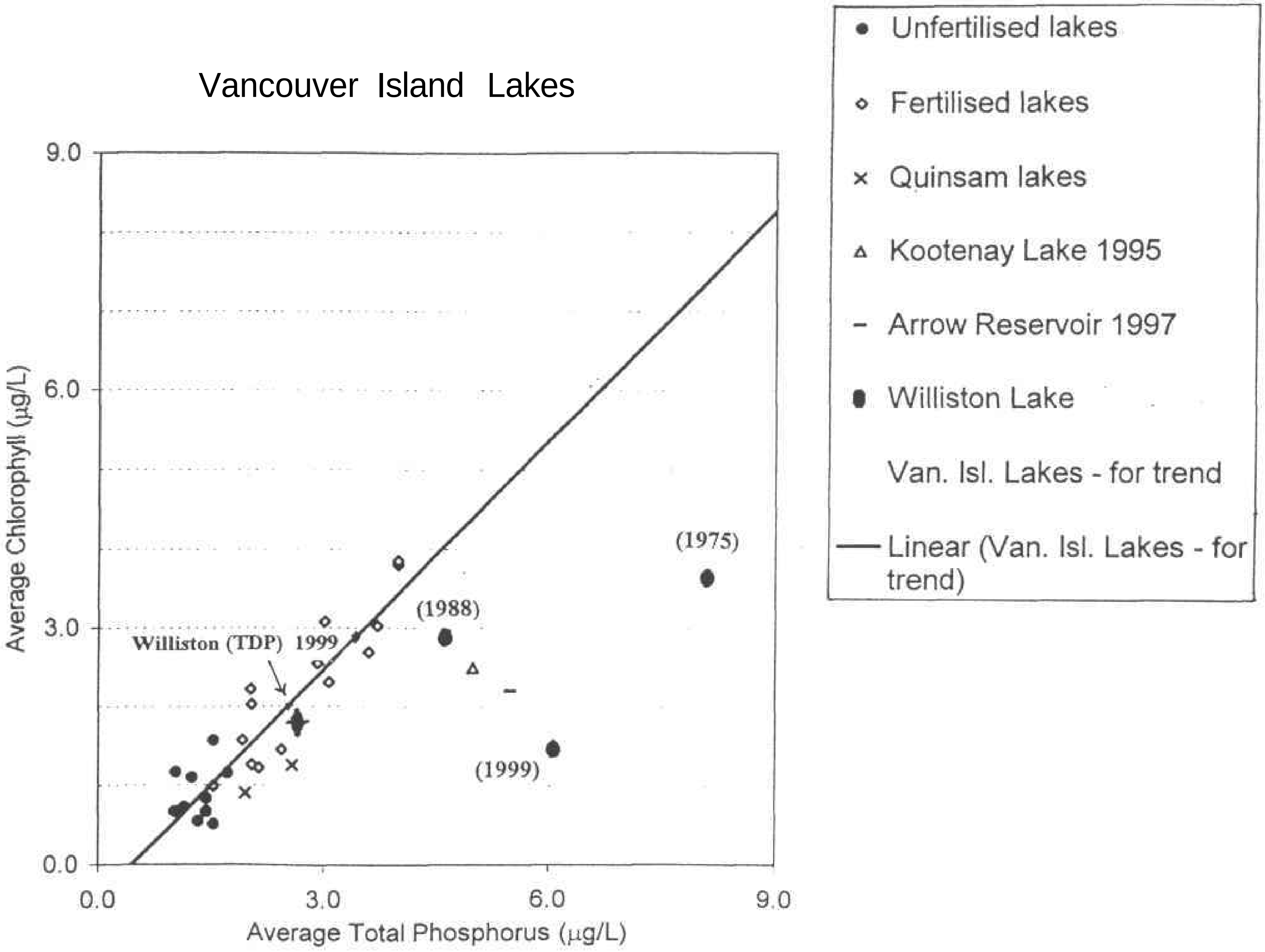


Figure 8. Relation between average TP concentration and average chlorophyll for Vancouver Island lakes, (modified from MacIsaac and Stockner 1985).

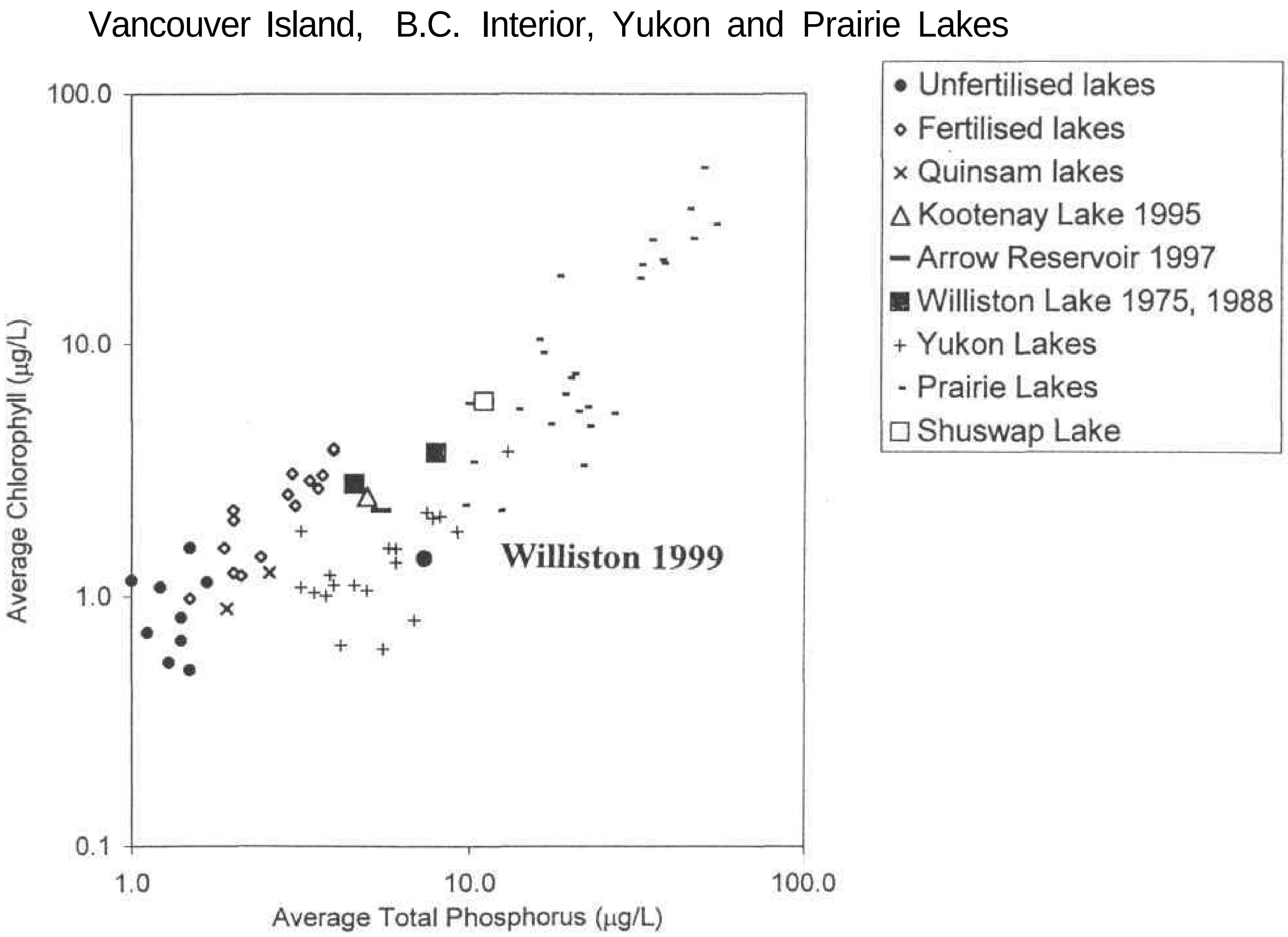


Figure 9. Relation between average TP concentration and average chlorophyll for Vancouver Island, Yukon Territory and prairie lakes, (modified from MacIsaac and Stockner 1985).

Appendix 1

(Phytoplankton species list)

Appendix1, Table 1. Williston Reservoir phytoplankton species, codes and biovolumes (mm^3/ L).

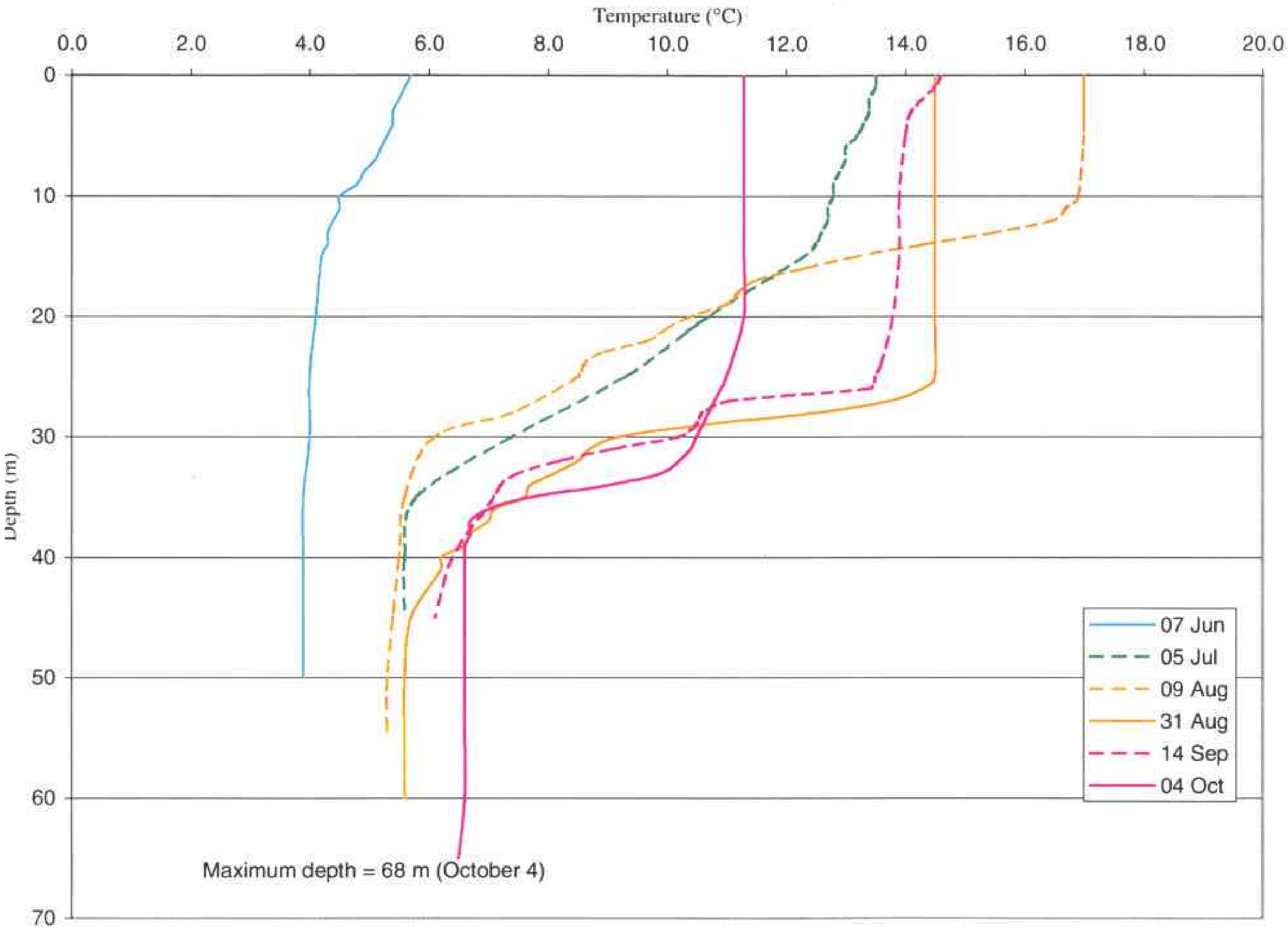
Code	Class	Biovolume	Species
AM	Bacillariophyte	80	Achnanthes sp2
AN	Bacillariophyte	100	Achnanthes sp1
AY	Bacillariophyte	100	Asterionella formosa var1
AZ	Bacillariophyte	120	Asterionella formosa var2
CP	Bacillariophyte	200	Cocconeis sp.
CU	Bacillariophyte	250	Cyclotella comta var1
CZ	Bacillariophyte	500	Cyclotella comta var2
GV	Bacillariophyte	50	Cyclotella stelligera var1
CR	Bacillariophyte	100	Cyclotella steiligera var2
CS	Bacillariophyte	150	Cyclotella stelligera var3
CW	Bacillariophyte	50	Cyclotella sp3
CT	Bacillariophyte	150	Cyclotella sp2
CM	Bacillariophyte	150	Cymbella sp1
CO	Bacillariophyte	250	Cymbella sp2
DF	Bacillariophyte	150	Diatoma sp.
ED	Bacillariophyte	100	Eunotia sp1
EV	Bacillariophyte	200	Eunotia sp2
EW	Bacillariophyte	500	Eunotia sp3
FF	Bacillariophyte	80	Fragilaria construens var2
FG	Bacillariophyte	150	Fragiiaria construens var3
FC	Bacillariophyte	120	Fragilaria crotonensis
FS	Bacillariophyte	100	Fragilaria sp.
MC	Bacillariophyte	250	Aulicoseira distans var1
MD	Bacillariophyte	350	Aulicoseira distans var2
MI	Bacillariophyte	200	Aulicoseira italica var1
MJ	Bacillariophyte	250	Aulicoseira italica var2
MZ	Bacillariophyte	350	Aulicoseira sp.
NV	Baciilariophyte	500	Navicula sp.
NZ	Baciilariophyte	200	Nitzschia sp.
RC	Bacillariophyte	50	Rhizosolenia sp.
SE	Bacillariophyte	1500	Stephanodiscus sp.
SN	Bacillariophyte	100	Fragilaria acus var1
SO	Bacillariophyte	150	Fragilaria acus var2
SU	Bacillariophyte	1000	Fragilaria ulna
SP	Bacillariophyte	200	Fragilaria sp1
SR	Bacillariophyte	250	Fragilaria sp3
TF	Baciilariophyte	500	Tabellaria fenestrata
TB	Bacillariophyte	500	Tabellaria flocculosa
BQ	Chryso-cryptoph	100	Bitrichia sp3
BS	Chryso-cryptoph	200	Bitrichia sp4
CH	Chryso-cryptoph	250	Chilomonas sp.
XX	Chryso-cryptoph	20	Chromulina sp1
XY	Chryso-cryptoph	50	Chromulina sp3
CA	Chryso-cryptoph	150	Chroomonas acuta var1
CB	Chryso-cryptoph	200	Chroomonas acuta var2
YQ	Chryso-cryptoph	500	Chryptomonas sp1
YO	Chryso-cryptoph	700	Chryptomonas sp4
CC	Chryso-cryptoph	75	Chrysochromulina sp.
DC	Chryso-cryptoph	100	Dinobryon cysts

Code	Class	Biovolume	Species
DN	Chryso-cryptoph	150	Dinobryon sp2
DO	Chryso-cryptoph	200	Dinobryon sp5
DP	Chryso-cryptoph	350	Dinobryon sp6
KB	Chryso-cryptoph	40	Kephyrion sp2
KA	Chryso-cryptoph	50	Kephyrion sp1
MK	Chryso-cryptoph	200	Maliomonas sp7
MF	Chryso-cryptoph	350	Mallomonas sp8
MH	Chryso-cryptoph	500	Maliomonas sp5
ME	Chryso-cryptoph	700	Mallomonas sp4
MG	Chryso-cryptoph	750	Mallomonas sp6
ML	Chryso-cryptoph	1500	Mallomonas sp1
YZ	Chryso-cryptoph	10	Small microflagellates
OC	Chryso-cryptoph	250	Ochromonas sp.
PT	Chryso-cryptoph	100	Pseudokephrion sp.
PP	Chryso-cryptoph	150	Pseudopedinella sp.
RM	Chryso-cryptoph	60	Rhodomonas sp1
RN	Chryso-cryptoph	80	Rhodomonas sp2
RO	Chryso-cryptoph	100	Rhodomonas sp3
GT	Dinophyte	100	Gymnodinium sp6
GY	Dinophyte	1000	Gymnodinium sp1
GZ	Dinophyte	1500	Gymnodinium sp2
GW	Dinophyte	2500	Gymnodinium sp5
PJ	Dinophyte	350	Peridinium sp4
PK	Dinophyte	450	Peridinium sp3
XC	Chlorophyte	80	Ankistrodesmus sp3
XA	Chlorophyte	100	Ankistrodesmus sp2
CL	Chlorophyte	500	Coelastrum sp.
CN	Chlorophyte	500	Cosmarium sp.
CK	Chlorophyte	200	Crucigenia sp.
XU	Chlorophyte	250	Crucigeniella apiculata
DM	Chlorophyte	1000	Desmids
EJ	Chlorophyte	100	Elakatothrix sp2
EL	Chlorophyte	250	Elakatothrix sp3
EK	Chlorophyte	500	Elakatothrix sp1
CO	Chlorophyte	500	Oocystis sp.
SI	Chlorophyte	60	Scenedesmus sp.
SD	Chlorophyte	1500	Staurodesmus sp.
TE	Chlorophyte	50	Tetrahaedron sp.
AB	Cyanophyte	300	Anabaena sp1 (small)
AC	Cyanophyte	900	Anabaena circinalis
AH	Cyanophyte	100	Aphanothecae sp.
AP	Cyanophyte	1500	Aphanizomenon sp.
MS	Cyanophyte	20	Merismopedia sp.
ZN	Cyanophyte	20	Oscillatoria sp2
ZO	Cyanophyte	350	Oscillatoria limnetica
SC	Cyanophyte	5	Synechococcus sp. (<2 µm)
CY	Cyanophyte	10	Synechocystis
ST	Chlorophyte	1000	Staurastrum sp.
PL	Chlorophyte	350	Planctonema sp.
PS	Chlorophyte	100	Paulschultzia sp.

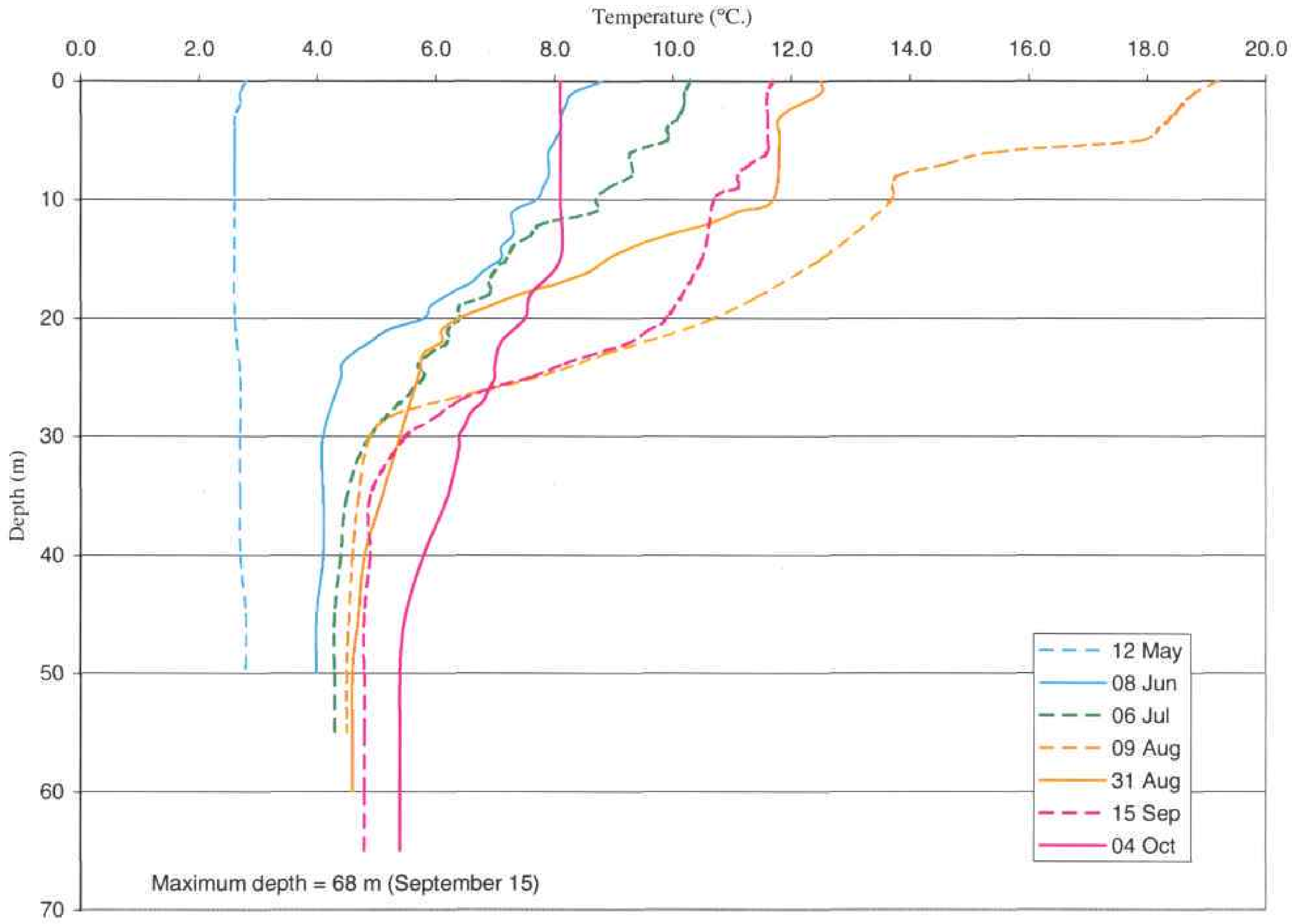
Code	Class	Biovoiume	Species
KI	Chlorophyte	50	Kirchneriella sp.
CI	Chryso-cryptoph	75	Chrysoikos sp.
PI	Bacillariophyte	2000	Pinnularia sp.
GG	Baciilariophyte	750	Gomphonema sp.
MX	Cyanophyte	500	Microcystis sp.
LB	Cyanophyte	500	Lyngbya sp.
CX	Chlorophyte	150	Coccomyxa sp.
CJ	Bacillariophyte	350	Ceratoneis sp.
SX	Chryso-cryptoph	75	Stenokalyx
GO	Chlorophyte	500	Gonium
CE	Dinophyte	5000	Ceratium
QD	Chlorophyte	250	Quadrigula
UL	Chlorophyte	700	Ulothrix
CD	Chlorophyte	150	Closteriopsis
MO	Chlorophyte	200	Monoraphidium
SY	Chryso-cryptoph	700	Synura
LA	Chlorophyte	30	Langerheimia
SS	Bacillariophyte	500	Suriella
CF	Chryso-cryptoph	250	Chrysidiastrum
DI	Chlorophyte	900	Dichtyosphaerium
OA	Cyanophyte	750	Oscillatoria agardhii

Appendix 2

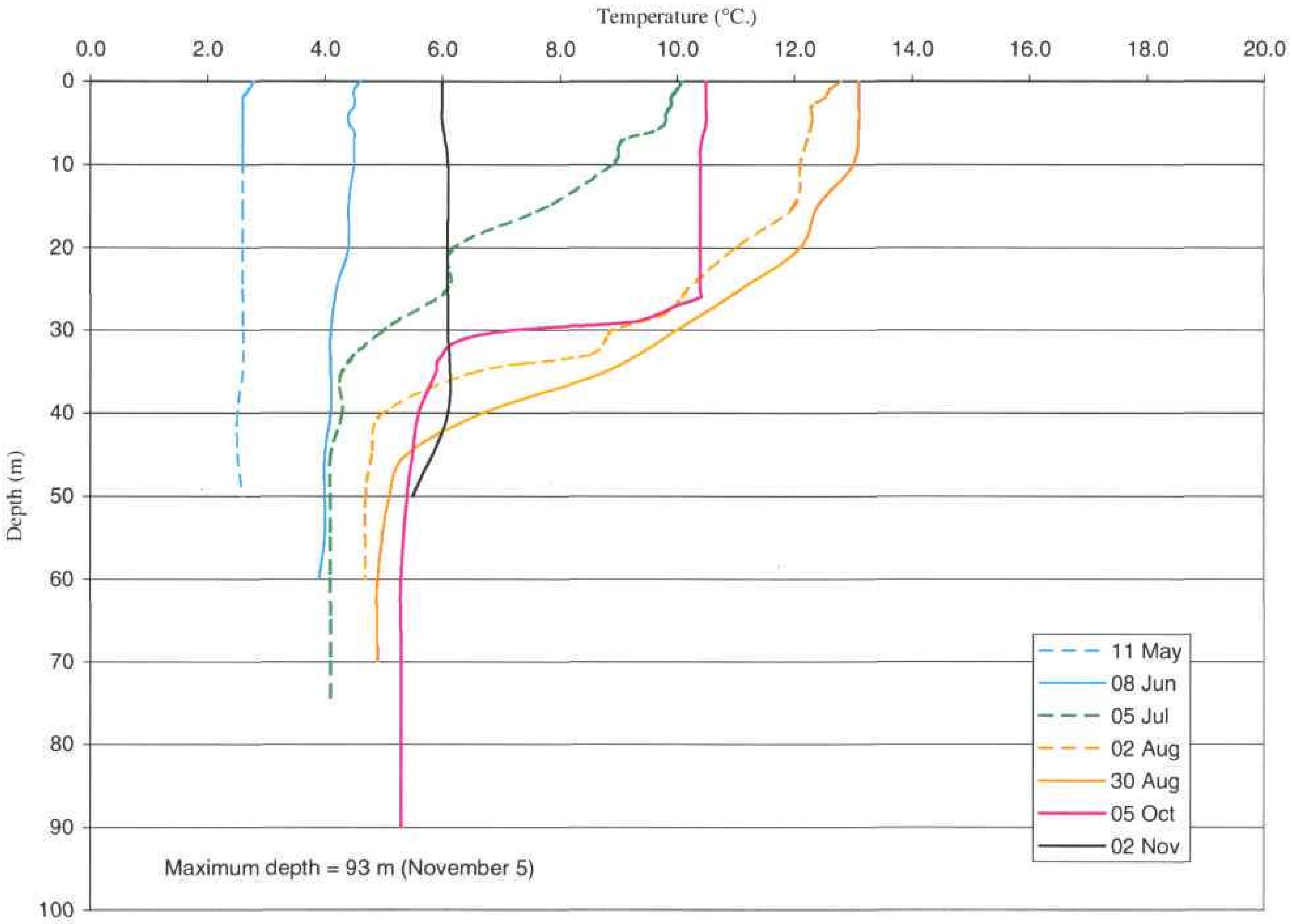
(Temperature and Oxygen depth profiles)



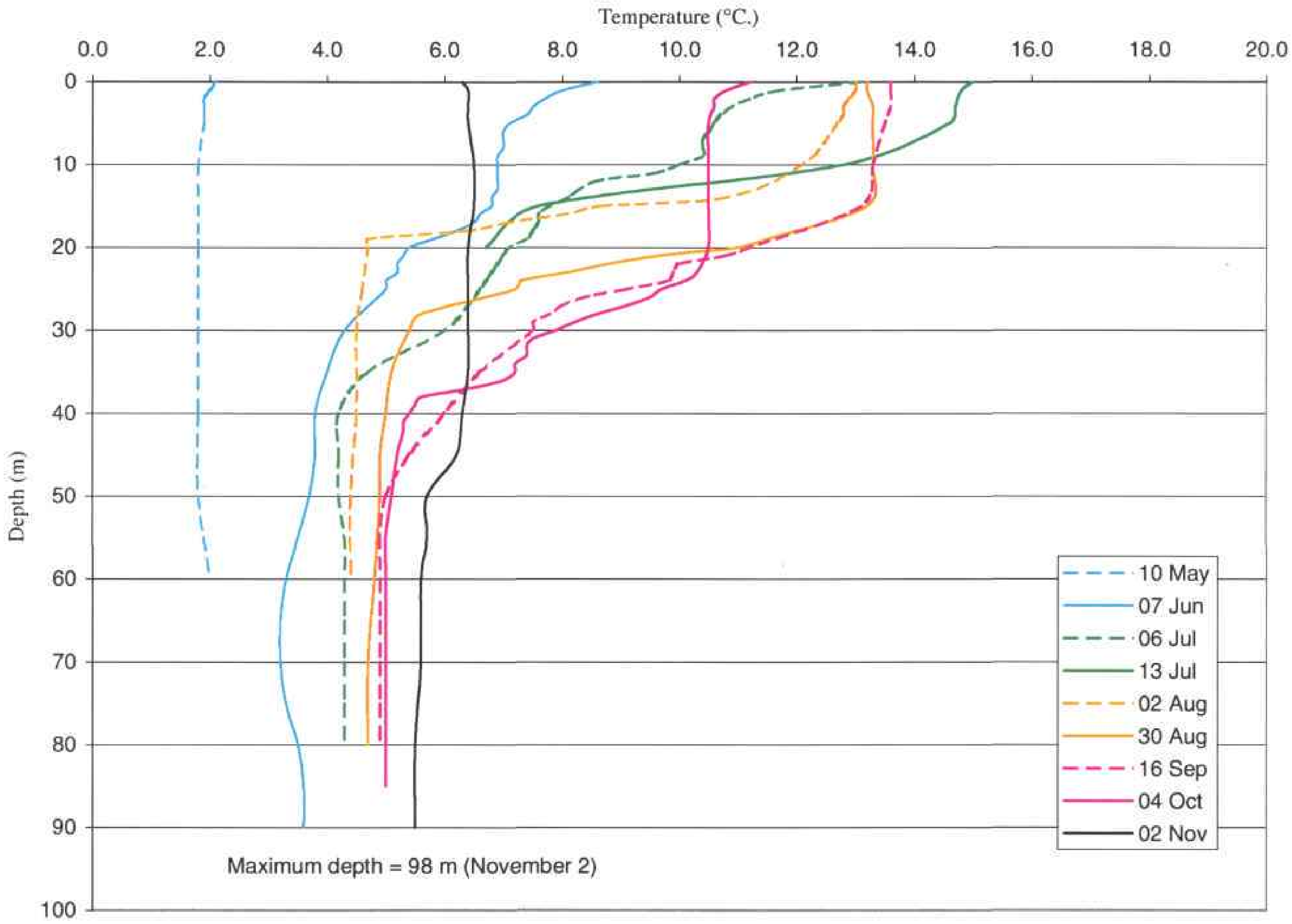
Finlay Reach station (E234184) seasonal temperature versus depth profile.



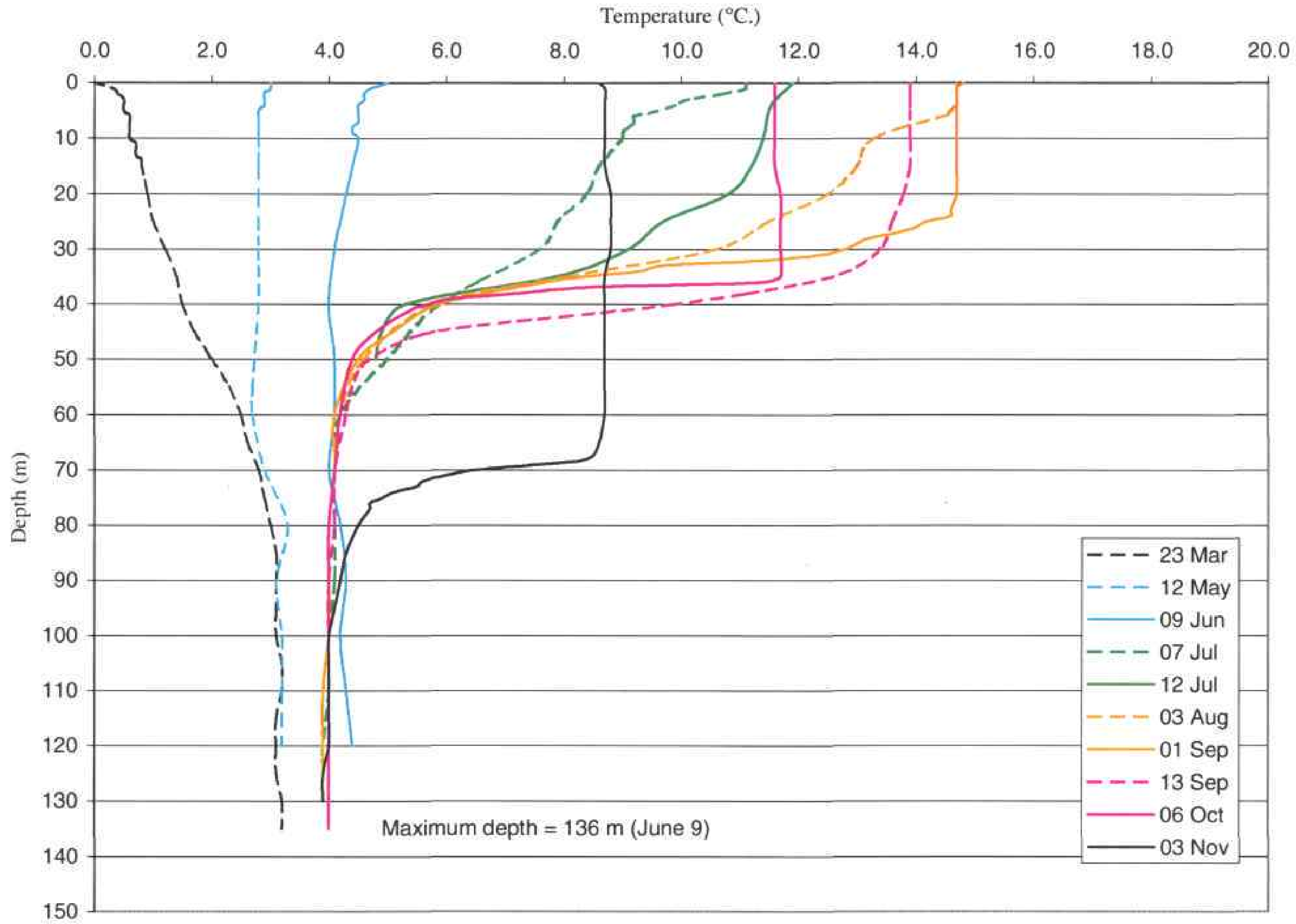
Parsnip Reach station (E234185) seasonal temperature versus depth profile.



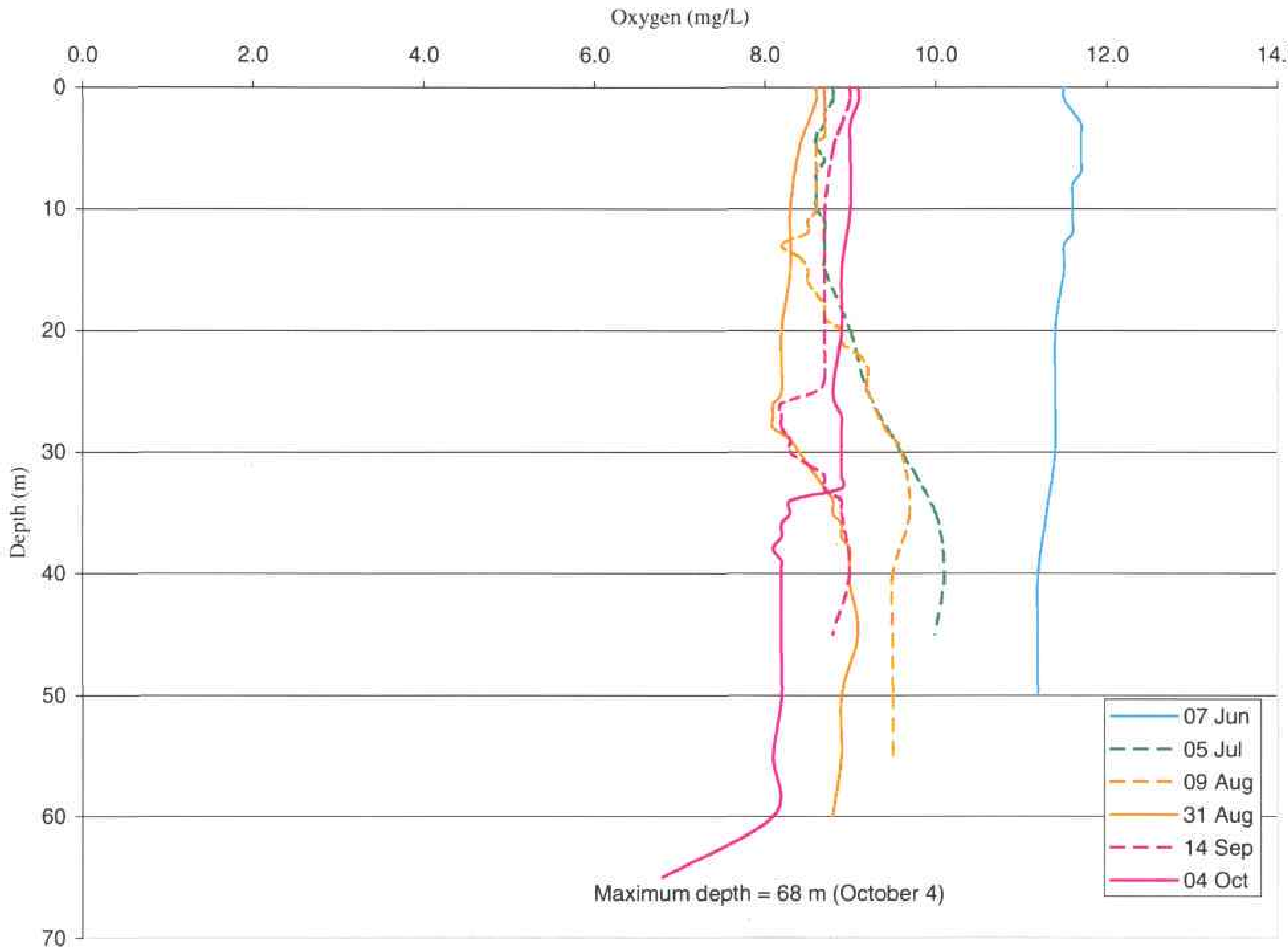
Peace Reach station (E234186) seasonal temperature versus depth profile.



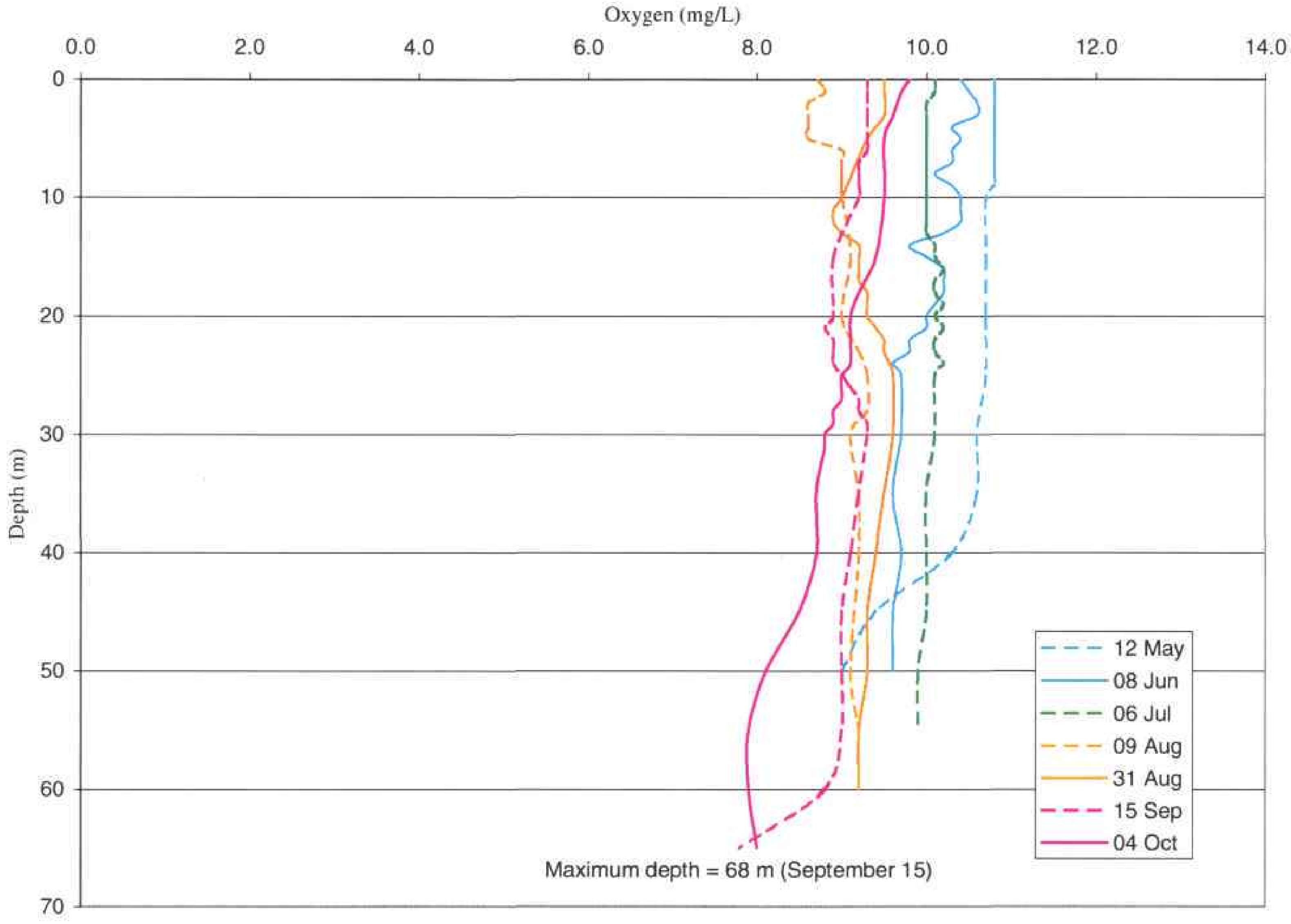
Junction station (E234187) seasonal temperature versus depth profile.



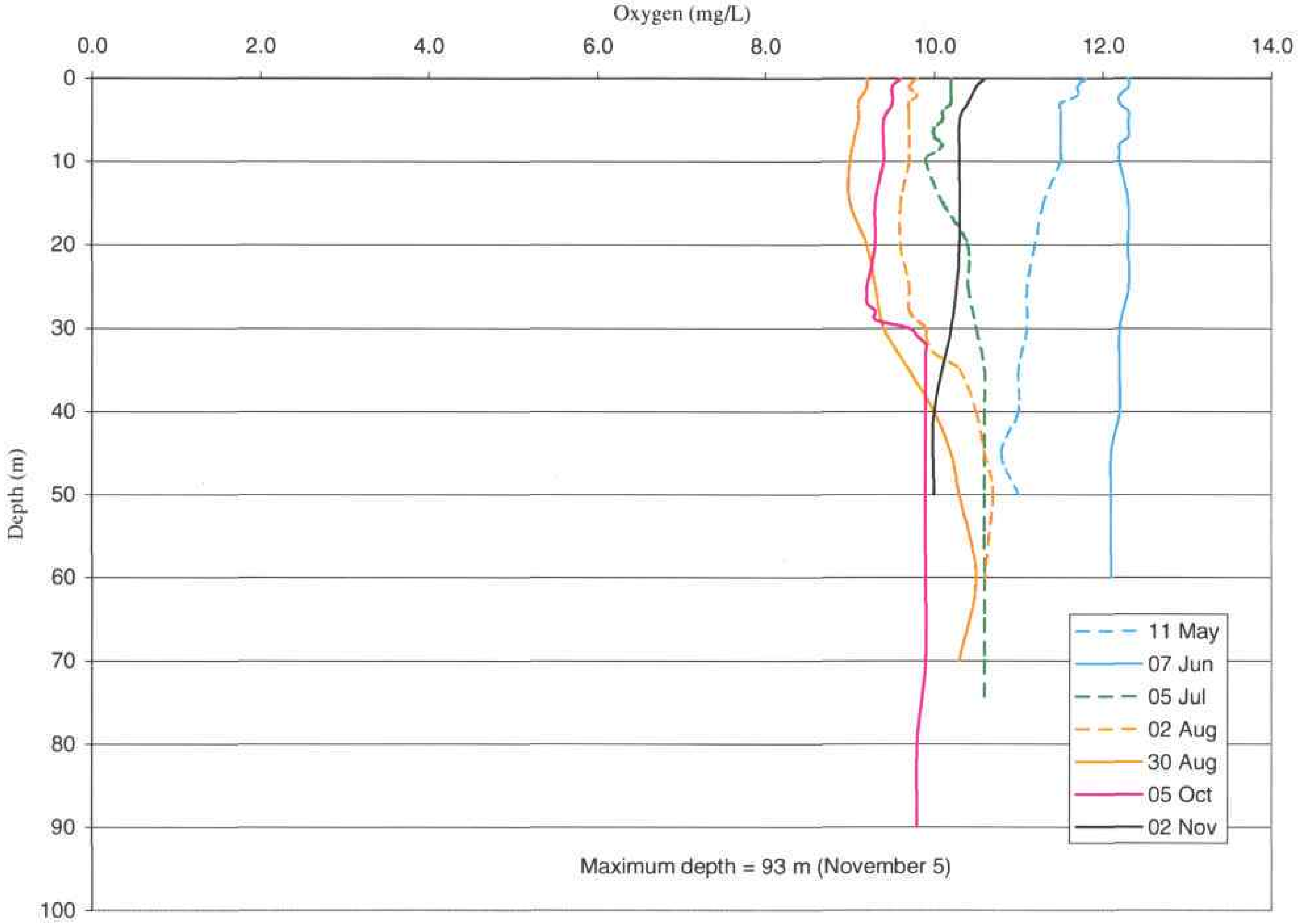
Forebay station (E234188) seasonal temperature versus depth profile.



Finlay Reach station (E234184) seasonal oxygen versus depth profile.

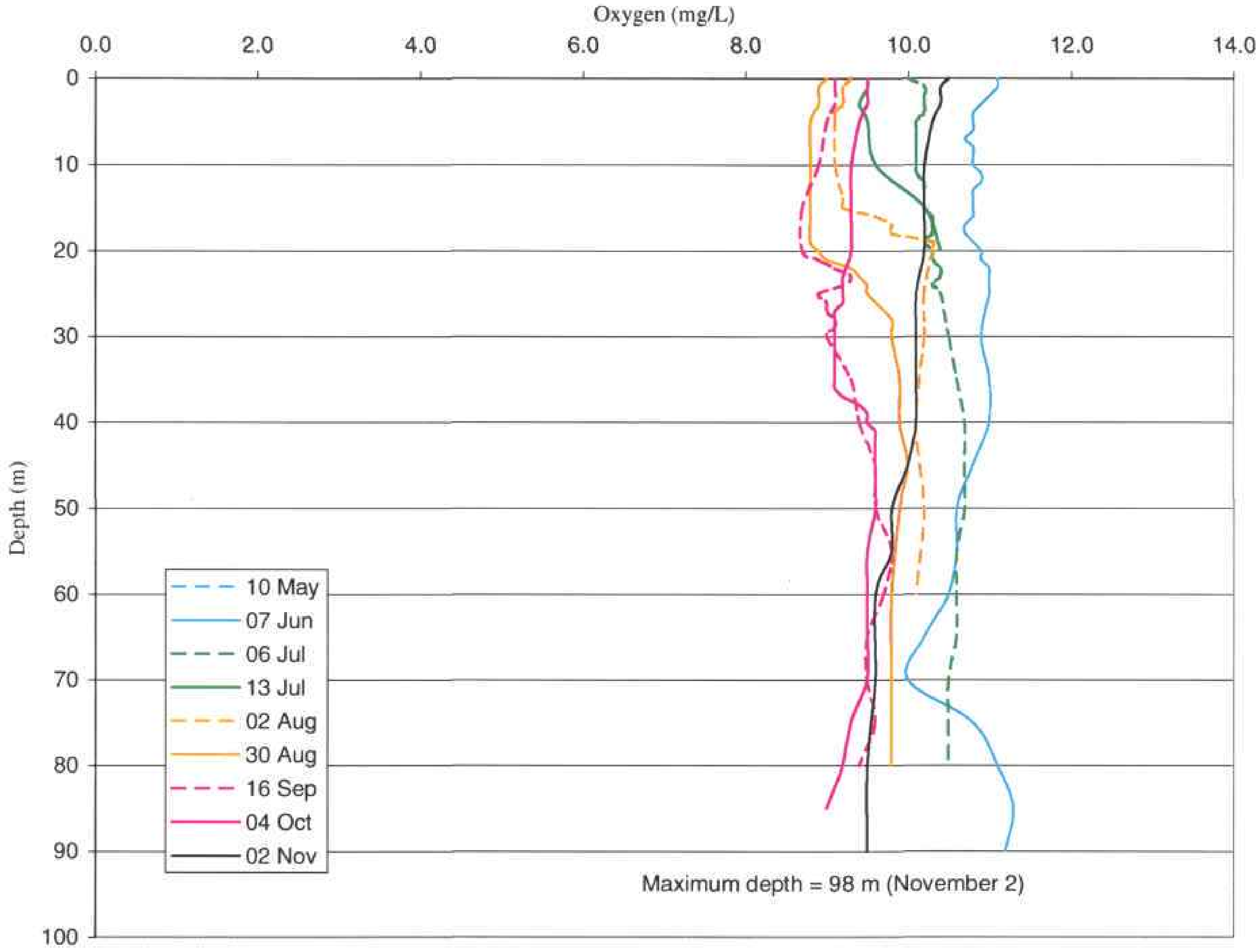


Parsnip Reach station (E234185) seasonal oxygen versus depth profile.

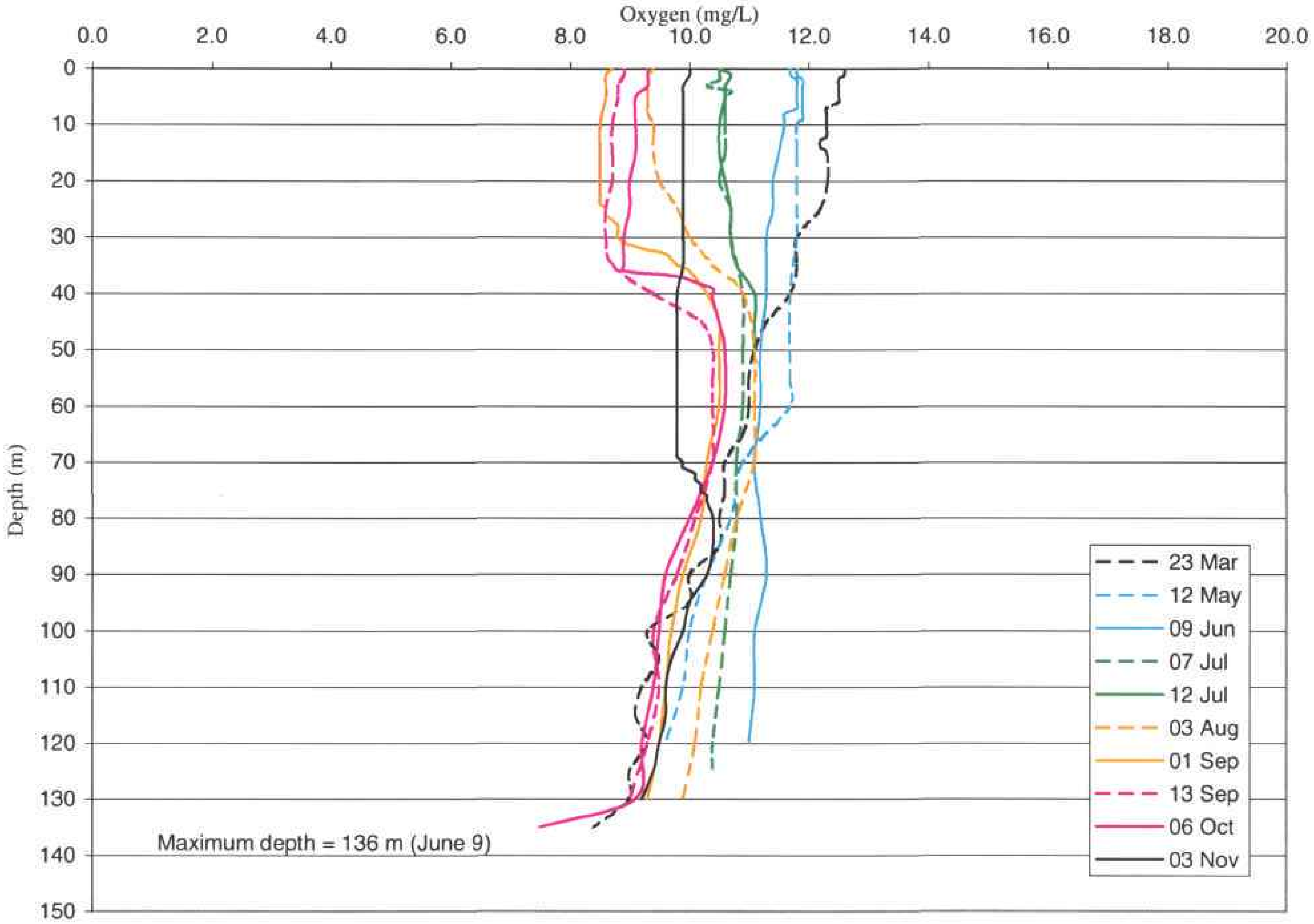


Maximum depth = 93 m (November 5)

Peace Reach station (E234186) seasonal oxygen versus depth profile.



Junction station (E234187) seasonal oxygen versus depth profile.



Forebay station (E234188) seasonal oxygen versus depth profile.

Appendix 3

(Water sample analysis results)

Key for water sample analysis results tables.

Date	**Depth**	**Chl-a**	**NH_3**	**NO3**	**TN**	**TDN**	**TP**	**TDP**	**TDS**	**pH**	**S-D**
1	2	3	4	5	6	7	8	9	10	11	12

1. Date- date sample was collected from Williston Reservoir.
2. Depth- depth (metres) sample was collected from. The water surface is referenced as 0 metres.
3. Chl-a- chlorophyll-a content measured in µg/L.
4. NH_3- nitrogen content in the form of ammonia reported in mg/L.
5. NO3- nitrogen in the form of nitrite and nitrate reported in mg/L.
6. TN- total nitrogen content reported in mg/L.
7. TDN- total dissolved nitrogen content reported in mg/L.
8. TP- total phosphorous content reported in mg/L.
9. TDP- total dissolved phosphorous content reported in mg/L.
10. TDS- total dissolved solids (or residue filterable) reported in mg/L.
11. pH- pH measured in the field to the nearest 0.1 value.
12. S-D- Secchi disk depth measured to the nearest 0.1 m.

EMS Site E234184 (Williston Reservoir, Finlay Reach)

Date	Depth	Chl-a	NH3	NO3	TN	TDN	TP	TDP	TDS	PH	S-D
7-Jun	1	1.9	<0.005	0.013	0.12	0.06	0.009	0.003	130	8.1	2.9
7-Jun	3	2.2	0.005	0.013	0.11	0.05	0.009	0.004	130	8.2	2.9
7-Jun	5	1.9	0.006	0.015	0.11	0.05	0.01	0.005	110	8.1	2.9
7-Jun	15		<0.005	0.043	0.11	0.08	0.007	0.004	120	8.3	2.9
5-Jul	1	1.1	<0.005	0.022	0.14	0.12	0.008	0.002	120	8.3	1.9
5-Jul	1		<0.005	0.021	0.14	0.1	0.007	0.004	110	8.3	1.9
5-Jul	3	1.4	<0.005	0.021	0.17	0.15	0.008	0.002	120	8.5	1.9
5-Jul	5	1.4	<0.005	0.022	0.17	0.1	0.009	0.003	120	8.3	1.9
5-Jul	20		<0.005	0.029	0.23	0.14	0.009	0.003	120	8.2	1.9
9-Aug	1	1.6	0.005	<0.002	0.14	0.07	0.006	0.006	110	8.6	5
9-Aug	3	1.6	0.006	<0.002	0.14	0.13	0.006	0.003	110	8.5	5
9-Aug	5	1.1	<0.005	<0.002	0.11	0.05	0.008	0.002	100	8.5	5
9-Aug	30		<0.005	0.056	0.17	0.1	0.007	0.003	120	8.1	5
31-Aug	1	0.5	<0.005	0.018	0.17	0.11	0.002	<0.002	120	8.5	4.7
31-Aug	1		<0.005	0.017	0.13	0.1	0.004	<0.002	120	8.5	4.7
31-Aug	3	0.5	,<0.005	0.017	0.18	0.08	0.002	<0.002	120	8.4	4.7
31-Aug	5	0.5	<0.005	0.063	0.14	0.09	0.003	<0.002	120	8.7	4.7
31-Aug	35		<0.005	0.053	0.14	0.12	<0.002	<0.002	130	8.5	4.7
4-Oct	1	1.6	<0.005	<0.002	0.11	0.09	0.005	0.003	120	8.5	7
4-Oct	3	1.6	<0.005	<0.002	0.1	0.09	0.007	0.003	120	8.6	7
4-Oct	5	1.6	<0.005	<0.002	0.1	0.08	0.006	0.005	110	8.5	7
4-Oct	40		<0.005	0.06	0.14	0.12	0.007	0.004	140	8.2	7
Mean		1.4	0.005	0.014	0.13	0.09	0.007	0.003	119	8.4	4.3

EMS Site E234185 (Williston Reservoir, Parsnip Reach)

Date	Depth	Chl-a	NH3	NO3	TN	TDN	TP	TDP	TDS	pH	S-D
10 May	1	0.5	0.008	0.12	0.24	0.2	0.006	0.006	100	8.2	2.2
10 May	5	0.5	0.006	0.109	0.21	0.19	0.006	0.004	110	8.2	2.2
10 May	15		0.008	0.124	0.24	0.21	0.007	0.005	110	8	2.2
08 Jun	1	2.5	0.008	0.172	0.34	0.33	0.005	0.004	80	7.7	2.2
08 Jun	3	1.3	0.007	0.177	0.36	0.38	<0.002	0.003	80	7.3	2.2
08 Jun	5	1.2	<0.005	0.185	0.48	0.35	0.004	0.003	80	7.5	2.2
08 Jun	25		<0.005	0.184	0.3	0.28	<0.002	0.003	110	7.8	2.2
06 Jul	1	1.6	<0.005	0.084	0.23	0.2	0.008		80	8	2.3
06 Jul	3	1.9	<0.005	0.087	0.24	0.21	0.008	0.007	80	8.1	2.3
06 Jul	5	1.4	<0.005	0.09	0.24	0.21	0.008	0.005	80	7.9	2.3
06 Jul	30		<0.005	0.122	0.23	0.23	0.006	0.005	100	7.7	2.3
09 Aug	1	2.1	0.008	0.022	0.25	0.12	0.008	0.003	70	9	3.9
09 Aug	3	1.6	0.009	0.022	0.2	0.13	0.009	0.004	60	8.6	3.9
09 Aug	3		0.009	0.022	0.16	0.12	0.009	0.004	80	8.5	3.9
09 Aug	5	2.1	0.007	0.022	0.2	0.11	0.008	0.004	70	8.5	3.9
09 Aug	30		<0.005	0.116	0.3	0.25	0.006	0.004	100	8	3.9
31 Aug	1	1.1	<0.005	0.053	0.18	0.14	0.002	0.005	100	8.5	4
31 Aug	3	2.1	<0.005	0.053	0.24	0.16	0.003	<0.002	80	8.6	4
31 Aug	5	1.6	<0.005	0.053	0.19	0.15	0.003	<0.002	70	8.7	4
31 Aug	35		<0.005	0.1	0.21	0.18	0.003	<0.002	100	8.5	4
05 Oct	1	1.6	0.03	0.034	0.17	0.15	0.008	0.007	90	8.5	4.8
05 Oct	3	1.6	0.014	0.036	0.18	0.15	0.008	0.007	80	8.4	4.8
05 Oct	5	2.14	<0.005	0.047	0.22	0.14	0.006	0.007	90	8.4	4.8
05 Oct	40		<0.005	0.07	0.17	0.16	0.006	0.01	100	8.1	4.8
Mean		1.6	0.007	0.080	0.24	0.20	0.006	0.005	88	8.2	3.2

EMS Site E234186 (Williston Reservoir, Peace Reach, Clearwater)

Date	Depth	Chl-a	NH3	NO3	TN	TDN	TP	TDP	TDS	pH	S-D
11 May	1	0.8	<0.005	0.059	0.11	0.12	0.003	<0.002	120	8.2	4.1
11 May	5	0.7	<0.005	0.058	0.12	0.11	0.004	<0.002	130	8.1	4.1
11 May	15		<0.005	0.059	0.12	0.11	0.003	0.002	120	8.1	4.1
08 Jun	1	1.3	<0.005	0.081	0.2	0.15	<0.002	<0.002	130	7.8	3.7
08 Jun	3	1.3	<0.005	0.081	0.17	0.13	<0.002	<0.002	120	7.5	3.7
08 Jun	5	1.9	<0.005	0.081	0.17	0.13	<0.002	<0.002	150	7.5	3.7
08 Jun	25		<0.005	0.082	0.15	0.11	<0.002	<0.002	130	7.5	3.7
05 Jul	1	1.4	<0.005	0.075	0.21	0.18	0.006	0.002	100	8.4	3.3
05 Jul	3	1.6	<0.005	0.075	0.19	0.25	0.007	0.004	100	8.2	3.3
05 Jul	5	2.4	<0.005	0.076	0.19	0.19	0.005	0.005	100	8.1	3.3
05 Jul	30		<0.005	0.075	0.16	0.17	0.004	0.002	110	8	3.3
02 Aug	1	2.1	<0.005	0.058	0.17	0.16	0.005	0.003	90	8.3	4.2
02 Aug	3	1.1	<0.005	0.058	0.19	0.15	0.005	0.003	90	8.3	4.2
02 Aug	3		<0.005	0.057	0.18	0.15	0.005	<0.002	100	8.3	4.2
02 Aug	5	1.6	,<0.005	0.058	0.19	0.15	0.005	0.003	90	8.3	4.2
02 Aug	35		<0.005	0.072	0.16	0.17	0.004	0.003	110	8.2	4.2
30 Aug	1	1.1	<0.005	0.054	0.18	0.16	0.007	<0.002	110	8.4	3.9
30 Aug	3	1.6	<0.005	0.053	0.14	0.14	0.006	0.002	110		3.9
30 Aug	5	<0.4	<0.005	0.054	0.18	0.15	0.006	<0.002	100	8.3	3.9
30 Aug	40		<0.005	0.076	0.15	0.14	0.006	<0.002	130	8.2	3.9
05 Oct	1	2.14	0.005	0.045	0.15	0.13	0.006	0.004	90	8.4	4.2
05 Oct	1		<0.005	0.045	0.16	0.14	0.007	0.005	90	8.4	4.2
05 Oct	3	1.6	<0.005	0.045	0.14	0.12	0.006	0.006	100	8.4	4.2
05 Oct	5	1.6	<0.005	0.044	0.17	0.13	0.006	0.004	100	8.4	4.2
05 Oct	40		<0.005	0.076	0.19	0.15	0.028	0.005	120	8.3	4.2
02 Nov	1	<0.4	<0.005	0.067	0.14	0.15	0.003	0.003	110	8.2	4.5
02 Nov	1		<0.005	0.066	0.14	0.16	0.003	0.002	100	8.3	4.5
02 Nov	3	1.1	<0.005	0.067	0.13	0.18	0.004	0.002	110	8.3	4.5
02 Nov	5	2.1	<0.005	0.066	0.14	0.14	0.004	0.002	110	8.3	4.5
02 Nov	20		<0.005	0.067	0.14	0.14	0.024	0.004	110		4.5
Mean=		1.4	0.005	0.063	0.16	0.15	0.006	0.003	111	8.2	4

EMS Site E234187 (Williston Reservoir, Junction)

Date	Depth	Chl-a	NH3	NO3	TN	TDN	TP	TDP	TDS	pH	S-D
10 May	1	0.4	0.007	0.071	0.16	0.14	0.004	0.003	120	8.1	3.1
10 May	5	<0.4	0.007	0.071	0.15	0.14	0.005	0.002	120	8	3.1
10 May	15		0.007	0.072	0.18	0.14	0.004	0.002	110	8	3.1
07 Jun	1	2.7	0.007	0.132	0.31	0.23	0.012	0.006	100	8	2.3
07 Jun	3	2.4	0.007	0.141	0.3	0.26	0.011	0.007	90	8	2.3
07 Jun	5	2.7	0.007	0.143	0.31	0.26	0.011	0.007	100	8.2	2.3
07 Jun	25		0.006	0.097	0.21	0.17	0.008	0.005	110	8.1	2.3
06 Jul	1	2.1	<0.005	0.076	0.21	0.2	0.007	0.005	90	8.1	2.4
06 Jul	3	2.1	<0.005	0.075	0.22	0.21	0.007	0.005	90	8.1	2.4
06 Jul	5	2.4	<0.005	0.075	0.22	0.21	0.007	0.004	90	8.1	2.4
06 Jul	5		<0.005	0.076	0.26	0.2	0.01	0.004	80	8.1	2.4
06 Jul	35		<0.005	0.052	0.15	0.12	0.004	0.003	120	8	2.4
02 Aug	1	1.6	<0.005	0.056	0.19	0.16	0.006	<0.002	70	8.3	3.1
02 Aug	3	0.5	0.006	0.055	0.19	0.16	0.006	0.004	80	8.3	3.1
02 Aug	5	1.1	0.006	0.056	0.18	0.16	0.006	0.003	80	8.3	3.1
02 Aug	20		<0.005	0.073	0.15	0.14	0.003	<0.002	110	8.1	3.1
30 Aug	1		<0.005	0.049	0.18	0.15	0.004	0.003	90	8.4	3.2
30 Aug	1	1.1	<0.005	0.048	0.16	0.17	0.009	0.005	90	8.4	3.2
30 Aug	3	1.1	<0.005	0.048	0.19	0.14	0.006	0.002	90	8.2	3.2
30 Aug	5	1.6	<0.005	0.049	0.17	0.14	0.01	0.002	100	8.3	3.2
30 Aug	25		<0.005	0.081	0.16	0.15	0.004	<0.002	100	8	3.2
04 Oct	1	1.1	<0.005	0.024	0.17	0.12	0.007	0.006	100	8.4	5.9
04 Oct	3	<0.4	<0.005	0.023	0.15	0.12	0.007	0.005	90	8.5	5.9
04 Oct	5	1.6	<0.005	0.024	0.14	0.14	0.007	0.004	100	8.4	5.9
04 Oct	5		<0.005	0.023	0.14	0.13	0.022	0.008	90	8.4	5.9
04 Oct	40		<0.005	0.076	0.16	0.16	0.005	0.004	110	8.1	5.9
02 Nov	1	0.5	<0.005	0.063	0.15	0.15	0.003	0.003	110	8.5	3.9
02 Nov	1		<0.005	0.063	0.14	0.13	0.004	0.002	110	8.2	3.9
02 Nov	3	<0.4	<0.005	0.062	0.15	0.17	0.004	0.003	120	8.4	3.9
02 Nov	5	1.1	<0.005	0.061	0.13	0.13	0.003	0.004	110	8.4	3.9
02 Nov	20		<0.005	0.061	0.13	0.16	0.012	0.004	110	8.5	3.9
Mean=		1.4	0.006	0.068	0.19	0.17	0.010	0.004	100	8.2	3.4

EMS Site E234188 (Williston Reservoir, Peace Reach, Forebay)

Date	Depth	Chl-a	NH3	NO3	TN	TDN	TP	TDP	TDS	pH	S-D
23 Mar	1	3.5	<0.005	0.092	0.18	0.18	0.005	0.004	110	8.3	
23 Mar	1		<0.005	0.072	0.14	0.14	0.006	0.004	110	8.3	
23 Mar	3	3	<0.005	0.074	0.14	0.12	0.005	0.005	100	8.2	
23 Mar	5	2.4	<0.005	0.073	0.11	0.12	0.004	0.004	110	8.2	
23 Mar	15		<0.005	0.074	0.11	0.11	0.004	0.003	110	8.4	
23 Mar	15		<0.005	0.077	0.12	0.12	0.007	0.006	120	8.2	
12 May	1	0.4	<0.005	0.067	0.15	0.14	0.004	0.003	120	8.2	4.1
12 May	5	<0.4	<0.005	0.067	0.13	0.14	0.004	0.002	120	8.1	4.1
12 May	15		<0.005	0.067	0.14	0.13	0.004	0.003	110	8	4.1
12 May	30		<0.005	0.066	0.13	0.12	0.004	0.003	120		4.1
09 Jun	1	1.2	<0.005	0.065	0.14	0.11	0.004	<0.002	130	6.6	3.3
09 Jun	3	1.8	<0.005	0.069	0.14	0.1	0.004	<0.002	120	6.4	3.3
09 Jun	5	1.4	<0.005	0.067	0.14	0.11	0.004	<0.002	130	6.7	3.3
09 Jun	5		<0.005	0.065	0.13	0.11	0.003	<0.002	130	6.8	3.3
09 Jun	25		<0.005	0.07	0.13	0.13	0.003	<0.002	130	6.7	3.3
07 Jul	1	1.3	<0.005	0.05	0.16	0.13	0.011	0.003	100	8.3	2.2
07 Jul	3	1.4	0.005	0.051	0.16	0.13	0.014	0.003	110	8.4	2.2
07 Jul	5	1	0.005	0.051	0.15	0.12	0.008	0.003	110	8.3	2.2
07 Jul	40		0.007	0.061	0.16	0.13	0.004	0.002	120	8.1	2.2
03 Aug	1	1.6	0.006	0.054	0.16	0.14	<0.002	<0.002	100	8.4	2.4
03 Aug	3	1.1	0.008	0.053	0.18	0.13	0.01	<0.002	110	8.4	2.4
03 Aug	5	1.1	0.007	0.053	0.16	0.13	0.009	<0.002	100	8.5	2.4
03 Aug	40		0.009	0.066	0.14	0.13	<0.002	<0.002	110	8.2	2.4
01 Sep	1	0.5	0.014	0.047	0.23	0.15	0.011	0.005	100	8.4	1.7
01 Sep	3	0.5	0.02	0.047	0.21	0.15	0.009	0.008	110	8.9	1.7
01 Sep	5	<0.4	0.022	0.047	0.18	0.15	0.005	<0.002	110	8.9	1.7
01 Sep	35		0.014	0.078	0.18	0.14	0.006	0.008	100	8.7	1.7
06 Oct	1	0.53	<0.005	0.058	0.14	0.13	0.007	0.006	100	8.5	
06 Oct	3	1.07	<0.005	0.06	0.15	0.14	0.007	0.005	100	8.6	
06 Oct	5	1.07	<0.005	0.06	0.15	0.14	0.006	0.004	110	8.5	
06 Oct	40		<0.005	0.073	0.14	0.12	0.005	0.003	110	8.4	
03 Nov	1	1.1	<0.005	<0.002	0.15	0.16	0.003	<0.002	110	8.3	3.1
03 Nov	1		<0.005	0.06	0.18	0.16	0.004	0.004	110	8.3	3.1
03 Nov	3	1.6	<0.005	0.059	0.14	0.17	0.003	0.003	110	8.3	3.1
03 Nov	5	1.1	<0.005	0.061	0.14	0.18	0.003	<0.002	110	8.2	3.1
03 Nov	20		<0.005	0.06	0.15	0.17	0.004	0.004	110	8.2	3.1
Mean=		1.3	0.007	0.06	0.16	0.14	0.006	0.003	111	8.1	2.8

No EMS site designation (Peace River, 500 m downstream of Peace Canyon Dam)

Date	Depth	Chl-a	NH3	NO3	TN	TDN	TP	TDP	TDS	pH	S-D
12 May	0		0.008	0.066	0.2	0.17	0.007	0.004	150		
10 Jun	0		<0.005	0.063	0.14	0.15	0.006	<0.002	120		
08 Jul	0		0.007	0.058	0.2	0.17	0.009	0.003	110		
03 Aug	0		0.009	0.063	0.16	0.13	<0.002	<0.002	110		
02 Sep	0		<0.005	0.07	0.23	0.14	0.008	0.004	110		
07 Oct	0		<0.005	0.063	0.15	0.13	0.007	0.009	100		
03 Nov	0		<0.005	0.063	0.16	0.18	0.004	0.004	110		
mean=			0.006	0.064	0.18	0.15	0.006	0.004	116.0		