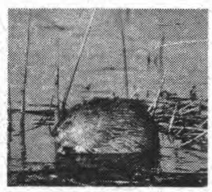
Canada Alberta Northwest Territories

Northern River Basins Study







NORTHERN RIVER BASINS STUDY PROJECT REPORT NO. 67

GROWTH RATE AND BIOMASS RESPONSES OF PERIPHYTIC ALGAE TO PHOSPHORUS ENRICHMENT

IN EXPERIMENTAL FLUMES, ATHABASCA RIVER, APRIL AND MAY, 1994






DATE DUE

Prepared for the
Northern River Basins Study
under Project 2613-C2

by

Alec R. Dale and Patricia A. Chambers
National Hydrology Research Institute, Environment Canada

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PREFACE:

The Northern River Basins Study was initiated through the "Canada-Alberta-Northwest Territories Agreement Respecting the Peace-Athabasca-Slave River Basin Study, Phase II - Technical Studies" which was signed September 27, 1991. The purpose of the Study is to understand and characterize the cumulative effects of development on the water and aquatic environment of the Study Area by coordinating with existing programs and undertaking appropriate new technical studies.

This publication reports the method and findings of particular work conducted as part of the Northern River Basins Study. As such, the work was governed by a specific terms of reference and is expected to contribute information about the Study Area within the context of the overall study as described by the Study Final Report. This report has been reviewed by the Study Science Advisory Committee in regards to scientific content and has been approved by the Study Board of Directors for public release.

It is explicit in the objectives of the Study to report the results of technical work regularly to the public. This objective is served by distributing project reports to an extensive network of libraries, agencies, organizations and interested individuals and by granting universal permission to reproduce the material.

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Whereas the above publication is the result of a project conducted under the Northern River Basins Study and the terms of reference for that project are deemed to be fulfilled,
IT IS THEREFORE REQUESTED BY THE STUDY OFFICE THAT;
this publication be subjected to proper and responsible review and be considered for release to the public.

F. J. Wrona — 10 Jan 96

(Dr. Fred J. Wrona, Science Director) — (Date)

Whereas it is an explicit term of reference of the Science Advisory Committee "to review, for scientific content, material for publication by the Board",
IT IS HERE ADVISED BY THE SCIENCE ADVISORY COMMITTEE THAT;
this publication has been reviewed for scientific content and that the scientific practices represented in the report are acceptable given the specific purposes of the project and subject to the field conditions encountered.
SUPPLEMENTAL COMMENTARY HAS BEEN ADDED TO THIS PUBLICATION: [ ] Yes [ ] No

P. A. Larkin — Jan 8/96

(Dr. P. A. Larkin, Ph.D., Chair) — (Date)

Whereas the Study Board is satisfied that this publication has been reviewed for scientific content and for immediate health implications,
IT IS HERE APPROVED BY THE BOARD OF DIRECTORS THAT;
this publication be released to the public, and that this publication be designated for: **[ ] STANDARD AVAILABILITY [ ] EXPANDED AVAILABILITY**

Lucille Partington — Jan. 11/96

(Lucille Partington, Co-chair) — (Date)

Robert McLeod — 11/01/96

(Robert McLeod, Co-chair) — (Date)

GROWTH RATE AND BIOMASS RESPONSES OF PERIPHYTIC ALGAE TO PHOSPHORUS ENRICHMENT IN EXPERIMENTAL FLUMES, ATHABASCA RIVER, APRIL AND MAY, 1994

STUDY PERSPECTIVE

A particular area of concern related to municipal and industrial effluent discharges in the northern river basins is the effect of nutrients (nitrogen and phosphorus) on the aquatic environment. Nutrients enter a river from municipal and industrial effluents, agricultural and timber-harvesting runoff, natural runoff, groundwater sources and tributary inflow. Added nutrients can cause changes in abundance and production of benthic biota and fish. Nutrients may also affect dissolved oxygen concentrations as a result of enhanced plant growth, which is in turn decomposed by bacteria that consume oxygen. The changes to the biological communities resulting from the addition of nutrients and their subsequent effect on the chemical and physical components of the ecosystem is referred to scientifically as eutrophication. Understanding the impacts of nutrients on the aquatic environment is therefore critical for managing industrial and municipal effluent discharges to the Peace, Athabasca and Slave rivers in order to minimize eutrophication and safeguard ecosystem health.

Related Study Questions

4a) *What are the contents and nature of the contaminants entering the system and what is their distribution and toxicity in the aquatic ecosystem with particular reference to water, sediments and biota?*

5 *Are the substances added to the river by natural and man made discharges likely to cause deterioration of the water quality?*

13b) *What are the cumulative effects of man made discharges on the water and aquatic environment?*

This report presents the results of an experiment conducted in artificial streams (flumes) in which the growth of periphyton (algae) was studied in relation to phosphorus concentrations in the water. The goal of this study was to determine (1) whether periphyton growth in the Athabasca River was phosphorus (P) limited, and (2) if the degree of P limitation varied from a similar fall 1993 study. The experiment was designed to test periphyton growth and biomass response to a gradient of P additions during early spring. The flumes were located on-site, adjacent to the Athabasca River at Hinton.

The experiment ran for four weeks and consisted of four treatments: a control of zero P-addition and three experimental levels of 1, 10 and 25 µg/L P. Relative specific growth rates as indicated by measuring the buildup of chlorophyll *a* demonstrated that growth rate saturation occurred at 2-4 µg/L of phosphorus for spring 1994. These algal growth rates were similar to values observed in the Thompson River, British Columbia. Comparison of spring peak biomass data with the previous fall data for the Athabasca River showed that peak biomass levels were similar for both trials. Phosphorus concentrations required to reach maximum biomass levels in spring were higher than those required to saturate growth rates, but substantial increases in biomass were still observed with small additions (3-4 µg/L) of phosphorus.

Results from this study showed that growth of periphytic algae in the upper Athabasca River is limited by phosphorus. Addition of phosphorus to the upper Athabasca River would increase benthic algal growth in the absence of other growth-limiting factors. Experiments are continuing with artificial streams to assess seasonal differences in the response of benthic algae to phosphorus addition. These studies, in addition to similar experiments involving benthic invertebrates, will be used to evaluate food web responses to nutrient and contaminant additions. The results will provide necessary information for setting regulatory guidelines for nutrient loading in the Athabasca River.

REPORT SUMMARY

During spring 1994, a phosphorus (P) enrichment experiment was run in flow-through troughs located on the Athabasca River at Hinton, Alberta to examine growth rate and biomass response of periphyton to P additions. P additions of 0 (control), 1, 10, and 25 μg/L were applied to 12 randomly selected troughs from which tile substrata were sampled to measure time-course accrual of chlorophyll *a*. Relative specific growth rates ($\mu:\mu_{max}$) showed Monod type kinetics with growth rate saturation occurring at 2-4 μg/L soluble reactive phosphorus (SRP) for spring 1994. Spring $\mu:\mu_{max}$ was similar to values observed in the Thompson River, British Columbia. Spring 1994 algal growth rates could not be compared directly to growth rates from a similar experiment conducted in fall 1993 since a contaminant species was present in the fall trial. This contamination led to artificially elevated growth rates during the fall trial. However, comparison of spring peak biomass (PB) data with fall data that was not contaminated showed that relative peak biomass ($PB:PB_{max}$) levels were similar for both trials. P concentrations required to reach maximum $PB:PB_{max}$ in spring were higher than those required to saturate $\mu:\mu_{max}$ but substantial increases in biomass were still observed with small additions (3-4 μg/L SRP) of P. Additional experiments studying the response of periphyton to P enrichment at Hinton and further downstream would allow determination of spatial and temporal variability in nutrient limitation in the upper Athabasca River. Results from this and other studies will provide necessary information for setting regulatory guidelines for nutrient loading on the Athabasca River.

ACKNOWLEDGEMENTS

Funding for this project was made available from the Northern River Basins Study. We thank Weldwood of Canada Ltd. for access through mill property and to their chemistry lab, and for providing a site to run the experiment. Winterization of the troughs was carried out by Eric Marles and Warren Zyla. Additional field support was provided by Julie Knox with generous assistance from Cheryl Podemski, Mary Ferguson and Daryl Halliwell. Laboratory analyses were completed by Trinh Luong (chlorophyll *a*) and Gertie Hutchinson (water chemistry, University of Alberta).

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1.0 INTRODUCTION

The limiting effect of nutrients (N and P) on aquatic production and the eutrophication of aquatic systems by nutrient addition is well known and has been widely studied (Schindler *et al.*, 1971; Dillon and Rigler, 1974). In the case of lakes, nutrient addition as a result of sewage, industrial, or agricultural inputs has been shown to increase primary, benthic invertebrate, zooplankton, and fish production whereas nutrient abatement can reverse these effects (e.g., Beeton, 1965; Edmondson and Lehman, 1981; Stockner and Shortreed, 1985). Likewise, nutrient addition to streams and rivers has increased periphyton standing crop as well as benthic invertebrate and fish growth rates (Cole, 1973; Peterson *et al.*, 1985; Perrin *et al.*, 1987; Johnston *et al.*, 1990). Fish standing crop for rivers throughout North American has also been found to be correlated with total phosphorus concentrations (Hoyer and Canfield, 1991). One frequently used method to determine nutrient limitation in lotic systems is to examine the effects of augmentation of a limiting nutrient on the growth of periphyton (the attached algae on rocks or sediment) in artificial streams (Kevern *et al.*, 1966; Stockner and Shortreed, 1976; Horner *et al.*, 1983; Bothwell, 1988, 1993; Welch *et al.*, 1992). Although many studies have shown that N is often limiting or co-limiting for algal growth (Smith, 1982; Dodds *et al.*, 1989), most periphyton communities tend to be P limited (Elwood *et al.*, 1981; Biggs and Close, 1989; Horner *et al.*, 1990; Bothwell, 1993). However, there are discrepancies in the literature about the concentrations of P required to saturate cellular growth rates (Tilman and Kilham, 1976; Brown and Button, 1979) and those resulting in high periphyton biomass *in situ* (Horner *et al.*, 1983; Bothwell, 1985, 1989). Bothwell (1989) attributes this disparity to growth of the periphyton community reaching an asymptote at a P concentration higher than required to saturate growth rates of individual cells or thin periphyton films. Moreover, there are problems in comparing growth rates and biomass from artificial stream experiments conducted in different geographic locales or at different times of year due to varying effects of physical factors such as light and temperature. To standardize for these abiotic variables, growth and biomass are often expressed as a ratio of the maximum growth or biomass observed in an experiment. These relative specific growth rate and biomass models effectively factor out physical variation between experiments and are useful in comparing responses of periphyton to nutrient addition under varying abiotic regimes (Bothwell, 1988, 1989; Perrin *et al.*, 1995).

The aim of this experiment was to determine whether periphyton growth in the upper Athabasca River was P-limited during spring. This work forms part of the Northern River Basins Study (NRBS), a joint study between the governments of Canada, Alberta and the Northwest Territories. The aim of the NRBS is to gather comprehensive information on water quality, fish and fish habitat, riparian vegetation and wildlife, hydrology, and use of aquatic resources for the Peace, Athabasca, and Slave river basins in order to predict and assess the cumulative effects of development on the water and aquatic environment of these basins within Alberta and the Northwest Territories.

Existing water quality data (Sentar Consultants Ltd., 1994) and the results of a fall 1993 artificial stream experiment (Perrin *et al.*, 1995) indicate that P is the nutrient limiting periphyton growth in the upper Athabasca River. To further assess nutrient limitation in the upper Athabasca River at temperatures at or below 0 °C, an experiment was conducted in spring 1994 using winterized artificial streams located beside the Athabasca River at Hinton, Alberta. The results of this experiment will aid in assessment of the effect of nutrient loading on periphyton growth in the upper Athabasca River and provide necessary information for setting regulatory guidelines for nutrient loading.

2.0 METHODS AND MATERIALS

2.1 STUDY SITE AND APPARATUS

This experiment was conducted at the Environment Canada study site located at the Weldwood of Canada Ltd. pulp mill in Hinton, Alberta (Figure 1). A detailed description of the study site is given in Perrin *et al.* (1995). The experimental apparatus had a design similar to the experimental troughs research apparatus (EXTRA) facility (Bothwell, 1988) with modifications described by Perrin *et al.* (1995). In general, the apparatus consisted of 12 flow-through troughs (2m long x 19cm wide and 5cm deep) fabricated from clear acrylic (Plate 1). River water was supplied from the mill intake located upstream of the combined municipal and mill discharge at Hinton and pumped into a head tank. Modifications to the design of Perrin *et al.* (1995) included a reduction to a single 1200L head tank (Figures 2 and 3) and extensive modifications to winterize the system.

Winterization modifications were made to allow for operation of the experimental troughs in sub-zero temperatures. Modifications included construction of insulated plywood enclosures around the valve assemblies, waste trough, head tank table, and trough tables (Plates 2 aandb). Nutrient delivery lines were also insulated to prevent freezing. Nutrient solutions were stored in an enclosure beneath the head tank and could be heated with a 1500W ceramic space-heater or 100W immersion heaters. A ceramic space-heater was also placed in each of the four enclosures surrounding the trough valve assemblies and used to further heat the system. Plexiglass trough covers were constructed to provide protection from snow; however these were not used. A list of materials for winterization modifications is given in Appendix B.

Water flow in each trough was set at 24 L/min (assuming average water depth of 2 cm above tile surfaces and ignoring inter-tile spaces, this equates to a velocity of approximately 0.1 m/s) and was recalibrated every 2-3 days. Replicate clay tiles (4.5 cm x 4.5 cm x 1.0 cm, top surface = 20.25 cm^2) were placed throughout the length of each trough to provide a substratum for periphyton growth. Tiles were arranged into three reaches (upper, middle, and lower), each consisting of three rows of eight tiles placed equidistance (approx. 2 cm) apart (Plate 3). Tiles were blocked into reaches to allow testing for differences in sedimentation or scour rates along the trough length. This orientation created channels of higher velocity around tiles, similar to flows around natural gravel (Perrin *et al.*, 1995). Extra tiles were placed above and below the experimental reaches to maintain flow continuity for the entirety of the reaches. Troughs were cleaned once or twice daily with a syphon hose to ensure that the sediment between the tiles did not accumulate and cover the tiles. However, it was not possible to eliminate direct sedimentation on the tiles.

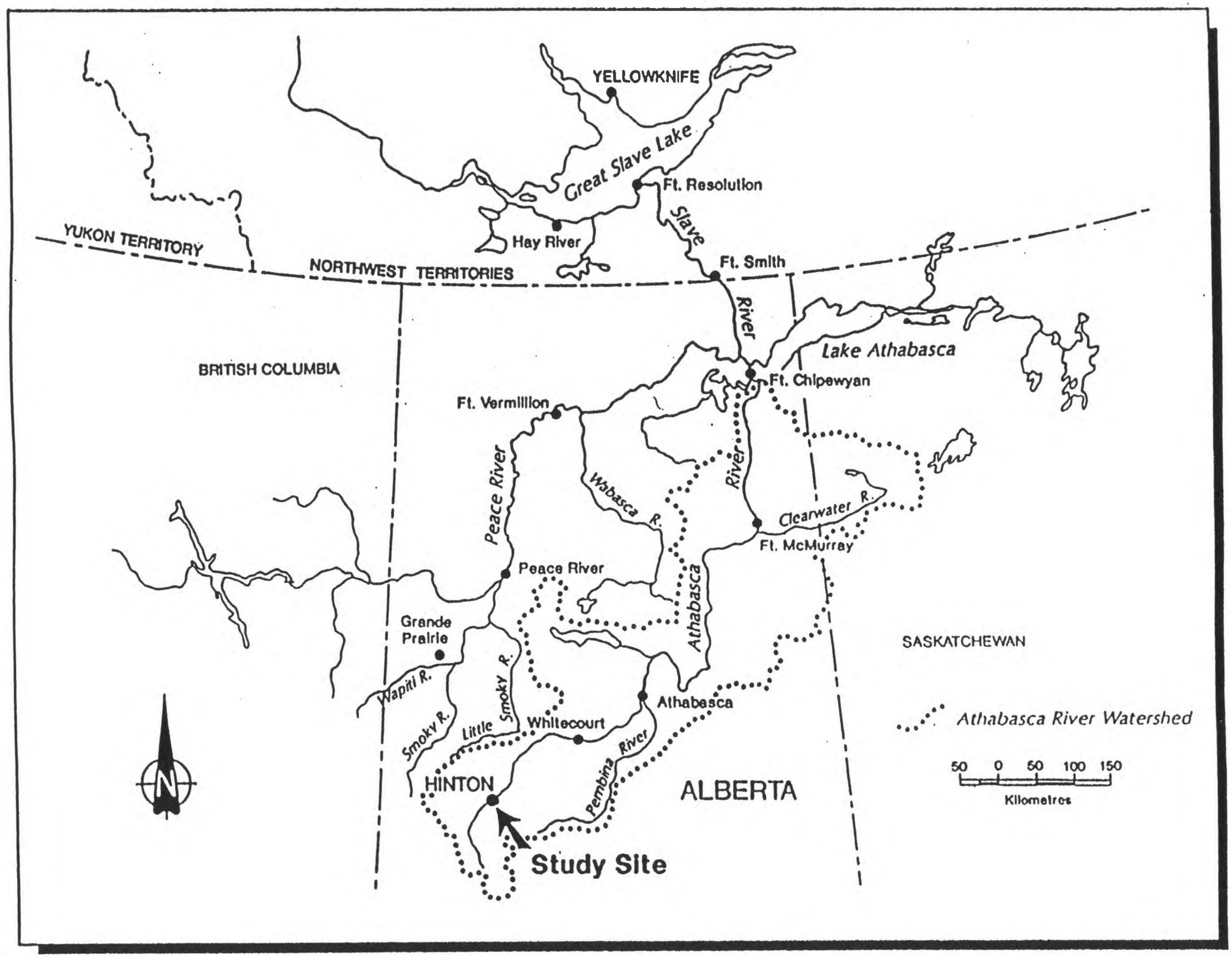
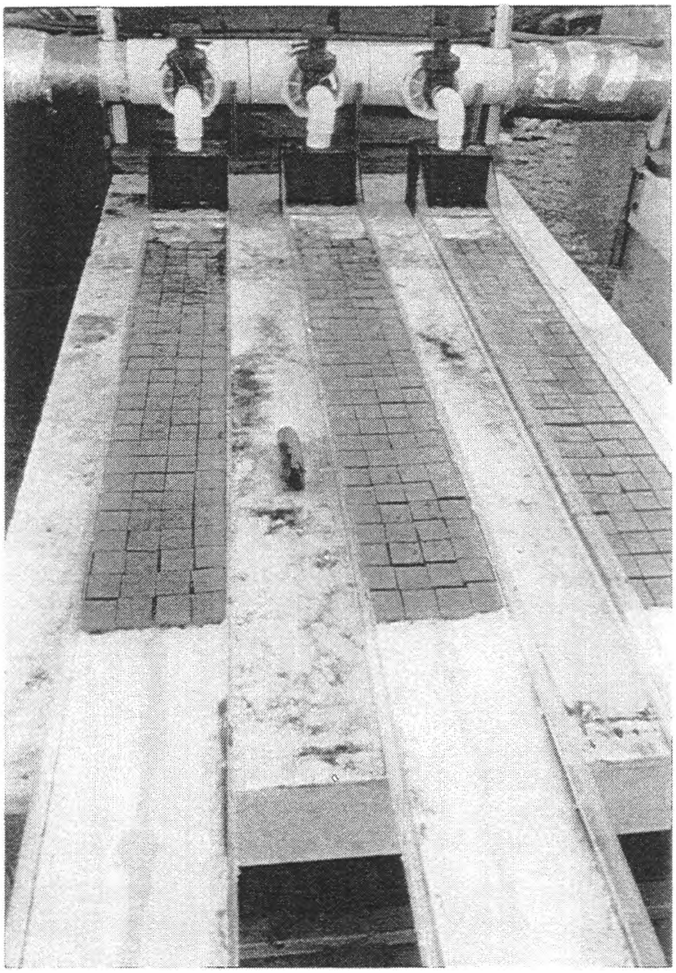


Figure 1. Map of the Athabasca River watershed showing location of study site (from Perrin *et al.*, 1995).

Plate 1. **Acrylic troughs used for experiments of phosphorus addition on periphyton growth (Hinton, Alberta; spring 1994). Note: photo is of preliminary setup and tile arrangement differs from that in the experimental design.**



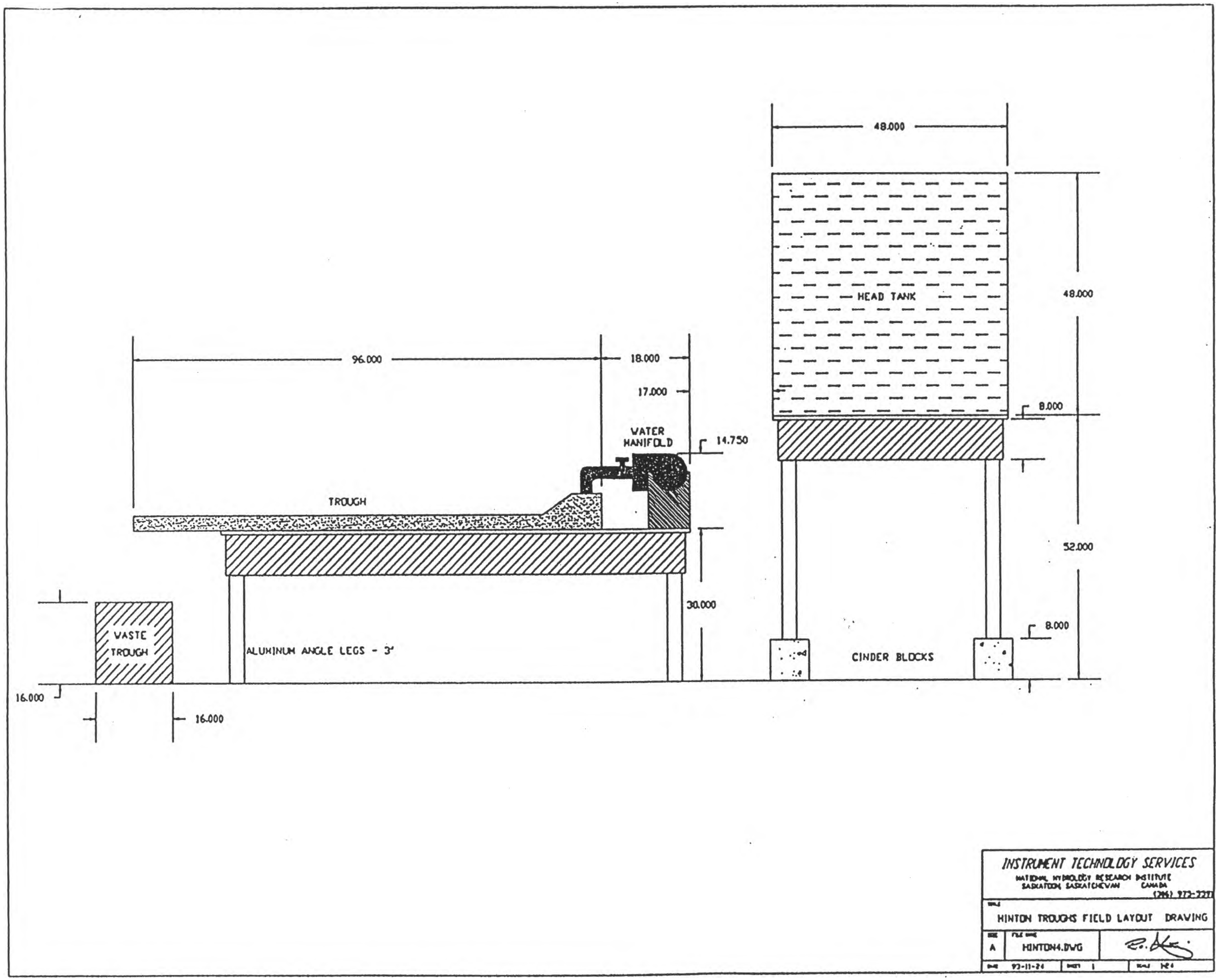


Figure 2. Side view schematic of periphyton trough layout (Hinton, Alberta; spring 1994).

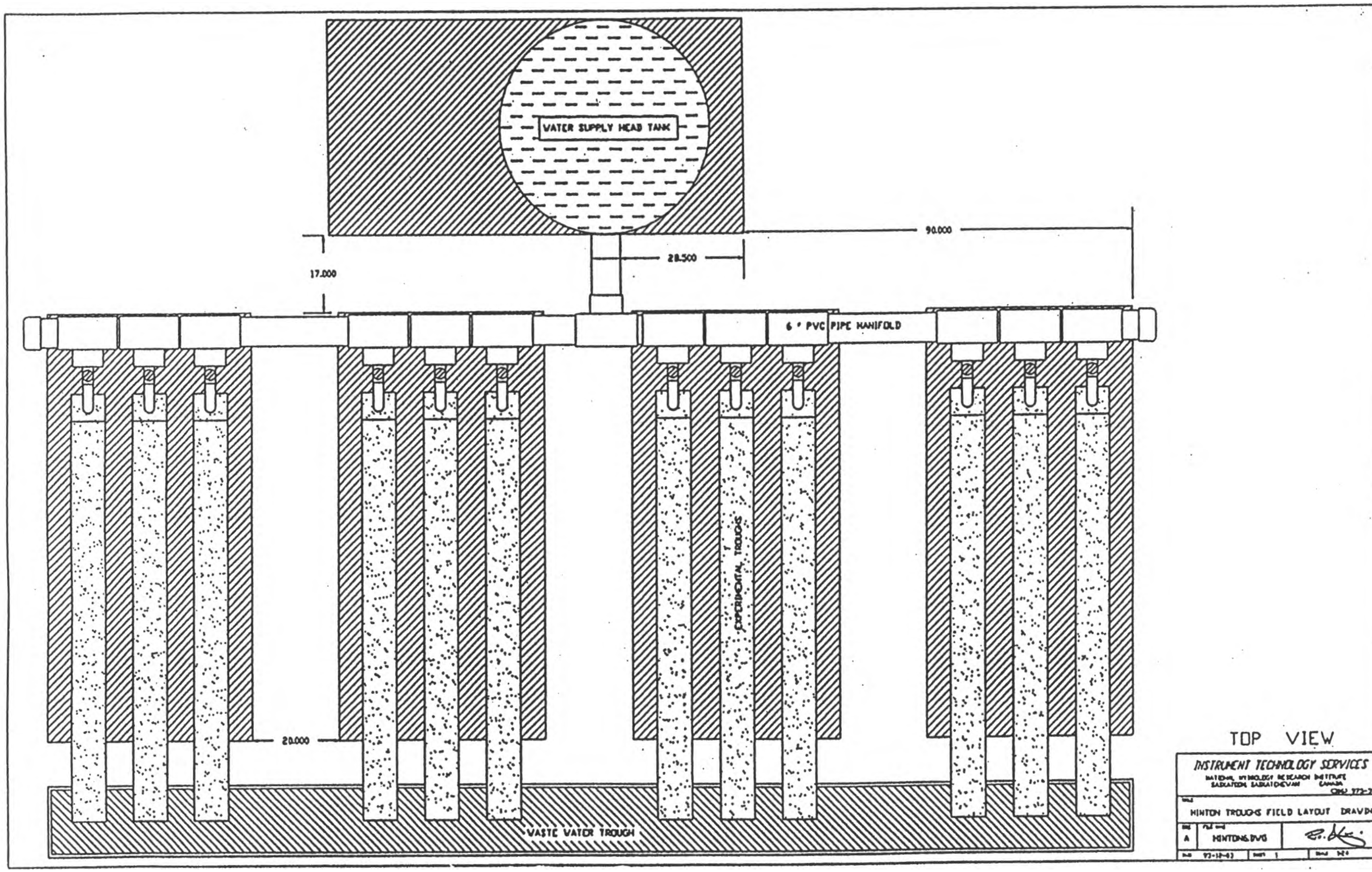
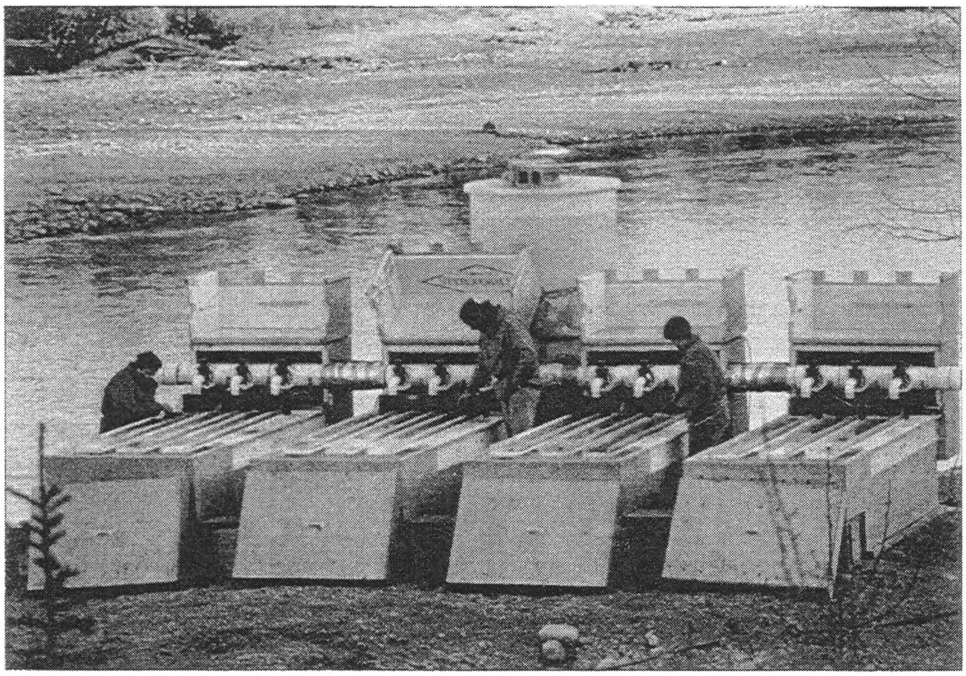


Figure 3. Top view schematic of periphyton trough layout (Hinton, Alberta; spring 1994).

Plate 2. **Plywood enclosures constructed around valve assemblies, waste trough, head tank table and trough tables with removable and hinged covers: (a) off, and (b) on.**

a



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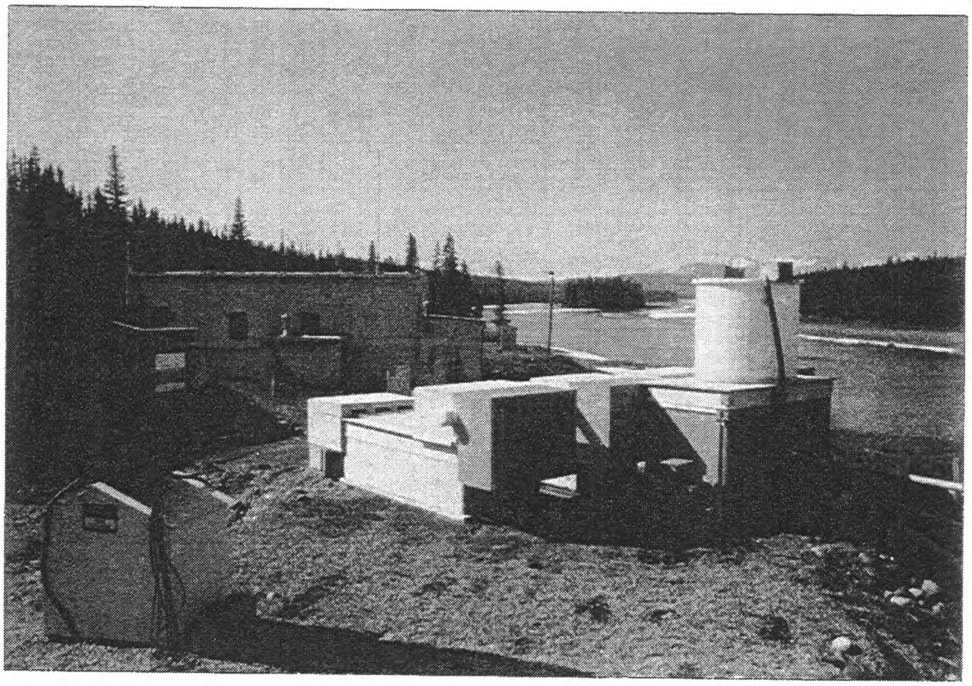
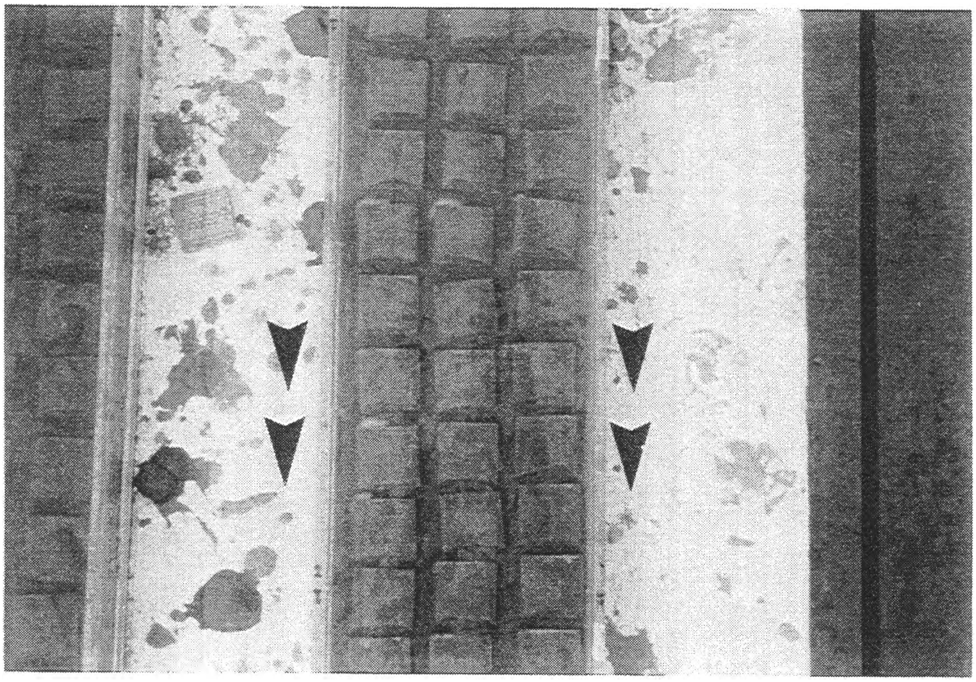


Plate 3. **Arrangement of clay tiles in experimental trough. Arrows indicate direction of flow.**



2.2 EXPERIMENTAL DESIGN

The experiment was designed to determine periphyton growth and biomass accumulation in response to a gradient of P additions during spring. The experiment ran for four weeks (April 21 to May 18, 1994) and consisted of four treatments: a control of zero P addition and three experimental addition levels of 1, 10, and 25 µg/L P as $KH_2PO_4 3H_2O$. Three replicates of each of the four treatments were applied to 12 randomly selected troughs. Stock solutions of 40, 400, and 1000 mg/L P as $KH_2PO_4 3H_2O$ were continuously metered into the 1, 10, and 25 µg/L treatment troughs respectively, at a rate of 0.6 ml/min using a Technicon Model III metering pump (Pulse Instrumentation, Saskatoon, SK.).

2.3 SAMPLING AND ANALYTICAL PROCEDURES

A Li-Cor LI-1000 data logger with an LII90SA quantum sensor located on a 3 m platform in an unshaded area beside the river was used to measure hourly integrated values of photosynthetically active radiation (PAR). This provided PAR readings that were indicative of conditions at the surface of the Athabasca River at Hinton. Mean daily values of PAR ($E/d/m^2$) were calculated from the hourly data. A Ryan Instruments RTM 2000 thermograph was submerged in the head tank and recorded water temperatures at one hour intervals. Since the residence time in the head tank was only four minutes and the distance from the river intake was approximately 100m, water temperature in the head tank was taken as representative of river conditions. Mean daily temperatures were calculated from the hourly data.

Sampling commenced six days after the start of the experiment to allow for algal colonization on the tile substrata. Delaying the onset of sampling effectively limits the influence of algal settlement rates on the calculated growth rates (Bothwell, 1983; Bothwell and Jasper, 1983). Subsequent samples were taken at 6-8 day intervals. On each sampling day, three tiles were randomly selected from each reach (9 tiles/trough) to sample for chlorophyll *a* (chl*a*). Tiles were sampled by scraping the biomass and associated sediment from the top surface of each tile into a scintillation vial. Samples were placed on ice then placed in the dark and frozen at -15°C until analyzed.

The large amount of sediment in the samples required a modification of the procedure for chl*a* analysis. We used a modification of the procedure described by Nalepa and Quigley (1987) for sediment chlorophyll determinations. All samples were thawed, weighed (sample and vial) and homogenized in a blender for 10 seconds. Sub-samples (approx. 0.2 g) of material from each vial were then weighed and extracted in 90% ethanol at 4°C for one hour. The cleaned and dried vials were re-weighed to determine the wet weight of the entire sample. After extraction and boiling in a water bath for 7 min., sub-samples were cooled, centrifuged, and then analyzed fluorometrically according to Nusch (1980). Chl*a* concentration for the sample was then determined by correcting the chl*a* concentration for the sub-sample by the weight of the entire sample.

Water samples were collected from the head tank and the outlet of each trough once a week. Samples from the troughs and de-ionized water used to make the nutrient solutions were analyzed for soluble reactive phosphorus (SRP). Samples from the head tank were analyzed for SRP, nitrate and nitrite (NO_2

+ NO_3 (as N)), ammonium (NH_4^+ (as N)), total phosphorus (TP), and total dissolved phosphorus (TDP). All samples were packed on ice and shipped the same day to the University of Alberta for analysis. Samples for P analysis were placed in Nalgene polyethylene bottles and samples for N analysis were placed in polystyrene bottles. TDP and SRP samples were filtered through pre-washed 0.45 µm Millepore filters; TP and TDP samples were digested and analyzed by Menzel and Corwin's (1965) potassium persulfate method. $NO_2 + NO_3$ samples were filtered through pre-washed 0.45 µm Millepore membrane filters. NH_4 and $NO_2 + NO_3$ were analyzed with a Technicon autoanalyzer (Stainton *et al.*, 1977).

2.4 DATA ANALYSIS

All statistical analyses were performed using Minitab for Windows version 10.1 (Minitab, 1994). To test for differences in sedimentation rates and biomass accrual along the trough length, analysis of covariance was performed where log chl*a* concentration was the dependent variable, date was a covariate, P-level was a factor and reach was a blocking factor. Chl*a* data were log transformed to reduce heteroscadicity.

Rates of biomass accrual (expressed as the specific net growth rate, k) were determined by regression of chl*a* data fit to the exponential growth equation:

$$y=(a)10^{kt} \quad (1)$$

where y is the chl*a* concentration (mg/m^2) on day t, a is the initial chl*a* concentration and k is the slope or specific net growth rate. Values of k were divided by log 2 (i.e., 0.301) to give the specific growth rate (μ) in units of divisions per day. Specific growth rates were averaged for trough replicates to give a mean specific growth rate for each treatment. The mean specific growth rate for each treatment was normalized to the maximum mean growth rate (μ_{max}) attained in the experiment (found in the 25 µg/L P treatment) to give relative specific growth rates (μ:μ_{max}) as described by Bothwell (1988). Peak biomass was determined as the highest mean chl*a* concentration attained for each treatment. Peak biomass was normalized to the highest mean biomass attained for all treatments (PB_{max}) to give relative peak biomass (PB:PB_{max}) as described by Bothwell (1989). Differences between spring 1994 and fall 1993 PB:PB_{max} data were determined by comparing the slopes of the linearized data using analysis of covariance with PB:PB_{max} as the dependent variable, square root of P concentration as the independent variable, and season as the covariate. The square root transformation was used as it provided reduced variability over the log transformation.

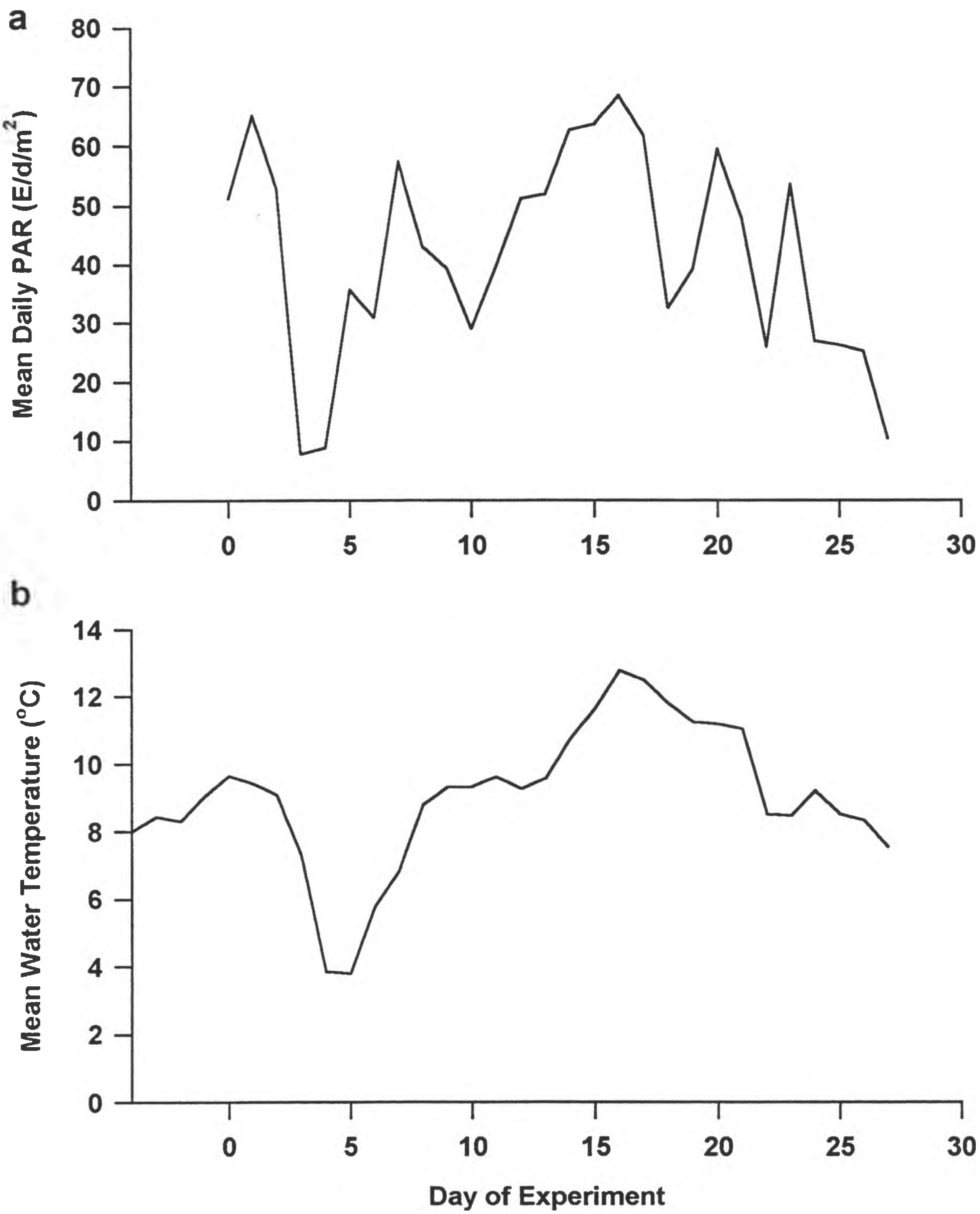


Figure 4. **Mean daily: (a) photosynthetically active radiation (PAR), and (b) temperatures for flume experiments (Hinton, Alberta; spring 1994). The experiment started on day 0 (April 21, 1994) and finished on day 27 (May 18, 1994).**

3.0 RESULTS

3.1 PHYSICAL AND CHEMICAL ENVIRONMENT

Irradiance fluctuated greatly over the course of the experiment (Figure 4a) reflecting variability in prevailing weather conditions. There was a marked decrease in PAR from 53 $E/d/m^2$ on day 2 to a minimum of 7.7 $E/d/m^2$ on day 4, then a gradual increase to a maximum of 68 $E/d/m^2$ on day 16. The mean PAR value for the duration of the experiment was 42 $E/d/m^2$. Mean daily water temperatures varied with PAR over the experimental period (Figure 4b). Temperature dropped rapidly from 9.1 °C on day 2 to a minimum of 3.8 °C on day 4, then increased to a maximum of 12.8 °C on day 16. Temperature then fluctuated between 7.5 and 12 °C until the end of the experiment. The mean temperature over the duration of the experiment was 9.1 °C.

Siltation occurred in the troughs due to the onset of freshet conditions in the Athabasca River (Figure 5). Despite daily cleaning, large deposits of silt accumulated on tile surfaces (Plate 4). Where siltation and biomass accrual was greatest, sloughing on the leading edge of the tiles became apparent after day 15 (Plate 5 aandb). There was no significant difference in biomass (chl*a*) accrual between reaches ($p = 0.6666$), suggesting that siltation and sloughing rates were equal for all reaches. Thus, we pooled the data for the three reaches within each trough.

Weekly water chemistry data were averaged for each P-treatment and for the head tank to give mean concentrations for the experiment (Table 1). Nutrient concentrations in the head tank averaged 2.0 ± 0.3, 2.8 ± 0.4, 33 ± 5, 67 ± 9, and 43 ± 30 (mean ± SE) for SRP, TDP, TP, NO_2+NO_3, and NH_4, respectively. SRP concentrations measured in the troughs were relatively close to the desired gradient if the standard errors and inherent variability in the system were considered (Table 1). For previous periphyton growth analyses using these troughs, Perrin *et al.* (1995) expressed the P concentrations of the treatments as the SRP concentration for the control trough plus the concentration of P added. These values did not necessarily represent actual P concentrations in the troughs. We used mean SRP concentrations measured for each treatment in our analyses since they represented the true P concentrations of the troughs.

P addition (µg/L)	Mean ambient SRP concentration (µg/L) ± SE
Head Tank	2.0 ± 0.3
0	2.1 ± 0.2
1	2.7 ± 0.2
10	10.6 ± 0.5
25	24.7 ±1.3

Table 1. Mean SRP concentrations for the head tank and the four treatments (April 21-May 18, 1994).

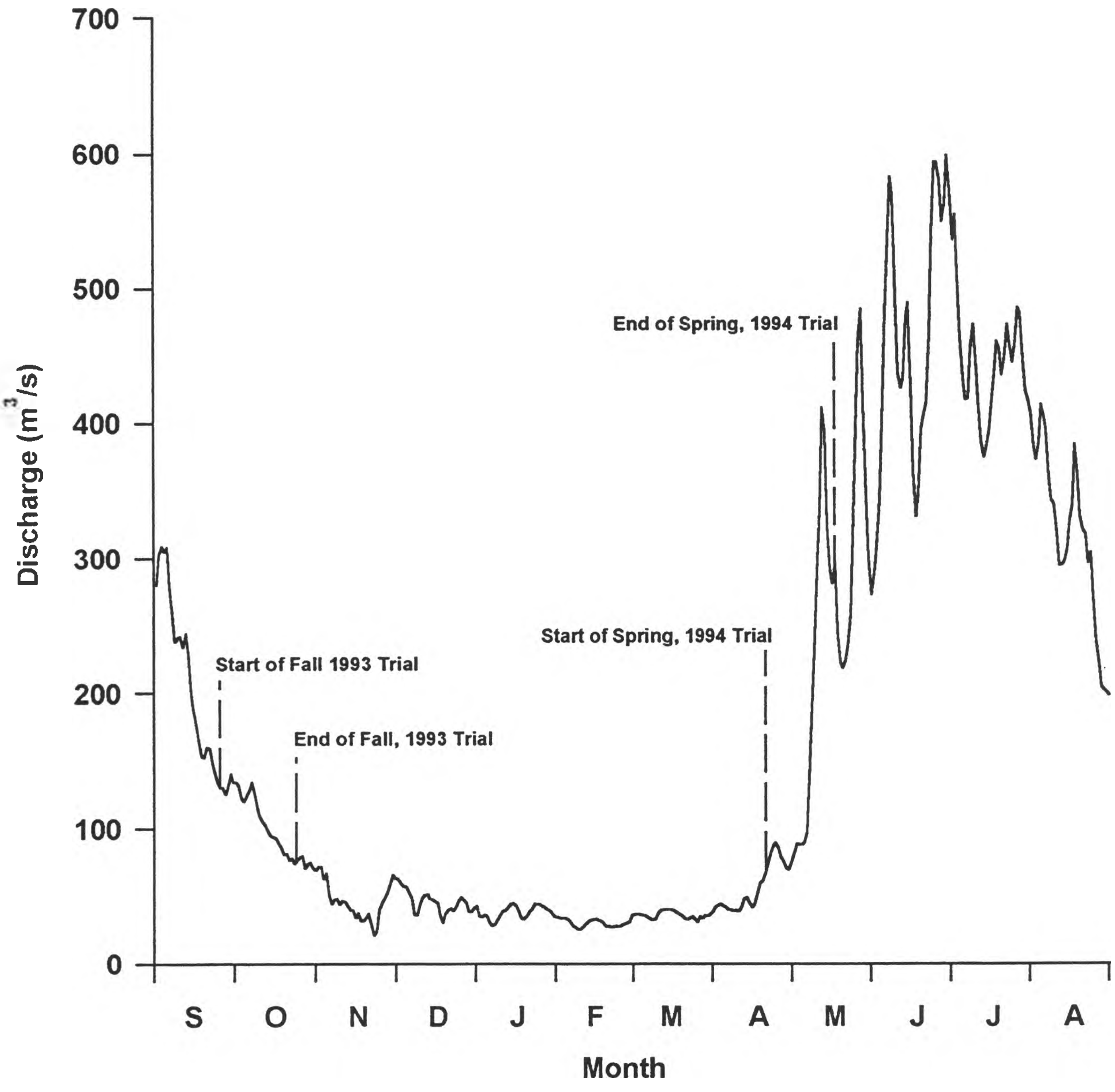


Figure 5. **Mean daily discharge for the Athabasca River at Hinton, September 1993 to August 1994, showing start and end dates for the fall 1993 and spring 1994 flume experiment.**

Plate 4. **Silt accumulation on tiles in trough # 2 (1 µg/L P) on day 17 (May 8, 1994).**

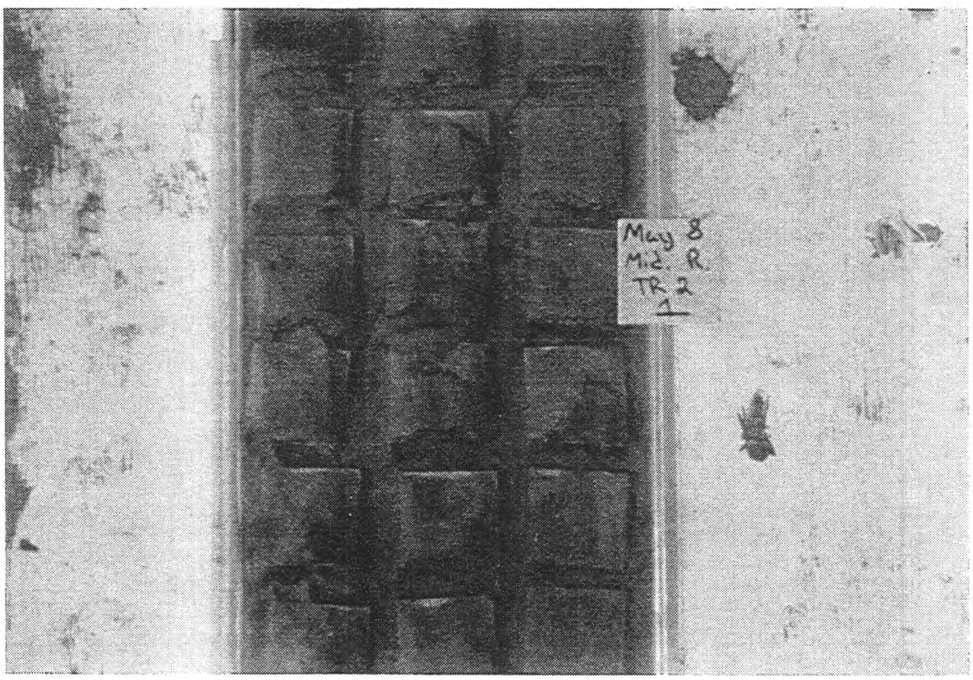
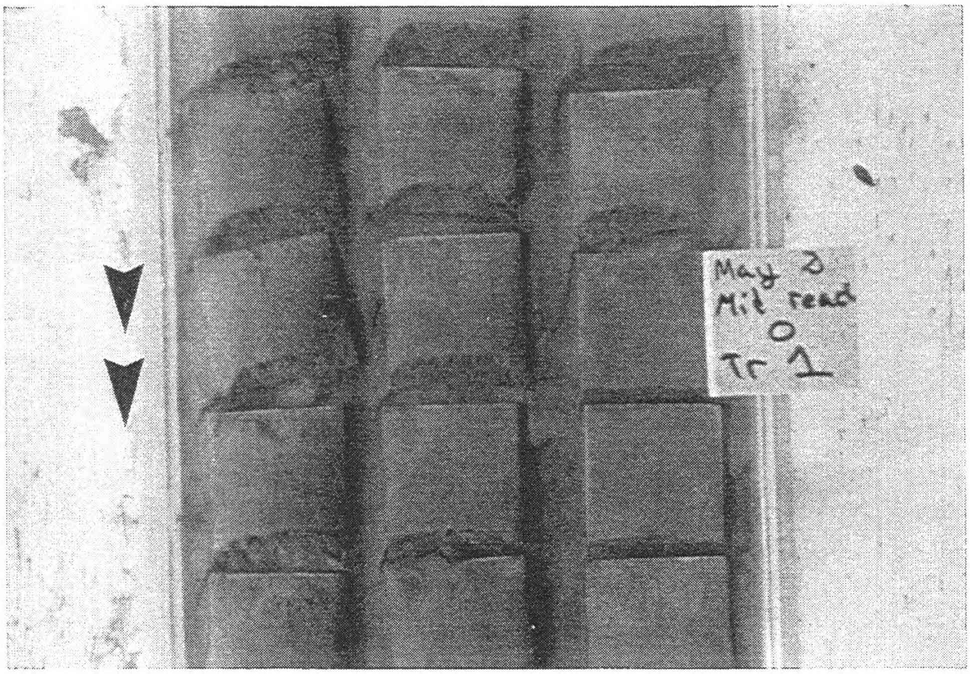


Plate 5. **Silt accumulation in troughs showing: (a) minimal sloughing on downstream edge of tiles in control trough (0 µg/L) on day 17 (May 8, 1994), and (b) high degree of sloughing on tile in 25 µg/L treatment on day 27 (May 18, 1994).**

a



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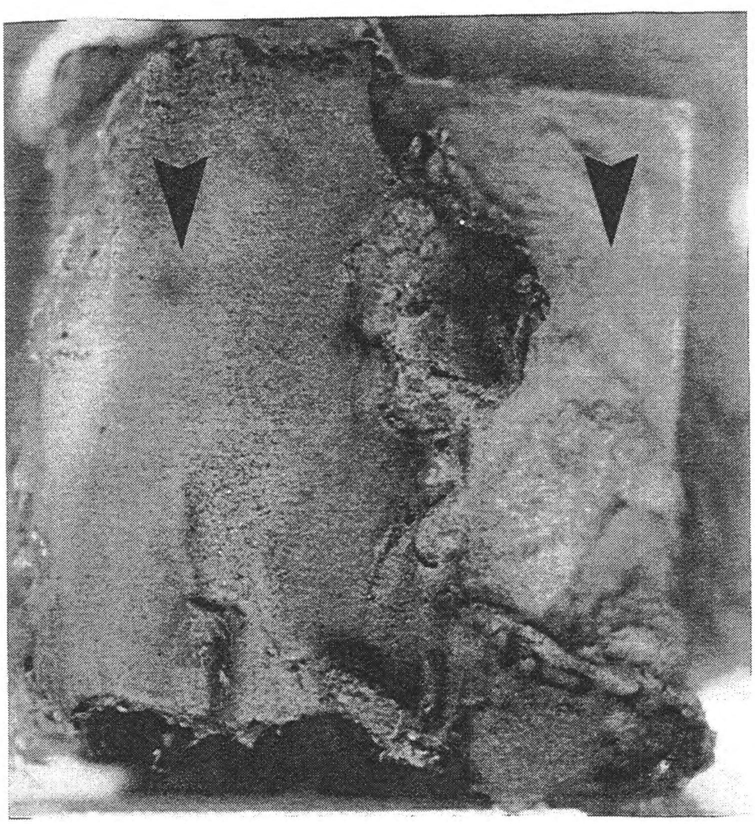

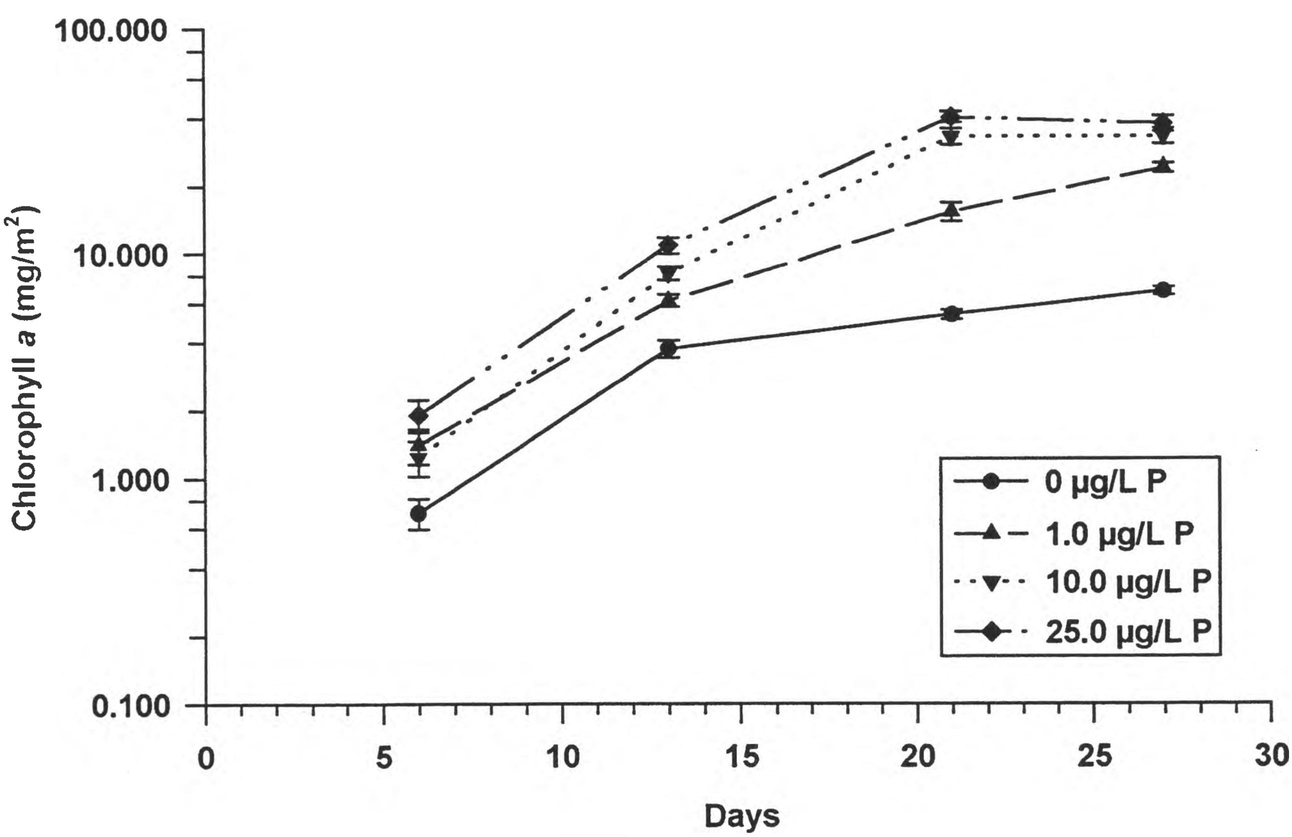

Figure 6. Time course accrual of algal periphyton biomass measured as chlorophyll *a* on tile substrata for spring 1994 flume experiment (mean ± SE).

3.2 TIME-COURSE BIOMASS CURVES

For all treatments and the control, periphyton biomass (expressed as chl*a* concentration) increased logarithmically over the first 20 days of the experiment (Figure 6). Biomass in the 0 and 1 μg/L P treatments continued to increase after 20 days but appeared to level off in the 10 and 25 μg/L P treatments. This decrease in rate of chl*a* accrual corresponded to increased sloughing of biomass.

3.3 GROWTH RATE AND BIOMASS VERSUS PHOSPHORUS

Regression analysis performed on spring accrual data from the first three sampling dates provided specific growth rates. The last sampling period was not used in the analysis due to the influence of increased sloughing. Specific growth rates for an experiment run under similar conditions (May 7-30, 1984, mean temperature = 9.1°C, mean PAR = 29.5) on the Thompson River, British Columbia (after Bothwell, 1988) were graphed with the Athabasca data to compare trends. Statistical analyses were not conducted since original data from the Thompson River were not available. Curvilinear relationships in μ were observed for the Athabasca River, suggesting Monod type growth kinetics (Bothwell, 1988), with P-saturated μ occurring between 2.0 to 4.0 μg/L SRP (Figure 7a). Although μ was lower in the Athabasca than the Thompson River, the P-saturation growth rate occurred at similar P concentrations (Figure 7a). The μ values were then normalized to μ_{max} to factor out physical effects of light, temperature and sedimentation (Figure 7b). The μ_{max} value for the Athabasca River in spring 1994 was 0.32 div/d at 10 μg/L P. When μ values were normalized to μ_{max}, relative specific growth rates ($\mu:\mu_{max}$) were similar for both the Thompson and Athabasca Rivers (Figure 7b). While it appears that $\mu:\mu_{max}$ saturates at a higher level in the Thompson River this may simply occur because of the lack of P-additions between 1 and 10 μg/L in the Athabasca experiment.

Fall 1993 PB data (which were obtained from Perrin *et al.* (1995)) for the styrofoam substrata) were compared to spring 1994 data (Figure 8). For both spring and fall, PB showed a curvilinear response to P addition (Figure 8a). Although fall PB values were higher for most P additions, the relationship was similar for both trials with the sharpest increases in PB occurring at low SRP concentrations (3-4 μg/L) and maximum PB values occurring between 25-35 μg/L SRP (Figure 8a). The low PB value observed in the fall 5 μg/L treatment appears to deviate from the other data. However, because of the lack of treatment replication, it is difficult to evaluate whether or not this data point was valid. PB_{max} values occurred in the 25 μg/L troughs and were 40 and 73 mg/m^2 for the spring and fall trials, respectively. When the physical effects of the two trials were factored out by normalizing PB to PB_{max} ($PB:PB_{max}$), the same curvilinear trends were apparent (Figure 8b). There were no significant differences between the slopes (p= 0.453) or the y-intercepts (p = 0.338) of the two trials. This suggests that the periphyton biomass response to increased P concentrations was the same for the

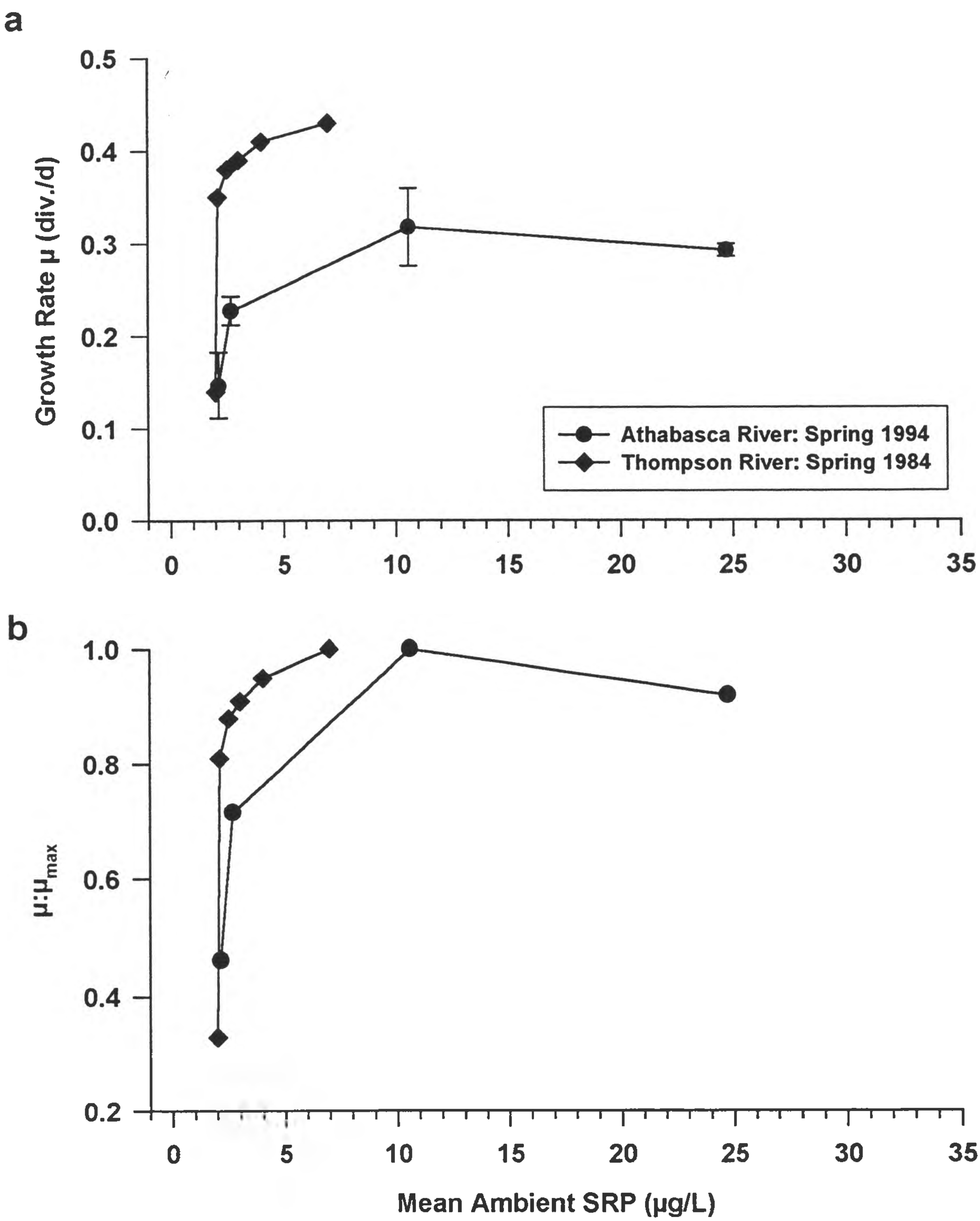

Figure 7. Upper Athabasca River spring 1994 and Thompson River periphyton growth response to P additions showing: (a) specific cellular growth rates ($\mu \pm$ SE), and (b) relative specific growth rates ($\mu:\mu_{max}$).

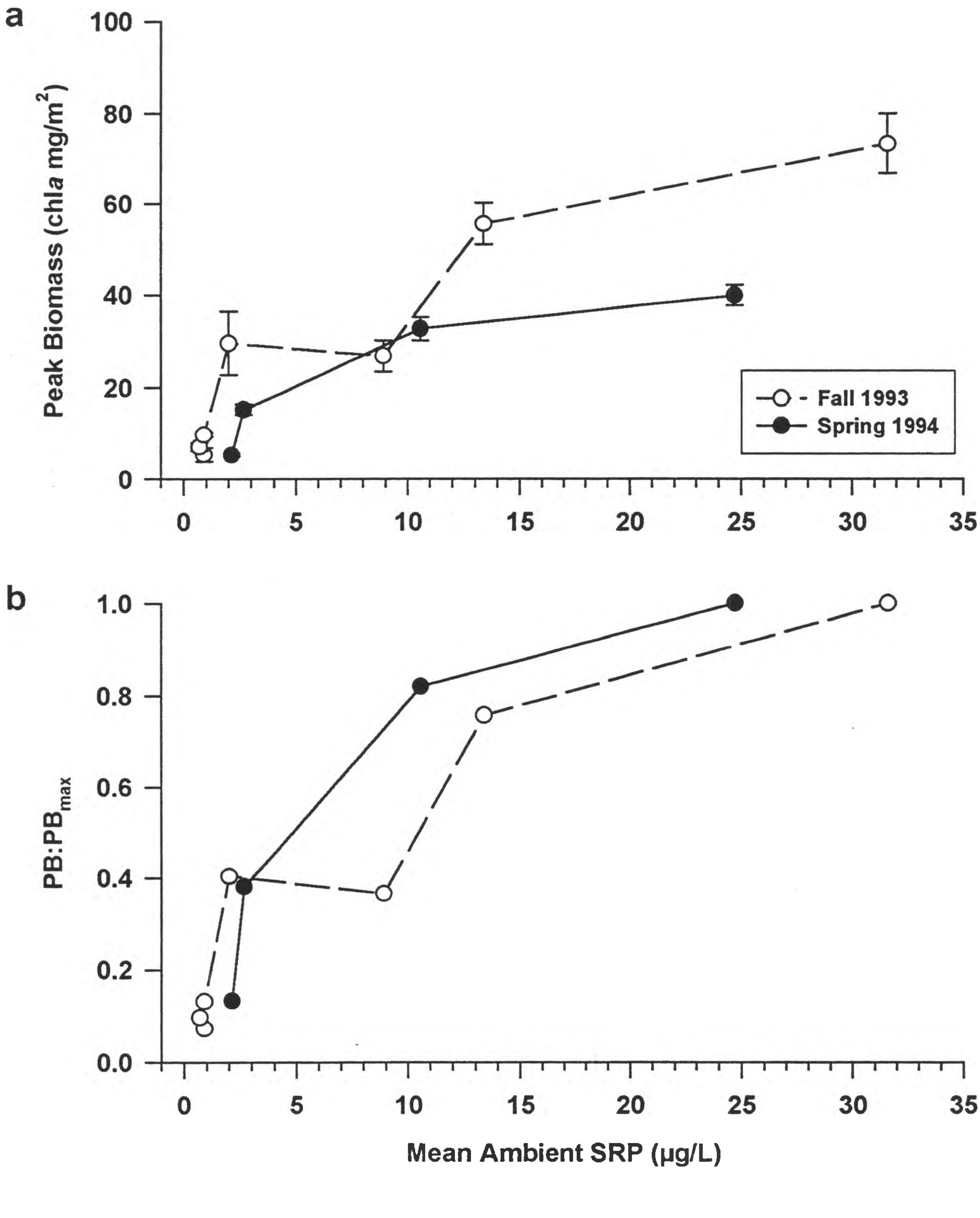

Figure 8. **Comparison of spring and fall Athabasca periphyton biomass response to P additions showing: (a) peak biomass (PB ± SE), and (b) relative peak biomass ($PB:PB_{max}$).**

spring and fall. The significant model ($p < 0.001$) produced by regression of the combined data was:

$$PB{:}PB_{max} = 0.004 + 0.194\sqrt{P} \qquad r^2 = 0.83 \qquad (2)$$

where P is measured SRP concentration.

4.0 DISCUSSION

Periphyton growth in the upper Athabasca River appears to be P limited during spring. Our results showed that growth rate saturation occurred at an SRP concentration of approximately 2 to 4 µg/L. Growth-saturating P concentrations for the upper Athabasca River were similar to the levels of 3-4 µg/L SRP required to saturate growth rates in experimental troughs on the Thompson River (Bothwell, 1985; Bothwell *et al.*, 1989). We were, however, unable to obtain accurate estimates of µ at saturation and growth-saturating P concentrations from the spring trial since growth saturated at concentrations intermediate between our treatments of 2.7 and 10.6 µg/L ambient SRP. While N and P may co-limit algal growth in other locales (Hershey *et al.*, 1988; Dodds *et al.*, 1989; Hullar and Vestal, 1989), growth limitation by N is unlikely in the upper Athabasca River. Perrin *et al.* (1995) showed that periphytic algal growth in the Athabasca River during fall 1993 was not N-limited. In addition, *in situ* experiments conducted in fall 1993 and 1994 with nutrient diffusing substrata showed that the Athabasca River upstream of Hinton was P, and not N, limited (Scrimgeour *et al.*, 1995; Scrimgeour and Chambers, in sub. to NRBS).

Values of µ were lower for the spring 1994 Athabasca trial than for a spring (May7-30, 1984) Thompson River experiment (Bothwell, 1989), despite the fact that mean temperatures were identical (9.1 °C) and irradiance values were slightly higher in the Athabasca River (42 sompared to 30 $E/m^2/d$). Bothwell (1988) showed that temperature was the most important physical factor controlling algal growth rates in experimental troughs on the Thompson River. Reduction in shading (i.e., increased PAR) has also been related to increased algal biomass in streams (Hansmann and Phinney, 1973; Murphy and Hall, 1981), just as reuctions in PAR have been shown to decrease algal production (McIntire, 1973). The lower µ in the spring 1994 Athabasca trial may be due to increased siltation which decreased algal growth rates by affecting settlement rates and light penetration. Biofilms in rivers and streams consist of heterogeneous assemblages of bacteria, fungi, algae, and micro-invertebrates contained within a polysaccharide matrix (Lock *et al.*, 1984). During the spring experiment, silt accumulation on tiles appeared to be greatest after the initial establishment of the periphyton biofilm. Silt continued to accumulate and more periphyton growth occurred on top of the first layer of silt. This process continued throughout the experiment with several layers of silt and biofilm accumulating. It is possible that the polysaccharide matrix gluing the biofilm together also trapped fine silt particles allowing them to build up and new periphyton settlement to occur, resulting in an increase in chl*a* accrual due to settlement and not solely to growth (cell division). Bothwell and Jasper (1983) showed that chl*a* accrual due to settlement increased linearly whereas accrual due to algal growth increased exponentially over time. Thus, if more accrual due to settlement was occurring in the spring trial, the resulting µ value would be lower. Increased silt levels would also have the effect of decreasing light penetration, resulting in decreased algal growth and lower μ values, especially in P-limited conditions (Bothwell, 1985, 1988). When μ values were normalized to μ_{max}, the growth rate response was similar between the spring 1994 Athabasca River and Thompson River experiments.

Although direct comparisons of algal growth rates cannot be made between the spring 1994 and fall 1993 Athabasca trials, μ appeared higher in fall (Perrin *et al.*, 1995). The higher growth rates in the fall trial, despite lower temperature and irradiance, were probably due to different growth rates of the dominant taxa in the fall. In the fall experiment, the green algae *Chlorella sp.* was dominant on tiles whereas preliminary results for the spring experiment indicate that the community was diatom dominated. Algal growth rates can vary due to differences in competitive interactions of species in response to manipulation of a limiting nutrient (Tilman *et al.*, 1982). Perrin *et al.* (1995) attributed the higher $\mu:\mu_{max}$ in the fall 1993 Athabasca trial relative to the Thompson River trial (Bothwell, 1988) to the dominance of *Chlorella sp.* in the Athabasca experiment at P additions > 1 µg/L. The $\mu:\mu_{max}$ for the spring experiment in the Athabasca River was similar to that of the Thompson River where diatoms also dominated.

The response of peak algal biomass (PB) to P addition represents the net effect of P addition on algal growth, which is important since algal biomass is of a direct concern to environmental managers. Peak biomass appeared similar for both the spring and fall trials at low P concentrations (2-4 µg/L) but fall values were higher under P-replete conditions. There was no significant difference (p = 0.34) in $PB:PB_{max}$ between the spring and fall trials. Thus the biomass response to P addition was similar between the spring and fall trials, despite the fact that growth rates appeared higher during the fall trial. This similarity in $PB:PB_{max}$ values could be due to the effects of increased sloughing in the spring trial. Although PB_{max} in the spring trial occurred on day 21 (i.e., before high levels of sloughing occurred), some sloughing may have already occurred before day 21, especially in P-replete troughs. Thus the PB_{max} value we measured may have already been reduced. A lower PB_{max} value, relative to PB would, in turn, increase $PB:PB_{max}$ values.

For the spring trial, $PB:PB_{max}$ continued to increase at P concentrations higher than those required to saturate relative specific growth rates. Two phases can be seen in the $PB:PB_{max}$ curves for the Athabasca River: a phase of faster biomass accrual occurring at P concentrations lower than 3 µg/L SRP and a phase of slower biomass accrual occurring above 3-4 µg/L. The shift in the $PB:PB_{max}$ curve occurred at a P concentration that was similar to the concentration required for saturation of $\mu:\mu_{max}$ (2-4 µg/L SRP) during spring. Increases in $PB:PB_{max}$ at P concentrations higher than those required to saturate $\mu:\mu_{max}$ indicate that while growth rates of individual cells and thin periphyton films have saturated, growth of the community as a whole has not (Bothwell, 1989). Bothwell (1989) showed similar results in the Thompson River with Phase I (0-1 µg/L added P) characterized by cellular level (Monod type) kinetics, and Phase II (2-30 µg/L added P) characterized by community level diffusion kinetics. Although relatively high P concentrations (10-25 µg/L SRP) are required to reach the maximum observed biomass, high accumulations of periphytic algae can still occur with low P concentrations (2-4 µg/L SRP). $PB:PB_{max}$ can be described as a square root linear function of ambient SRP concentration (equation 2). Such an equation could prove to be useful in establishing water quality guidelines for the

Athabasca River, since algal biomass as a proportion of the maximum potential biomass can be predicted from SRP. However, it should be noted that *in situ* biomass measurements will vary from trough measurements due to factors such as invertebrate grazing, increased flow rates, and attenuation of light due to depth or turbidity.

In summary, these studies have shown that periphyton growth in the upper Athabasca River is P-limited in spring with growth-rate saturation occurring at concentrations of approximately 2-4 μg/L SRP. P concentrations required to reach maximum PB are higher than those required to saturate growth rates but large increases in biomass can still occur with small additions of P. The response of algal growth to P addition in the upper Athabasca River is similar to that reported by Bothwell (1988, 1989) for the Thompson River. Moreover, an empirical equation predicting μ_{max} from temperature for the Thompson River accurately predicted μ_{max} for the upper Athabasca River. Additional experiments focusing on changes in periphyton growth response to P addition at Hinton and further downstream would elucidate how temporally and spatially variable nutrient limitation is in the Athabasca River. These findings will aid in developing water quality guidelines for the Athabasca River.

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APPENDIX A: Terms of Reference

NORTHERN RIVER BASINS STUDY

TERMS OF REFERENCE

Project 2613-C1: Winterization of Periphyton Flumes and March Periphyton Experiment

I. Introduction

In the winter/spring of 1993, the Northern River Basins Study contracted the construction of experimental flumes for testing the impact of nutrients and contaminants from pulp mill effluents on periphyton and aquatic macroinvertebrates. These flumes performed satisfactorily during experiments conducted in September and October 1993. However, in order to optimize the likelihood of successfully running experiments in late winter (March-April) the flumes must now be retrofitted.

II. Objectives

The objectives of this project are:

1) to winterize the existing periphyton flumes in order to be able to run experiments at temperatures at or below 0°C; and,
2) to run an experiment in March 1994 to examine the growth of the benthic biofilm in response to additions of phosphorus (P) and nitrogen (N).

III. Requirements

1) The following work is to be carried out on the flumes:

   i) insulate the tables which the flumes sit on;
   ii) enclose the troughs in a plexiglass box which warm air can be blown through;
   iii) construct an additional electrical panel to meet the additional power requirements of the flume set-up;
   iv) construct an insulated box to house the nutrient solutions and the nutrient delivery system; and,
   v) seal and insulate the waste water collection system.

2) Upon completion of the winterization of the experimental flumes conduct an experiment in which the growth of the benthic biofilm will be assessed under eleven P, N, or N+P regimes: river water alone: river water + 0.1, 0.2, 0.5,

1.0, 5.0, 10.0, 25.0 or 50 μg/L P; river water + 100 μg/L N; and river water + 50 μg/L P + 100 μg/L N.

IV. Reporting Requirements

1) The contractor is to provide ten copies of the draft report to the NRBS Component Coordinator by December 31st, 1993. The draft report is to summarize the results of the nutrient addition experiments on the growth of benthic biofilm. The style of the report is to conform to the NRBS style manual.

2) Three weeks after receipt of review comments the contractor is to supply the component coordinator with two unbound, camera-ready copies, five cerlox bound copies and an electronic copy (Word Perfect 5.1 format) of the final report.

V. Project Administration

This project is being conducted under the Nutrients Component of the Northern River Basins Study. The Scientific Authority for this project is:

Dr. Patricia Chambers
Nutrients Component Leader
Northern River Basins Study
c/o National Hydrology Research Institute
11 Innovation Blvd.
Saskatoon, Saskatchewan
S7N 3H5
phone: (306) 975-5592
fax: (306) 975-5143

Questions of technical nature should be directed towards her.

The component coordinator for this project is:

Greg Wagner
Northern River Basins Study
690 Standard Life Centre
10405 Jasper Avenue
Edmonton, Alberta
T5J 3N4
phone: (403) 427-1742
fax: (403) 422-3055

Questions of an administrative nature should be directed to him.

APPENDIX B: List of materials used in winterization of periphyton flumes.

1.Plywood -
- Enclosures - Head and foot of troughs - 16 sheets 1/4"
- Head table - enclosure - 4 sheets 3/8"
- Tables - sides and floors - 10 sheets 1/4"
- Trough -ITS construction - 3/4" - 1 sheet

2. Lumber -
- 2x2" - 8' - 10
- 1x2" - 8' - 28

3. Fasteners -
- screws 1" - 6 box
- screws 2" - 3 box
- screws 3" - 1 box
- hinges - 8 pairs

4. Insulation -
- 3/4" styrofoam 4x8' - 2 under troughs
- 2" foil back 48" - 20 ft. Manifold
- 1.5" blue board 2x8'- 32 for enclosures
- 1.5" blue board 2x8'- 8 under tables
- Nutrient Line insulation - 30'(1.29/3ft)

5. Plexiglass -
- 75x109" sheet - (OP-4)

6. Heaters -
- 1500W - 120v Ceramic - 5
- 100W Immersion heaters for nutrient - 8

APPENDIX C: Raw chlorophyll *a* data, Hinton flume experiment spring, 1994.

Note: Troughs 4, 9, and 11 = 0 µg/L P; 3,6, and 8 = 1 µg/L P; 2,7, and 10 = 10 µg/L P; 1, 5, and 12 = 25 µg/L P

ID	Date	Trough	Tile #'s	Chla (µg/cm2)	ID	Date	Trough	Tile #'s	Chla (µg/cm2)
377	27-Apr-94	1	L6	0.08	768	12-May-94	7	U3	1.61
378	27-Apr-94	1	L7	0.29	769	12-May-94	7	U20	3.06
379	27-Apr-94	1	L14	0.71	770	12-May-94	7	U23	2.10
380	27-Apr-94	1	M6	0.03	771	12-May-94	7	M3	4.70
381	27-Apr-94	1	M7	0.28	772	12-May-94	7	M20	1.27
382	27-Apr-94	1	M14	0.09	773	12-May-94	7	M23	1.83
383	27-Apr-94	1	U6	0.05	774	12-May-94	7	L3	1.72
384	27-Apr-94	1	U7	0.09	775	12-May-94	7	L20	3.01
385	27-Apr-94	1	U14	0.46	776	12-May-94	7	L23	3.37
386	27-Apr-94	2	L6	0.13	777	12-May-94	8	U3	0.84
387	27-Apr-94	2	L7	0.15	778	12-May-94	8	U20	1.15
388	27-Apr-94	2	L14	0.03	779	12-May-94	8	U23	1.49
389	27-Apr-94	2	M6	0.05	780	12-May-94	8	M3	1.76
390	27-Apr-94	2	M7	0.07	781	12-May-94	8	M20	0.56
391	27-Apr-94	2	M14	0.18	782	12-May-94	8	M23	0.41
392	27-Apr-94	2	U6	0.02	783	12-May-94	8	L3	0.73
393	27-Apr-94	2	U7	0.10	784	12-May-94	8	L20	2.16
394	27-Apr-94	2	U14	0.34	785	12-May-94	8	L23	2.27
395	27-Apr-94	3	L6	0.12	786	12-May-94	9	U3	0.36
396	27-Apr-94	3	L7	0.02	787	12-May-94	9	U20	0.64
397	27-Apr-94	3	L14	0.07	788	12-May-94	9	U23	0.41
398	27-Apr-94	3	M6	0.08	789	12-May-94	9	M3	0.48
399	27-Apr-94	3	M7	0.07	790	12-May-94	9	M20	0.46
400	27-Apr-94	3	M14	0.15	791	12-May-94	9	M23	0.60
401	27-Apr-94	3	U6	0.07	792	12-May-94	9	L3	0.39
402	27-Apr-94	3	U7	0.05	793	12-May-94	9	L20	0.36
403	27-Apr-94	3	U14	0.53	794	12-May-94	9	L23	0.27
404	27-Apr-94	4	L6	0.04	795	12-May-94	10	U3	3.21
405	27-Apr-94	4	L7	0.04	796	12-May-94	10	U20	4.02
406	27-Apr-94	4	L14	0.02	797	12-May-94	10	U23	4.79
407	27-Apr-94	4	M6	0.08	798	12-May-94	10	M3	3.95
408	27-Apr-94	4	M7	0.06	799	12-May-94	10	M20	4.49
409	27-Apr-94	4	M14	0.11	800	12-May-94	10	M23	4.22
410	27-Apr-94	4	U6	0.11	801	12-May-94	10	L3	3.90
411	27-Apr-94	4	U7	0.01	802	12-May-94	10	L20	5.06
412	27-Apr-94	4	U14	0.21	803	12-May-94	10	L23	6.15
413	27-Apr-94	5	L6	0.43	804	12-May-94	11	U3	0.49
414	27-Apr-94	5	L7	0.07	805	12-May-94	11	U20	0.59
415	27-Apr-94	5	L14	0.01	806	12-May-94	11	U23	0.68
416	27-Apr-94	5	M6	0.07	807	12-May-94	11	M3	0.72
417	27-Apr-94	5	M7	0.11	808	12-May-94	11	M20	0.74
418	27-Apr-94	5	M14	0.13	809	12-May-94	11	M23	0.73
419	27-Apr-94	5	U6	0.15	810	12-May-94	11	L3	0.60
420	27-Apr-94	5	U7	0.10	811	12-May-94	11	L20	0.64

421	27-Apr-94	5	U14	0.18	812	12-May-94	11	L23	0.50
422	27-Apr-94	6	L6	0.08	813	12-May-94	12	U3	5.01
423	27-Apr-94	6	L7	0.03	814	12-May-94	12	U20	5.42
424	27-Apr-94	6	L14	0.02	815	12-May-94	12	U23	5.73
425	27-Apr-94	6	M6	0.25	816	12-May-94	12	M3	4.18
426	27-Apr-94	6	M7	0.14	817	12-May-94	12	M20	3.35
427	27-Apr-94	6	M14	0.08	818	12-May-94	12	M23	5.31
428	27-Apr-94	6	U6	0.11	819	12-May-94	12	L3	4.64
429	27-Apr-94	6	U7	0.07	820	12-May-94	12	L20	3.98
430	27-Apr-94	6	U14	0.47	821	12-May-94	12	L23	3.35
431	27-Apr-94	7	L6	0.03	485	18-May-94	1	U1	6.81
432	27-Apr-94	7	L7	0.22	486	18-May-94	1	U2	7.90
433	27-Apr-94	7	L14	0.08	487	18-May-94	1	U5	8.08
434	27-Apr-94	7	M6	0.08	488	18-May-94	1	U12	6.74
435	27-Apr-94	7	M7	0.29	489	18-May-94	1	U16	4.65
436	27-Apr-94	7	M14	0.25	490	18-May-94	1	U22	7.87
437	27-Apr-94	7	U6	0.01	491	18-May-94	1	M1	5.33
438	27-Apr-94	7	U7	0.26	492	18-May-94	1	M2	6.36
439	27-Apr-94	7	U14	0.43	493	18-May-94	1	M5	7.77
440	27-Apr-94	8	L6	0.20	494	18-May-94	1	M12	4.59
441	27-Apr-94	8	L7	0.13	495	18-May-94	1	M16	1.66
442	27-Apr-94	8	L14	0.09	496	18-May-94	1	M22	1.91
443	27-Apr-94	8	M6	0.20	497	18-May-94	1	L1	2.64
444	27-Apr-94	8	M7	0.20	498	18-May-94	1	L2	0.93
445	27-Apr-94	8	M14	0.22	499	18-May-94	1	L5	1.00
446	27-Apr-94	8	U6	0.01	500	18-May-94	1	L12	1.73
447	27-Apr-94	8	U7	0.03	501	18-May-94	1	L16	0.72
448	27-Apr-94	8	U14	0.29	502	18-May-94	1	L22	2.44
449	27-Apr-94	9	L6	0.03	503	18-May-94	2	U1	4.46
450	27-Apr-94	9	L7	0.08	504	18-May-94	2	U2	2.62
451	27-Apr-94	9	L14	0.02	505	18-May-94	2	U5	2.39
452	27-Apr-94	9	M6	0.00	506	18-May-94	2	U12	1.00
453	27-Apr-94	9	M7	0.10	507	18-May-94	2	U16	4.04
454	27-Apr-94	9	M14	0.03	508	18-May-94	2	U22	2.78
455	27-Apr-94	9	U6	0.00	509	18-May-94	2	M1	5.56
456	27-Apr-94	9	U7	0.00	510	18-May-94	2	M2	1.58
457	27-Apr-94	9	U14	0.11	511	18-May-94	2	M5	1.09
458	27-Apr-94	10	L6	0.05	512	18-May-94	2	M12	2.30
459	27-Apr-94	10	L7	0.03	513	18-May-94	2	M16	2.55
460	27-Apr-94	10	L14	0.03	514	18-May-94	2	M22	1.62
461	27-Apr-94	10	M6	0.07	515	18-May-94	2	L1	2.71
462	27-Apr-94	10	M7	0.01	516	18-May-94	2	L2	1.48
463	27-Apr-94	10	M14	0.18	517	18-May-94	2	L5	1.38
464	27-Apr-94	10	U6	0.03	518	18-May-94	2	L12	1.61
465	27-Apr-94	10	U7	0.03	519	18-May-94	2	L16	2.28
466	27-Apr-94	10	U14	0.21	520	18-May-94	2	L22	3.27
467	27-Apr-94	11	L6	0.11	521	18-May-94	3	U1	2.18
468	27-Apr-94	11	L7	0.13	522	18-May-94	3	U2	3.26
469	27-Apr-94	11	L14	0.03	523	18-May-94	3	U5	2.75
470	27-Apr-94	11	M6	0.16	524	18-May-94	3	U12	2.30
471	27-Apr-94	11	M7	0.07	525	18-May-94	3	U16	2.55
472	27-Apr-94	11	M14	0.12	526	18-May-94	3	U22	3.43

473	27-Apr-94	11	U6	0.01	527	18-May-94	3	M1	3.57
474	27-Apr-94	11	U7	0.05	528	18-May-94	3	M2	2.09
475	27-Apr-94	11	U14	0.16	529	18-May-94	3	M5	3.21
476	27-Apr-94	12	L6	0.10	530	18-May-94	3	M12	4.37
477	27-Apr-94	12	L7	0.22	531	18-May-94	3	M16	2.15
478	27-Apr-94	12	L14	0.08	532	18-May-94	3	M22	2.69
479	27-Apr-94	12	M6	0.43	533	18-May-94	3	L1	2.40
480	27-Apr-94	12	M7	0.30	534	18-May-94	3	L2	2.43
481	27-Apr-94	12	M14	0.20	535	18-May-94	3	L5	2.68
482	27-Apr-94	12	U6	0.03	536	18-May-94	3	L12	0.93
483	27-Apr-94	12	U7	0.22	537	18-May-94	3	L16	1.36
484	27-Apr-94	12	U14	0.22	538	18-May-94	3	L22	2.09
269	04-May-94	1	L4	1.69	539	18-May-94	6	U1	2.05
270	04-May-94	1	L15	1.77	540	18-May-94	6	U2	1.98
271	04-May-94	1	L18	1.40	541	18-May-94	6	U5	2.60
272	04-May-94	1	M4	1.75	542	18-May-94	6	U12	1.95
273	04-May-94	1	M15	1.15	543	18-May-94	6	U16	2.50
274	04-May-94	1	M18	1.10	544	18-May-94	6	U22	4.01
275	04-May-94	1	U4	0.76	545	18-May-94	6	M1	3.21
276	04-May-94	1	U15	1.05	546	18-May-94	6	M2	1.61
277	04-May-94	1	U18	1.28	547	18-May-94	6	M5	3.18
278	04-May-94	2	L4	1.00	548	18-May-94	6	M12	1.66
279	04-May-94	2	L15	1.10	549	18-May-94	6	M16	3.37
280	04-May-94	2	L18	0.89	550	18-May-94	6	M22	5.05
281	04-May-94	2	M4	0.70	551	18-May-94	6	L1	3.78
282	04-May-94	2	M15	1.32	552	18-May-94	6	L2	2.36
283	04-May-94	2	M18	1.25	553	18-May-94	6	L5	2.28
284	04-May-94	2	U4	0.59	554	18-May-94	6	L12	1.35
285	04-May-94	2	U15	0.59	555	18-May-94	6	L16	2.95
286	04-May-94	2	U18	0.86	556	18-May-94	6	L22	2.73
287	04-May-94	3	L4	0.74	557	18-May-94	8	U1	2.04
288	04-May-94	3	L15	0.47	558	18-May-94	8	U2	2.70
289	04-May-94	3	L18	0.78	559	18-May-94	8	U5	1.89
290	04-May-94	3	M4	0.87	560	18-May-94	8	U12	1.56
291	04-May-94	3	M15	0.87	561	18-May-94	8	U16	1.19
292	04-May-94	3	M18	0.97	562	18-May-94	8	U22	2.12
293	04-May-94	3	U4	0.42	563	18-May-94	8	M1	2.42
294	04-May-94	3	U15	0.45	564	18-May-94	8	M2	2.14
295	04-May-94	3	U18	0.48	565	18-May-94	8	M5	2.56
296	04-May-94	4	L4	0.50	566	18-May-94	8	M12	1.48
297	04-May-94	4	L15	0.27	567	18-May-94	8	M16	1.78
298	04-May-94	4	L18	0.31	568	18-May-94	8	M22	1.89
299	04-May-94	4	M4	0.48	569	18-May-94	8	L1	2.05
300	04-May-94	4	M15	0.28	570	18-May-94	8	L2	1.89
301	04-May-94	4	M18	0.39	571	18-May-94	8	L5	1.82
302	04-May-94	4	U4	0.34	572	18-May-94	8	L12	1.36
303	04-May-94	4	U15	0.02	573	18-May-94	8	L16	1.46
304	04-May-94	4	U18	0.29	574	18-May-94	8	L22	1.16
305	04-May-94	5	L4	1.13	575	18-May-94	9	U1	0.49
306	04-May-94	5	L15	1.45	576	18-May-94	9	U2	0.32
307	04-May-94	5	L18	2.31	577	18-May-94	9	U5	0.23
308	04-May-94	5	M4	0.73	578	18-May-94	9	U12	0.35

309	04-May-94	5	M15	1.13	579	18-May-94	9	U16	0.55
310	04-May-94	5	M18	0.83	580	18-May-94	9	U22	0.67
311	04-May-94	5	U4	0.77	581	18-May-94	9	M1	0.67
312	04-May-94	5	U15	0.65	582	18-May-94	9	M2	0.66
313	04-May-94	5	U18	0.72	583	18-May-94	9	M5	0.62
314	04-May-94	6	L4	0.54	584	18-May-94	9	M12	0.42
315	04-May-94	6	L15	0.40	585	18-May-94	9	M16	1.03
316	04-May-94	6	L18	0.62	586	18-May-94	9	M22	0.90
317	04-May-94	6	M4	0.63	587	18-May-94	9	L1	0.73
318	04-May-94	6	M15	0.49	588	18-May-94	9	L2	0.60
319	04-May-94	6	M18	0.65	589	18-May-94	9	L5	0.81
320	04-May-94	6	U4	0.41	590	18-May-94	9	L12	0.57
321	04-May-94	6	U15	0.38	591	18-May-94	9	L16	0.68
322	04-May-94	6	U18	0.47	592	18-May-94	9	L22	0.50
323	04-May-94	7	L4	0.40	593	18-May-94	11	U1	0.53
324	04-May-94	7	L15	0.25	594	18-May-94	11	U2	0.38
325	04-May-94	7	L18	0.27	595	18-May-94	11	U5	0.60
326	04-May-94	7	M4	0.91	596	18-May-94	11	U12	0.69
327	04-May-94	7	M15	0.85	597	18-May-94	11	U16	0.41
328	04-May-94	7	M18	0.68	598	18-May-94	11	U22	0.73
329	04-May-94	7	U4	0.56	599	18-May-94	11	M1	0.87
330	04-May-94	7	U15	0.88	600	18-May-94	11	M2	0.75
331	04-May-94	7	U18	0.76	601	18-May-94	11	M5	0.83
332	04-May-94	8	L4	0.50	602	18-May-94	11	M12	0.87
333	04-May-94	8	L15	1.13	603	18-May-94	11	M16	0.68
334	04-May-94	8	L18	0.80	604	18-May-94	11	M22	0.60
335	04-May-94	8	M4	0.33	605	18-May-94	11	L1	0.92
336	04-May-94	8	M15	0.50	606	18-May-94	11	L2	0.26
337	04-May-94	8	M18	0.65	607	18-May-94	11	L5	0.66
338	04-May-94	8	U4	0.55	608	18-May-94	11	L12	0.58
339	04-May-94	8	U15	0.74	609	18-May-94	11	L16	0.72
340	04-May-94	8	U18	0.72	610	18-May-94	11	L22	0.67
341	04-May-94	9	L4	0.34	611	18-May-94	12	U1	6.41
342	04-May-94	9	L15	0.38	612	18-May-94	12	U2	3.66
343	04-May-94	9	L18	0.26	613	18-May-94	12	U5	5.84
344	04-May-94	9	M4	0.32	614	18-May-94	12	U12	2.36
345	04-May-94	9	M15	0.17	615	18-May-94	12	U16	1.78
346	04-May-94	9	M18	0.29	616	18-May-94	12	U22	3.77
347	04-May-94	9	U4	0.10	617	18-May-94	12	M1	2.62
348	04-May-94	9	U15	0.30	618	18-May-94	12	M2	4.90
349	04-May-94	9	U18	0.26	619	18-May-94	12	M5	1.62
350	04-May-94	10	L4	0.63	620	18-May-94	12	M12	2.76
351	04-May-94	10	L15	1.17	621	18-May-94	12	M16	1.74
352	04-May-94	10	L18	0.97	622	18-May-94	12	M22	2.72
353	04-May-94	10	M4	0.52	623	18-May-94	12	L1	4.08
354	04-May-94	10	M15	1.23	624	18-May-94	12	L2	3.72
355	04-May-94	10	M18	0.92	625	18-May-94	12	L5	2.82
356	04-May-94	10	U4	1.24	626	18-May-94	12	L12	0.92
357	04-May-94	10	U15	0.63	627	18-May-94	12	L16	0.00
358	04-May-94	10	U18	0.83	628	18-May-94	12	L22	1.69
359	04-May-94	11	L4	0.80	629	18-May-94	4	U1	0.47
360	04-May-94	11	L15	0.46	630	18-May-94	4	U2	0.56

361	04-May-94	11	L18	0.49	631	18-May-94	4	U5	0.33
362	04-May-94	11	M4	0.60	632	18-May-94	4	U12	0.66
363	04-May-94	11	M15	0.64	633	18-May-94	4	U16	0.66
364	04-May-94	11	M18	0.50	634	18-May-94	4	U22	0.96
365	04-May-94	11	U4	0.33	635	18-May-94	4	M1	0.88
366	04-May-94	11	U15	0.30	636	18-May-94	4	M2	0.82
367	04-May-94	11	U18	0.68	637	18-May-94	4	M5	0.92
368	04-May-94	12	L4	1.38	638	18-May-94	4	M12	0.87
369	04-May-94	12	L15	0.61	639	18-May-94	4	M16	0.80
370	04-May-94	12	L18	1.43	640	18-May-94	4	M22	0.79
371	04-May-94	12	M4	0.96	641	18-May-94	4	L1	0.88
372	04-May-94	12	M15	1.39	642	18-May-94	4	L2	0.99
373	04-May-94	12	M18	0.45	643	18-May-94	4	L5	0.92
374	04-May-94	12	U4	0.23	644	18-May-94	4	L12	0.80
375	04-May-94	12	U15	0.52	645	18-May-94	4	L16	0.67
376	04-May-94	12	U18	0.60	646	18-May-94	4	L22	0.86
711	12-May-94	1	U3	2.72	647	18-May-94	5	U1	4.50
712	12-May-94	1	U20	5.55	648	18-May-94	5	U2	3.98
713	12-May-94	1	U23	6.31	649	18-May-94	5	U5	1.21
714	12-May-94	1	M3	3.51	650	18-May-94	5	U12	2.91
715	12-May-94	1	M20	4.17	651	18-May-94	5	U16	3.10
716	12-May-94	1	M23	3.41	652	18-May-94	5	U22	3.53
717	12-May-94	1	L3	4.85	653	18-May-94	5	M1	6.25
718	12-May-94	1	L20	3.24	654	18-May-94	5	M2	7.80
719	12-May-94	1	L23	4.80	655	18-May-94	5	M5	3.49
720	12-May-94	2	U3	2.45	656	18-May-94	5	M12	1.15
721	12-May-94	2	U20	1.21	657	18-May-94	5	M16	1.71
722	12-May-94	2	U23	2.10	658	18-May-94	5	M22	5.86
723	12-May-94	2	M3	2.14	659	18-May-94	5	L1	5.16
724	12-May-94	2	M20	2.52	660	18-May-94	5	L2	3.13
725	12-May-94	2	M23	1.92	661	18-May-94	5	L5	5.34
726	12-May-94	2	L3	5.85	662	18-May-94	5	L12	2.03
727	12-May-94	2	L20	4.28	663	18-May-94	5	L16	1.43
728	12-May-94	2	L23	3.47	664	18-May-94	5	L22	6.27
729	12-May-94	3	U3	0.85	665	18-May-94	7	U1	5.23
730	12-May-94	3	U20	3.24	666	18-May-94	7	U2	5.97
732	12-May-94	3	U23	2.78	667	18-May-94	7	U5	2.40
734	12-May-94	3	M3	1.78	668	18-May-94	7	U12	8.15
735	12-May-94	3	M20	1.28	669	18-May-94	7	U16	5.17
736	12-May-94	3	M23	1.05	670	18-May-94	7	U22	1.93
737	12-May-94	3	L3	1.56	671	18-May-94	7	M1	2.23
738	12-May-94	3	L20	2.28	672	18-May-94	7	M2	2.14
739	12-May-94	3	L23	1.51	673	18-May-94	7	M5	2.34
740	12-May-94	4	U3	0.48	674	18-May-94	7	M12	2.17
741	12-May-94	4	U20	0.68	675	18-May-94	7	M16	6.18
742	12-May-94	4	U23	0.50	676	18-May-94	7	M22	3.56
743	12-May-94	4	M3	0.52	677	18-May-94	7	L1	7.30
744	12-May-94	4	M20	0.60	678	18-May-94	7	L2	5.74
745	12-May-94	4	M23	0.56	679	18-May-94	7	L5	7.30
746	12-May-94	4	L3	0.59	680	18-May-94	7	L12	3.98
747	12-May-94	4	L20	0.32	681	18-May-94	7	L16	2.97
748	12-May-94	4	L23	0.39	682	18-May-94	7	L22	3.59

749	12-May-94	5	U3	2.86	683	18-May-94	10	U1	1.39
751	12-May-94	5	U20	1.76	684	18-May-94	10	U2	1.14
752	12-May-94	5	U23	3.16	685	18-May-94	10	U5	3.82
753	12-May-94	5	M3	3.07	686	18-May-94	10	U12	1.35
754	12-May-94	5	M20	2.78	687	18-May-94	10	U16	3.66
755	12-May-94	5	M23	2.51	688	18-May-94	10	U22	4.03
756	12-May-94	5	L3	2.87	689	18-May-94	10	M1	6.54
757	12-May-94	5	L20	4.78	690	18-May-94	10	M2	1.80
758	12-May-94	5	L23	4.47	691	18-May-94	10	M5	5.34
759	12-May-94	6	U3	1.11	692	18-May-94	10	M12	3.10
760	12-May-94	6	U20	1.85	693	18-May-94	10	M16	5.94
761	12-May-94	6	U23	0.43	694	18-May-94	10	M22	3.15
762	12-May-94	6	M3	0.85	695	18-May-94	10	L1	3.95
763	12-May-94	6	M20	1.26	696	18-May-94	10	L2	2.79
764	12-May-94	6	M23	2.06	697	18-May-94	10	L5	0.44
765	12-May-94	6	L3	1.25	698	18-May-94	10	L12	0.87
766	12-May-94	6	L20	2.15	699	18-May-94	10	L16	2.25
767	12-May-94	6	L23	2.41	700	18-May-94	10	L22	2.94

APPENDIX D: **Raw irradiance data, Hinton flume experiment spring, 1994.**

Date	Time	Light (µE/s/m²)	Date	Time	Light (µE/s/m²)	Date	Time	Light (µE/s/m²)
21-Apr-94	600	0.0032	29-Apr-94	2300	0.0027	09-May-94	1500	648
21-Apr-94	700	6.533	30-Apr-94	600	0.12	09-May-94	1600	396.2
21-Apr-94	800	85.69	30-Apr-94	700	27.38	09-May-94	1700	338.4
21-Apr-94	900	199.6	30-Apr-94	800	128.8	09-May-94	1800	295.6
21-Apr-94	1000	623.2	30-Apr-94	900	272.5	09-May-94	1900	263.7
21-Apr-94	1100	1025	30-Apr-94	1000	618.1	09-May-94	2000	198.8
21-Apr-94	1200	1245	30-Apr-94	1100	878.3	09-May-94	2100	92.93
21-Apr-94	1300	1128	30-Apr-94	1200	1155	09-May-94	2200	11.2
21-Apr-94	1400	1089	30-Apr-94	1300	1246	09-May-94	2300	0.0443
21-Apr-94	1500	1034	30-Apr-94	1400	954.2	10-May-94	600	1.311
21-Apr-94	1600	1023	30-Apr-94	1500	895.8	10-May-94	700	42.74
21-Apr-94	1700	697.1	30-Apr-94	1600	413	10-May-94	800	151.7
21-Apr-94	1800	665.6	30-Apr-94	1700	537.7	10-May-94	900	338.8
21-Apr-94	1900	784.3	30-Apr-94	1800	531.3	10-May-94	1000	453.5
21-Apr-94	2000	371.6	30-Apr-94	1900	317.7	10-May-94	1100	476.6
21-Apr-94	2100	85.66	30-Apr-94	2000	142.7	10-May-94	1200	881.6
21-Apr-94	2200	2.314	30-Apr-94	2100	66.49	10-May-94	1300	1467
22-Apr-94	600	0.0067	30-Apr-94	2200	4.479	10-May-94	1400	1217
22-Apr-94	700	9.61	30-Apr-94	2300	0.0026	10-May-94	1500	736.1
22-Apr-94	800	72.58	01-May-94	400	6.753	10-May-94	1600	564.2
22-Apr-94	900	152.6	01-May-94	500	0.0003	10-May-94	1700	796.6
22-Apr-94	1000	624.2	01-May-94	600	0.0601	10-May-94	1800	401.4
22-Apr-94	1100	1067	01-May-94	700	5.947	10-May-94	1900	303
22-Apr-94	1200	1317	01-May-94	800	28.42	10-May-94	2000	202.9
22-Apr-94	1300	1496	01-May-94	900	71.24	10-May-94	2100	105.6
22-Apr-94	1400	1585	01-May-94	1000	175.9	10-May-94	2200	16.39
22-Apr-94	1500	1571	01-May-94	1100	224	10-May-94	2300	0.0897
22-Apr-94	1600	1472	01-May-94	1200	251.9	11-May-94	600	1.292
22-Apr-94	1700	1275	01-May-94	1300	329.4	11-May-94	700	43.86
22-Apr-94	1800	1018	01-May-94	1400	1138	11-May-94	800	155.7
22-Apr-94	1900	700.2	01-May-94	1500	1653	11-May-94	900	394.4
22-Apr-94	2000	360.1	01-May-94	1600	1433	11-May-94	1000	638.6
22-Apr-94	2100	88.42	01-May-94	1700	680	11-May-94	1100	1123
22-Apr-94	2200	2.541	01-May-94	1800	408.3	11-May-94	1200	1500
23-Apr-94	200	0.0003	01-May-94	1900	131.3	11-May-94	1300	1631
23-Apr-94	600	0.0104	01-May-94	2000	75.59	11-May-94	1400	1471
23-Apr-94	700	11.4	01-May-94	2100	85.66	11-May-94	1500	1395
23-Apr-94	800	105.2	01-May-94	2200	5.373	11-May-94	1600	1228
23-Apr-94	900	242.4	01-May-94	2300	0.0054	11-May-94	1700	920
23-Apr-94	1000	677.6	02-May-94	600	0.097	11-May-94	1800	859.4
23-Apr-94	1100	1048	02-May-94	700	13.08	11-May-94	1900	493.6
23-Apr-94	1200	1394	02-May-94	800	97.88	11-May-94	2000	361
23-Apr-94	1300	1569	02-May-94	900	271.1	11-May-94	2100	146.1
23-Apr-94	1400	1538	02-May-94	1000	550.8	11-May-94	2200	13.25
23-Apr-94	1500	1505	02-May-94	1100	911.7	11-May-94	2300	0.045
23-Apr-94	1600	1473	02-May-94	1200	1206	12-May-94	600	0.3545

23-Apr-94	1700	946.8	02-May-94	1300	635.2	12-May-94	700	23.82
23-Apr-94	1800	812.5	02-May-94	1400	779	12-May-94	800	99.59
23-Apr-94	1900	237.5	02-May-94	1500	1008	12-May-94	900	278.5
23-Apr-94	2000	44.4	02-May-94	1600	655.4	12-May-94	1000	172.4
23-Apr-94	2100	13.88	02-May-94	1700	741.1	12-May-94	1100	492.8
23-Apr-94	2200	0.474	02-May-94	1800	859.6	12-May-94	1200	495.4
23-Apr-94	2300	0.0006	02-May-94	1900	295.9	12-May-94	1300	505.4
24-Apr-94	0	0.0004	02-May-94	2000	138.6	12-May-94	1400	712.2
24-Apr-94	100	0.0008	02-May-94	2100	49.27	12-May-94	1500	1651
24-Apr-94	200	0.0008	02-May-94	2200	3.946	12-May-94	1600	1692
24-Apr-94	300	0.0009	02-May-94	2300	0.006	12-May-94	1700	1499
24-Apr-94	400	0.0023	03-May-94	600	0.2641	12-May-94	1800	1114
24-Apr-94	500	0.0032	03-May-94	700	26.26	12-May-94	1900	723.1
24-Apr-94	600	0.0049	03-May-94	800	85.86	12-May-94	2000	277
24-Apr-94	700	1.983	03-May-94	900	257	12-May-94	2100	185
24-Apr-94	800	22.15	03-May-94	1000	788.5	12-May-94	2200	23.39
24-Apr-94	900	76.96	03-May-94	1100	1106	12-May-94	2300	0.1789
24-Apr-94	1000	100.7	03-May-94	1200	1140	13-May-94	500	0.0004
24-Apr-94	1100	189.4	03-May-94	1300	1554	13-May-94	600	1.615
24-Apr-94	1200	262.9	03-May-94	1400	1205	13-May-94	700	47.5
24-Apr-94	1300	280.7	03-May-94	1500	1084	13-May-94	800	80.86
24-Apr-94	1400	291.2	03-May-94	1600	775.5	13-May-94	900	182.2
24-Apr-94	1500	265	03-May-94	1700	1060	13-May-94	1000	299
24-Apr-94	1600	198.5	03-May-94	1800	830.6	13-May-94	1100	327.1
24-Apr-94	1700	151.8	03-May-94	1900	387.4	13-May-94	1200	537
24-Apr-94	1800	121.5	03-May-94	2000	276.9	13-May-94	1300	327.6
24-Apr-94	1900	103.3	03-May-94	2100	71.52	13-May-94	1400	547.4
24-Apr-94	2000	59.29	03-May-94	2200	8.779	13-May-94	1500	828.2
24-Apr-94	2100	16.33	03-May-94	2300	0.0132	13-May-94	1600	743.9
24-Apr-94	2200	0.6708	04-May-94	600	0.3499	13-May-94	1700	171.2
24-Apr-94	2300	0.0019	04-May-94	700	30.82	13-May-94	1800	409.5
25-Apr-94	0	0.0016	04-May-94	800	108.3	13-May-94	1900	747.6
25-Apr-94	100	0.002	04-May-94	900	280.6	13-May-94	2000	356.4
25-Apr-94	200	0.0025	04-May-94	1000	766.7	13-May-94	2100	74.07
25-Apr-94	300	0.0037	04-May-94	1100	1141	13-May-94	2200	15.12
25-Apr-94	400	0.0031	04-May-94	1200	1382	13-May-94	2300	0.1425
25-Apr-94	500	0.0022	04-May-94	1300	1572	14-May-94	500	0.0013
25-Apr-94	600	0.0074	04-May-94	1400	1224	14-May-94	600	2.386
25-Apr-94	700	2.187	04-May-94	1500	908.3	14-May-94	700	46.73
25-Apr-94	800	12.53	04-May-94	1600	603.9	14-May-94	800	102.6
25-Apr-94	900	59.87	04-May-94	1700	997.6	14-May-94	900	413.9
25-Apr-94	1000	103.7	04-May-94	1800	931.5	14-May-94	1000	806
25-Apr-94	1100	102	04-May-94	1900	421.4	14-May-94	1100	1161
25-Apr-94	1200	202.3	04-May-94	2000	257.5	14-May-94	1200	1487
25-Apr-94	1300	355.7	04-May-94	2100	172.3	14-May-94	1300	1313
25-Apr-94	1400	488.5	04-May-94	2200	12.57	14-May-94	1400	1345
25-Apr-94	1500	428.1	04-May-94	2300	0.0186	14-May-94	1500	1642
25-Apr-94	1600	239.3	05-May-94	600	0.0755	14-May-94	1600	1026
25-Apr-94	1700	174.1	05-May-94	700	12.63	14-May-94	1700	920.6
25-Apr-94	1800	117.4	05-May-94	800	114.3	14-May-94	1800	793.5
25-Apr-94	1900	89.16	05-May-94	900	287.8	14-May-94	1900	301.9
25-Apr-94	2000	55.6	05-May-94	1000	727.1	14-May-94	2000	238.3

25-Apr-94	2100	18.55	05-May-94	1100	1206	14-May-94	2100	157.9
25-Apr-94	2200	0.8658	05-May-94	1200	948.7	14-May-94	2200	28.69
25-Apr-94	2300	0.0009	05-May-94	1300	1422	14-May-94	2300	0.3066
26-Apr-94	100	0.0002	05-May-94	1400	1619	15-May-94	500	0.0008
26-Apr-94	200	6.078	05-May-94	1500	1677	15-May-94	600	2.417
26-Apr-94	300	0.0003	05-May-94	1600	1335	15-May-94	700	54.69
26-Apr-94	400	0.0001	05-May-94	1700	1209	15-May-94	800	190
26-Apr-94	500	9.453	05-May-94	1800	1091	15-May-94	900	369.3
26-Apr-94	600	0.0148	05-May-94	1900	784.1	15-May-94	1000	812.5
26-Apr-94	700	8.554	05-May-94	2000	476.4	15-May-94	1100	929
26-Apr-94	800	72.43	05-May-94	2100	120.7	15-May-94	1200	999.3
26-Apr-94	900	232.1	05-May-94	2200	11.71	15-May-94	1300	1114
26-Apr-94	1000	427.2	05-May-94	2300	0.0196	15-May-94	1400	330.2
26-Apr-94	1100	626.7	06-May-94	600	0.5376	15-May-94	1500	328.9
26-Apr-94	1200	879	06-May-94	700	42.96	15-May-94	1600	202.5
26-Apr-94	1300	959.1	06-May-94	800	171.9	15-May-94	1700	290.3
26-Apr-94	1400	1349	06-May-94	900	334.8	15-May-94	1800	138.9
26-Apr-94	1500	1578	06-May-94	1000	787.8	15-May-94	1900	105.8
26-Apr-94	1600	1394	06-May-94	1100	1175	15-May-94	2000	42.6
26-Apr-94	1700	558.1	06-May-94	1200	1359	15-May-94	2100	21.79
26-Apr-94	1800	495	06-May-94	1300	1605	15-May-94	2200	4.188
26-Apr-94	1900	246.1	06-May-94	1400	1680	15-May-94	2300	0.0451
26-Apr-94	2000	160.5	06-May-94	1500	1668	16-May-94	0	0.0011
26-Apr-94	2100	76.72	06-May-94	1600	1561	16-May-94	100	0.0004
26-Apr-94	2200	2.833	06-May-94	1700	985.8	16-May-94	500	0.0006
27-Apr-94	600	0.0244	06-May-94	1800	604.8	16-May-94	600	0.2156
27-Apr-94	700	11.01	06-May-94	1900	664.6	16-May-94	700	7.396
27-Apr-94	800	73.68	06-May-94	2000	443.2	16-May-94	800	26.36
27-Apr-94	900	280.4	06-May-94	2100	160.9	16-May-94	900	79.95
27-Apr-94	1000	259.5	06-May-94	2200	16.76	16-May-94	1000	197.2
27-Apr-94	1100	185.8	06-May-94	2300	0.0316	16-May-94	1100	316
27-Apr-94	1200	394.3	07-May-94	600	0.506	16-May-94	1200	384.5
27-Apr-94	1300	1051	07-May-94	700	33.91	16-May-94	1300	501
27-Apr-94	1400	1154	07-May-94	800	99.55	16-May-94	1400	953
27-Apr-94	1500	392	07-May-94	900	315.7	16-May-94	1500	797.2
27-Apr-94	1600	543.6	07-May-94	1000	806.2	16-May-94	1600	1096
27-Apr-94	1700	522.3	07-May-94	1100	1182	16-May-94	1700	771.8
27-Apr-94	1800	356.6	07-May-94	1200	1429	16-May-94	1800	470.1
27-Apr-94	1900	699.2	07-May-94	1300	1478	16-May-94	1900	400.5
27-Apr-94	2000	406.6	07-May-94	1400	1647	16-May-94	2000	234.6
27-Apr-94	2100	89.5	07-May-94	1500	1675	16-May-94	2100	117.4
27-Apr-94	2200	5.977	07-May-94	1600	1580	16-May-94	2200	26.59
27-Apr-94	2300	0.002	07-May-94	1700	1410	16-May-94	2300	0.2837
28-Apr-94	600	0.0504	07-May-94	1800	1145	17-May-94	500	0.0005
28-Apr-94	700	16.04	07-May-94	1900	826.6	17-May-94	600	2.768
28-Apr-94	800	79.98	07-May-94	2000	438.6	17-May-94	700	29.95
28-Apr-94	900	183.2	07-May-94	2100	161.7	17-May-94	800	121.8
28-Apr-94	1000	687.4	07-May-94	2200	17.16	17-May-94	900	166.8
28-Apr-94	1100	1124	07-May-94	2300	0.0497	17-May-94	1000	465.2
28-Apr-94	1200	1338	08-May-94	500	4.727	17-May-94	1100	661
28-Apr-94	1300	1537	08-May-94	600	0.8844	17-May-94	1200	513.6
28-Apr-94	1400	1625	08-May-94	700	41.54	17-May-94	1300	384.1

28-Apr-94	1500	1414	08-May-94	800	154.8	17-May-94	1400	393.4
28-Apr-94	1600	1370	08-May-94	900	340.7	17-May-94	1500	567.4
28-Apr-94	1700	983.5	08-May-94	1000	785.2	17-May-94	1600	537.3
28-Apr-94	1800	597.8	08-May-94	1100	1169	17-May-94	1700	633.4
28-Apr-94	1900	674.8	08-May-94	1200	1407	17-May-94	1800	592.2
28-Apr-94	2000	252.1	08-May-94	1300	1444	17-May-94	1900	239.4
28-Apr-94	2100	72.34	08-May-94	1400	1522	17-May-94	2000	161.1
28-Apr-94	2200	3.323	08-May-94	1500	1661	17-May-94	2100	50.38
28-Apr-94	2300	0.0002	08-May-94	1600	1583	17-May-94	2200	11.21
29-Apr-94	600	0.053	08-May-94	1700	1486	17-May-94	2300	0.1108
29-Apr-94	700	12.69	08-May-94	1800	1112	18-May-94	200	5.403
29-Apr-94	800	101.6	08-May-94	1900	558.9	18-May-94	500	0.0011
29-Apr-94	900	277.8	08-May-94	2000	236.3	18-May-94	600	0.635
29-Apr-94	1000	678.4	08-May-94	2100	64.34	18-May-94	700	14.15
29-Apr-94	1100	1134	08-May-94	2200	9.905	18-May-94	800	36.69
29-Apr-94	1200	1338	08-May-94	2300	0.0243	18-May-94	900	56.23
29-Apr-94	1300	1489	09-May-94	600	0.903	18-May-94	1000	91.58
29-Apr-94	1400	854.7	09-May-94	700	43.9	18-May-94	1100	105
29-Apr-94	1500	735.4	09-May-94	800	156.3	18-May-94	1200	133.3
29-Apr-94	1600	740	09-May-94	900	204.7	18-May-94	1300	258.4
29-Apr-94	1700	554.9	09-May-94	1000	263.6	18-May-94	1400	228.6
29-Apr-94	1800	307.6	09-May-94	1100	302.4	18-May-94	1500	327.4
29-Apr-94	1900	274	09-May-94	1200	547.8	18-May-94	1600	284
29-Apr-94	2000	311.7	09-May-94	1300	1262	18-May-94	1700	243.4
29-Apr-94	2100	151.9	09-May-94	1400	1742	18-May-94	1800	11.62
29-Apr-94	2200	6.862						

APPENDIX E: Raw temperature data, Hinton flume experiment spring, 1994.

Date	Time	Temp	Date	Time	Temp	Date	Time	Temp
08-Apr-94	22:00:00	12.3	22-Apr-94	07:00:00	7.9	05-May-94	15:00:00	11.1
08-Apr-94	23:00:00	16.2	22-Apr-94	08:00:00	7.8	05-May-94	16:00:00	11.4
09-Apr-94	00:00:00	17.6	22-Apr-94	09:00:00	7.6	05-May-94	17:00:00	11.8
09-Apr-94	01:00:00	18.3	22-Apr-94	10:00:00	7.7	05-May-94	18:00:00	12.2
09-Apr-94	02:00:00	19.0	22-Apr-94	11:00:00	7.9	05-May-94	19:00:00	12.3
09-Apr-94	03:00:00	19.1	22-Apr-94	12:00:00	8.5	05-May-94	20:00:00	12.6
09-Apr-94	04:00:00	19.3	22-Apr-94	13:00:00	8.6	05-May-94	21:00:00	12.6
09-Apr-94	05:00:00	19.4	22-Apr-94	14:00:00	9.0	05-May-94	22:00:00	12.6
09-Apr-94	06:00:00	19.4	22-Apr-94	15:00:00	9.4	05-May-94	23:00:00	12.5
09-Apr-94	07:00:00	19.6	22-Apr-94	16:00:00	9.8	06-May-94	00:00:00	12.2
09-Apr-94	08:00:00	18.6	22-Apr-94	17:00:00	10.1	06-May-94	01:00:00	11.8
09-Apr-94	09:00:00	12.4	22-Apr-94	18:00:00	10.3	06-May-94	02:00:00	11.5
09-Apr-94	10:00:00	13.7	22-Apr-94	19:00:00	10.5	06-May-94	03:00:00	11.1
09-Apr-94	11:00:00	14.4	22-Apr-94	20:00:00	10.6	06-May-94	04:00:00	10.6
09-Apr-94	12:00:00	12.3	22-Apr-94	21:00:00	10.9	06-May-94	05:00:00	10.1
09-Apr-94	13:00:00	11.9	22-Apr-94	22:00:00	10.6	06-May-94	06:00:00	9.7
09-Apr-94	14:00:00	11.4	22-Apr-94	23:00:00	10.6	06-May-94	07:00:00	9.6
09-Apr-94	15:00:00	6.1	23-Apr-94	00:00:00	10.5	06-May-94	08:00:00	9.5
09-Apr-94	16:00:00	6.6	23-Apr-94	01:00:00	10.3	06-May-94	09:00:00	9.8
09-Apr-94	17:00:00	5.7	23-Apr-94	02:00:00	9.9	06-May-94	10:00:00	10.1
09-Apr-94	18:00:00	5.8	23-Apr-94	03:00:00	9.5	06-May-94	11:00:00	10.6
09-Apr-94	19:00:00	5.8	23-Apr-94	04:00:00	9.0	06-May-94	12:00:00	10.9
09-Apr-94	20:00:00	5.8	23-Apr-94	05:00:00	8.4	06-May-94	13:00:00	11.4
09-Apr-94	21:00:00	5.8	23-Apr-94	06:00:00	7.8	06-May-94	14:00:00	11.8
09-Apr-94	22:00:00	6.0	23-Apr-94	07:00:00	7.4	06-May-94	15:00:00	12.1
09-Apr-94	23:00:00	6.0	23-Apr-94	08:00:00	7.1	06-May-94	16:00:00	12.4
10-Apr-94	00:00:00	6.1	23-Apr-94	09:00:00	7.1	06-May-94	17:00:00	12.8
10-Apr-94	01:00:00	6.1	23-Apr-94	10:00:00	7.2	06-May-94	18:00:00	13.0
10-Apr-94	02:00:00	6.4	23-Apr-94	11:00:00	7.6	06-May-94	19:00:00	13.4
10-Apr-94	03:00:00	6.4	23-Apr-94	12:00:00	7.9	06-May-94	20:00:00	13.6
10-Apr-94	04:00:00	6.4	23-Apr-94	13:00:00	8.3	06-May-94	21:00:00	13.4
10-Apr-94	05:00:00	6.3	23-Apr-94	14:00:00	8.8	06-May-94	22:00:00	13.6
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10-Apr-94	07:00:00	6.0	23-Apr-94	16:00:00	9.6	07-May-94	00:00:00	13.7
10-Apr-94	08:00:00	5.7	23-Apr-94	17:00:00	9.9	07-May-94	01:00:00	13.4
10-Apr-94	09:00:00	6.1	23-Apr-94	18:00:00	10.0	07-May-94	02:00:00	13.0
10-Apr-94	10:00:00	6.9	23-Apr-94	19:00:00	10.2	07-May-94	03:00:00	12.5
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10-Apr-94	12:00:00	6.2	23-Apr-94	21:00:00	10.6	07-May-94	05:00:00	11.4
10-Apr-94	13:00:00	6.4	23-Apr-94	22:00:00	10.6	07-May-94	06:00:00	11.0
10-Apr-94	14:00:00	6.8	23-Apr-94	23:00:00	10.6	07-May-94	07:00:00	10.8
10-Apr-94	15:00:00	6.8	24-Apr-94	00:00:00	10.4	07-May-94	08:00:00	10.8
10-Apr-94	16:00:00	6.8	24-Apr-94	01:00:00	10.2	07-May-94	09:00:00	10.9
10-Apr-94	17:00:00	6.7	24-Apr-94	02:00:00	9.6	07-May-94	10:00:00	11.2
10-Apr-94	18:00:00	6.6	24-Apr-94	03:00:00	9.1	07-May-94	11:00:00	11.6
10-Apr-94	19:00:00	6.5	24-Apr-94	04:00:00	8.5	07-May-94	12:00:00	12.1
10-Apr-94	20:00:00	6.4	24-Apr-94	05:00:00	8.1	07-May-94	13:00:00	12.4

10-Apr-94	21:00:00	6.4	24-Apr-94	06:00:00	7.8	07-May-94	14:00:00	12.9
10-Apr-94	22:00:00	6.4	24-Apr-94	07:00:00	7.4	07-May-94	15:00:00	13.4
10-Apr-94	23:00:00	6.4	24-Apr-94	08:00:00	7.3	07-May-94	16:00:00	13.6
11-Apr-94	00:00:00	6.7	24-Apr-94	09:00:00	6.9	07-May-94	17:00:00	14.0
11-Apr-94	01:00:00	6.7	24-Apr-94	10:00:00	6.7	07-May-94	18:00:00	14.2
11-Apr-94	02:00:00	6.7	24-Apr-94	11:00:00	6.7	07-May-94	19:00:00	14.3
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11-Apr-94	07:00:00	6.4	24-Apr-94	16:00:00	6.7	08-May-94	00:00:00	13.9
11-Apr-94	08:00:00	6.2	24-Apr-94	17:00:00	6.7	08-May-94	01:00:00	13.4
11-Apr-94	09:00:00	6.0	24-Apr-94	18:00:00	6.4	08-May-94	02:00:00	13.0
11-Apr-94	10:00:00	5.9	24-Apr-94	19:00:00	6.4	08-May-94	03:00:00	12.6
11-Apr-94	11:00:00	6.1	24-Apr-94	20:00:00	6.1	08-May-94	04:00:00	11.8
11-Apr-94	12:00:00	6.4	24-Apr-94	21:00:00	6.0	08-May-94	05:00:00	11.1
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11-Apr-94	14:00:00	7.2	24-Apr-94	23:00:00	5.6	08-May-94	07:00:00	10.3
11-Apr-94	15:00:00	7.4	25-Apr-94	00:00:00	5.3	08-May-94	08:00:00	10.3
11-Apr-94	16:00:00	7.6	25-Apr-94	01:00:00	5.1	08-May-94	09:00:00	10.3
11-Apr-94	17:00:00	7.9	25-Apr-94	02:00:00	4.9	08-May-94	10:00:00	10.6
11-Apr-94	18:00:00	7.8	25-Apr-94	03:00:00	4.7	08-May-94	11:00:00	11.0
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11-Apr-94	20:00:00	7.3	25-Apr-94	05:00:00	4.3	08-May-94	13:00:00	11.8
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11-Apr-94	22:00:00	7.3	25-Apr-94	07:00:00	3.8	08-May-94	15:00:00	12.8
11-Apr-94	23:00:00	7.6	25-Apr-94	08:00:00	3.7	08-May-94	16:00:00	13.1
12-Apr-94	00:00:00	7.6	25-Apr-94	09:00:00	3.7	08-May-94	17:00:00	13.6
12-Apr-94	01:00:00	7.8	25-Apr-94	10:00:00	3.6	08-May-94	18:00:00	13.9
12-Apr-94	02:00:00	7.8	25-Apr-94	11:00:00	3.6	08-May-94	19:00:00	14.3
12-Apr-94	03:00:00	7.9	25-Apr-94	12:00:00	3.6	08-May-94	20:00:00	14.4
12-Apr-94	04:00:00	7.6	25-Apr-94	13:00:00	3.6	08-May-94	21:00:00	14.5
12-Apr-94	05:00:00	7.3	25-Apr-94	14:00:00	3.7	08-May-94	22:00:00	14.4
12-Apr-94	06:00:00	7.3	25-Apr-94	15:00:00	3.7	08-May-94	23:00:00	14.2
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12-Apr-94	08:00:00	6.6	25-Apr-94	17:00:00	3.5	09-May-94	01:00:00	13.0
12-Apr-94	09:00:00	6.4	25-Apr-94	18:00:00	3.5	09-May-94	02:00:00	12.3
12-Apr-94	10:00:00	6.1	25-Apr-94	19:00:00	3.5	09-May-94	03:00:00	11.7
12-Apr-94	11:00:00	6.0	25-Apr-94	20:00:00	3.2	09-May-94	04:00:00	11.1
12-Apr-94	12:00:00	6.0	25-Apr-94	21:00:00	3.2	09-May-94	05:00:00	10.6
12-Apr-94	13:00:00	6.1	25-Apr-94	22:00:00	3.3	09-May-94	06:00:00	10.3
12-Apr-94	14:00:00	6.4	25-Apr-94	23:00:00	3.0	09-May-94	07:00:00	10.3
12-Apr-94	15:00:00	6.8	26-Apr-94	00:00:00	2.9	09-May-94	08:00:00	10.3
12-Apr-94	16:00:00	6.9	26-Apr-94	01:00:00	2.9	09-May-94	09:00:00	10.5
12-Apr-94	17:00:00	6.7	26-Apr-94	02:00:00	2.9	09-May-94	10:00:00	10.7
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12-Apr-94	19:00:00	6.7	26-Apr-94	04:00:00	2.6	09-May-94	12:00:00	11.6
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12-Apr-94	21:00:00	6.7	26-Apr-94	06:00:00	2.4	09-May-94	14:00:00	11.7
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12-Apr-94	23:00:00	6.7	26-Apr-94	08:00:00	2.5	09-May-94	16:00:00	12.1
13-Apr-94	00:00:00	6.7	26-Apr-94	09:00:00	2.6	09-May-94	17:00:00	12.3

13-Apr-94	01:00:00	6.7	26-Apr-94	10:00:00	2.7	09-May-94	18:00:00	12.7
13-Apr-94	02:00:00	6.7	26-Apr-94	11:00:00	3.1	09-May-94	19:00:00	12.8
13-Apr-94	03:00:00	6.7	26-Apr-94	12:00:00	3.3	09-May-94	20:00:00	12.8
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13-Apr-94	06:00:00	6.0	26-Apr-94	15:00:00	4.4	09-May-94	23:00:00	12.3
13-Apr-94	07:00:00	5.7	26-Apr-94	16:00:00	4.8	10-May-94	00:00:00	11.8
13-Apr-94	08:00:00	5.5	26-Apr-94	17:00:00	4.9	10-May-94	01:00:00	11.6
13-Apr-94	09:00:00	5.3	26-Apr-94	18:00:00	5.1	10-May-94	02:00:00	11.2
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13-Apr-94	12:00:00	4.6	26-Apr-94	21:00:00	5.4	10-May-94	05:00:00	10.2
13-Apr-94	13:00:00	4.6	26-Apr-94	22:00:00	5.7	10-May-94	06:00:00	10.0
13-Apr-94	14:00:00	4.7	26-Apr-94	23:00:00	6.4	10-May-94	07:00:00	10.2
13-Apr-94	15:00:00	5.1	27-Apr-94	00:00:00	6.1	10-May-94	08:00:00	10.3
13-Apr-94	16:00:00	5.2	27-Apr-94	01:00:00	6.1	10-May-94	09:00:00	10.6
13-Apr-94	17:00:00	5.2	27-Apr-94	02:00:00	6.0	10-May-94	10:00:00	10.9
13-Apr-94	18:00:00	5.3	27-Apr-94	03:00:00	5.8	10-May-94	11:00:00	11.3
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13-Apr-94	20:00:00	4.9	27-Apr-94	05:00:00	5.3	10-May-94	13:00:00	11.6
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14-Apr-94	06:00:00	4.4	27-Apr-94	15:00:00	5.8	10-May-94	23:00:00	11.5
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14-Apr-94	08:00:00	3.8	27-Apr-94	17:00:00	6.2	11-May-94	01:00:00	10.7
14-Apr-94	09:00:00	3.5	27-Apr-94	18:00:00	6.5	11-May-94	02:00:00	10.3
14-Apr-94	10:00:00	3.8	27-Apr-94	19:00:00	6.7	11-May-94	03:00:00	10.0
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14-Apr-94	19:00:00	3.5	28-Apr-94	04:00:00	6.1	11-May-94	12:00:00	11.4
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14-Apr-94	21:00:00	3.4	28-Apr-94	06:00:00	5.4	11-May-94	14:00:00	11.8
14-Apr-94	22:00:00	3.6	28-Apr-94	07:00:00	5.0	11-May-94	15:00:00	12.1
14-Apr-94	23:00:00	3.7	28-Apr-94	08:00:00	4.9	11-May-94	16:00:00	12.2
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15-Apr-94	03:00:00	3.7	28-Apr-94	12:00:00	5.9	11-May-94	20:00:00	12.4
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15-Apr-94	05:00:00	3.1	28-Apr-94	14:00:00	6.7	11-May-94	22:00:00	12.1
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15-Apr-94	08:00:00	2.8	28-Apr-94	17:00:00	7.8	12-May-94	01:00:00	11.0
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15-Apr-94	10:00:00	3.1	28-Apr-94	19:00:00	8.3	12-May-94	03:00:00	10.6
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15-Apr-94	14:00:00	3.5	28-Apr-94	23:00:00	9.3	12-May-94	07:00:00	10.6
15-Apr-94	15:00:00	4.0	29-Apr-94	00:00:00	9.4	12-May-94	08:00:00	10.6
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16-Apr-94	06:00:00	5.7	29-Apr-94	15:00:00	8.9	12-May-94	23:00:00	11.0
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16-Apr-94	08:00:00	5.5	29-Apr-94	17:00:00	9.3	13-May-94	01:00:00	10.0
16-Apr-94	09:00:00	5.3	29-Apr-94	18:00:00	9.6	13-May-94	02:00:00	9.5
16-Apr-94	10:00:00	5.7	29-Apr-94	19:00:00	10.0	13-May-94	03:00:00	9.0
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16-Apr-94	12:00:00	6.3	29-Apr-94	21:00:00	10.6	13-May-94	05:00:00	8.7
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16-Apr-94	14:00:00	7.3	29-Apr-94	23:00:00	11.1	13-May-94	07:00:00	8.6
16-Apr-94	15:00:00	7.9	30-Apr-94	00:00:00	11.1	13-May-94	08:00:00	8.5
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16-Apr-94	17:00:00	8.1	30-Apr-94	02:00:00	10.6	13-May-94	10:00:00	8.4
16-Apr-94	18:00:00	8.3	30-Apr-94	03:00:00	10.3	13-May-94	11:00:00	8.4
16-Apr-94	19:00:00	8.2	30-Apr-94	04:00:00	9.8	13-May-94	12:00:00	8.3
16-Apr-94	20:00:00	8.1	30-Apr-94	05:00:00	9.3	13-May-94	13:00:00	8.4
16-Apr-94	21:00:00	8.1	30-Apr-94	06:00:00	8.7	13-May-94	14:00:00	8.3
16-Apr-94	22:00:00	8.3	30-Apr-94	07:00:00	8.1	13-May-94	15:00:00	8.2
16-Apr-94	23:00:00	8.5	30-Apr-94	08:00:00	8.0	13-May-94	16:00:00	8.2
17-Apr-94	00:00:00	9.0	30-Apr-94	09:00:00	7.8	13-May-94	17:00:00	8.4
17-Apr-94	01:00:00	9.2	30-Apr-94	10:00:00	7.7	13-May-94	18:00:00	8.1
17-Apr-94	02:00:00	9.2	30-Apr-94	11:00:00	7.9	13-May-94	19:00:00	8.1
17-Apr-94	03:00:00	9.0	30-Apr-94	12:00:00	8.1	13-May-94	20:00:00	7.9
17-Apr-94	04:00:00	8.7	30-Apr-94	13:00:00	8.5	13-May-94	21:00:00	7.9
17-Apr-94	05:00:00	8.3	30-Apr-94	14:00:00	8.6	13-May-94	22:00:00	7.6
17-Apr-94	06:00:00	7.9	30-Apr-94	15:00:00	8.9	13-May-94	23:00:00	7.6
17-Apr-94	07:00:00	7.6	30-Apr-94	16:00:00	9.0	14-May-94	00:00:00	7.6
17-Apr-94	08:00:00	7.3	30-Apr-94	17:00:00	9.3	14-May-94	01:00:00	7.3

17-Apr-94	09:00:00	7.1	30-Apr-94	18:00:00	9.5	14-May-94	02:00:00	7.1
17-Apr-94	10:00:00	7.1	30-Apr-94	19:00:00	9.8	14-May-94	03:00:00	7.0
17-Apr-94	11:00:00	7.2	30-Apr-94	20:00:00	10.0	14-May-94	04:00:00	6.9
17-Apr-94	12:00:00	7.3	30-Apr-94	21:00:00	10.2	14-May-94	05:00:00	6.9
17-Apr-94	13:00:00	7.4	30-Apr-94	22:00:00	10.4	14-May-94	06:00:00	6.9
17-Apr-94	14:00:00	7.4	30-Apr-94	23:00:00	10.5	14-May-94	07:00:00	7.2
17-Apr-94	15:00:00	7.6	01-May-94	00:00:00	10.4	14-May-94	08:00:00	7.6
17-Apr-94	16:00:00	7.8	01-May-94	01:00:00	10.3	14-May-94	09:00:00	7.8
17-Apr-94	17:00:00	8.0	01-May-94	02:00:00	10.0	14-May-94	10:00:00	8.2
17-Apr-94	18:00:00	8.1	01-May-94	03:00:00	9.8	14-May-94	11:00:00	8.2
17-Apr-94	19:00:00	8.2	01-May-94	04:00:00	9.5	14-May-94	12:00:00	8.7
17-Apr-94	20:00:00	8.1	01-May-94	05:00:00	9.2	14-May-94	13:00:00	8.9
17-Apr-94	21:00:00	8.1	01-May-94	06:00:00	8.9	14-May-94	14:00:00	9.2
17-Apr-94	22:00:00	8.2	01-May-94	07:00:00	8.5	14-May-94	15:00:00	9.3
17-Apr-94	23:00:00	8.1	01-May-94	08:00:00	8.4	14-May-94	16:00:00	9.5
18-Apr-94	00:00:00	8.4	01-May-94	09:00:00	8.1	14-May-94	17:00:00	9.6
18-Apr-94	01:00:00	8.5	01-May-94	10:00:00	8.1	14-May-94	18:00:00	9.8
18-Apr-94	02:00:00	8.5	01-May-94	11:00:00	7.9	14-May-94	19:00:00	10.0
18-Apr-94	03:00:00	8.5	01-May-94	12:00:00	8.1	14-May-94	20:00:00	10.0
18-Apr-94	04:00:00	8.4	01-May-94	13:00:00	8.7	14-May-94	21:00:00	10.0
18-Apr-94	05:00:00	8.1	01-May-94	14:00:00	9.2	14-May-94	22:00:00	10.0
18-Apr-94	06:00:00	7.9	01-May-94	15:00:00	9.4	14-May-94	23:00:00	9.8
18-Apr-94	07:00:00	7.9	01-May-94	16:00:00	9.6	15-May-94	00:00:00	9.4
18-Apr-94	08:00:00	7.8	01-May-94	17:00:00	9.8	15-May-94	01:00:00	9.2
18-Apr-94	09:00:00	7.7	01-May-94	18:00:00	9.8	15-May-94	02:00:00	8.9
18-Apr-94	10:00:00	7.6	01-May-94	19:00:00	9.9	15-May-94	03:00:00	8.6
18-Apr-94	11:00:00	7.8	01-May-94	20:00:00	10.0	15-May-94	04:00:00	8.5
18-Apr-94	12:00:00	7.9	01-May-94	21:00:00	10.0	15-May-94	05:00:00	8.4
18-Apr-94	13:00:00	8.1	01-May-94	22:00:00	10.0	15-May-94	06:00:00	8.5
18-Apr-94	14:00:00	8.4	01-May-94	23:00:00	10.0	15-May-94	07:00:00	8.7
18-Apr-94	15:00:00	8.5	02-May-94	00:00:00	10.1	15-May-94	08:00:00	8.9
18-Apr-94	16:00:00	8.8	02-May-94	01:00:00	10.0	15-May-94	09:00:00	9.2
18-Apr-94	17:00:00	8.9	02-May-94	02:00:00	9.8	15-May-94	10:00:00	9.5
18-Apr-94	18:00:00	9.0	02-May-94	03:00:00	9.7	15-May-94	11:00:00	9.8
18-Apr-94	19:00:00	9.0	02-May-94	04:00:00	9.4	15-May-94	12:00:00	9.7
18-Apr-94	20:00:00	9.0	02-May-94	05:00:00	9.1	15-May-94	13:00:00	9.6
18-Apr-94	21:00:00	9.2	02-May-94	06:00:00	8.7	15-May-94	14:00:00	9.8
18-Apr-94	22:00:00	9.3	02-May-94	07:00:00	8.5	15-May-94	15:00:00	9.5
18-Apr-94	23:00:00	9.4	02-May-94	08:00:00	8.4	15-May-94	16:00:00	9.5
19-Apr-94	00:00:00	9.5	02-May-94	09:00:00	8.4	15-May-94	17:00:00	9.5
19-Apr-94	01:00:00	9.5	02-May-94	10:00:00	8.7	15-May-94	18:00:00	9.5
19-Apr-94	02:00:00	9.5	02-May-94	11:00:00	8.5	15-May-94	19:00:00	9.5
19-Apr-94	03:00:00	9.4	02-May-94	12:00:00	8.7	15-May-94	20:00:00	9.4
19-Apr-94	04:00:00	9.2	02-May-94	13:00:00	9.0	15-May-94	21:00:00	9.3
19-Apr-94	05:00:00	8.9	02-May-94	14:00:00	9.3	15-May-94	22:00:00	9.2
19-Apr-94	06:00:00	8.4	02-May-94	15:00:00	9.8	15-May-94	23:00:00	8.9
19-Apr-94	07:00:00	7.9	02-May-94	16:00:00	10.0	16-May-94	00:00:00	8.5
19-Apr-94	08:00:00	7.6	02-May-94	17:00:00	10.3	16-May-94	01:00:00	8.3
19-Apr-94	09:00:00	7.3	02-May-94	18:00:00	10.4	16-May-94	02:00:00	8.1
19-Apr-94	10:00:00	7.0	02-May-94	19:00:00	10.9	16-May-94	03:00:00	7.9
19-Apr-94	11:00:00	6.8	02-May-94	20:00:00	10.7	16-May-94	04:00:00	7.9
19-Apr-94	12:00:00	6.7	02-May-94	21:00:00	10.8	16-May-94	05:00:00	7.9

19-Apr-94	13:00:00	6.7	02-May-94	22:00:00	10.8	16-May-94	06:00:00	8.0
19-Apr-94	14:00:00	7.1	02-May-94	23:00:00	10.7	16-May-94	07:00:00	8.1
19-Apr-94	15:00:00	7.4	03-May-94	00:00:00	10.6	16-May-94	08:00:00	8.2
19-Apr-94	16:00:00	7.9	03-May-94	00:00:00	10.3	16-May-94	09:00:00	8.4
19-Apr-94	17:00:00	8.1	03-May-94	01:00:00	9.8	16-May-94	10:00:00	8.5
19-Apr-94	18:00:00	8.4	03-May-94	02:00:00	9.3	16-May-94	11:00:00	8.5
19-Apr-94	19:00:00	8.7	03-May-94	03:00:00	8.9	16-May-94	12:00:00	8.6
19-Apr-94	20:00:00	9.0	03-May-94	04:00:00	8.4	16-May-94	13:00:00	8.7
19-Apr-94	21:00:00	9.2	03-May-94	05:00:00	7.9	16-May-94	14:00:00	8.7
19-Apr-94	22:00:00	9.4	03-May-94	06:00:00	7.6	16-May-94	15:00:00	8.7
19-Apr-94	23:00:00	9.5	03-May-94	07:00:00	7.6	16-May-94	16:00:00	8.7
20-Apr-94	00:00:00	9.6	03-May-94	08:00:00	7.6	16-May-94	17:00:00	8.6
20-Apr-94	01:00:00	9.8	03-May-94	09:00:00	7.8	16-May-94	18:00:00	8.9
20-Apr-94	02:00:00	9.8	03-May-94	10:00:00	7.8	16-May-94	19:00:00	9.0
20-Apr-94	03:00:00	9.8	03-May-94	11:00:00	8.1	16-May-94	20:00:00	8.9
20-Apr-94	04:00:00	9.3	03-May-94	12:00:00	8.2	16-May-94	21:00:00	9.2
20-Apr-94	05:00:00	9.0	03-May-94	13:00:00	8.5	16-May-94	22:00:00	9.2
20-Apr-94	06:00:00	8.4	03-May-94	14:00:00	8.9	16-May-94	23:00:00	9.0
20-Apr-94	07:00:00	8.1	03-May-94	15:00:00	9.6	17-May-94	00:00:00	8.8
20-Apr-94	08:00:00	7.8	03-May-94	16:00:00	10.0	17-May-94	01:00:00	8.5
20-Apr-94	09:00:00	7.6	03-May-94	17:00:00	10.3	17-May-94	02:00:00	8.0
20-Apr-94	10:00:00	7.6	03-May-94	18:00:00	10.5	17-May-94	03:00:00	7.8
20-Apr-94	11:00:00	7.6	03-May-94	19:00:00	10.7	17-May-94	04:00:00	7.6
20-Apr-94	12:00:00	7.9	03-May-94	20:00:00	10.8	17-May-94	05:00:00	7.6
20-Apr-94	13:00:00	8.2	03-May-94	21:00:00	10.8	17-May-94	06:00:00	7.6
20-Apr-94	14:00:00	8.5	03-May-94	22:00:00	10.7	17-May-94	07:00:00	7.6
20-Apr-94	15:00:00	8.7	03-May-94	23:00:00	10.6	17-May-94	08:00:00	7.9
20-Apr-94	16:00:00	9.1	04-May-94	00:00:00	10.3	17-May-94	09:00:00	8.1
20-Apr-94	17:00:00	9.4	04-May-94	01:00:00	10.0	17-May-94	10:00:00	8.4
20-Apr-94	18:00:00	9.7	04-May-94	02:00:00	9.6	17-May-94	11:00:00	8.5
20-Apr-94	19:00:00	9.9	04-May-94	03:00:00	9.0	17-May-94	12:00:00	8.5
20-Apr-94	20:00:00	10.0	04-May-94	04:00:00	8.5	17-May-94	13:00:00	8.7
20-Apr-94	21:00:00	10.3	04-May-94	05:00:00	7.9	17-May-94	14:00:00	8.9
20-Apr-94	22:00:00	10.5	04-May-94	06:00:00	7.6	17-May-94	15:00:00	8.9
20-Apr-94	23:00:00	10.6	04-May-94	07:00:00	7.6	17-May-94	16:00:00	8.9
21-Apr-94	00:00:00	10.6	04-May-94	08:00:00	7.6	17-May-94	17:00:00	9.0
21-Apr-94	01:00:00	10.5	04-May-94	09:00:00	7.8	17-May-94	18:00:00	8.9
21-Apr-94	02:00:00	10.3	04-May-94	10:00:00	8.1	17-May-94	19:00:00	8.7
21-Apr-94	03:00:00	10.0	04-May-94	11:00:00	8.5	17-May-94	20:00:00	8.6
21-Apr-94	04:00:00	9.8	04-May-94	12:00:00	8.7	17-May-94	21:00:00	8.4
21-Apr-94	05:00:00	9.3	04-May-94	13:00:00	9.1	17-May-94	22:00:00	8.1
21-Apr-94	06:00:00	8.9	04-May-94	14:00:00	9.5	17-May-94	23:00:00	8.1
21-Apr-94	07:00:00	8.5	04-May-94	15:00:00	9.9	18-May-94	00:00:00	7.9
21-Apr-94	08:00:00	8.2	04-May-94	16:00:00	10.3	18-May-94	01:00:00	7.6
21-Apr-94	09:00:00	8.1	04-May-94	17:00:00	10.5	18-May-94	02:00:00	7.4
21-Apr-94	10:00:00	8.1	04-May-94	18:00:00	10.9	18-May-94	03:00:00	7.3
21-Apr-94	11:00:00	8.5	04-May-94	19:00:00	11.3	18-May-94	04:00:00	7.1
21-Apr-94	12:00:00	8.6	04-May-94	20:00:00	11.6	18-May-94	05:00:00	7.1
21-Apr-94	13:00:00	8.9	04-May-94	21:00:00	11.8	18-May-94	06:00:00	6.9
21-Apr-94	14:00:00	9.1	04-May-94	22:00:00	11.8	18-May-94	07:00:00	7.0
21-Apr-94	15:00:00	9.4	04-May-94	23:00:00	11.8	18-May-94	08:00:00	6.9
21-Apr-94	16:00:00	9.7	05-May-94	00:00:00	11.5	18-May-94	09:00:00	7.1

21-Apr-94	17:00:00	10.1	05-May-94	01:00:00	11.1	18-May-94	10:00:00	7.3
21-Apr-94	18:00:00	10.6	05-May-94	02:00:00	10.6	18-May-94	11:00:00	7.3
21-Apr-94	19:00:00	10.8	05-May-94	03:00:00	10.2	18-May-94	12:00:00	7.3
21-Apr-94	20:00:00	10.8	05-May-94	04:00:00	9.8	18-May-94	13:00:00	5.7
21-Apr-94	21:00:00	10.9	05-May-94	05:00:00	9.3	18-May-94	14:00:00	6.0
21-Apr-94	22:00:00	11.0	05-May-94	06:00:00	9.0	18-May-94	15:00:00	7.6
21-Apr-94	23:00:00	10.9	05-May-94	07:00:00	9.0	18-May-94	16:00:00	8.1
22-Apr-94	00:00:00	10.8	05-May-94	08:00:00	9.0	18-May-94	17:00:00	9.7
22-Apr-94	01:00:00	10.6	05-May-94	09:00:00	9.2	18-May-94	18:00:00	10.0
22-Apr-94	02:00:00	10.2	05-May-94	10:00:00	9.3	18-May-94	19:00:00	9.7
22-Apr-94	03:00:00	9.8	05-May-94	11:00:00	9.7	18-May-94	20:00:00	9.0
22-Apr-94	04:00:00	9.3	05-May-94	12:00:00	10.0	18-May-94	21:00:00	8.2
22-Apr-94	05:00:00	8.9	05-May-94	13:00:00	10.4	18-May-94	22:00:00	7.1
22-Apr-94	06:00:00	8.3	05-May-94	14:00:00	10.8	18-May-94	23:00:00	5.8

APPENDIX F: **Raw water chemistry data, Hinton flume experiment spring, 1994.**

Note: -1.0 = not requested; -5 = below detection

Trough #	Treatment	Date	NO_3	NH_3	SRP	TP	TDP
1	25	10-Apr-94	-1.0	-1.0	3.3	-1.0	3.5
2	10	10-Apr-94	-1.0	-1.0	1.6	-1.0	1.7
3	1	10-Apr-94	-1.0	-1.0	1.1	-1.0	1.2
4	0	10-Apr-94	-1.0	-1.0	1.1	-1.0	2.2
5	25	10-Apr-94	-1.0	-1.0	3.9	-1.0	4.7
6	1	10-Apr-94	-1.0	-1.0	1.0	-1.0	1.6
7	10	10-Apr-94	-1.0	-1.0	1.5	-1.0	2.8
8	1	10-Apr-94	-1.0	-1.0	0.9	-1.0	1.8
9	0	10-Apr-94	-1.0	-1.0	0.8	-1.0	2.2
10	10	10-Apr-94	-1.0	-1.0	2.0	-1.0	2.7
11	0	10-Apr-94	-1.0	-1.0	0.8	-1.0	5.8
12	25	10-Apr-94	-1.0	-1.0	2.5	-1.0	5.4
HEAD		10-Apr-94	58.1	9.7	1.1	12.0	1.3
1	25	21-Apr-94	-1.0	-1.0	18.8	-1.0	-1.0
2	10	21-Apr-94	-1.0	-1.0	10.6	-1.0	-1.0
3	1	21-Apr-94	-1.0	-1.0	3.6	-1.0	-1.0
4	0	21-Apr-94	-1.0	-1.0	2.8	-1.0	-1.0
5	25	21-Apr-94	-1.0	-1.0	21.0	-1.0	-1.0
6	1	21-Apr-94	-1.0	-1.0	3.6	-1.0	-1.0
7	10	21-Apr-94	-1.0	-1.0	12.2	-1.0	-1.0
8	1	21-Apr-94	-1.0	-1.0	3.3	-1.0	-1.0
9	0	21-Apr-94	-1.0	-1.0	2.8	-1.0	-1.0
10	10	21-Apr-94	-1.0	-1.0	15.2	-1.0	-1.0
11	0	21-Apr-94	-1.0	-1.0	3.2	-1.0	-1.0
12	25	21-Apr-94	-1.0	-1.0	21.8	-1.0	-1.0
HEAD		21-Apr-94	53.3	20.2	2.8	37.6	1.8
1	25	27-Apr-94	-1.0	-1.0	19.1	-1.0	-1.0
2	10	27-Apr-94	-1.0	-1.0	10.6	-1.0	-1.0
3	1	27-Apr-94	-1.0	-1.0	3.2	-1.0	-1.0
4	0	27-Apr-94	-1.0	-1.0	2.0	-1.0	-1.0
5	25	27-Apr-94	-1.0	-1.0	20.1	-1.0	-1.0
6	1	27-Apr-94	-1.0	-1.0	3.0	-1.0	-1.0
7	10	27-Apr-94	-1.0	-1.0	9.6	-1.0	-1.0
8	1	27-Apr-94	-1.0	-1.0	3.2	-1.0	-1.0
9	0	27-Apr-94	-1.0	-1.0	2.9	-1.0	-1.0
10	10	27-Apr-94	-1.0	-1.0	11.3	-1.0	-1.0
11	0	27-Apr-94	-1.0	-1.0	2.6	-1.0	-1.0
12	25	27-Apr-94	-1.0	-1.0	19.6	-1.0	-1.0
HEAD		27-Apr-94	44.8	7.4	1.8	24.6	3.2
1	25	04-May-94	-1.0	-1.0	22.3	-1.0	-1.0
2	10	04-May-94	-1.0	-1.0	9.4	-1.0	-1.0
3	1	04-May-94	-1.0	-1.0	2.0	-1.0	-1.0
4	0	04-May-94	-1.0	-1.0	1.8	-1.0	-1.0
5	25	04-May-94	-1.0	-1.0	26.8	-1.0	-1.0
6	1	04-May-94	-1.0	-1.0	2.1	-1.0	-1.0

7	10	04-May-94	-1.0	-1.0	9.7	-1.0	-1.0
8	1	04-May-94	-1.0	-1.0	1.8	-1.0	-1.0
9	0	04-May-94	-1.0	-1.0	1.4	-1.0	-1.0
10	10	04-May-94	-1.0	-1.0	11.4	-1.0	-1.0
11	0	04-May-94	-1.0	-1.0	1.7	-1.0	-1.0
12	25	04-May-94	-1.0	-1.0	29.8	-1.0	-1.0
HEAD		04-May-94	64.1	165.0	1.4	43.1	3.5
1	25	12-May-94	-1.0	-1.0	28.3	-1.0	-1.0
2	10	12-May-94	-1.0	-1.0	10.9	-1.0	-1.0
3	1	12-May-94	-1.0	-1.0	2.4	-1.0	-1.0
4	0	12-May-94	-1.0	-1.0	1.8	-1.0	-1.0
5	25	12-May-94	-1.0	-1.0	32.5	-1.0	-1.0
6	1	12-May-94	-1.0	-1.0	2.0	-1.0	-1.0
7	10	12-May-94	-1.0	-1.0	11.2	-1.0	-1.0
8	1	12-May-94	-1.0	-1.0	2.1	-1.0	-1.0
9	0	12-May-94	-1.0	-1.0	1.5	-1.0	-1.0
10	10	12-May-94	-1.0	-1.0	11.5	-1.0	-1.0
11	0	12-May-94	-1.0	-1.0	1.2	-1.0	-1.0
12	25	12-May-94	-1.0	-1.0	32.8	-1.0	-1.0
HEAD		12-May-94	89.9	17.7	1.7	-1.0	-1.0
1	25	18-May-94	-1.0	-1.0	20.1	-1.0	-1.0
2	10	18-May-94	-1.0	-1.0	8.3	-1.0	-1.0
3	1	18-May-94	-1.0	-1.0	3.1	-1.0	-1.0
4	0	18-May-94	-1.0	-1.0	2.3	-1.0	-1.0
5	25	18-May-94	-1.0	-1.0	30.3	-1.0	-1.0
6	1	18-May-94	-1.0	-1.0	2.4	-1.0	-1.0
7	10	18-May-94	-1.0	-1.0	8.6	-1.0	-1.0
8	1	18-May-94	-1.0	-1.0	2.3	-1.0	-1.0
9	0	18-May-94	-1.0	-1.0	2.3	-1.0	-1.0
10	10	18-May-94	-1.0	-1.0	8.1	-1.0	-1.0
11	0	18-May-94	-1.0	-1.0	1.6	-1.0	-1.0
12	25	18-May-94	-1.0	-1.0	27.5	-1.0	-1.0
HEAD		18-May-94	84.3	6.6	2.5	24.9	2.7