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Investigation into the Benthic Vegetation of the
Upper Waikato River, New Zealand.

A thesis
submitted as a partial fulfilment
of the requirements of the Degree of
Master of Science in Biological Science
at the
University of Waikato
by

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University of Waikato
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Plate 1. The Upper Waikato River, showing the Taupo Borough-Pollution Control Plant (TB-PCP) and the diffuser structure which discharges treated sewage to this river, November 1989. Note the marginal growths of *Enteromorpha* on exposed river margins. Photo was taken when the river level was lowered for the purposes of aerial photography.

diffuser structure





Plate 2. Epiphytic *Enteromorpha* growths on exposed low-mixed associations and *Lagarosiphon major* beds. Photo was taken approximately 300m below the TB-PCP discharge looking upstream (right bank) towards Cherry Island, Upper Waikato River, November 1989. Photo was taken when the river level was lowered for the purposes of aerial photography.

ABSTRACT

The discharge of treated sewage from the Taupo Borough-Pollution Control Plant was associated with a dramatic change in downstream phytobenthos associations found in the Upper Waikato River. Displacement of epilithic moss assemblages by *Cladophora*, and domination of epiphyte habitats by *Enteromorpha* were observed downstream of this discharge. In essence, this situation is a species replacement series in response to a changing water quality gradient attributable to the inflow of treated sewage.

Aerial photographs, transect surveys and and drift diving showed that the extent of phytobenthos development through the entire length of the Upper Waikato River was primarily limited by substrate availability. Areas of gravel/pebble/sand were not immobile long enough in current flow to allow for the development of macroscopic vegetation either up- or downstream of the sewage discharge. However, there were similar stable habitats for phytobenthos development both up- and downstream of the sewage discharge. The greatest change in water quality attributable to the TB-PCP discharge was increase in both $\text{NH}_4\text{-N}$ (relative significance to all loads 61.5%) and DRP (relative significance to all loads 55.6%). However, even below the TB-PCP discharge average concentrations of $\text{NH}_4\text{-N}$ (ca. 10 mg m^{-3}) and DRP (ca. 4 mg m^{-3}) were still low and water may still be classified as oligotrophic. The ratio of $\text{TN-DON}:\text{TP-DOP}$ is low in water leaving Lake Taupo (10.4), the inflow from the TBB-PCP sewage discharge further decreases this ratio to 6.2, measured at

Reid's Farm. A prediction of ^{from} nitrogen limitation of algal growth was made from these low ratios.

Nutritional studies of *Oedogonium* upstream of the TB-PCP sewage discharge supported the hypothesis of N limitation derived from N:P ratios. *Oedogonium* consistently exhibited tissue nitrogen levels below critical values. The same nutritional studies applied to *Enteromorpha* and *Cladophora* growths downstream of the TB-PCP sewage discharge showed that neither species was consistently limited by available N or P nutrients, and both species showed a greater susceptibility to N limitation. This was not expected from the predictions based on N:P ratios. *Enteromorpha* and *Cladophora* may be able to sustain adequate tissue N levels by maintaining high uptake rates. Both AAR and PUR rates were high for these species in the NATS monitoring programme. However, due to the high pulse concentration and the static nature of these techniques, results are not likely to be indicative of in-situ conditions. These results merely indicate that the algae have the capacity for high uptake rates. A greater relative importance of N compared to P inputs from the TB-PCP discharge for *Enteromorpha* and *Cladophora* growth was concluded from the pilot algae transplant experiment. Phosphorus tissue NATS did not show P limitation of upstream transplants after one and two weeks, compared to decreases in N tissue tests below critical levels. Results from this transplant experiment support the hypothesis that N concentrations in the Upper Waikato River above the TB-PCP discharge may be too low to support significant *Enteromorpha* and *Cladophora* growths. The increase in ammoniacal nitrogen from the TB-PCP discharge may represent a critical change for periphytic algal growth, given the physical environs of this river.

Three new techniques have been trialled in this study:

- # use of a chain transect to survey phytobenthos of a deep, swift flowing river,

- # use of $\delta^{15}\text{N}$ signatures of plants growing up- and downstream of a point-source discharge in order to ascertain the extent of effluent N nutrient utilisation by plants growing downstream of the sewage discharge,

- # algae transplant experiment as a method for examining the relative importance of increased nutrient loads to changes in phytobenthos correlated to the inflow from point-source discharges.

Preliminary application of these techniques has been useful in the Upper Waikato River to describe the biological impact of the TB-PCP discharge on benthic vegetation.

In the Upper Waikato River phytobenthos associations found below the TB-PCP sewage discharge during 1989-1990 are not consistent with the 'oligotrophic plant assemblage' described by Coffey (1979). A major habitat degradation in the Upper Waikato River has occurred and is associated with the inflow from the Taupo Borough-Pollution Control Plant. No change in Coffey's (1979) classification of 'oligotrophic plant assemblage' of the Waikato River from the Lake Taupo Control Gates to the upstream end of the point of inflow of the TB-PCP sewage discharge was concluded from this study.

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STUDY INTRODUCTION

This study is an investigation into the benthic vegetation of the Upper Waikato River, New Zealand.

The Waikato River is New Zealand's longest river with the Upper Waikato River forming the first 5.85 km, from the outlet at Lake Taupo to the Huka Falls (Figures 1 and 2). There are five point-source discharges to this reach of river; a treated sewage discharge and four stream inflows, one of which (Huka Falls Stream) has been used as an industrial waste discharge from Fletcher Wood Panels Limited, Taupo up until mid-1989 (Figure 2).

The impact of these discharges on in-situ biota is of concern to the Waikato Regional Council (formerly the Waikato Catchment Board). Increases in benthic algae downstream of the treated sewage discharge and an absence of plants in the initial mixing zone of the Fletcher Wood Panel's discharge with the river have been reported (Coffey and Miller, (1987); Miller et al, (1988). The previous studies provided preliminary descriptions of in-situ summer phytobenthos with some standing crop estimates.

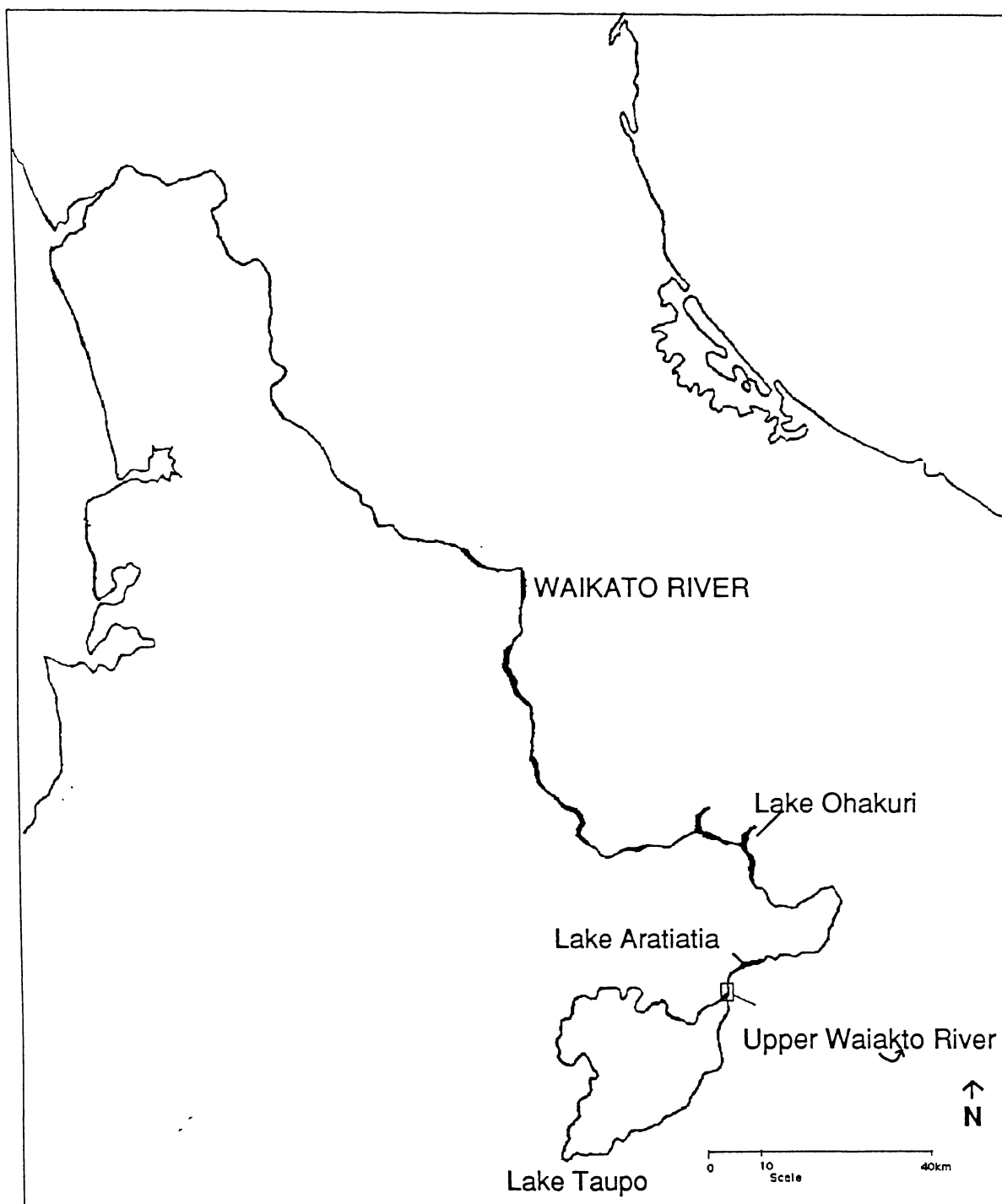


Figure 1. Map of the Waikato River and Lake Taupo showing the study area: the Upper Waikato River, North Island New Zealand.

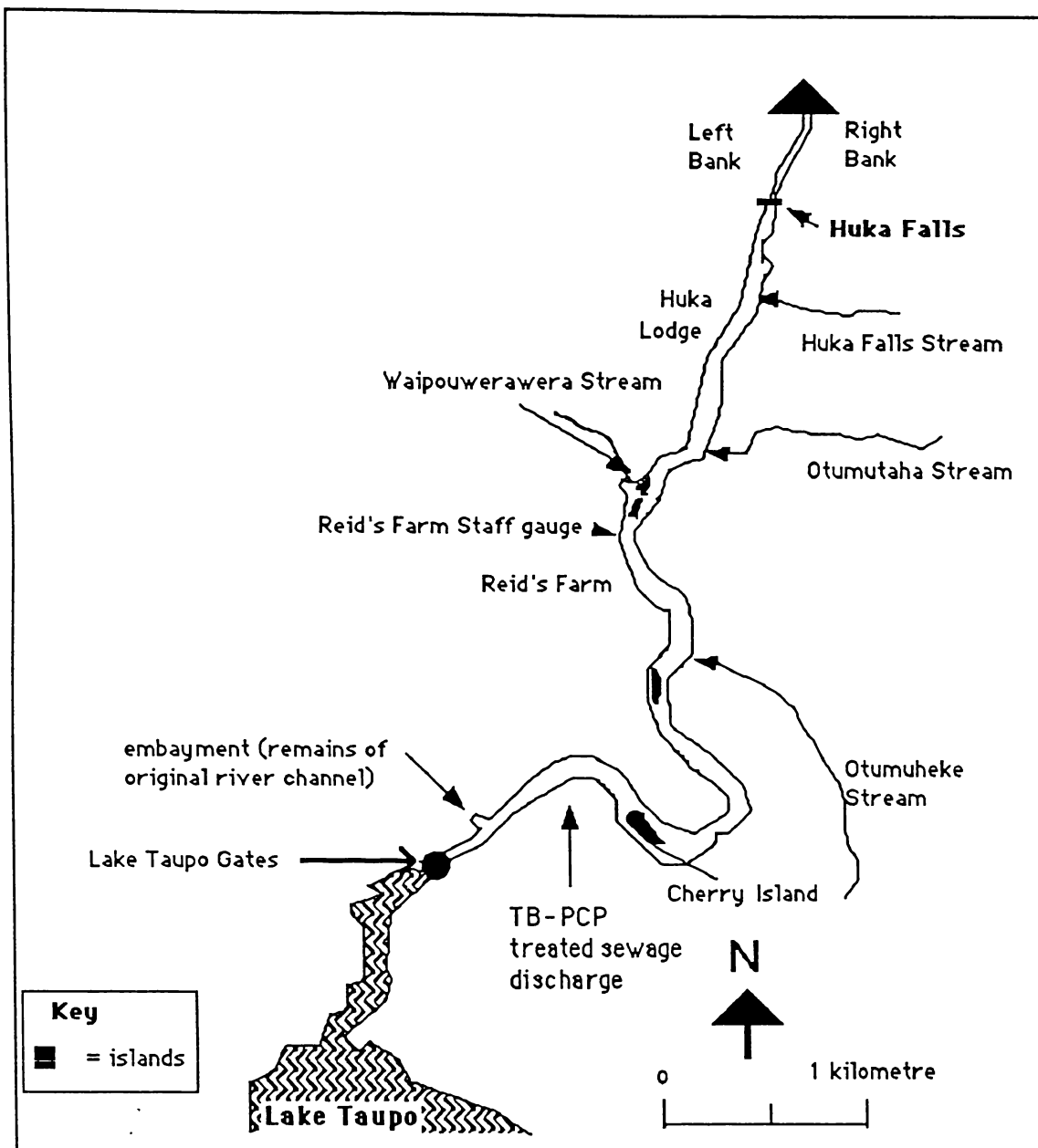


Figure 2. Locality map of Upper Waikato River study area, showing the inflow of major tributaries and the Taupo Borough - Pollution Control Plant (TB-PCP) discharge into this river with place names used in the text.

The Upper Waikato River is deep and fast flowing. In previous studies SCUBA divers were towed across the river by boat at various locations. Although this survey method allows detection of severe trends there is a major limitation incurred by lack of repeatability of diver passage across the river and this limitation precludes the application of this technique for monitoring purposes. A surveillance technique for phytobenthos in this reach of river was required by the Waikato Regional Council.

Significant inputs of nutrients (nitrogen and phosphorus) to the Upper Waikato River are due to the discharge of treated sewage from the Taupo Borough Pollution Control Plant (TB-PCP), (Huser, 1987). This coincides with increases in periphytic algal abundance downstream of this discharge (Miller et al,1988). An understanding of the nature of these nutrient's role in the incidence and proliferation of periphytic algae in this reach of river was also required by the Waikato Regional Council.

The objectives of this study were to :

1. Document the distribution and abundance of benthic vegetation (summer and winter) in the Upper Waikato River.
2. Describe the biological impact of major point-source discharges (TB-PCP and tributaries) to the Upper Waikato River.
- 3 Trial the use of permanent transect methodology in a deep, fast flowing lotic environment and
4. asses the usefulness of this method as a surveillance technique for point-source discharge impact monitoring.

5. Investigate the role of nitrogen (N) and phosphorus (P) in the incidence and proliferation of dominant benthic algae in the Upper Waikato River.

The study area and the nature of discharges are described in Chapter One. The first four objectives are incorporated into Chapter Two, whilst the remaining objective is reported in Chapter Three. Chapter Four summarises the major findings of this investigation.

Chapter One : Study Area: UPPER WAIKATO
RIVER

1:1 Introduction

In order to understand and interpret the phytobenthos composition and the impact of nutrient inputs to the Upper Waikato River it is necessary to;

#place the Upper Waikato River in context to both Lake Taupo and the Waikato River as a whole (including relevant features of the catchments involved),

#review previous studies carried out on submerged aquatic flora in both Lake Taupo and the Waikato River,

#describe both the past and present water quality of the Upper Waikato River including all point-source discharges.

1:2 CATCHMENT CHARACTERISTICS

1:2.1 LAKE TAUPO and the WAIKATO RIVER

New Zealand's longest river, the Waikato River (length 425km), drains the country's largest lake, Lake Taupo (catchment area 3289km², lake area 623km², volume 59 km³). Basement strata of the Waikato region is comprised of Mesozoic "greywacke-type" rocks. This area has been affected by several different phases of volcanism. Remnants of lava flows from the Tongariro-Ruapehu complex form the ignimbrite sheets which today cover most of the mid-Waikato region. These have been overlain by pumiceous pyroclastic deposits from subsequent volcanic eruptions. Layers of ash have weathered to form the low fertility yellow brown pumice soils that dominate the study area (McBride et al, 1979). Significant geothermal activity occurs within

this area and shallow, geothermally influenced aquifers beneath Taupo (Tauhara Geothermal Field) are used for both domestic and commercial purposes (Huser, 1989).

The Waikato River is a highly valued recreational area and tourist attraction, and forms an important agricultural, industrial and domestic water resource as well as being a receiving water for a variety of both point-source and diffuse discharges generated from activities within the catchment. There are eight hydroelectric dams on the Waikato River, with an additional two geothermal and two thermal power stations sited along its length. The Waikato River becomes increasingly enriched with nitrogen and phosphorus from the Taupo Gates along its length to final outflow at Port Waikato (Neilson, 1979). Neilson (1979) showed that a considerable part of this enrichment occurred between the Taupo Gates and Lake Ohakuri (Figure 1), and that the major sources of these nutrients were agricultural and geothermal in origin. The discharge of treated sewage in the Upper Waikato River, at this time, was noted as a large future nutrient load on the Waikato River. Coffey (1979) classified submerged plant and animal associations in this river reach, (from the Taupo Gates to the upstream end of Lake Ohakuri), as an oligotrophic assemblage.

1:2.2 UPPER WAIKATO RIVER

The Upper Waikato River has an immediate catchment area of 44km² which centres around the Taupo township (Figure 2). This area comprises predominantly rolling land with the exception of the multiple volcanic cones of Mt. Tauhara and the presence of deeply incised gullies (Huser, 1989). The residential and industrial area of Taupo township covers approximately 1/3 (15km²) of the total area (Huser, 1989). A mixture of scrub, indigenous/native forest and pastoral land cover the remainder of the catchment area. Blackberry, bracken, pines, willows and remnant native bush dominate the riparian vegetation along the Upper Waikato River, with a few wetland areas containing willows, and rushes (variously dominated by *Typha orientalis*, *Schoenoplectus validus*, *Eleocharis spp*), (Miller et al, 1988).

The river flow has been controlled at the Lake Taupo outlet since 1941 when the present channel was blown out of bedrock; an embayment on the left bank side forms the remains of the original channel (Figure 2). Flow is optimised for electricity generation and managed for flood control downstream, and can vary from no flow (eg. during a major flood) to a maximum flow of 330m³s⁻¹ (McBride et al, 1979). A marked diurnal discharge pattern is imposed on the Upper Waikato River due to electricity generation requirements. Flow is low overnight and is maximal from mid-morning through to evening (Figure 3). The mean flow at the Lake Taupo Gates was 155.5m³s⁻¹ (mean current velocity 1.5 ms⁻¹) for the period 1980-1989 (Huser, 1989 in prep).

Treated sewage is discharged from the TB-PCP 1.05km downstream of the Lake Taupo Control Gates via a diffuser structure

which extends approximately 30m out into the main channel (Plate 1). Cherry Island, 500m downstream of this sewage discharge, has been developed as a tourist attraction. Downstream of Cherry Island the river narrows and passes through a cliff lined area with marked geothermal activity on the right bank side (Hell's Gate). The Otumuheke Stream discharges warm geothermal waters from this area (Hell's Gate-Spa Thermal Park) to the river approximately 3.25km downstream from the control gates. This tributary is the largest of the four stream inflows entering this section of the Waikato River, and is fed by hot, sulphate rich springs and also receives significant amounts of steam heated groundwater along its course (Huser, 1989 in prep).

Draining the Tukairangi and Karapiti (Craters of the Moon) thermal areas, the Waipouwerawera Stream enters the river approximately 4.75km downstream of the control gates. This area provides camping and picnicking facilities (Reid's Farm), and is the site of a continuous flow recorder. A section of rapids in this area is regularly used by canoeists.

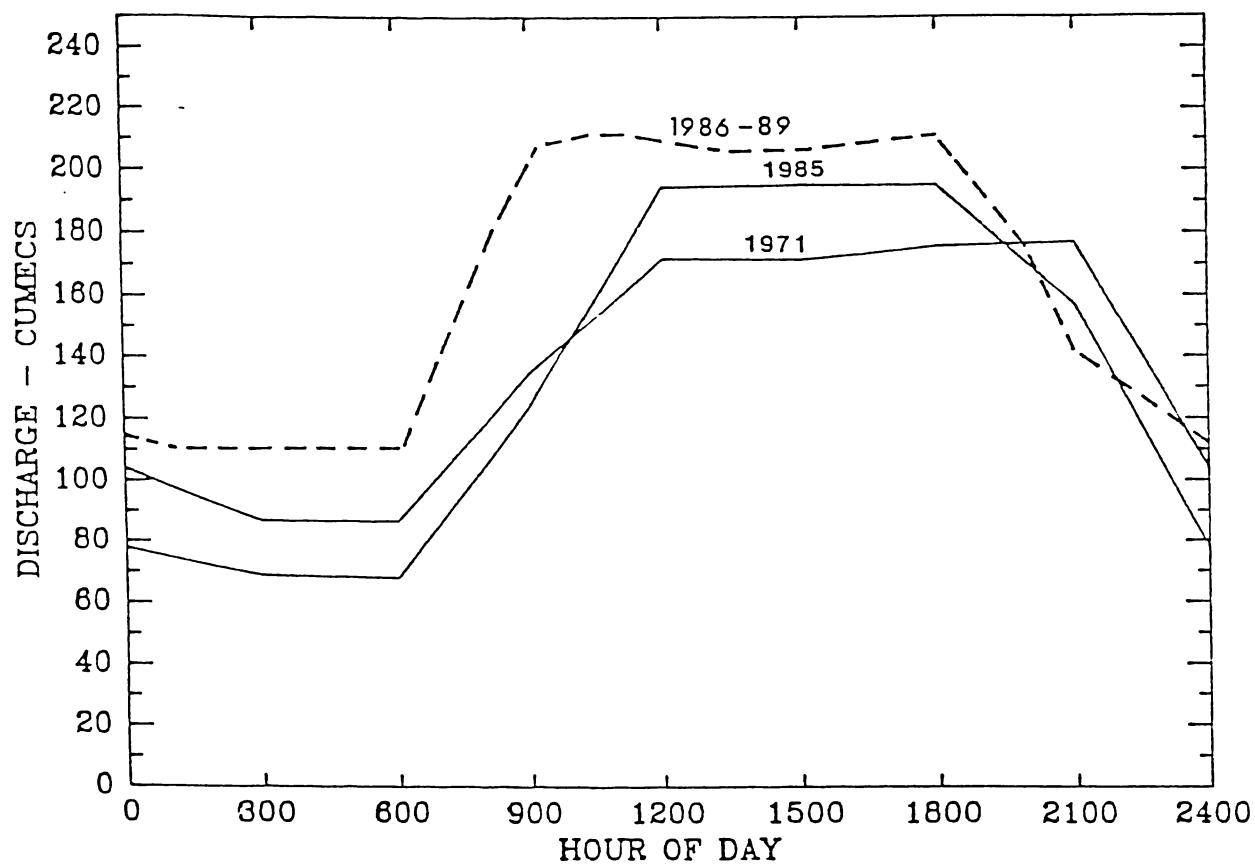


Figure 3. Discharge Profiles (1971, 1985 and 1986-1989) at the Lake Taupo Control Gates, from Huser (1989 in prep).

The Otumuhaha Stream, (Nursery Stream in Coffey and Miller, (1987); Miller et al, (1988)), enters the Upper Waikato River on the right bank side approximately 4.65km downstream of the control gates. This stream received effluent from Fletcher Wood Panels Ltd. up until 1989 when a change to land disposal was implemented and under new water right conditions, only stormwater overflow is now discharged to this stream. The Taupo District Council abstracts water for industrial and domestic use approximately 0.4km downstream of the inflow of the Otumuhaha Stream.

The Huka Lodge, a famous trout fishing attraction, is sited on the left bank approximately 5.05km downstream of the control gates. Directly opposite the lodge, the Huka Falls Stream enters the Upper Waikato River. Fed mainly by groundwater, this stream drains a forested gully (Huser, 1989 in prep).

The Upper Waikato River section ends with the spectacular Huka Falls, 5.85km downstream of the Lake Taupo Control Gates. The Waikato River continues past these falls and the Wairakei Geothermal Power Station to Lake Aratiatia, the first of the impounded hydroelectric dams.

1:3 Submerged Aquatic Flora of Lake Taupo and the Waikato River

Submerged aquatic flora (ie. excluding free floating macrophytes and emergent life forms), may be grouped into three major categories; phytoplankton, macrophytes and periphytic algae. The Department of Scientific and Industrial Research (DSIR) has carried out studies on phytoplankton and submerged macrophytes in Lake Taupo, and how they reflect and are influenced by water quality (eg. White and Payne, (1977); Vincent, (1983); White et al, (1980), (1985), (1986); Gibbs, (1987); Viner and White, (1987); Howard-Williams and Davies, (1988)). There have also been a number of investigations into the submerged macrophytes and phytoplankton in the Waikato River (eg. Hill, (1969), (1975); Magadza, (1973), (1978); Coffey, (1974), (1975), (1979); Lam (1979), (1981), Lam and Rhonberg (1979); Davis and Simons (1984); Bayly (1989)). Until recently river studies have focussed on the Lower Waikato River and on the eight impounded sections (hydroelectric dams).

1:3.1 PHYTOPLANKTON

Diatoms, (*Melosira spp*, *Asterionella formosa*) dominate the phytoplankton of Lake Taupo in winter with significant populations of *Botryococcus braunii* in summer (Viner and White, (1987); Vincent, (1983); Bayly, (1989)). Maximum biomass of phytoplankton occurs in winter and nitrogen has been implicated as the most likely limiting nutrient at this time, with phosphorus limitation more likely in the summer (White and Payne, 1977). This pattern of nutrient limitation is

attributed to higher relative phosphorus loadings, (due to the volcanic nature of the catchment) and the pattern of lake stratification (summer monomictic). In an overseas context, these findings are interesting and reflect a major influence of volcanic activity in the Taupo catchment. The majority of lakes studied overseas have implicated phosphorus as limiting growth with nitrogen usually being massively in excess of algal requirements (White, 1983).

The importance of biological coupling of the lentic and lotic parts of the L. Taupo and Waikato River System has been recently identified by Bayly (1989). The phytoplankton of the river is overwhelmingly dominated by diatoms (mainly *Melosira spp.*) (Lam, 1981). This study identified different nutrient limitation for different components of the phytoplankton; diatoms were not limited by the natural concentrations of nitrate and phosphate when the silica requirement was met, whilst N₂-fixing blue-green algae were limited by phosphate and the non-fixing blue-green and green algae limited by both nitrate and phosphate.

Huser (1989) confirmed the dominant influence of Lake Taupo on the composition of the phytoplankton in the Upper Waikato River. The fast flowing nature of this river section results in a travel time of approximately 1.5 hours from the outflow at Lake Taupo to the Huka Falls, which is insufficient time to allow for reproduction of algal cells (Huser, 1989). Therefore a direct, immediate impact on the phytoplankton by growth occurring within this river reach is unlikely (Huser, 1989). The impact of nutrients discharged to the Upper Waikato River on phytoplankton are therefore reflected by change downstream of this river section.

1:3.2 SUBMERGED MACROPHYTES

The successive invasion of both Lake Taupo and the Waikato River by the hydrocharitaceans; *Elodea canadensis*, *Lagarosiphon major*, *Egeria densa* (the latter with reference to the river only), and more recently by *Ceratophyllum demersum* has dominated the submerged macrophytic flora of these systems (Coffey, (1974); Howard-Williams and Davies, (1988)). These invasions have been associated with the displacement of native vegetation and growth of these weed species cause ongoing problems, such as clogging screens and restricting waterbody use (Coffey, (1974 and 1975); Johnstone, (1981); Howard-Williams and Davies (1988)). *Lagarosiphon major* was first recorded from Lake Taupo in 1966; by 1979 it had occupied most, if not all, potentially colonisable sites and is the dominant weed in Lake Taupo (Howard-Williams and Davies, 1988).

In relation to both Lake Taupo and the mid- to lower reaches of the Waikato River, the submerged macrophyte vegetation of the Upper Waikato River has received significantly less investigation. This may be due in part to the deep, swift flowing nature of this section of river and the logistical difficulties of working in such environments. The submerged macrophyte vegetation of the Waikato River from the Lake Taupo outlet to Lake Ohakuri, (which includes the present study area from the outlet to the Huka Falls), was characterised as an oligotrophic assemblage by Coffey (1979). *Elodea* was reported as the dominant submerged macrophyte in Coffey's Section 1 (approximately the present study area) with *Lagarosiphon* as the sub-dominant macrophyte from 1966 to 1974. Miller et al, (1988) reported *Lagarosiphon* as the dominant hydrocharitacean in the Upper Waikato River. It is likely that the change in dominance from *Elodea* to *Lagarosiphon* occurred during the same time as that reported by Howard-Williams and Davies (1988) for Lake Taupo. A full submerged macrophyte species list has not been

published for the Upper Waikato River prior to the present study, nor has vegetation distribution and structure been described.

1:3.3 PERIPHYTIC ALGAE

Apart from taxonomic observations, with in a few cases limited quantification (eg. Hill, (1970); Coffey, (1975); Forsyth and Howard-Williams (1983)), there has been little investigation into periphytic algae in either Lake Taupo or the Waikato River. Coffey (1979) noted the paucity of taxonomic and ecological data on periphyton in the Waikato River. This is true for New Zealand as a whole (Biggs and Price, 1987) and the need for research in this area has been identified (Cassie, (1979); Biggs and Price, (1987); Quinn and Hickey, (1987)). The proliferation of periphytic algae is often associated with nitrogen (N) and phosphorus (P) enrichment of water bodies (Round, 1981).

There have been numerous documented cases overseas of deterioration of lake, river/stream and estuarine/coastal water quality due to inflows from sewage discharges that result in nuisance levels of periphytic algal growth (eg Tewari, (1972); Koltz et al , (1976); Jupp and Spence, (1977); Mantai , (1978); Saldick and Coleridge, (1978); Ho, (1979); Birch et al , (1981); Schramm and Booth, (1981); Auer and Canale, (1982); Francke and Den Oude, (1983); Owens and Stewart, (1983); Wharfe et al, (1984); Bothwell, (1985); Soulsby, et al (1985) Richardson and Schwegler, (1986); Makinen and Aulio, (1986)).

Periphytic algal growth can cause numerous problems in water ways including; marked pH changes and dissolved oxygen fluctuations, taste and odour problems, asethetic degradation of the waterbody, interference with user activities, (eg swimming, fishing), clogging of intake filters, degradation of habitat for in-water users, (eg

smothering of trout spawning areas). Filamentous green algae, and in particular *Cladophora glomerata*, often dominate these nuisance growths downstream of sewage discharges in rivers. Extensive research effort has been invested overseas to identify principal factor(s) that cause these proliferations. Factors responsible for both the quantitative and qualitative changes on lotic flora include; temperature, light, water movements, substrates, nutrients and grazing. These factors do not act in isolation but interact and affect both the spatial and temporal distribution of periphytic algae.

Given suitable physical habitat, the input of readily assimilable nutrients, especially phosphate, ammonia and nitrate from discharges, are often implicated as causative factors in the incidence of algal proliferations. Further increased growth of these algal proliferations may be limited by one or more of these N/P macronutrients. Identification of possible limiting nutrient(s) is important in deciding the assimilative capacity of a particular waterbody for a discharge and for prediction of waterbody's response to possible changes in discharge loads. Overseas studies have often correlated increased P loadings with increased algal growth compared with areas not affected by discharges, and have often identified P nutrient levels in discharge sites as limiting further growth (eg Auer and Canale, 1980). The exact interaction between all factors, (physical, chemical and biotic), that affect algal growth is unique for each waterbody and its discharge and makes investigation of specific nuisance growths important.

DSIR is presently monitoring the biomass of *Enteromorpha* growths in Lake Taupo. (Howard-Williams pers comm). Nuisance growths of *Enteromorpha* in Lake Taupo are associated with groundwater contamination by both sewage and agricultural run-off.

Miller et al, (1988) reported *Enteromorpha* as the dominant periphytic algae downstream of the sewage discharge in the Upper Waikato River.

1:4 UPPER WAIKATO RIVER WATER QUALITY

Water quality of the Upper Waikato River is primarily determined by Lake Taupo, and is also influenced by point-source discharges (including tributaries), and may be affected by diffuse discharges to this reach and in-stream river processes. Previous investigations into the water quality of the Waikato River have been summarised in Strachan, (1979); Schouten et al, (1981); and Mulholland, (1987). More recently Huser (1987, 1989 and 1989 in prep) has investigated water quality in the Upper Waikato River from routine monitoring and diurnal surveys. Huser's data and draft report has kindly been made available for the duration of this study and the following descriptions of average water qualities of all sources represent results from monthly sampling from January, 1987 to August, 1989. The following notes have been synthesized from all of these publications, but mainly rely on the more recent studies by Huser, which serve to define the water quality of this section of the Waikato River from the Taupo Control Gates to the Huka Falls. Mass flows of nutrients to the Upper Waikato River from all sources is given in Table 1. The relative significance of N and P nutrient loads from all sources is discussed after consideration of their respective water quality.

Table 1. Mass flows of nutrients (both as kg/day and as percent of total) from all sources to the Waikato River.

Source	TN		NH ₄ -N		NO ₃ -N		TP		DRP	
	kg/day	%	kg/day	%	kg/day	%	kg/day	%	kg/day	%
Taupo Gates	1034.5	84.7	55.0	31.2	45.7	60.1	57.8	51.3	8.1	14.2
Tributaries	17.7	1.5	5.4	3.1	6.3	8.3	7.4	6.6	6.3	11.0
Groundwater	37.7	3.1	7.4	4.2	16.8	22.1	13.0	11.6	11.0	19.2
TB-PCP	131.0	10.7	108.1	61.5	7.2	9.5	34.3	30.5	31.8	55.6
TOTAL	1220.9	100	175.9	100	76.0	100	112.5	100	57.2	100

Note: Data from Huser (1989 in prep) which relates to water quality monitoring data from January, 1987 to August 1989. See Figure 2 for location of tributaries and the TB-PCP discharge. TN= Total Nitrogen, NH₄-N= ammoniacal nitrogen, NO₃-N= nitrate, TP= Total Phosphorus and DRP= Dissolved Reactive Phosphorus.

1:4.1 Water Quality at the Taupo Control Gates

Although selectively draining from the comparatively enriched north-eastern bays of Lake Taupo, the water leaving Lake Taupo is classified as oligotrophic (Neilson, (1979); Huser, (1989)). Routine monitoring of the entire river did not begin until the mid-1970s, with early work having concentrated on the lower reaches of the Waikato River (Strachan, (1979); Schouten et al, (1981)).

The following description of water quality is from measurements made during January, 1987 to August, 1989. Mean annual temperature was 15 °C with a range from 11 (August) - 20.5 °C (February/March). Water pH (largely determined by carbonate species), had a mean value over the study period of 7.5 units. The low mineral content of the water is illustrated by its low mean conductivity (11.0 mSm⁻³). Turbidity and suspended solids were low and reflect the buffering capacity of Lake Taupo on fluctuations in these parameters. Dissolved colour measurements at 270nm and 400nm on freshly filtered samples averaged 0.007 and 0.001 absorbance units which indicate very low amounts of UV-light absorbing organic material.

The influence of the lithology of the Taupo Basin, (rhyolite pumice and welded ignimbrite and ash) and geothermal activity was reflected in the major dissolved ionic constituents in the water at the Taupo Gates. Bicarbonate (largely originating from weathering processes by carbonic acid), was the major anionic species and combined with dissolved carbon dioxide accounted for most of the carbon in the river water. Mean total alkalinity was low (37g m⁻³) which makes the water susceptible to pH changes. Mean water hardness recorded at the Taupo Gates during the monitoring period was 28.6g m⁻³ which is indicative of New Zealand's soft waters. However, the water

is harder than many New Zealand freshwaters, presumably as a result of geothermal inputs. Calcium (mean concentration 6.5g m^{-3}) and magnesium (mean concentration 2.6g m^{-3}) contribute to over 95% of water hardness, and comparison of alkalinity and hardness showed that all the hardness is chemically associated with the carbonates and bicarbonates of these divalent cations (Huser, 1989 in prep). Mean concentrations of both sodium (13.1g m^{-3}) and potassium (4.1g m^{-3}) are about twice world average freshwater conditions. Chloride in the Upper Waikato River is mainly derived from rainwater and geothermal fluids. The mean chloride concentration (9.1g m^{-3}) was slightly higher than average world freshwaters. Mean sulphate concentration was 7.7g m^{-3} , which is similar to average world freshwater values. Hydrated silica, (mean concentration 21g m^{-3}), was high and typical of water from the central plateau of the North Island, presumably due to the influence of the pumice/ignimbrite catchment.

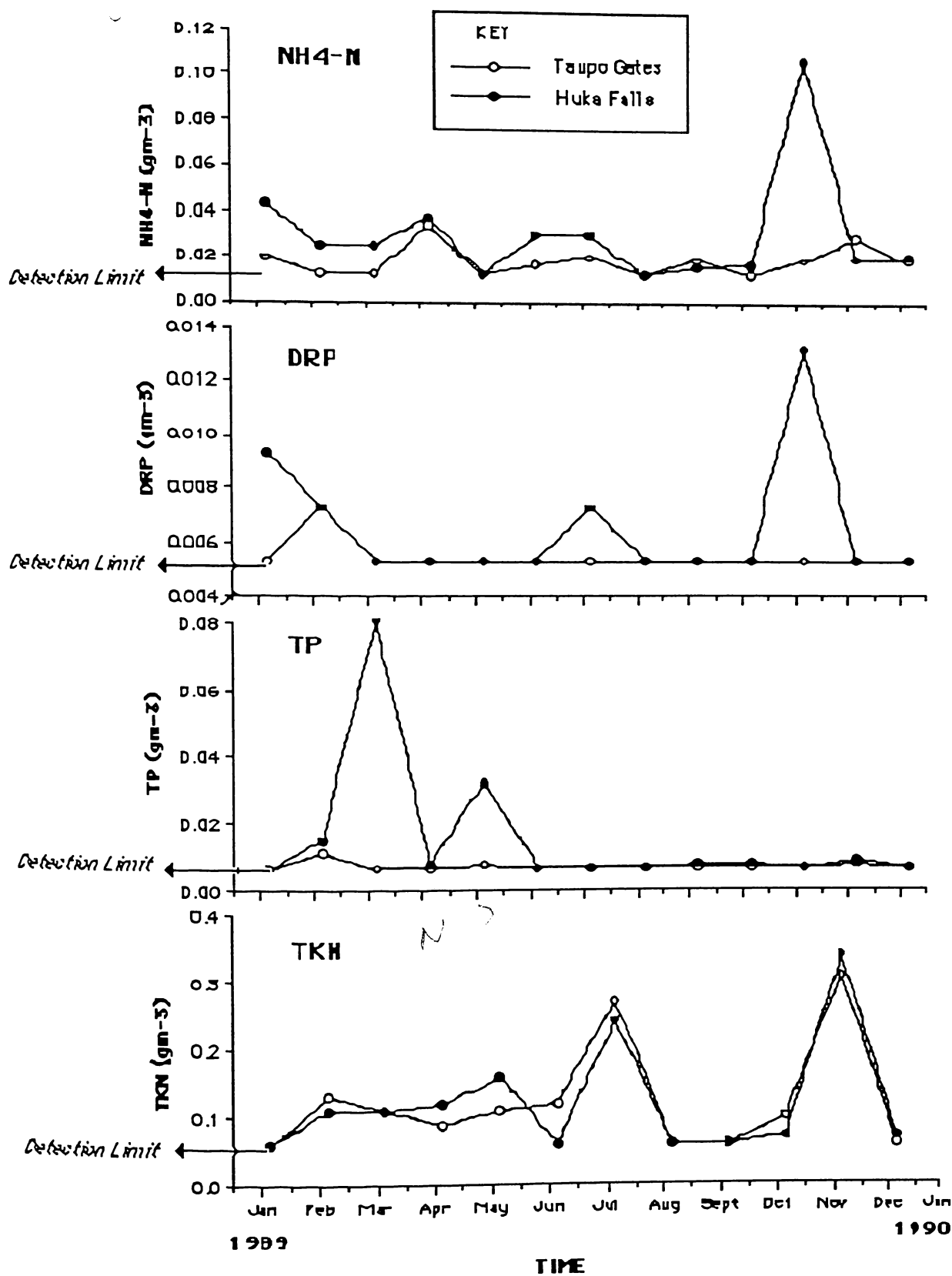
The influence of geothermal fluids and rhyolite pumice catchment also accounts for trace element composition in the Upper Waikato River water. Mean concentrations of trace elements were: boron - 0.18g m^{-3} , fluoride - 0.17g m^{-3} , arsenic - 0.010g m^{-3} , iron - $<0.020\text{g m}^{-3}$, manganese - $<0.020\text{g m}^{-3}$.

Dissolved oxygen (DO) concentrations at the Taupo Gates were near, or slightly above saturation, which is likely due to turbulence at the gates. Both Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) levels at the Taupo Control Gates were low (below 1g m^{-3}), indicating of the low organic matter content of water leaving Lake Taupo.

Lake Taupo acts as a sink for incoming P and N loads. All phosphorus nutrient species and nitrogen, (with the exception of Total Kjeldahl Nitrogen (TKN)) were near or below the limit of detection for

their respective forms (Figure 4). The mean percentage composition of N and P nutrients in water leaving Lake Taupo are illustrated in Figure 5. Dissolved organic nitrogen (DON) dominated the nitrogen component of water leaving Lake Taupo, while dissolved organic phosphorus (DOP) and particulate phosphorus (PP) dominated the phosphorus component.

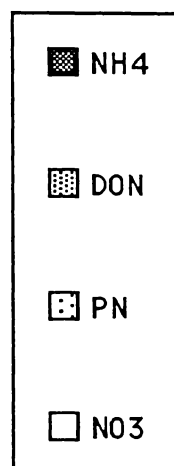
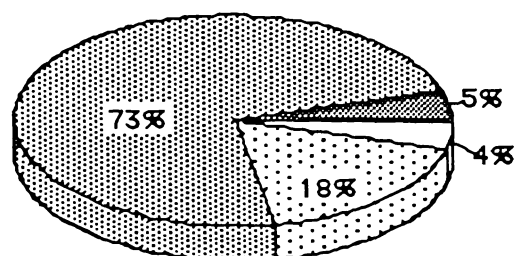
Figure 4. Concentrations of Ammoniacal Nitrogen ($\text{NH}_4\text{-N}$), Dissolved Reactive Phosphorus (DRP), Total Phosphorus (TP) and Total Keldjal Nitrogen (TKN) measured monthly from January, 1989 to January, 1990, at the Taupo Gates and at Huka Falls, Upper Waikato River.



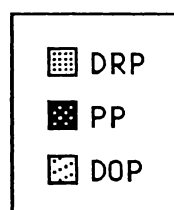
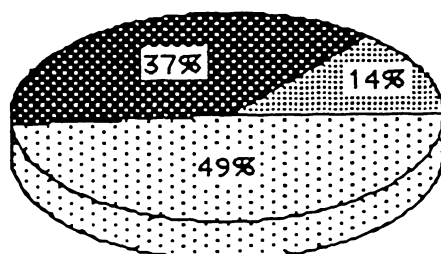
1989 1990
 1989 1990
 1989 1990

Figure 5. Percentage composition of Nitrogen and Phosphorus in water leaving Lake Taupo, (data from water quality monitoring January, 1987 to August, 1989 by the Waikato Regional Council), PN= particulate nitrogen, DON= dissolved organic nitrogen, $\text{NH}_4\text{-N}$ = ammoniacal nitrogen, $\text{NO}_3\text{-N}$ = nitrate nitrogen, DOP= dissolved organic phosphorus, DRP= dissolved reactive phosphorus, PP= particulate phosphorus.

NITROGEN



PHOSPHORUS



1:4.2 Tributary Water Quality

The points of inflow of the four tributaries (Otumuheke, Waipouwerawera, Otumuhaha and Huka Falls Streams) with the Upper Waikato River are illustrated in Figure 2. All tributaries are influenced by geothermal activity and dominated by groundwater input in this region, although to varying degrees. Water quality characteristics are summarised in Appendix 1 (data from Huser (1989 in prep)). Water quality data reported relate to monitoring from January, 1987 to August, 1989.

1:4.2.1 Otumuheke Stream

Mean flow was $0.115\text{m}^3\text{s}^{-1}$, with a mean temperature of $43.6\text{ }^{\circ}\text{C}$ reflecting the influence of hot geothermal fluids on this tributary. Comparitively high water hardness was due to increased levels of calcium and magnesium in spring waters. Levels of N and P nutrient species were high, also reflecting the dominating influence of geothermal spring waters.

1:4.2.2 Waipouwerawera Stream

A mean flow of $0.036\text{m}^3\text{s}^{-1}$ was recorded for this stream which recieves some geothermal fluids, reflected in slightly higher mean temperatures (25.7°C). The chemical composition was indicative of a minor input of geothermal fluid and levels suggested a surface stream dominated influence.

1:4.2.3 Otumuhaha Stream

Mean flow of this ephemeral stream was $0.022\text{m}^3\text{s}^{-1}$ and flow depended on the discharge from Fletcher Wood Panels Ltd. Likewise, the water quality of this stream at the point of inflow to the Upper Waikato River reflected the nature of this industrial discharge. Altered

disposal practices onto land since July, 1989 make the average water quality of this stream not particularly relevant to the present situation. Only stormwater overflow is discharged to the river at present.

1:4.2.4 Huka Falls Stream

Mean flow was $0.03\text{m}^3\text{s}^{-1}$ and the catchment included a large area of ephemeral headwaters. The discharge of geothermal fluids significantly affected the water quality of this stream. Moderate nutrient concentrations were present mainly as nitrate and phosphate.

1:4.3 Groundwater

Geothermal fluids from the Tauhara and Wairakei Geothermal Fields exert a significant influence on groundwater resources in the Upper Waikato River catchment, especially on tributary inflows. The Tauhara Field underlies the Taupo township, whilst the Wairakei Field affects the water quality of the Waipouwerawera Stream. Ascending geothermal fluid carries both heat and a distinctive chemical composition.

A groundwater resource exists outside the geothermal areas, which is primarily used for industrial water supplies and stock watering. Huser (1989 in prep) suggests the presence of "a perched, non-geothermal groundwater resource overlying an impermeable layer acting as an aquaclude". These soft waters have neutral pH and low amounts of dissolved minerals.

Groundwater beneath the Taupo township has been contaminated by septic tank effluent (Gibbs, 1979). Seepage of this groundwater into Lake Taupo and the Upper Waikato River carried significant amounts of nutrients, particularly dissolved inorganic N, which was associated with increased weed growth and algal slimes in Lake Taupo. With the

installation of the TB-PCP a significant decrease (approximately 50%) in nitrogen levels has been reported in most areas (Gibbs, 1988).

Nutrients from groundwater are difficult to quantify in a river system. Huser (1989 in prep) has estimated the groundwater component in all subcatchments to be greater than 50% of the theoretical discharge from the respective tributaries, which is consistent with the pumiceous, highly permeable soils in this area. The only exception to this was the Otumuhaha Stream, and the difference was attributed to the influence of the Fletcher's industrial discharge. Despite large error terms involved in these estimations, Huser (1989 in prep) concluded that they represented reasonable values as they compared well with other work carried out in the Taupo catchment. The significance of groundwater inflows is shown in Figure 15 and discussed later in this chapter in reference to all nutrient loads.

1.4.4 Sewage Discharge - Taupo Borough Council-Water Pollution Control Plant (TB-PCP)

Sewage disposal from the Taupo Township prior to the mid 1970's relied on the use of septic tanks. A change from septic tanks to coordinated disposal via a pollution control plant was formulated in the mid 1970s, resulting in the construction of the Taupo Borough Council Water Pollution Control Plant (TB-PCP). Commissioned in 1975, the plant was designed in three stages, and was extended to Stage 2 capacity (27,000 population equivalents), completed in 1987. The discharge is authorised under Water Right No. 850007 (Waikato Catchment Board). The plant is designed for an average dry flow of $7,400\text{m}^3\text{day}^{-1}$ and the water right allows the discharge of up to

28,750m³day⁻¹ (peak wet weather flow) of treated sewage for a period of five years from February, 1987.

The TB-PCP discharges treated sewage to the Upper Waikato River 1.05km downstream of the Lake Taupo Control Gates on the right bank side (NZMS 260 U18: 780 764, Figure 2, Plate 1).

The conditions of this water right require that:

- #the 5 day biochemical oxygen demand (BOD₅) load shall not exceed 238 kg per day (average),

- # the suspended solids (SS) load shall not exceed 250 kg per day (average),

- # the median faecal coliform (FC) and the median total coliform (TC) shall not exceed 3,000,000 per 100 ml and 15,000,000 per 100 ml respectively,

- # the average dry weather flow rate shall not exceed 5,000 m³ per day,

- # the grantee is required to monitor flow rate, BOD₅, SS, total nitrogen (TN), total phosphorus (TP), dissolved reactive phosphorus (DRP), FC and TC, (Huser 1987).

Treatment of incoming raw sewage is in five stages (Huser, 1987) and is schematically shown in Figure 6. Incoming raw sewage is passed through bar screens and grit removal facilities into a pre-aeration tank, followed by primary sedimentation in two parallel tanks. The effluent from this primary sedimentation is transferred to two high rate trickling filters containing stone media. This biological secondary treatment is designed to reduce the organic matter content (hence BOD) of the effluent (Huser, 1987). Finally, secondary sedimentation is achieved using a circular clarifier before the effluent is discharged to the Waikato River.

The Water Right monitoring data was made available for the duration of this study. Monitoring of the full suite of effluent quality parameters required by the water right began in July, 1987. Figures 7 to 11 illustrate the monitoring data from July, 1987 through to February, 1990. Overall trends in effluent quality can be summarised as follows:

Discharge Volume (Figure 7) varied from approximately $3,000\text{--}6,000\text{m}^3\text{day}^{-1}$ with an average of approximately $4,500\text{m}^3\text{day}^{-1}$ from July, 1987 to February, 1990. Peak discharge occurred during summer months which coincides with population increases in Taupo due to the influx of tourists and holiday-makers.

BOD₅ (Figure 8 a and b) concentration was variable (ca. $15\text{--}60\text{g.m}^{-3}$) and load varied from approximately $100\text{--}350\text{kg day}^{-1}$ with peak load occurring in the summer months.

Suspended Solids (Figure 9 a and b) concentration ranged from $10\text{--}35\text{g m}^{-3}$ with loads from $20\text{--}150\text{kg day}^{-1}$.

TN (Figure 10 a and b) concentration averaged ca. 35g m^{-3} . TN load also peaked in the summer months, overall average load was approximately 130kg day^{-1} .

TP (Figure 11 a and b) showed little fluctuation and was dominated by DRP (90% average). TP loads averaged approximately 35kg day^{-1} , with an average concentration of ca. 9g m^{-3} Total Phosphorus.

No significant changes in effluent composition and load pattern appear to have occurred from mid-1987 to January 1990.

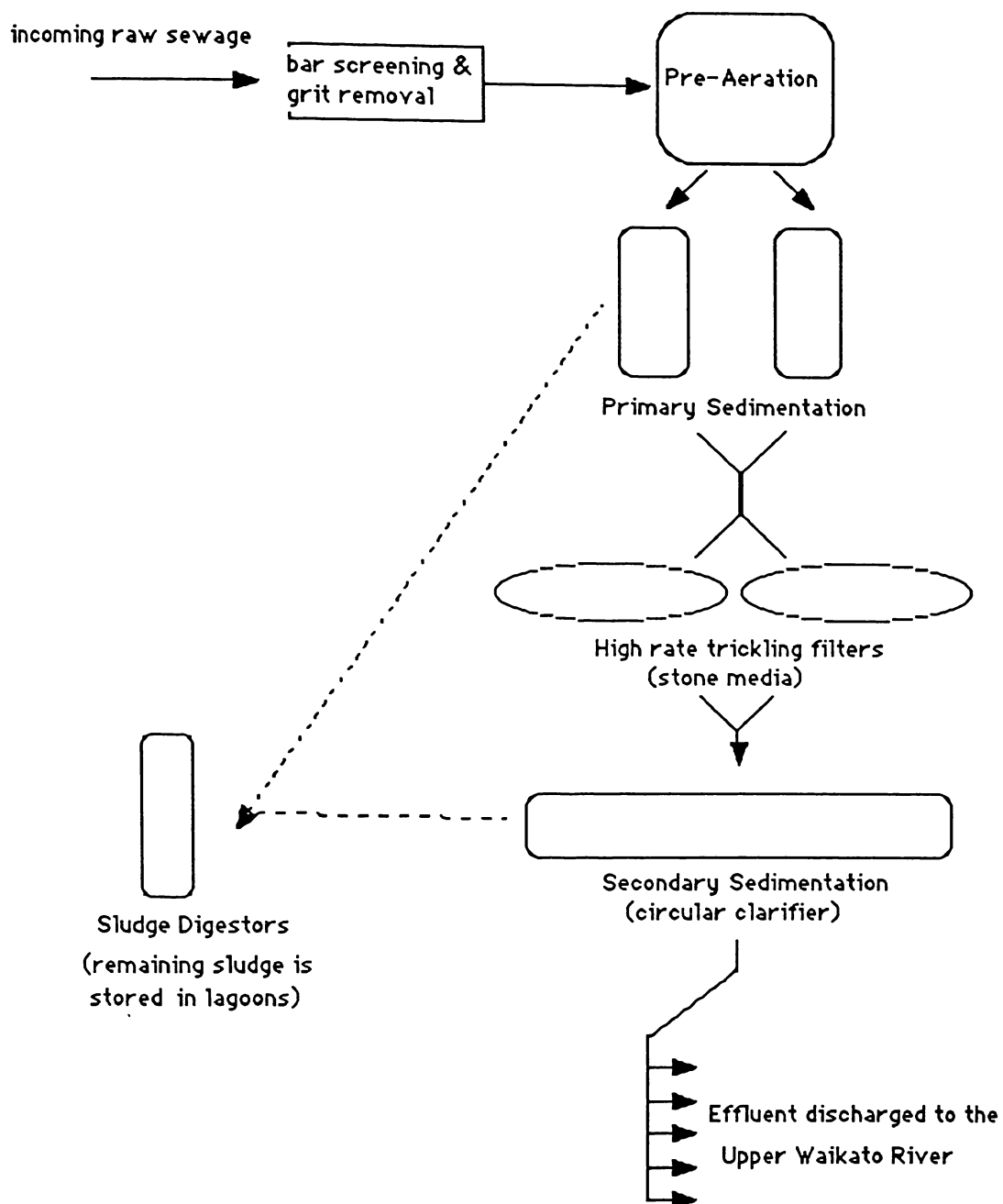


Figure 6. Schematic diagram of sewage processing at the Taupo Borough Pollution Control Plant (TB-PCP).

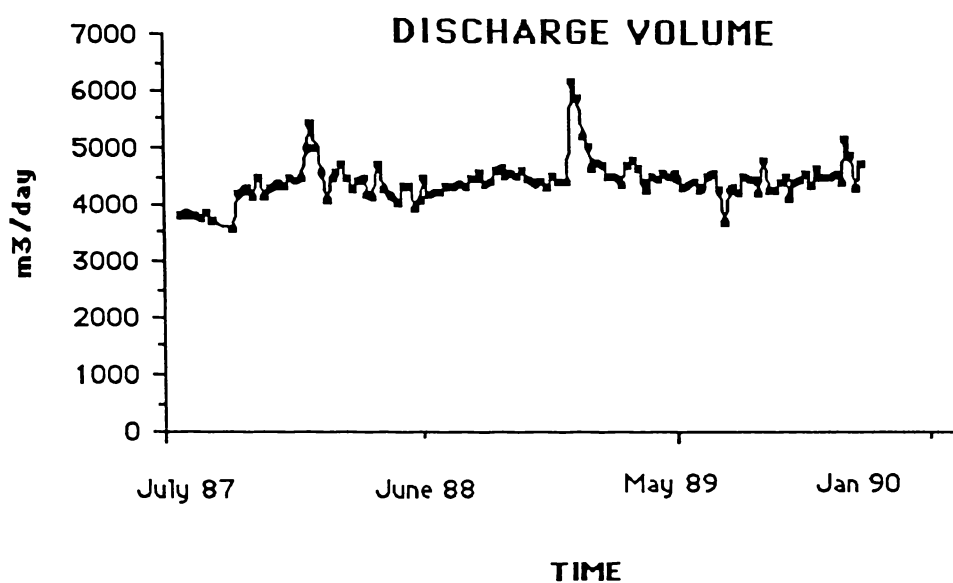
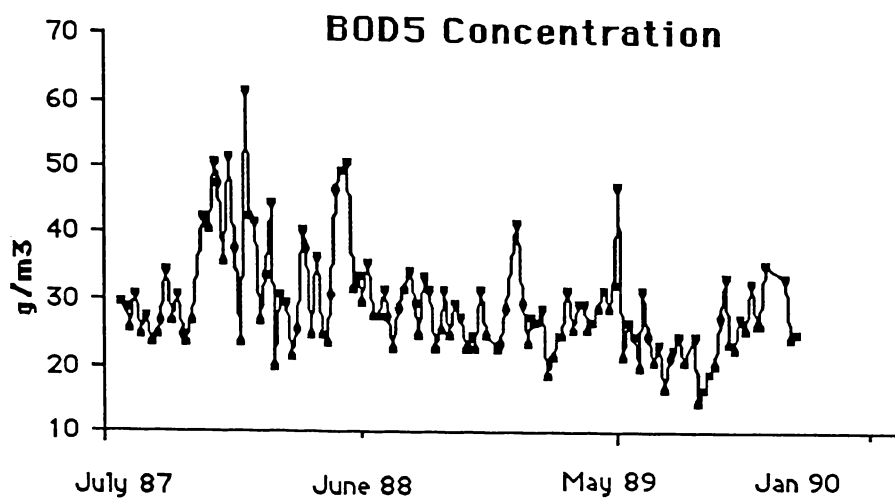


Figure 7. Mean daily discharge volume ($\text{m}^3 \text{ day}^{-1}$) from the Taupo Borough-Pollution Control Plant, from July 1987 to January 1990.

(a)



(b)

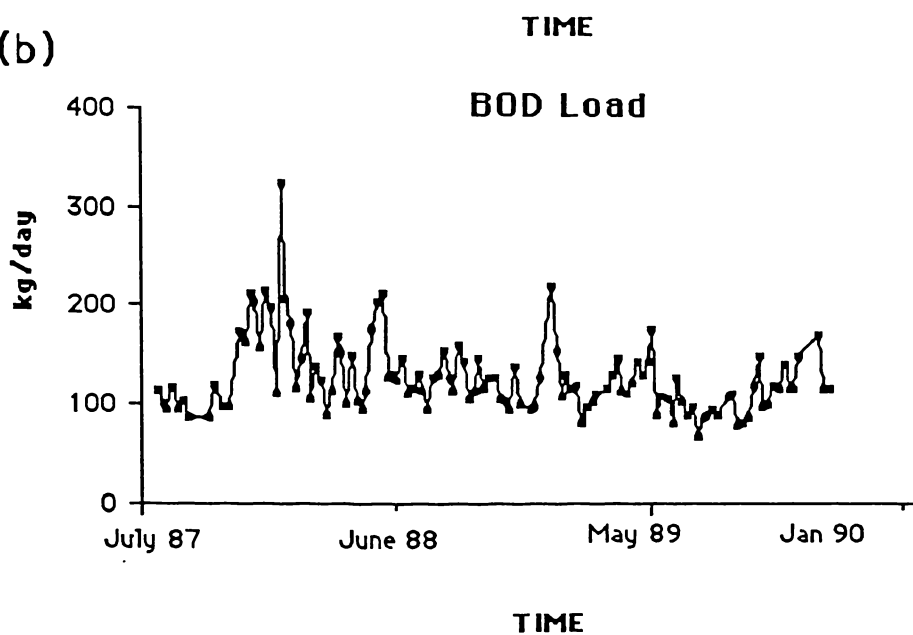


Figure 8. Mean daily Biological Oxygen Demand (BOD₅), concentration (a) and load (b), of Taupo Borough-Pollution Control Plant (TB-PCP) sewage effluent, from July, 1987 to January, 1990.

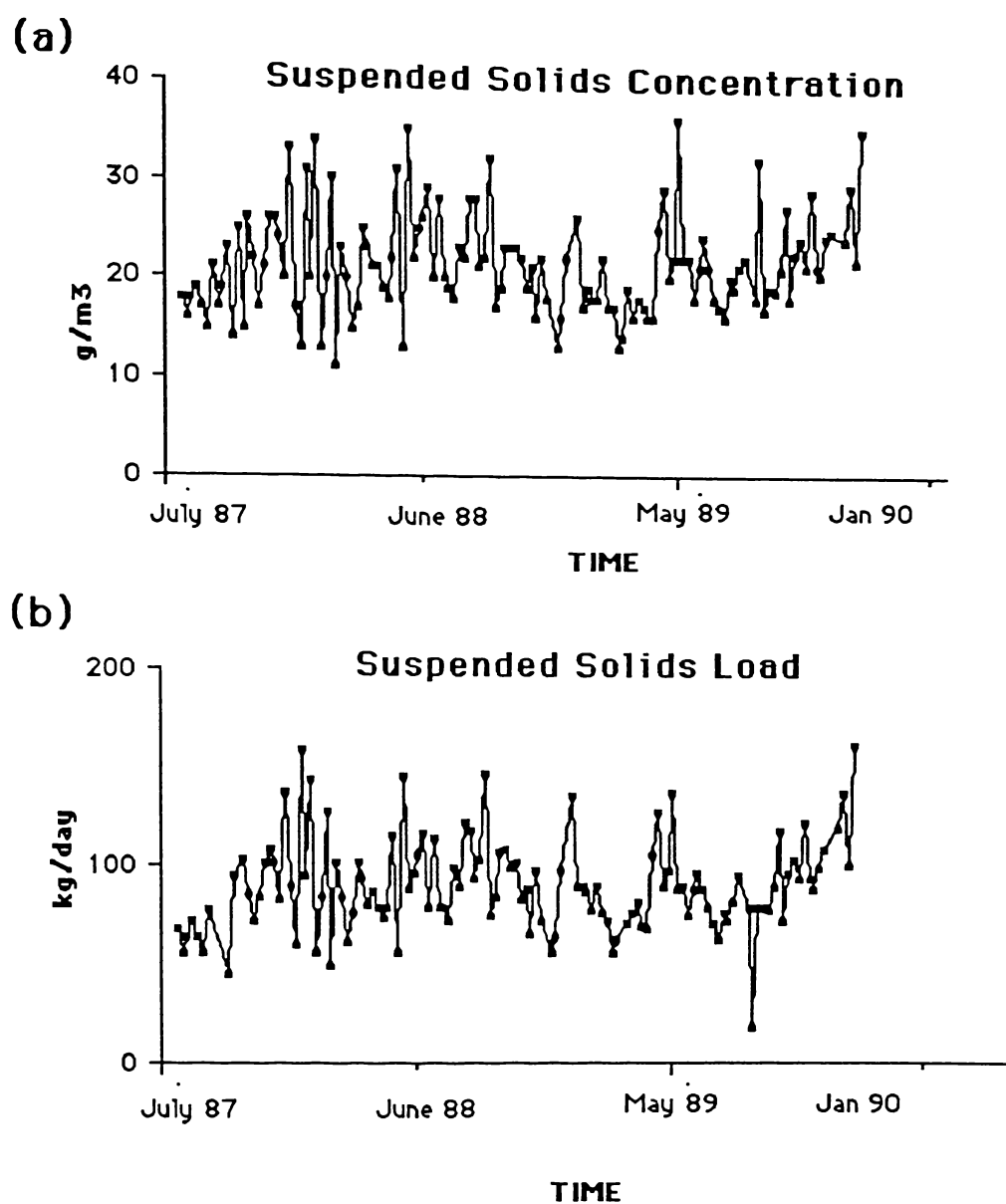
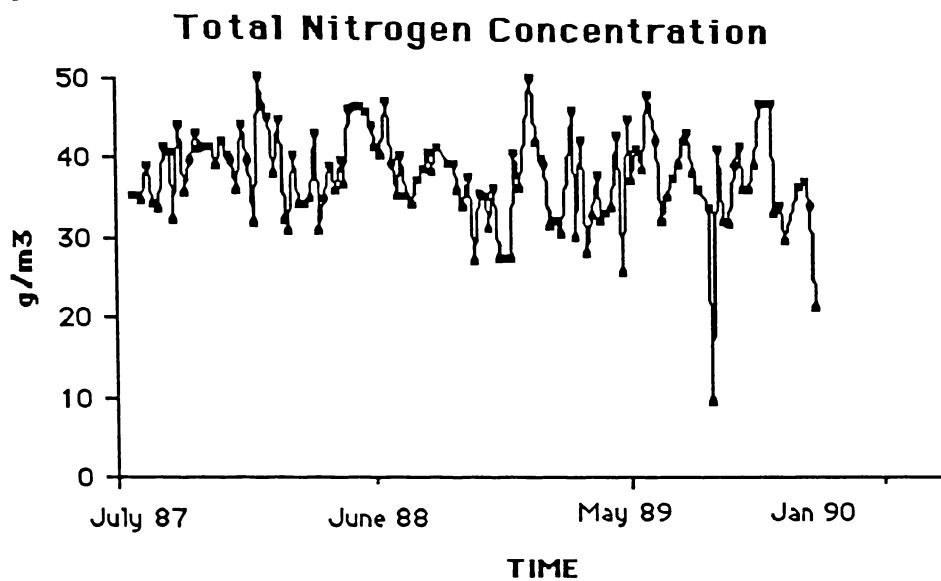


Figure 9. Mean daily Suspended Solids (SS), concentration (a) and load (b), of Taupo Borough-Pollution Control Plant (TB-PCP) sewage effluent, from July, 1987 to January, 1990.

(a)



(b)

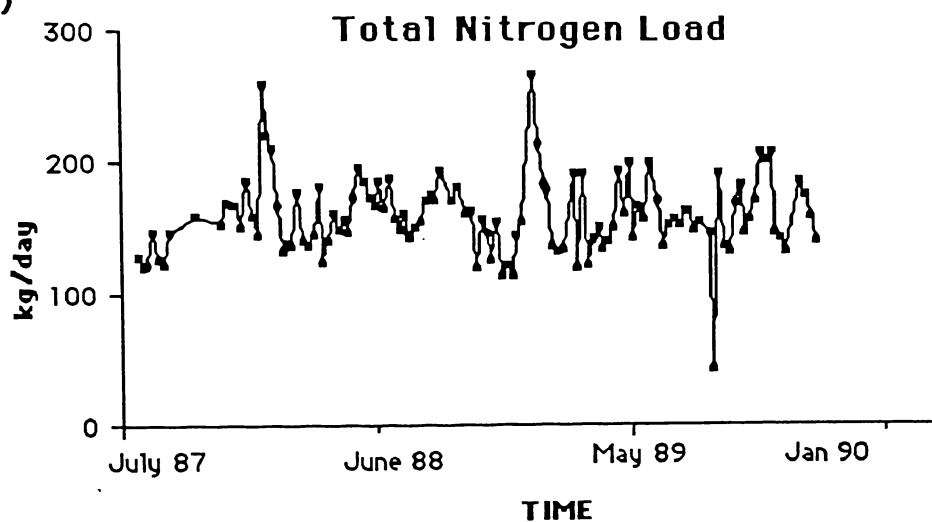


Figure 10. Mean daily Total Nitrogen (TN), concentration (a) and load (b), of Taupo Borough-Pollution Control Plant (TB-PCP) sewage effluent, from July, 1987 to January, 1990.

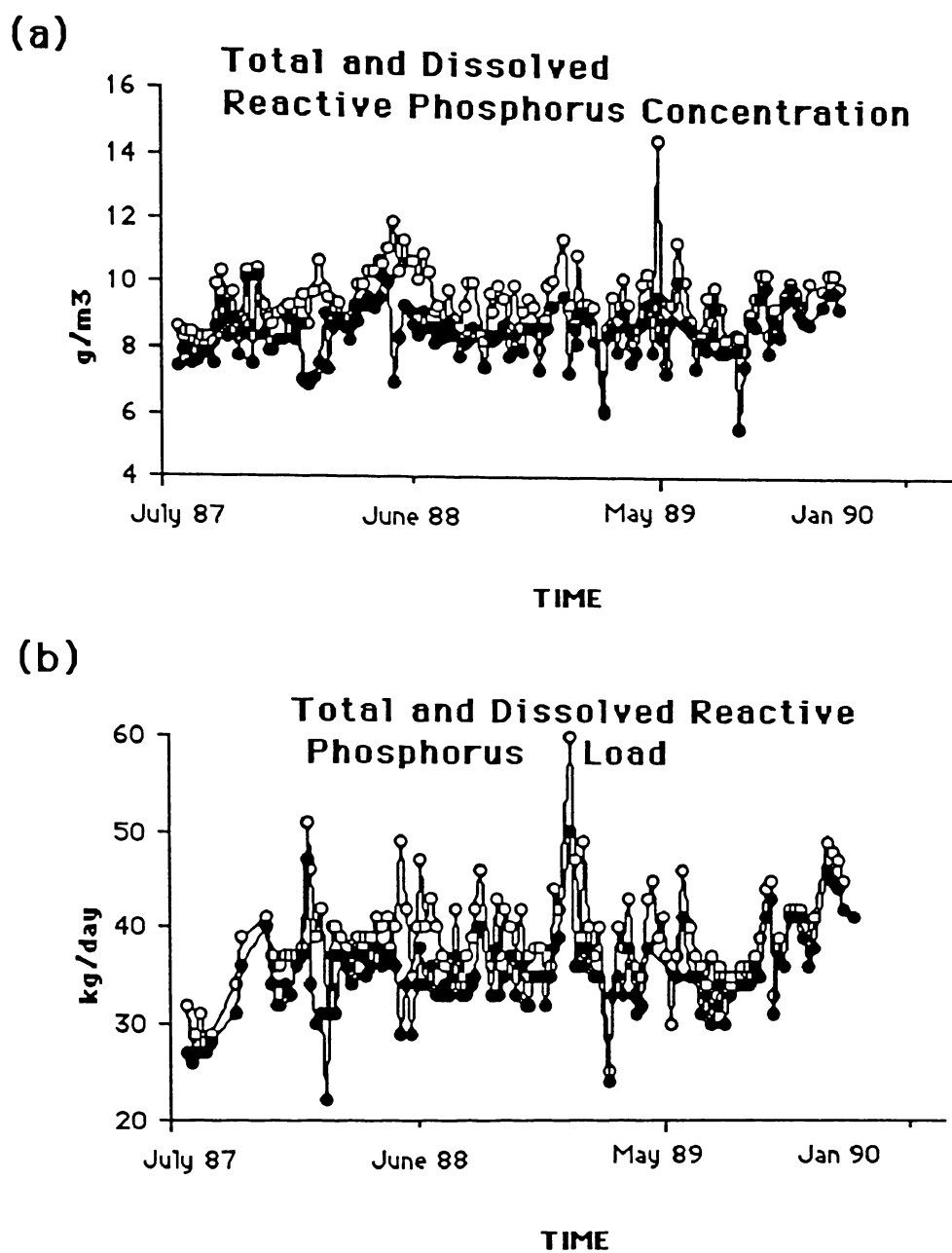


Figure 11. Mean daily Total Phosphorus (TP) and Dissolved Reactive Phosphorus (DRP), concentration (a) and load (b), of Taupo Borough Pollution Control Plant (TB-PCP) sewage effluent, from July, 1987 to January, 1990.

Huser (1989 in prep) monitored the effluent during dry weather conditions over a 24 hour period on the 27 January, 1987 (Huser, 1987), and again on the 19/20 of both January and July, 1988 (Huser, ¹⁹⁸⁹in prep). These studies serve to characterise the effluent composition in both summer and winter. The major findings of these studies that are relevant to the present investigation may be summarised as follows.

The flow pattern exhibited by the TB-PCP discharge showed a marked diurnal variation with peak flow at midday and minimum flow in the early morning. This flow pattern is commonly observed in predominantly domestic sewage systems (Huser, 1987).

Measurements of Absorbance Turbidity, Suspended Solids and BOD₅ were all equal to or greater at Cherry Island (approximately 500m downstream of the discharge) compared to above the TB-PCP discharge. However, any differences were not statistically significant ($p > 0.05$). SS and BOD₅ concentrations were correlated with flow trends. No significant differences in pH, Conductivity, Temperature and Dissolved Oxygen were found along the river during Huser's survey. Nutrient (N and P) concentrations in the effluent were relatively constant over a 24 hour period. Thus, their mass flows are therefore largely dependent on the discharge flow rate (Huser, 1987).

The percentage composition of the nitrogen and phosphorus component (from studies carried out by Huser 1987, 1989 in prep and Gibbs, 1982) is illustrated in Figure 12. Ammonical nitrogen dominated the N component of the effluent and DRP formed the major fraction of the phosphorus found in the final effluent before its discharge to the Upper Waikato River. A comparison of the 1982 data with 1987/88 data shows a marked increase (20%) on the NH₄-N concentration in the final effluent, which corresponded to the installation of the trickle filters and the final clarifier. These units were installed to reduce BOD (Huser,

1987) and observed increases in available nutrient forms such as $\text{NH}_4\text{-N}$ and DRP are commonly observed once trickle filters are installed (Huser pers comm). The removal of N and P from these treatment processes is nominal and unpredictable (Ferrier and Brown, 1978).

Huser (1989 in prep) has estimated nutrient (N and P) loads from the TB-PCP at various stages of the treatment plant's development (Table 3). Loads of N and P have significantly increased from 1979 to 1986, corresponding to population increases. The actual TN and TP loads discharged into the river from the TB-PCP were 151.2kgN day^{-1} and 37.4kgP day^{-1} (from compliance monitoring data July, 1987 - Sept, 1989). Final Stage 3 installation is estimated to discharge 312 kgN day^{-1} and 52 kg Pday^{-1} into the river.

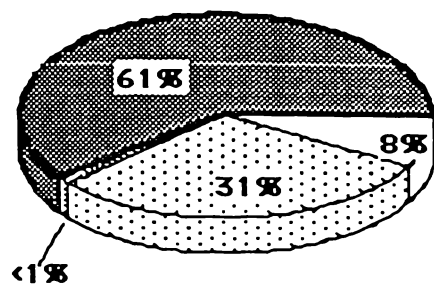
Table 2. Estimated nutrient loads from the Taupo Borough-Pollution Control Plant (TB-PCP) at various stages of proposed developments, from Huser (1989 in prep).

Stage	Year	Population	Nitrogen	Phosphorus
			(kg day ⁻¹)	(kg day ⁻¹)
1	1979	13,500	78	13
2	1986	27,000	156	26
3	?	54,000	312	52

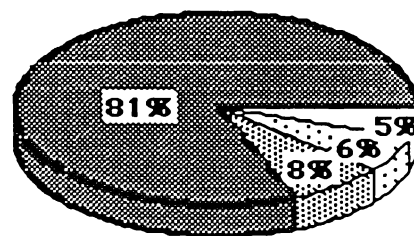
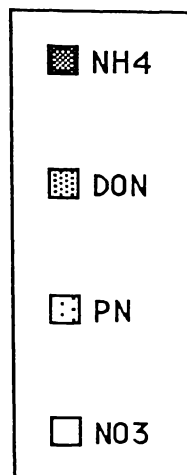
Figure 12. Percentage composition of forms of Nitrogen and Phosphorus in the TB-PCP effluent prior to discharge to the Upper Waikato River, showing the change in distribution of N and P species between 1982 and 1987/88.

Note: 1987/8 data is from Huser's diurnal studies, 1982 data is from Gibbs (1982). PN= particulate nitrogen, DON= dissolved organic nitrogen, DRP= dissolved reactive phosphorus, DOP= dissolved organic phosphorus, PP= particulate phosphorus, NO₃= nitrate and NH₄= ammoniacal nitrogen.

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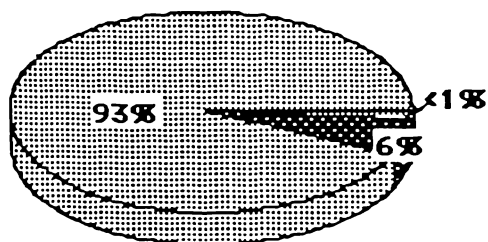


1982

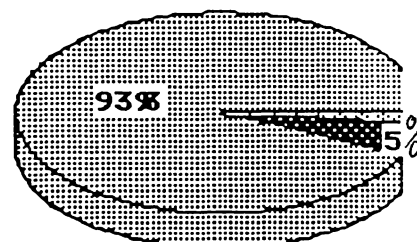
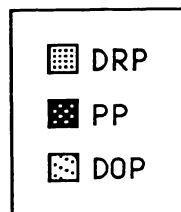


1987/88

PHOSPHORUS



1982



1987/88

1:5 Impact and Relative Significance of Nutrient (N and P) from all sources to the Upper Waikato River.

The Waikato Regional Council has monitored water quality at the Taupo Gates and Huka Falls from January, 1989 to January, 1990. Figure 4 illustrates the data for $\text{NH}_4\text{-N}$, DRP , TKN , and TP . No significant difference in water quality between the Taupo Gates and the Huka Falls were apparent, and water may be classified as oligotrophic. However, it is important to note that the lower values on these graphs are at the detection limits of the routine assay methods used by the Council. A more accurate representation of nutrient concentration changes is apparent from Huser's 24 hour monitoring studies, where the quality of receiving waters was monitored as well as the effluent, and more precise assay methods were used (see Appendix 2 for data). Diurnal studies were carried out on the 19/20th of both January and July, 1988. The river was monitored at four sites; Taupo Gates, Cherry Island, Reid's Farm and the Huka Falls. Figure 2 shows the relationship of these monitoring sites to the inflow of point-source discharges to the Upper Waikato River.

The impact of the TB-PCP discharge can be seen in Figures 13 and 14, which show longitudinal changes in mean nutrient (N and P) species concentrations from the 1988 summer and winter diurnal studies (data from Huser, 1989 in prep). There was no apparent difference between summer and winter in TN , DON , TP , DOP , DRP , nitrate or ammonia levels at each of the four sites. Slightly higher summer values of particulate N and P occurred at all four sites.

The generally low levels of N and P measured at the Taupo Gates reflects the oligotrophic status of Lake Taupo. Both N and P components

were dominated by particulate matter (mainly algal cells) and dissolved organic compounds (Figure 5). The higher PN and PP observed in summer was probably due to increased amounts of *Botryococcus* in seston originating from the lake (Bayly, 1989). Particulate N and P forms are not readily available for assimilation by aquatic flora, studies by White (1983) indicated that DON is biologically largely refractive. The inputs to the Upper Waikato River of biologically available nutrients such as $\text{NO}_3\text{-N}$, $\text{NH}_4\text{-N}$ and DRP from water leaving Lake Taupo is low throughout the year (Table 1, Figures 4, 5, 13 and 14).

Huser's 24 hour studies showed that concentrations of readily available plant nutrients at Taupo Gates were relatively constant over a 24 hour period . At all other sites a consistent pattern of diurnal changes in these nutrient levels occurred, with maximum concentrations around midday and minimum levels after midnight. This pattern matched the diurnal cycle of sewage discharge and reflects the influence of diurnal variation in nutrient levels from this discharge.

Figure 13. Longitudinal changes in mean N-nutrient concentrations along the Upper Waikato River during diurnal Summer (January, 1988) and Winter (July, 1988) studies at L. Taupo Control Gates, Cherry Island, Reid's Farm and Huka Falls.

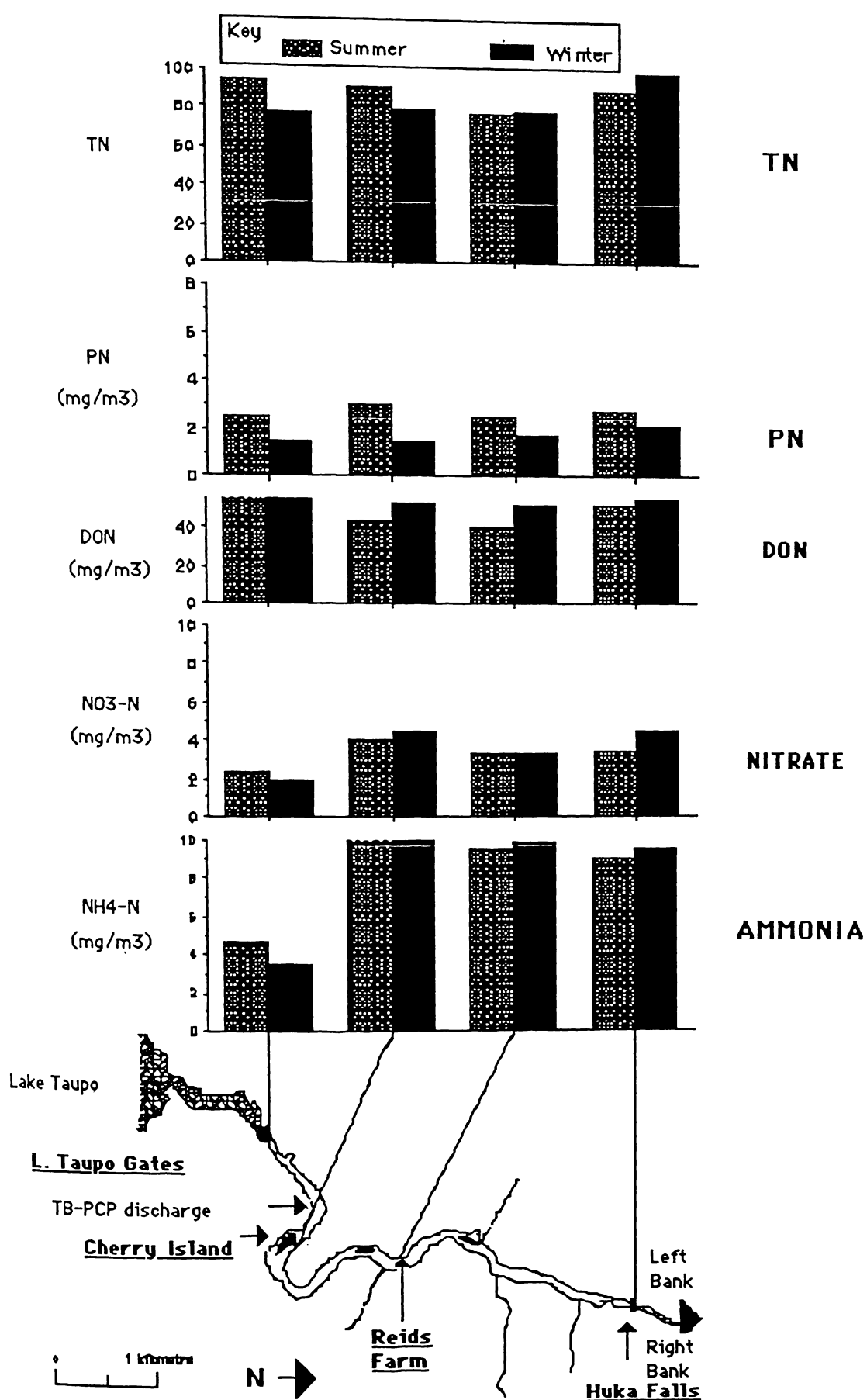
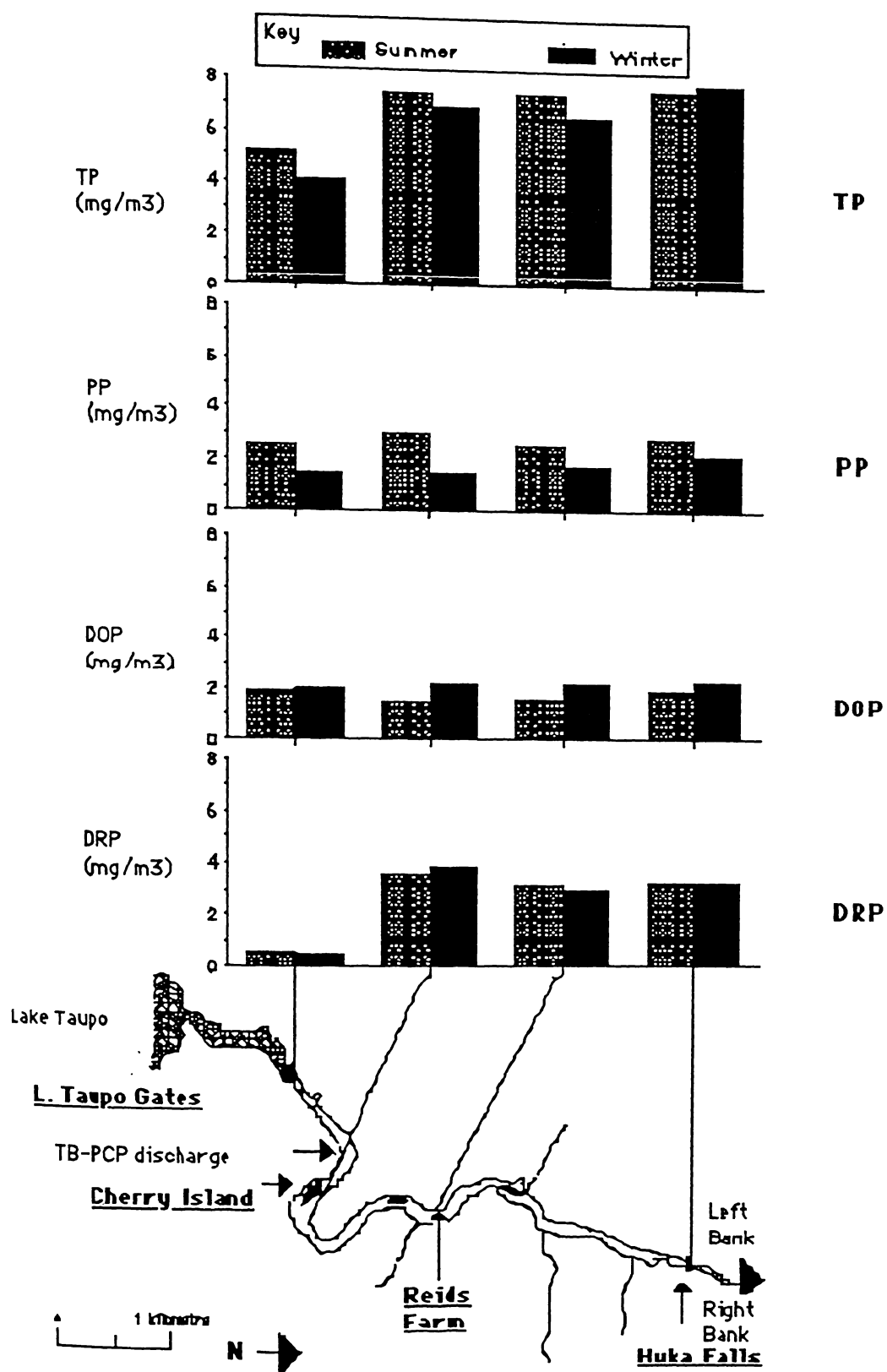


Figure 14. Longitudinal changes in P-nutrient concentrations along the Upper Waikato River during diurnal Summer (January, 1988) and Winter (July, 1988) studies at L. Taupo Control Gates, Cherry Island, Reids Farm and Huka Falls.



The direct impact of the TB-PCP discharge can be seen from a comparison of nutrient levels at the Taupo Gates and the Cherry Island site. Huser (1989 in prep) has calculated the following increases in nutrient concentrations (expressed as % increase relative to Taupo Gates water);

Nutrient Species	Summer Survey	Winter Survey
	19/20 Jan. 1988	10/20 July 1988
NO ₃ -N	50	65 %
NH ₄ -N	90	200 %
DRP	540	650 %
TP	50	60 %

Inspection of these increases and Figure 13 reveals that NH₄-N and DRP showed the most dramatic increases downstream of the sewage discharge, which was expected because of the domination of the effluent by these two components.

The levels of DON, DOP, PP and PN did not change markedly along the Upper Waikato River during either of the summer or winter diurnal surveys. This was expected as inputs of these nutrient components from the sewage discharge were minor (see Figures 12, 13 and 14). Total N remained approximately unchanged downstream of the sewage discharge. Ammonia and nitrate contributed a relatively small part to the total N which was dominated by dissolved organic and particulate species. This was in contrast to total P which increased by approximately 50% downstream of the sewage discharge, due to DRP forming a major fraction of total P in the river.

In order to put into perspective the impact of the sewage nutrient loads to the Upper Waikato River the significance of all loads needs to be considered. The relative significance of various sources of nutrients

to the Upper Waikato River is illustrated in Figure 15 as determined at the Huka Falls monitoring site (Huser, 1989 in prep). This figure shows that the TB-PCP discharge has a significant impact on the water quality of the Upper Waikato River in the form of increases in $\text{NH}_4\text{-N}$ and DRP. The background levels from the lake dominate TN, NO_3 and TP (although significant amounts come from the TB-PCP discharge due to DRP).

As a whole tributaries did not significantly increase N and P nutrient loads in comparison with the loads from Lake Taupo and the TB-PCP discharge (Figure 15). The Otumuheke Stream was the biggest contributor of nutrients via tributaries (60% TN and 85% TP from total tributary input), due to the input of geothermal fluids in this stream.

Groundwater was estimated to make only minor contributions to TN, ammonia-N and TP relative to the background river levels and the inputs from the TB-PCP discharge. Significant, although not major inputs, of nitrate and DRP is attributed to groundwater inflows (Figure 15).

Table 4 shows that the inflow from the TB-PCP discharge reduces N:P ratios of Upper Waikato River water. Most algae have N:P requirements ranging from about 10:1 to 30:1 (Redfield, 1963 quoted by Rosemarin, 1985). Ratios greater than this indicate that P limitation of algal growth is likely. For example *Cladophora glomerata* in Lake Ontario was found to be limited by P coinciding with N:P ratios of 70:1 by Rosemarin (1985). Conversely, ratios less than 10:1 may indicate a nitrogen limitation to plant growth. The TN-DON:TP-DOP ratio may be a more meaningful value as dissolved organic components are often largely biologically unavailable. Water; in Lake Taupo, at the L. Taupo Control Gates and at Reid's Farm (see Figure 2) all have low N:P ratios, at the lower end of the range of algal N:P requirements, indicating possible N

limitation of aquatic plant growth. The effect of the TB-PCP discharge decreases this ratios to where nitrogen limitation of algal growth may be predicted.

Table 3. Variation in nitrogen/phosphorus ratios between the waters in Lake Taupo, above (L. Taupo Gates) and below (Reid's Farm) the TB-PCP discharge and in the TB-PCP effluent (adapted from Huser, 1989 in prep).

SITE	TN:TP	TN-DON:TP-DOP	PN:PP	Reference
Lake Taupo	27.5	9.9	10.9	White et al (1985)
Upper Waikato River				
-L. Taupo Gates	18.4	10.4	9.8	Huser (in prep) 1989
-Reid's Farm (below TB-PCP discharge)	11.2	6.2	9.2	" "
TB-PCP effluent	3.8	3.6	4.5	" "

The assimilative capacity of the Upper Waikato River for the input of nutrients from the sewage discharge can be gauged from comparison of the data from Cherry Island, Reid's Farm and Huka Falls monitoring sites of Huser (1989 in prep). In-river processing may change the relative importance of various N and P species and decrease bulk loads by removal of dissolved nutrients through the action of aquatic plants, nitrification, denitrification and decay of plant material. Loss of ammoniacal nitrogen due to volatilisation may occur as a result of extreme turbulence at the Huka Falls (Huser, 1989 in prep).

Removal of dissolved nutrients ($\text{NH}_4\text{-N}$, $\text{NO}_3\text{-N}$ and DRP) appeared to be of minor importance in this river section. This is likely to be due to;

- the deep nature of the river, ie. a small ratio of channel surface area to water volume,

- the swift flow, if flow limits the development of benthic plant and animal communities. The assimilative capacity of the Upper Waikato River for the TB-PCP discharge is discussed further in Chapter 4 in the light of the results of this study.

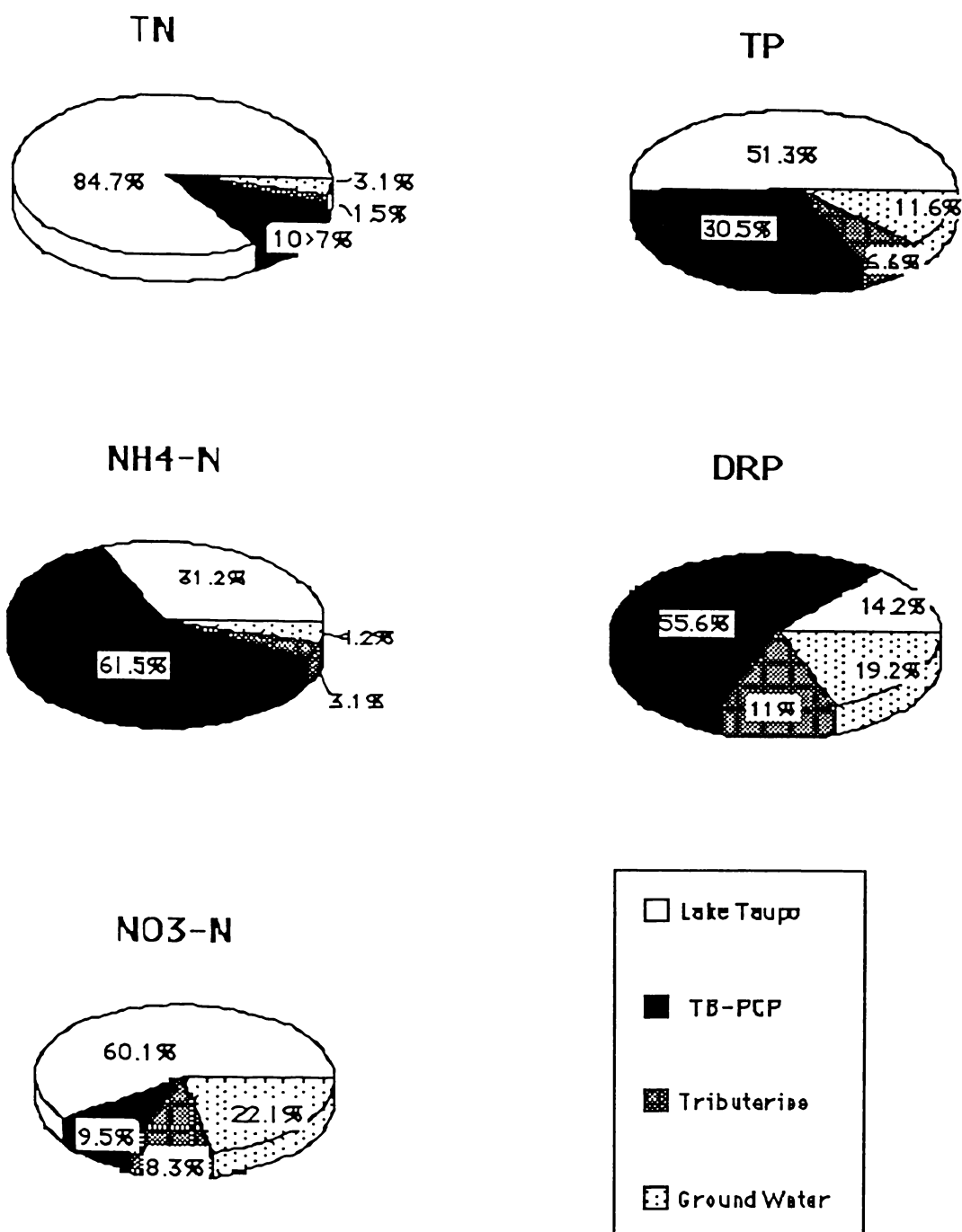


Figure 15. The percentage contribution to total supply of TN, TP, NH₄-N, and NO₃-N) in the Upper Waikato River derived from lake Taupo, TB-PCP sewage discharge, tributaries and groundwater.

1:6 Summary

Submerged macrophytes and phytoplankton of Lake Taupo and the lower Waikato River have been comparatively well studied. Little is known about the phytobenthos in the Upper Waikato River, except for preliminary studies by Dr. B. T. Coffey and myself. Even less is known about periphytic algal associations in these water bodies.

Although selectively draining from the comparatively enriched north-eastern bays of Lake Taupo, the water leaving Lake Taupo is classified as oligotrophic. However, marked decreases in water quality and change in submerged plant associations occur along the full length of the Waikato River. The Waikato River, from the Taupo Gates to Lake Ohakuri (which includes the Upper Waikato River), was classified by Coffey (1979) as having an oligotrophic assemblage of plants and animals. However increased nutrient loads in this section of river since that time necessitate a review of this classification. Standard water quality monitoring of N/P components showed that levels at the Huka Falls did not change significantly, with most nutrient components still near detectable limits (Figure 4). However, detailed investigations of water quality by Huser (1989 in prep), using more accurate analytical techniques, have shown significant increases in $\text{NH}_4\text{-N}$ and DRP downstream of the sewage discharge (Figure 13, 14). Both of these forms of N and P are highly biologically assimilable by primary producers and estimation of total loads of N/P nutrients to this section of river illustrate the relative importance of the TB-PCP as a source of $\text{NH}_4\text{-N}$ (61.5% of total input), and DRP (55.6% of total input), (Figure 15). Although there is an overall increase in nutrient load, the effect of these inputs is also to reduce water N:P ratios to levels where nitrogen limitation of plant growth may be postulated. In a lotic system the

volume of water that an organism derives its nutrients from, as well as the concentration of nutrients, determines the total available supply. Thus, even though total concentrations of $\text{NH}_4\text{-N}$ and DRP are still relatively low below the sewage discharge, given suitable water flow, these increases in plant nutrients may have a discernible impact on phytobenthos downstream of the sewage discharge.

The nutrient (N and P) load impact of other point-source discharges in this reach of river are minor compared with total background nutrient levels from Lake Taupo and the TB-PCP sewage discharge. Estimated groundwater inputs were significant only in the form of nitrate and DRP loads, but these never formed the dominant component for the respective nutrient species during the monitoring period (January, 1987 - August, 1989). The inputs from groundwater and tributaries were primarily influenced by geothermal activity in this catchment.

To assess the biological impact of these nutrient loads to the Upper Waikato River a resource assessment of benthic vegetation along the length of this river was carried out as part of this study.

CHAPTER TWO : Benthic Vegetation Resource Assessment

2:1 Introduction

In New Zealand, the major point sources of nutrients (nitrogen and phosphorus) and organic material going into waterways are from the discharge of sewage and wastes from factories processing agricultural products (Rutherford et al, 1987). In addition there is nutrient input from numerous small point sources of animal wastes from dairy sheds and piggeries, and from diffuse sources such as agricultural run off. Waste discharges have been implicated in the accelerated eutrophication of both rivers eg. Manawatu River, (Freeman, 1986) and lakes eg. Lake Rotorua, (Rutherford, 1984) .

Under the Water and Soil Conservation Act 1967 and the Amendment Act 1981, there is a statutory goal of promoting and protecting desirable water uses, including in-situ biological uses (McBride, 1984). The maintenance of these goals require physical/chemical and biological monitoring.

Discharge monitoring programmes have historically focussed on physical and chemical measurements of water quality. Defined compliance standards of these parameters are incorporated into monitoring programmes of both effluent sources and their receiving waters. Although easy to measure, these parameters are only one component of the change that may occur in a system and do not define the impact of waste discharge on in-situ users.

Biological compliance monitoring implies by definition that a standard has been specified against which measurements can be compared. Biological Oxygen Demand (BOD) and faecal coliform levels are the two standards most commonly used biological monitoring programmes designed to safeguard water rights (Roper, 1984).

Aside from monitoring, management also relies on biological surveys and surveillance techniques to assess impacts of waste discharge. Surveillance techniques rely on the direct observation and measurement of in-situ biota. These organisms are integrators of past environmental conditions within the generation time of the species present. Biological surveys can thus add valuable information to monitoring programmes, as water quality measurements reflect conditions only at the time of sampling. In addressing a seminar on Biological Monitoring in New Zealand Freshwaters, Roper (1984) identified the need for integration of biological surveillance techniques with standard physical/chemical monitoring in order to set realistic standards for effluent composition and inflow.

2:1.1 Biological Surveillance

In biological surveillance, whole ecosystem structure is seldom studied due to practical time and resource limitations. Well-developed methodologies exist for surveying invertebrate and fisheries populations

in rivers and these techniques have been widely applied to New Zealand rivers/streams (eg. Winterbourn, (1984); Penny, (1984); Jellyman, (1984)).

In comparison with invertebrates and fish, techniques for the assessment of benthic vegetation associations are less well developed. Quinn and Hickey (1987) noted the lack of research into the nature of benthic algal and macrophyte associations and rated this area of investigation as top priority in lotic research in New Zealand.

The advantages of using benthic vegetation associations for water quality surveillance include:

- #their fixed resident habitat,

- # plant life with both short population turnover times (eg algae) and longer turnover times (eg submerged angiosperms), which enables a time component to be estimated from single observations,

- #they are primary producers and thus directly assimilate chemical components of waste discharges.

The benthic vegetation is composed of:

- #algal periphyton

- #charophytes -not included with algae as there is evidence to suggest that their true taxonomic position lies somewhere between algae and mosses (Bold and Wynne, 1978). They are often included in the rooted, submerged, macrophyte life-form group.

- #mosses, liverworts and ferns

#angiosperms

Traditionally, studies on the ecology of the flora of running waters have divided the attached aquatic plants into small species, or 'microphytes', and large species designated 'macrophyte' (Hynes, 1970). Periphytic algae have customarily been grouped into the microphyte category whilst the remaining plant groups have collectively been termed 'macrophytes'. There is limited justification for this division on the basis of size, as many algal species form macrophytic growths (eg. *Enteromorpha* spp, *Cladophora glomerata*), and many species traditionally termed macrophytes are comparatively small (eg. *Pilularia*, *Glossostigma* spp.). The term 'microphyte' is not used in this study, attached algae and periphyton (refers to algal component only) are used in preference.

There is a valid functional basis for the micro/macrophyte separation. Tissue element concentrations in submerged macrophytes eg. *Lagarosiphon major*, are more attributable to root uptake from substrates than to foliar absorption directly from the surrounding waters (Patterson & Brown, 1979). There has been insufficient work carried out on attached algae and their substrate interactions (Wetzel, 1983). However it appears that epilithic algal associations receive the major portion of their required nutrients from the surrounding water. Epipellic algae may receive significant sources of required nutrients from the substrate as interstitial water concentrations of these nutrients may be high and very steep microgradients exist vertically within the surficial sediment (Wetzel, 1983). Epiphytic algae do not appear to receive major sources of macronutrients eg. phosphorus from the macrophyte substrate (Wetzel, 1983). Studies carried out by Wetzel show that ".....in all cases, it is

apparent that little, if any, phosphorus of macrophytic origin passes through the epiphytic complex to the surrounding water, as long as the plants and periphyton are actively growing. "

These nutrient source differences between macrophytes and algal periphyton become important in assessing the impact of waste discharges into lotic environments, as the ecodominance between 'macrophytes' and attached algae may be altered by changes in water quality attributable to these inflows.

Studies carried out on submerged vegetation have often focussed on either 'macrophytes' or attached algae, seldom have studies addressed the benthic vegetation as a whole. Techniques developed for assessment of phytobenthos are often applicable to only macrophytes or attached algae. A surveillance method that incorporates survey of both macrophytes and attached algae simultaneously would therefore provide a useful tool for waste discharge impact assessment.

2:1. 1.2

Surveillance Methodology- Macrophytes and Periphytic Algae.

A knowledge of the floristic composition (species list), life-form composition and the structure of the vegetation are a necessary basis of all ecological work (Kershaw, 1964). The analysis of the structure of the vegetation includes assessment of the vertical and horizontal arrangement of species and their abundances. These parameters may be

described and measured using transects. In terrestrial ecology, transects have been widely used to qualitatively and quantitatively describe vegetation patterns along environmental gradients. Chapman (1976) states that ".....long term changes in vegetation are best studied by use of permanent quadrats or transect techniques".

Macrophytes

The rationale and application of transect/profile techniques for assessing/surveying macrophytic submerged vegetation in marine (eg. Krausky et al, 1988) and lentic environments (eg. Sheldon and Boylen, 1978) have been well documented. In New Zealand the strategy, logistics and application of transect methodology to the assessment/monitoring of submerged macrophytes in New Zealand lakes has also been developed (eg. Clayton, 1983; Coffey, 1987).

Clayton (1983) proposed three basic methods of survey for submerged macrophytes in New Zealand lakes. These were;

#Method 1. Remote Sampling

#Method 2. Profile (qualitative SCUBA)

#Method 3. Transect (quantitative SCUBA)

All three methods provide a species list and estimates of abundance at different depths for different species. Methods 2 and 3 form in-situ observations of the benthic vegetation. In comparison with the profile method, the transect method provides a more comprehensive description of the macrophyte community present, whilst the former is a rapid

alternative. The profile method is best suited to application in baseline resource surveys, whilst the transect method is a practical monitoring technique. Both of these techniques have been widely applied to New Zealand lakes eg. Coffey and Clayton, (1987a and b).

Baseline resource assessments of submerged macrophytes in New Zealand rivers are limited and generally confined to taxonomic observations. In formulating a standard procedure for characterising river channels, Mosley (1982) used cover assessments of attached plant growth that were scored either by viewing from the river bank or by wading. Vegetation type was scored as either large weeds or algal slimes. In an address on biological monitoring in New Zealand, Harper (1984) restricted discussion of aquatic macrophyte assessment in flowing waters to that of drainage channels only.

In the literature the use of transect methodology to describe lotic macrophytes has been confined to shallow rivers/streams (<0.5-1m depth) or rivers which were sampled during periods of low flow (eg. U. S. Geological Survey Manual, 1977).

Direct observation and quantification of the submerged macrophytes in deep (>0.5m water depth), fast flowing rivers is logistically difficult. Drift diving (snorkel or SCUBA) techniques are of limited usefulness and do not readily permit quantifiable comparisons up- and downstream of a discharge. Divers may be towed by boats (Coffey and Miller, (1987); Miller et al, (1988)), however lack of diver control of passage across the riverbed is a limiting factor. Both techniques are also limited

in their application in on-going monitoring programmes due to poor repeatability of passage across the transect.

Periphytic Algae

The application of transect methodology to assess attached algal populations has also been restricted to shallow rivers/streams.

Blum (1957) applied the transect method of terrestrial plant ecologists to stream algae. In this study a rope was strung across the stream at various intervals. The importance of the various species was determined by the relative number of decametres within which the species was present. Hynes (1970) noted that this method although restricted in use to shallow streams, "..... undoubtedly gave results fairly closely resembling the actual status of the flora in the stream, and it would seem to be worthy of further use and refinement." Wharfe et al (1984) used a similar technique to assess the distribution and abundance of *Cladophora glomerata* in the River Great Ouse. In both studies the river water depth was less than 1m and current flow was not fast. Wharfe et al (1984) also assessed changes in average filament length between sites and this parameter was used to indicate the degree of nuisance of the algal growths to anglers.

There is a paucity of knowledge of benthic algal associations found in New Zealand freshwater environments. The Standard Biological Working Party of NWASCO (National Water and Soil Conservation Organisation), recommended the development of techniques utilising periphyton in the surveillance of water quality (Cassie, 1979). Limited observations have

been made as part of invertebrate studies and as investigations into the effects of algae on water quality (Biggs and Price, 1987).

The widespread occurrence of summer periphytic algal proliferations in New Zealand rivers has been surveyed by Biggs and Price (1987). Little is known about the composition or ecology of these proliferations (Biggs, 1987). Only one study in New Zealand has focussed on the ecology of a nuisance periphytic algal species (Freeman, 1983 and 1986).

Artificial substrates have been used widely overseas to monitor periphyton in streams and rivers. Biggs (1984) outlined the inherent problems in the use of artificial substrates in New Zealand flowing waters. Problems included; vandalism, loss (due to flooding), macrophyte swamping, and determination of a suitable length of placement time of substrates. Biggs (1988) has designed and evaluated a bottom-seated artificial substrate sampler suitable for use in shallow swift rivers in New Zealand.

The algae colonising an artificial substrate may be quantitatively and qualitatively different from the algal community present on natural substrates. Lowe and Gale (1980) noted that this difference "... may be particularly true in deep, clear rivers with good light penetration ". The use of artificial substrates can give only limited insight on the in-situ structure and architecture of the periphyton community, which is the foundation for the interpretation of its functional characteristics (Wetzel, 1983). The First International Workshop on Periphyton of Freshwater Ecosystems, held in Sweden 1982, recommended that the use

of artificial substrates should be restricted to comparative analyses of periphyton (Wetzel 1983). It would appear that artificial substrate techniques are perhaps best suited for use in-conjunction with surveillance techniques of in-situ biota, for example in the monitoring the change of a defined indicator species change over time

The rationale, logistics and application of transect methodology in the surveillance of benthic vegetation in lakes and in the sea has been described and evaluated by numerous workers. The same rationale is equally valid for evaluating benthic vegetation associations in rivers and streams and is useful for assessing the impact of waste discharges into these environments. However the logistics and application of this methodology is considerably more difficult to apply to those flowing water environments where water depth exceeds wading depth. It is appears that there is no suitable surveillance technique to assess in-situ phytobenthos of rivers with depths exceeding 0.5-1 metres.

2:1.2 Biological Surveillance of the Upper Waikato River.

The Upper Waikato River is a deep (average depth ca. 2-3m), fast flowing river that receives several point-source discharges along its length. The location and nature of these discharges have been described in Chapter One.

Coffey and Huser (1988) suggested the use of a heavy chain marked as a transect line to overcome the problems outlined in the above

discussion. They identified ten sites in the Upper Waikato River between the outlet gates of Lake Taupo and the Huka Falls, which were suitable for permanent transects to describe long-term changes in benthic vegetation of the Upper Waikato River.

This transect technique was trialled and evaluated in the Upper Waikato River as part of this study; and used to describe the distribution and abundance of phytobenthos (summer and winter) and the biological impact of point source discharges to the Upper Waikato River.

This part of the study was carried out in conjunction with Dr. B. T. Coffey of B. T. Coffey and Associates Ltd., as part of a contract to the Waikato Catchment Board. Initial transect descriptions and comments on benthic vegetation (macrophyte and algal) were reported in Coffey and Miller, (1989) and these have been summarised in Huser (1989).

In addition to the transect surveys, beds of *Lagarosiphon major* were monitored above and below the TB-PCP discharge for changes in biomass and ^{15}N composition. In the literature changes in biomass of plant species has been used extensively to monitor the impact of discharges. Increased growth may be attributable to nutrient inputs from discharges, however this is not a direct cause and effect link. Comparison of $\delta^{15}\text{N}$ values for plants above and below a discharge could indicate the extent of N nutrient utilisation from the effluent providing that the effluent ^{15}N signature and the water ^{15}N signature are significantly different (Silvester pers comm).

2:2 METHODS

The Upper Waikato River was divided into two main sections;

-Section 1: Upstream of the TB-PCP discharge, (NZMS 260 U18: 772 757 to 780 764),

-Section 2: Downstream of the TB-PCP discharge, (NZMS 260 U18: 780 764 to 789 792)

Section 2 of the river was further divided into three sub-sections related to the inflow of stream tributaries;

-Section 2a: Downstream of the TB-PC discharge to the Otumuheke Stream, (NZMS 260 U18: 780 764 to 786 769)

Section 2b: Downstream of the Otumuheke and upstream of the inflow of Otumuhaha Stream, (NZMS 260 U18: 786 769 to 786 781)

Section 2c: Downstream of the Otumuhaha Stream inflow to the Huka Falls, (NZMS 260 U18: 786 781 to 789 792)

The Waipouwerawera and Huka Falls Stream contribute minor amounts of nutrients compared to the TB-PCP discharge. In addition the Waipouwerawera Stream flows into a side channel of the river. For these reasons the Upper Waikato River was not divided into further sections based on these inflows.

Ten transects were surveyed during March, 1989. Permanent markers (transect anchor points) were established on both banks of the river at each of the ten transect sites by the Waikato Catchment Board. These markers were designed for the long-term re-location of transects and they are sufficiently robust to support a 6mm chain-transect for SCUBA

divers to work along in the high-flow river channel (Coffey and Miller, 1989).

The location of the river sections and the ten permanent transects is illustrated in Figure 16. Transects 2, 4 and 5 were re-surveyed in August, 1989 for winter comparisons and transect-path repeatability evaluation.

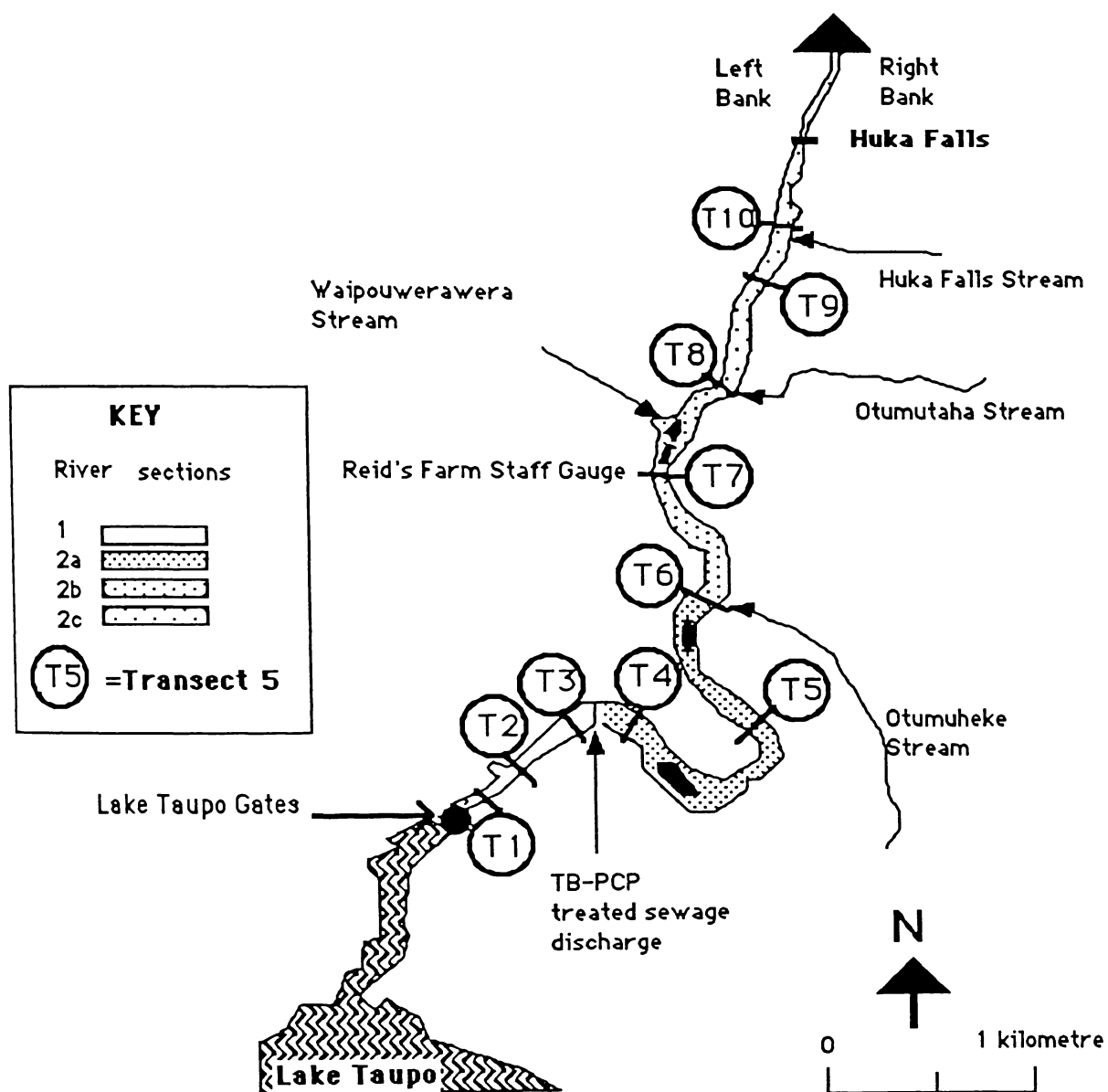


Figure 16. Location of river sections and permanent transects in the Upper Waikato River.

2:2.1 Transect Methodology

The use of a chain as a 'transect line' was initially described in Coffey and Miller, (1989). Transects were scored by B. T. Coffey and S. T. Miller in the March survey and by S. T. Miller in the August survey.

The 'transect line' used in this survey was a 100m long galvanised iron chain (47 x 27 mm links, link diameter of 6mm.), which was marked at 2 metre intervals. The transect chain was attached to the left bank transect marker via a length of 'end chain' so that it lay at ambient water level. This is an important consideration as this river is subject to marked changes in water levels.

A boat was used to feed out the the chain, under tension across the river bed. The transect chain was attached to the right bank marker in the same manner described above. The chain was retrieved by releasing from one end and pulling the chain in whilst the boat moved across the river.

To describe the transect a negatively buoyant SCUBA diver moves across the transect chain collecting samples and recording data relative to a visually estimated 1m² quadrat immediately upstream of the transect line. Quadrats were recorded at 2m intervals. Any marked changes in species composition or substrate type occurring between quadrats were noted.

Data recorded for each quadrat across the transect were:

#Distance across the transect.

Water Depth - measured using a capillary depth gauge attached to the diver's clipboard.

#Total Vegetation Cover Class - (using a modified Braun-Blanquet scale).

<u>Cover Class</u>	<u>Percentage Cover</u>
1	1-5%
2	6-25%
3	26-50%
4	51-75%
5	76-95%
6	96-100%

#Substrate type -bedrock, boulders, gravel, pebbles, sand or mud.

#Mean Height of vegetation and/or species present.

#Cover Class of individual species/vegetation associations present (using the cover scale above).

#Herbarium samples were collected for each type/species of vegetation. Collections were preserved as dry pressed and/or wet specimens. The preserving medium used for the wet samples was 50% river water, 46% glycerol and 4% formaldehyde. Fresh samples were chilled prior to sorting. A set of permanent slides were made for all

periphyton observed. Samples were mounted in the preserving medium and the slide was sealed using clear nailpolish.

#Quantitative samples were collected for biomass estimates.

Biomass Estimates

Quantitative samples of moss, charophyte and periphyton communities were collected by in a screw-top plastic jar (0.028m² mouth area) placed over the vegetation. To remove the plants the mouth of the jar was scraped over the area.

Quantitative samples represented the maximum standing crop of the dominant species observed on the transect. The terms 'maximum local standing crop' (mlsc) or 'maximum local biomass' are used when discussing the carrying capacity of individual plant species.

Standard hand-cropping techniques using a metal frame quadrat were used to quantify marginal macrophytes (quadrat size = 0.5m x 0.5m) and marginal low mixed associations (quadrat size = 0.25m x 0.25m).

The plastic jar method of assessing moss biomass was compared with hand cut 25cm x 25cm quadrats on the left bank at Transect 1.

Fresh samples were chilled prior to sorting. Samples were washed free of sediments, sorted and scored for dominant species. Samples were then dried (105 °C for 48 hours) in a hot air oven before weighing. All biomass figures are reported as dry weight unless otherwise stated.

Additional Observations

Observational notes were made and biomass samples taken in-between transect sites by shoreline inspection and drift diving during surveys. The river was drift-dived on numerous occasions during the study period.

Diving Considerations

Safety harnesses fitted with a quick release snap-shackle on a short (ca. 1m) length of stout rope were worn under SCUBA gear. This enabled the diver to be attached to the chain, but with both hands free for quadrat description and sample collection. Movement of the diver across the transect was unaided but monitored from the boat at all times. Clipboards and sample collection bags were also fitted with snap-shackles, so they could be attached to the chain where necessary. To minimise drag created by working in high current flow divers used low volume face masks and buoyancy control devices were not used when diving on the transects.

2:2.2 Aerial Photography

Aerial photography run of the Upper Waikato River and north-eastern bays of Lake Taupo was carried out on the 26th November, 1989. The Upper Waikato River was lowered to a minimum gate opening by Electricorp for the purposes of this survey.

Due to the presence of steep cliffs through this river reach, it was decided to use a helicopter in preference to a fixed-wing plane. The helicopter was positioned at right angles to river flow, to enable two sets of photographs to be taken simultaneously. Sequences were shot on both slide and print film and a polarising filter used to enable through water photographs. A video was also taken to aid in relocation of photographic sites.

Notes on the extent and type of vegetation present were made from drift diving the river on the same day as the aerial survey. Underwater photographic records were made of substrate types present and vegetation associations observed at this time.

Photographs were examined in detail and notes made on substrate/vegetation composition for the purposes of this study. Investigation of these photos enabled the suitability of using transect methodology to describe this reach of river to be assessed. Scale maps of substrate type and available habitat for phytobenthos will be carried out as part of further quantitative modelling work for the Waikato Regional Council (Miller, ¹⁹⁹⁰in prep).

2:2.3 *Lagarosiphon major* Monitoring

Beds of *Lagarosiphon major* are known to occur both up- and downstream of the TB-PCP discharge, although in the latter case there is

significant cover of epiphytic *Enteromorpha* (Miller et al, 1988). Two beds of *Lagarosiphon*, (one upstream and one downstream of the sewage discharge), were monitored for the duration of this study. These beds were chosen for similar water depth (0.5-2m at time of monitoring site location) and flow regime (measured with a gully metre). Replicate quadrats were cut during both the summer and winter survey and standing crop of *Lagarosiphon* and epiphytes measured. Preliminary ^{15}N -isotope and tissue-N (Kjeldahl digest) studies were also carried out in order to identify major sources of N nutrients to these plants.

2:3 Results

2:3.1 Transect Surveys

The raw transect data for Transects 1 -10 surveyed March, 1989 (summer) and Transects 2, 4 and 5 re-surveyed August, 1989 (winter) are contained in Appendix Two.

Five major types of macroscopic benthic vegetation were recognised:

#tall-growing submerged macrophytes,

#low mixed species,

#mosses,

#charophytes and

#periphyton.

The species found within these major groups are listed in Table 4.

Table 4. Species/genus list of benthic vegetation found in the Upper Waikato River, March and August 1989.

Low-mixed Species

Elatine gratioloides A. Cunn.

Eleocharis pusilla R. Braun

Glossostigma elatinoides Benth.

G. submersum Petrie

Isoetes kirkii A. Braun

Lilaeopsis ruthiana Affolter

Myriophyllum pedunculatum Hook

M. votschii Schindler

Pilularia novae-zelandiae T. Kirk

Ranunculus limosella F. Muell. ex. Kirk

R. amphitrichous Colenso

Mosses

Eurynchium austrinum (H.f. &W)Jaeg.

Fissidens rigidulus Hook f. & Wils.

Tridontium tasmanicum Hook f.

Craterneuropsis relaxa (Hook.f. & Wils.)Fleisch

Charophytes

C. fibrosa Ag. ex Bruz. em R. D. W.

Nitella hookeri A. Br.

Nitella hyalina (D. C.)Ag.

N. leptostachys A. Br.

N. psuedoflabellata A. Br.

Tall-growing Macrophytes

Ceratophyllum demersum L.

Elodea canadensis Michx.

Lagarosiphon major (Ridl.) Moss

Myriophyllum triphyllum Orchard

Potamogeton cheesmanii A. Benn.

P. crispus L.

P. pectinatus L.

Ranunculus fluitans auct N. Z.

Periphyton

Cladophora glomerata (L.) Kuetzing

Enteromorpha nana (Sommerf.) Bliding var *minima* ecad *rivularis* Collins

Oedogonium sp.

Spirogyra sp.

Nostoc spp.

Oscillatoria spp.

Tolypothrix spp.

diatoms

Vaucheria sp.

Batrachospermum sp.

Ghomphonema sp.

Note: only visually obvious growths of algae were recorded on the transects. The species list is compiled from all surveys and drift dives from March, 1989 - February, 1990.

Detailed transect descriptions for Transects 1- 10 -Summer Survey and Transects 2, 4 and 5 -Winter Survey, are given. They may serve as

baseline descriptions for future monitoring of these transects proposed by the Waikato Regional Council. There are few other detailed quantitative descriptions of lotic vegetation in New Zealand.

Two sets of figures have been drafted to aid interpretation of transect data and are included in the transect descriptions;

#The distribution of the major vegetation types (tall-growing submerged macrophytes, low mixed species, mosses, charophytes, and periphyton), are illustrated for each transect. These figures are also designed to show water depth (at time of sampling), substrate and vegetation type cover through each transect. It is important to note that total vegetation cover is not necessarily the sum of individual type components as the vegetation present is often in a tiered structure eg. epiphytic algae on mosses. The species composition at any point on the transect can be referenced in Appendix 2.

#Macroscopic periphyton assemblages in the Upper Waikato River were variously dominated by *Oedogonium* sp., *Nostoc* spp., *Enteromorpha nana* and *Cladophora glomerata*. The incidence and proliferation of these species in relation to point source discharges are of primary interest in this study. The distribution of these dominant periphytic species across each transect is also illustrated with transect and substrate profiles.

A representation of the total vegetation cover is illustrated on the depth profile diagram for each figure.

2:3.1.1**SECTION1****TRANSECT 1**

(ref. Figures 17 A and B)

Physical Environment

Transect 1 comprised a steep-sided bedrock/boulder lined channel approximately 42 metres wide with a maximum depth of 5m at the time of survey. A shallow mudbank overlying bedrock was present on the left bank. Substrate in the main channel was dominated by bedrock outcrops with intervening gravel/sand channels. Water flow was moderate on both the left and right banks and fast in the main channel.

Benthic Vegetation

Total vegetation cover was greatest in the main channel area on rock/boulder outcrops with a median total vegetation cover class of 5. A gravel channel was present at quadrat 5 and a sand channel was recorded at quadrat 17. These two channels did not support macroscopic plant cover at the time of survey, likely due to sediment mobility.

Benthic vegetation in Transect 1 was dominated by an epilithic moss association. This association grew to approximately 5cm average height and noticeable amounts of sand had accumulated within this association.

The moss *Tridontium tasmanicum* dominated this association (88% quadrat frequency) with a maximum local standing crop ranging from 490g m⁻².(mid-channel, measured by plastic jar technique) - 640g m⁻² (left bank, measured by quadrat technique). This formed

more than 80% of maximum standing crop in the main channel. Maximum cover of *Tridontium* was 5 with a median cover class of 4 recorded. *Fissidens rigidulus* was also commonly found as were occasional plants of *Eurhynchium austrinum* .

Charophytes (*Nitella hyalina*, *N. leptostachys*) and flow tolerant macrophytes (*Potamogeton pectinatus*, *P. crispus*, *Myriophyllum triphyllum* and *Ranunculus fluitans*) were common at low cover within the moss association. These plants tended to grow through the ground cover of mosses to lengths of approximately 100mm. Low-mixed species were present at low cover on the left bank margin.

Macroscopic periphyton on this transect was dominated by epiphytic growths of *Oedogonium* sp. (median cover class 1, maximum cover class 2) and *Nostoc* spp. (median cover class 1, maximum cover class 2). These algae were found predominantly as epiphytes on the mosses *Tridontium tasmanicum* and *Fissidens rigidulus*. *Oedogonium* is an unbranched filamentous green algae and was recorded in 72% of quadrats and grew to an average length of approximately 50mm, with a maximum length of 150mm. Numerous epiphytes, mainly diatoms were associated with these " cottony " growths of *Oedogonium*. *Nostoc* , a colonial cyanophyte that forms ball-like growths, was present in 76% of quadrats described. Three quantitative samples representing this plant association type were analysed from this transect. *Oedogonium* formed between 1-8% of maximum local biomass (corresponding to 35g m⁻² from quadrat 6). *Nostoc* growths had a maximum local standing crop of 84g m⁻², which constituted 11 % of maximum local biomass. No visually

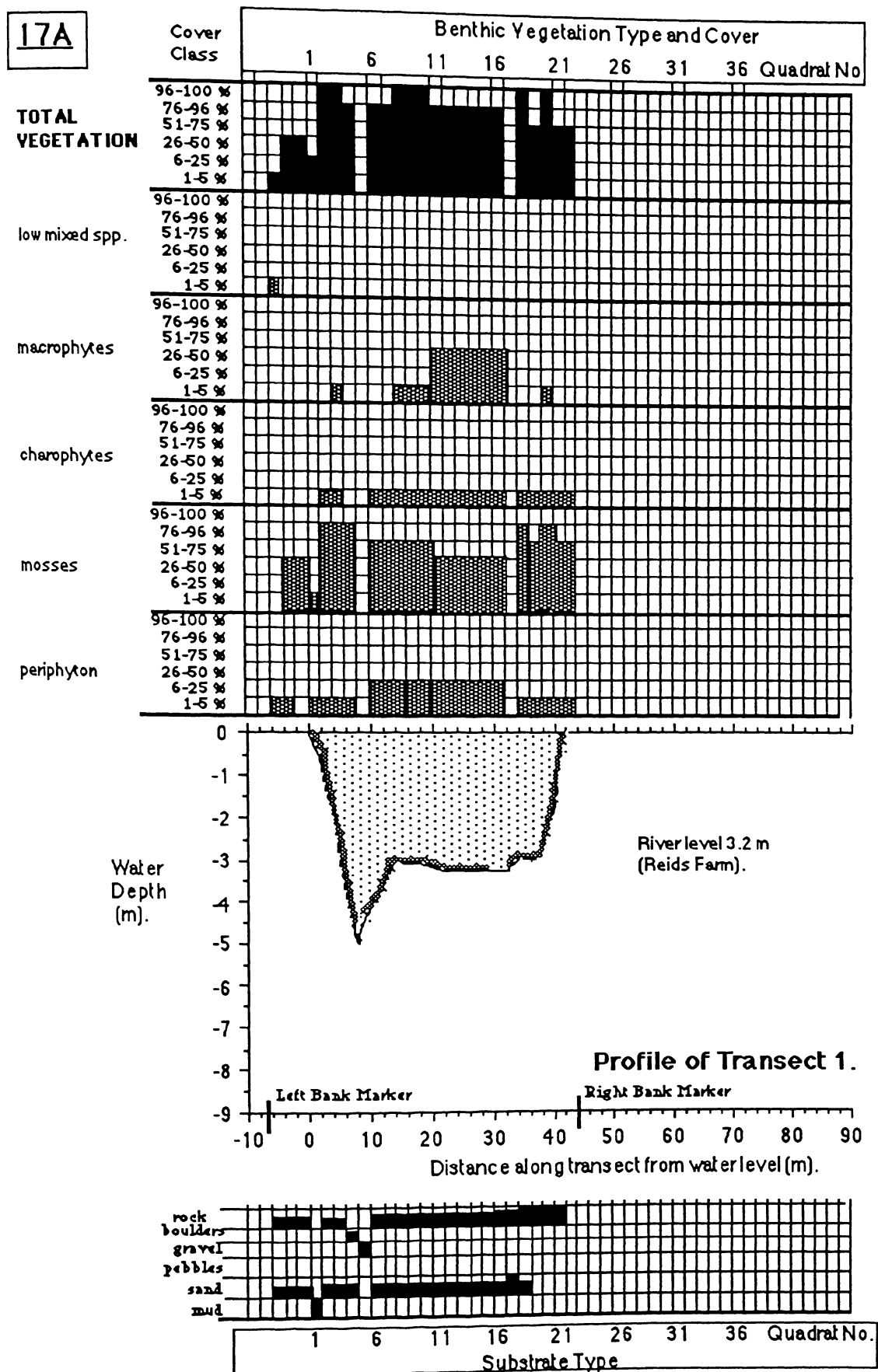
obvious growths of epilithic periphyton was observed on this transect.

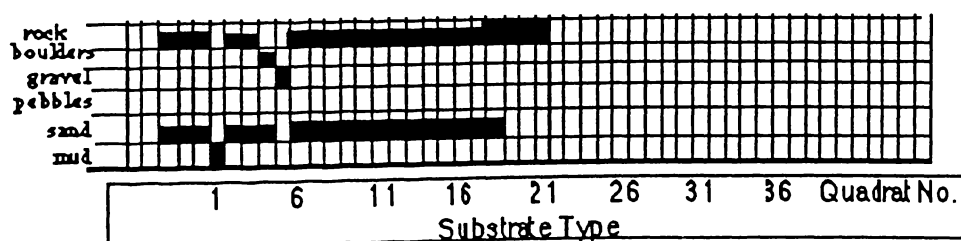
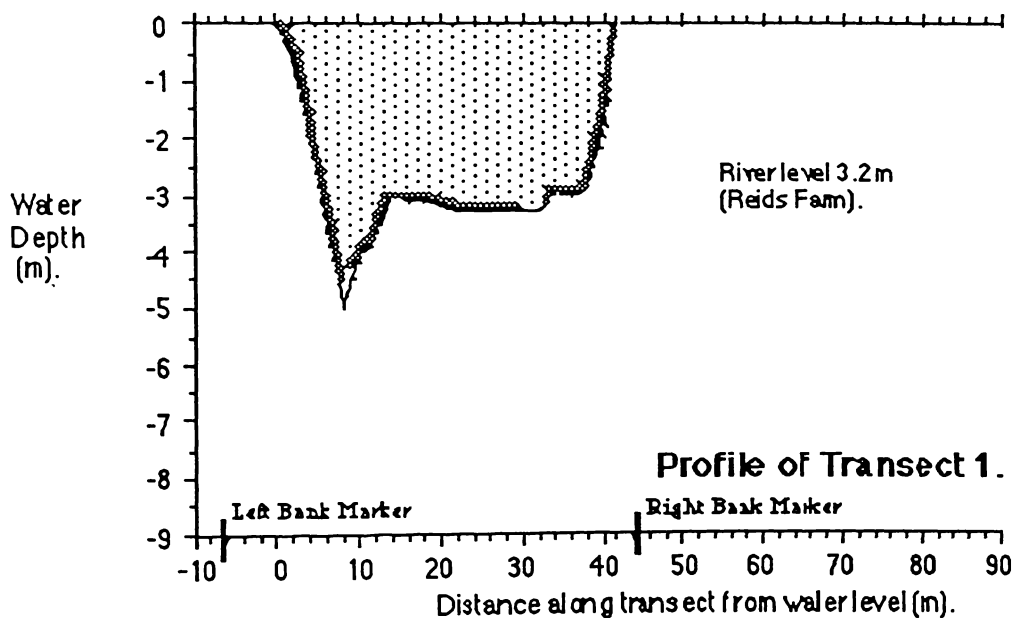
Enteromorpha was found growing in-situ in one quadrat only. No *Cladophora* was observed on this transect. *Tolypothrix distorta* and *T. tenuis* were also recorded as epiphytes on mosses (mainly *Tridontium tasmanicum*) from quadrats 9 and 10. They were observed in-situ as feathery epiphytic red-brown tufts, but would constitute negligible biomass in the association. Diatoms were commonly found as epiphytes on mosses and *Oedogonium* sp. Low covers of diatoms were also observed from microscopic examination of scrapings from sediments.

Figure 17. Permanent Transect 1, Upper Waikato River, March 1989.

**17A. Total Benthic Vegetation Composition
Summer Survey.**

**17B. Dominant Periphyton Composition -Summer
Survey.**





TRANSECT 2

(ref. Figures 18 A, B, C and D)

Physical Environment

Transect 2 formed a deep mobile pebble/gravel/sand lined channel 44 metres wide with a maximum depth of 6.8m at the time of the summer survey. Both the left and right bank consisted of exposed bedrock with a layer of accumulated sand/mud associated with vegetation cover. Water flow was fast through the main channel and dropped to a moderate flow on both banks. Re-survey of this transect showed no significant changes on transect profile or substrate composition.

Benthic Vegetation

Total vegetation cover was low in main channel quadrats with a maximum and median cover class of 1. *Fissidens rigidulus* with epiphytic *Oedogonium* dominated the benthic vegetation in this channel. Maximum local standing crop in mid-channel was 210g m⁻² for *Fissidens* and 3g m⁻² for *Oedogonium* sp., this association occurred on occasional rocks present in the sand/gravel channel.

Fissidens also dominated the riverbank submerged vegetation with a maximum cover class of 6 recorded on the left bank. *Tridontium tasmanicum* was only recorded from quadrat 23 and charophytes (*Nitella hyalina* and *Chara globularis*) were only recorded from the right bank. Maximum growth of *Oedogonium* was found on the right bank as an epiphyte on mosses. *Oedogonium* formed a maximum of 2% of total local biomass of the moss/charophyte association (corresponding to 28g m⁻² from quadrat 23).

Nostoc was found predominantly on the right bank growing in association with mosses. *Nostoc* formed a maximum of 2% of the local biomass (ref quadrat 23). No submerged macrophytes were recorded from this transect.

Although not recorded on this transect, low-mixed species were common on the right bank immediately downstream of Transect 2. Two 0.25m x 0.25m quadrats were dissected from this community (which was above water level at the time of this survey).

Quadrat 1.

species:	height (mm)	cover class	maximum local biomass (g m ⁻²)
<i>Elatine gratioloides</i>	10	1	1.6
<i>Eleocharis pusilla</i>	10	2	33.0
<i>Isoetes kirkii</i>	40	1	12.3
<i>Lilaeopsis ruthiana</i>	30	1	14.0
<i>Myriophyllum pedunculatum</i>	10	2	2.5
<i>Myriophyllum triphyllum</i>	70	2	21.5
<i>Myriophyllum votschii</i>	10	1	17.0
<i>Pilularia novae zealandiae</i>	20	1	9.0
<i>Potamogeton crispus</i>	40	1	5.1
total			138.5

Quadrat 2.

species:	height (mm)	cover class	maximum local biomass (g m ⁻²)
<i>Elatine gratioloides</i>	10	1	13.3
<i>Eleocharis pusilla</i>	20	2	78.5
<i>Isoetes kirkii</i>	60	1	23.8
<i>Lilaeopsis ruthiana</i>	30	1	41.0
<i>Myriophyllum pedunculatum</i>	10	2	1.7
<i>Myriophyllum triphyllum</i>	30	2	11.0
<i>Myriophyllum votschii</i>	10	1	3.1
<i>Pilularia novae zealandiae</i>	20	1	27.2
<i>Potamogeton crispus</i>	60	1	1.9
total			218.1

Re-survey of Transect 2 in winter showed basically the same pattern of benthic vegetation. *Tridontium* was more commonly found

at this time and charophytes were less frequent. Maximum local standing crop for *Fissidens* in the main channel was 163g m⁻², and 5g m⁻² for epiphytic *Oedogonium* on this moss. These were similar values to that recorded from the summer survey. Maximum local standing crop was 20g m⁻² for *Oedogonium* from quadrat 23 and 9g m⁻² for *Nostoc* from the winter survey.

Neither *Enteromorpha* nor *Cladophora* were recorded from Transect 2 in either summer and winter.

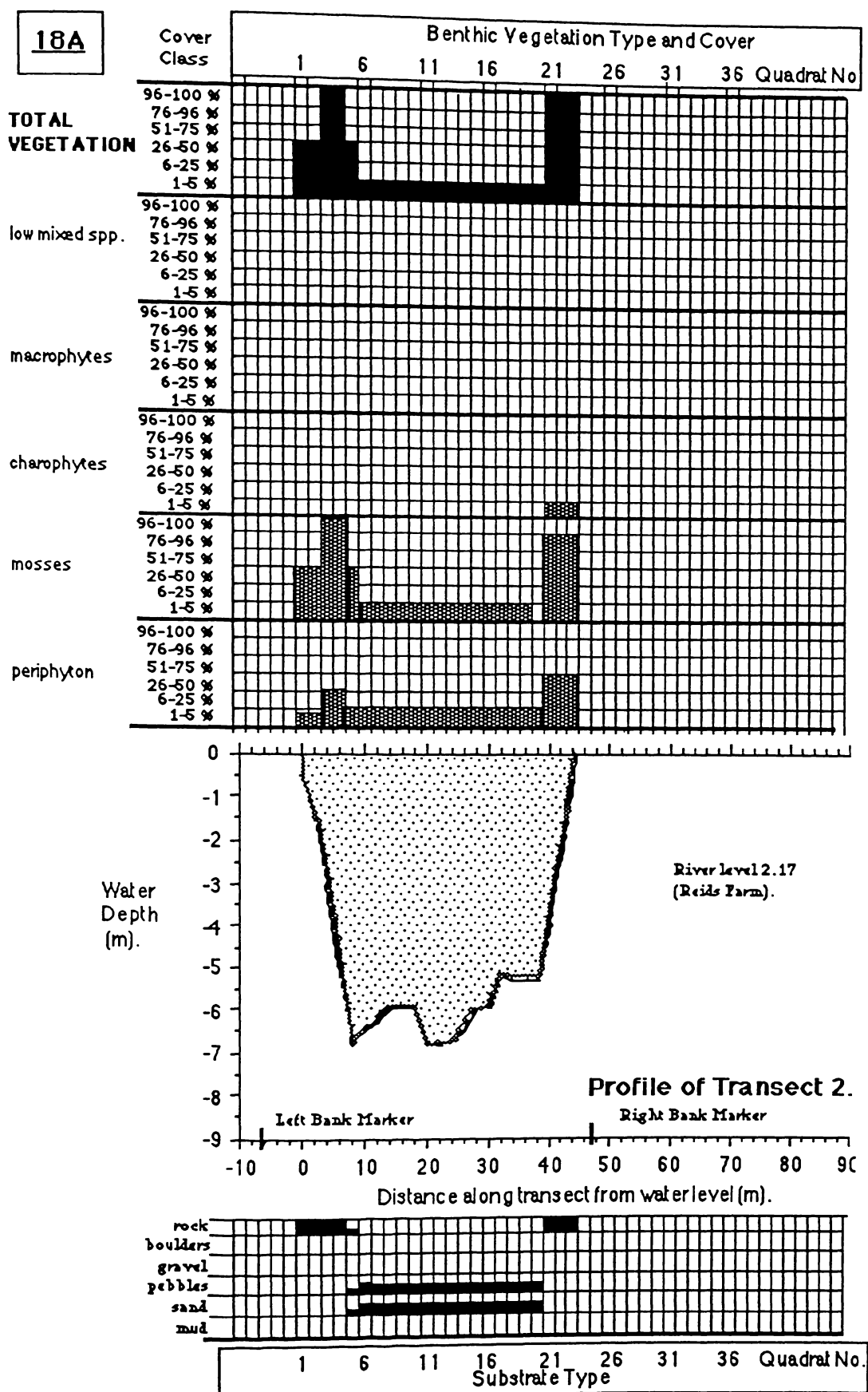
Figure 18. Permanent Transect 2, Upper Waikato River, March 1989.

**18A. Total Benthic Vegetation Composition
Summer Survey.**

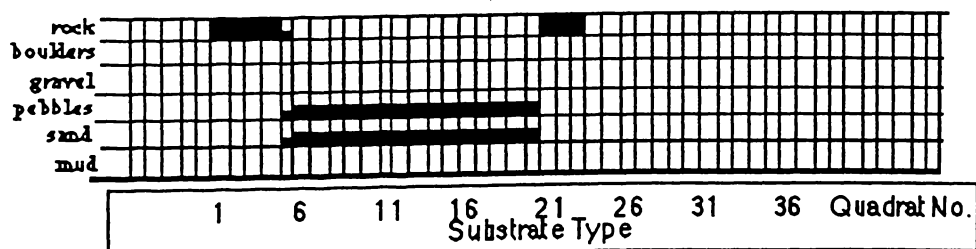
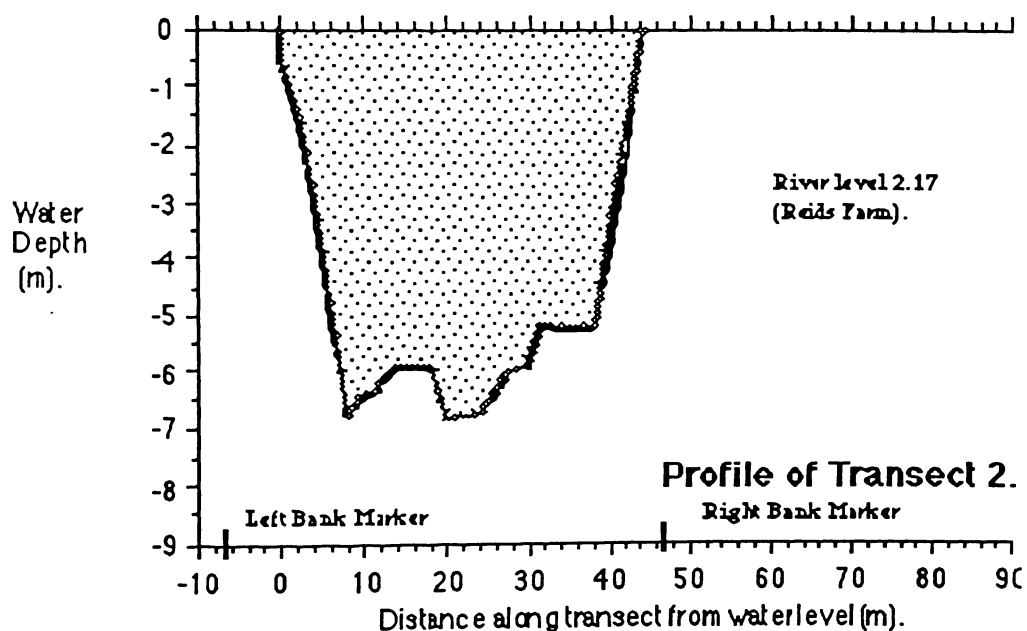
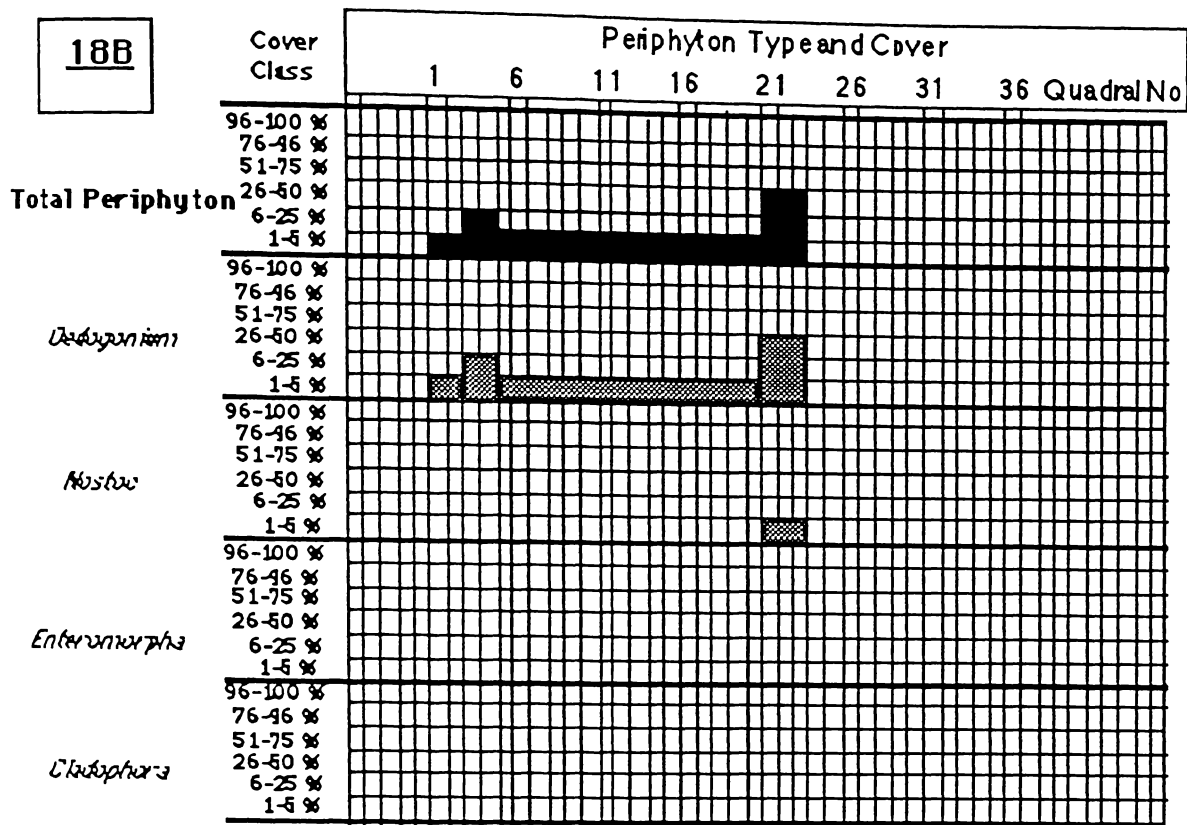
**18B. Dominant Periphyton Composition -Summer
Survey.**

**18C. Total Benthic Vegetation Composition
Winter Survey.**

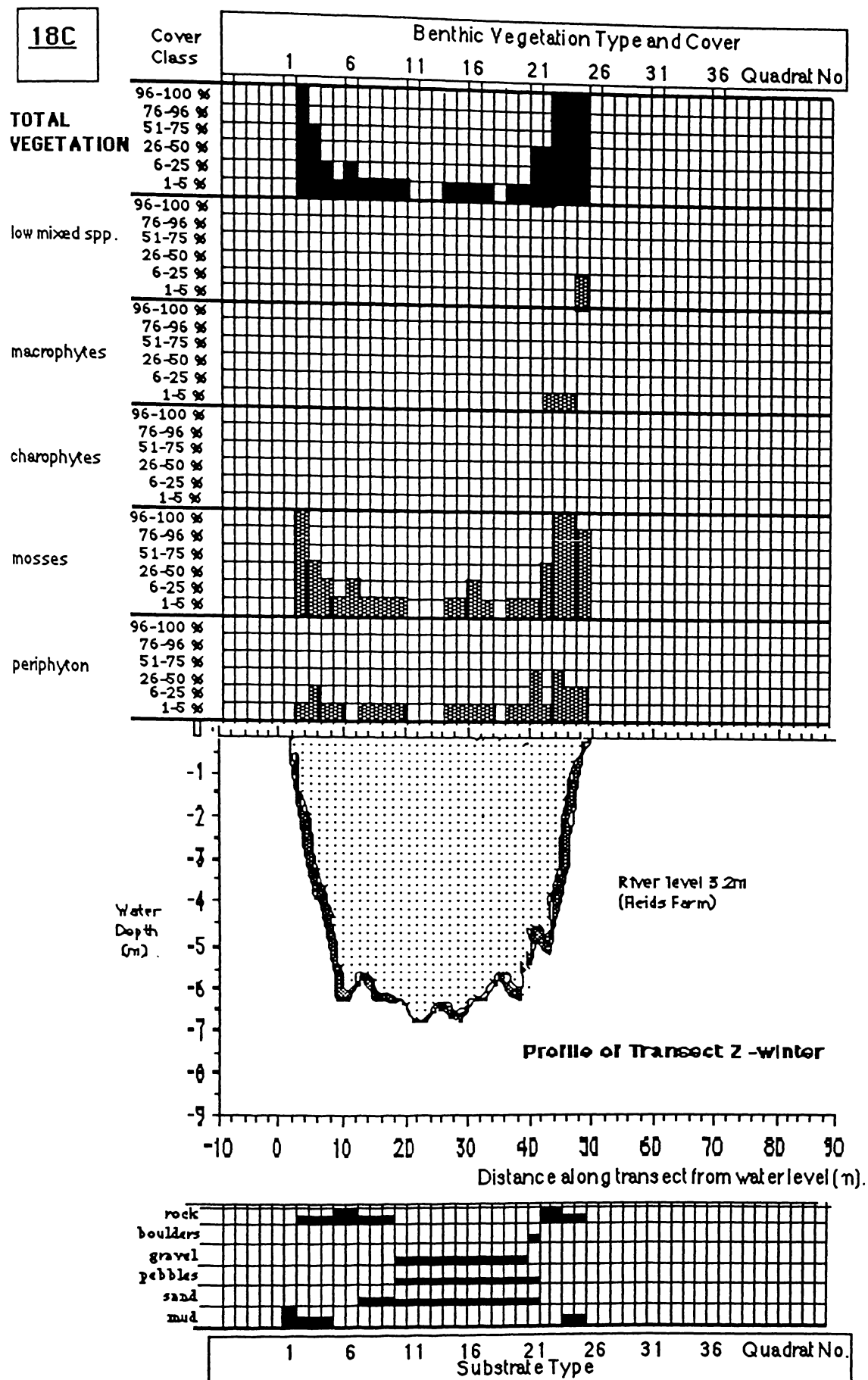
**18D. Dominant Periphyton Composition -Winter
Survey.**

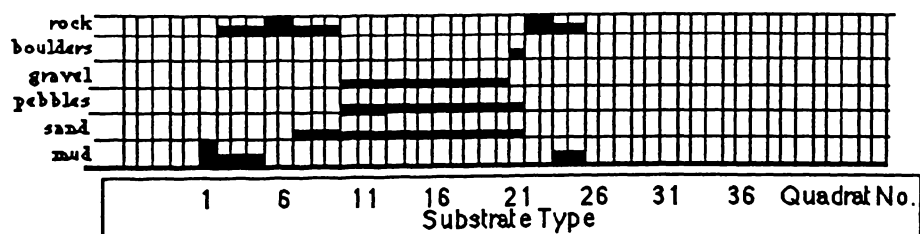
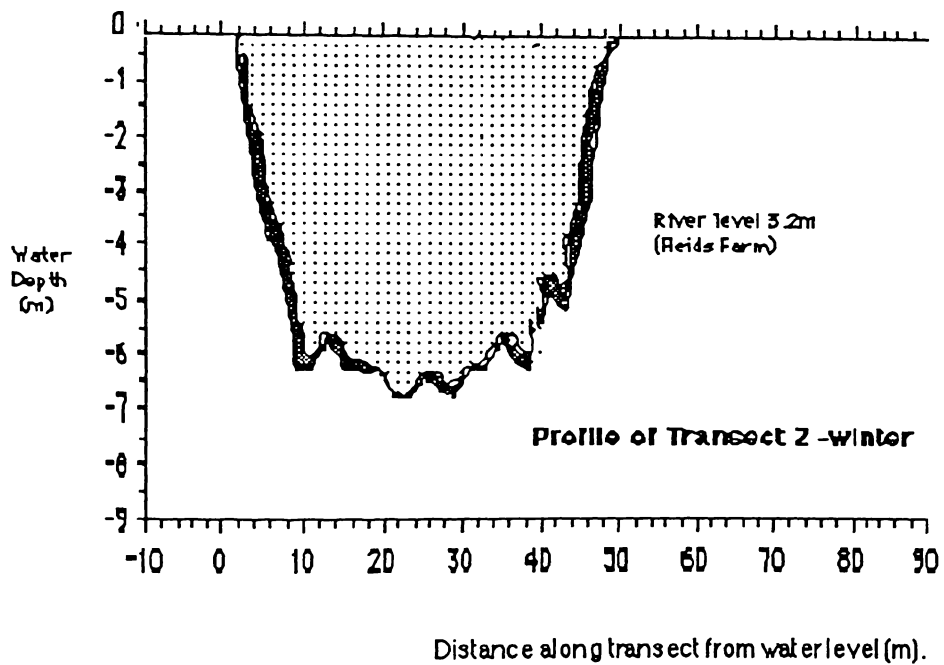
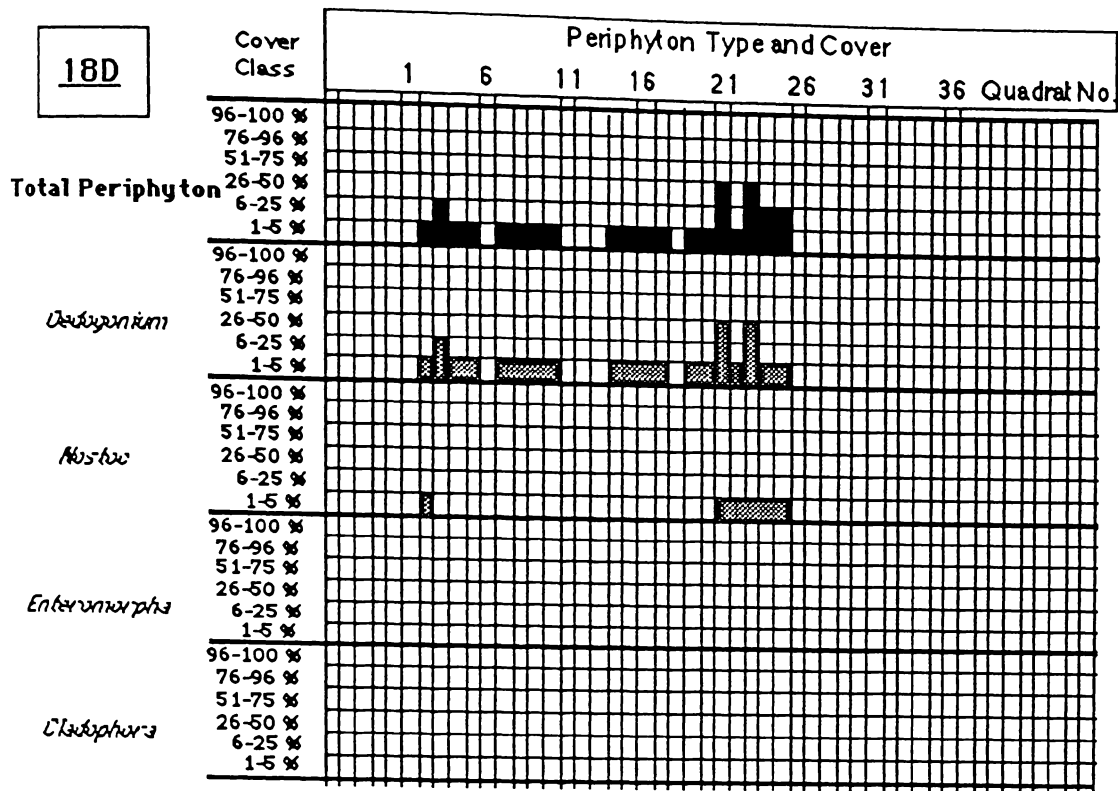


18B



18C





TRANSECT 3

(ref. Figures 19A and B)

Physical Environment

As in Transect 2 a gravel/sand channel supporting limited vegetation cover dominated Transect 3. This transect was 68m wide and crossed a relatively shallow river section with a maximum depth of 3.5 metres at the time of the summer survey. A gravel bed was present on the right bank whilst a sandy mud bank formed the left bank.

Benthic Vegetation

A bed of *Lagarosiphon major*, *Myriophyllum triphyllum* and *Nitella* spp. was present on the left bank of Transect 3. A distinct zonation pattern was observed in this bed with *Myriophyllum* occurring as a discrete band to 0.8m depth, followed by a bed of *Lagarosiphon* to 3.5 metres. A raised sand/mud bank directly adjacent to the *Lagarosiphon* supported a narrow band of charophytes (*Nitella hyalina* and *N. leptostachys*). All submerged macrophytes were free of macroscopic growths of attached algae. Microscopic examination of these plants revealed diatoms and *Oscillatoria* sp dominating the low cover of epiphytes.

The main channel of Transect 3 was dominated by a large mobile sand/pebble/gravel channel which was largely devoid of macroscopic vegetation. Limited macroscopic attached algal growth was observed on this transect. *Oedogonium* sp was recorded in six quadrats only and *Nostoc* was recorded in only two quadrats. These growths were associated with *Tridontium* which grew on

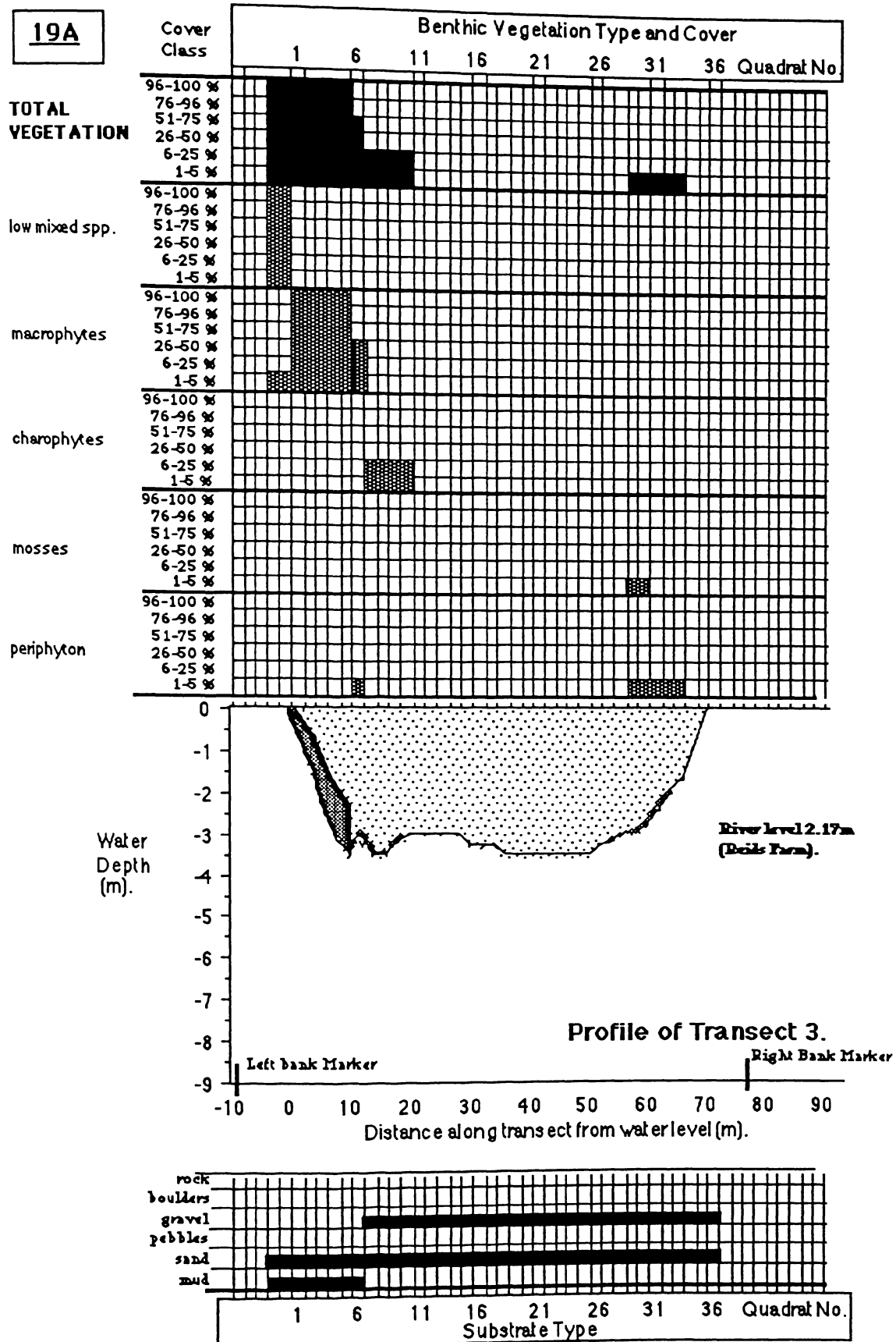
stable gravel on the right bank. Maximum cover classes of both *Oedogonium* and *Nostoc* were 1 and it was estimated that these algae would form less than 1% of total local biomass on this transect. Neither *Enteromorpha* nor *Cladophora* were recorded from this Transect 3.

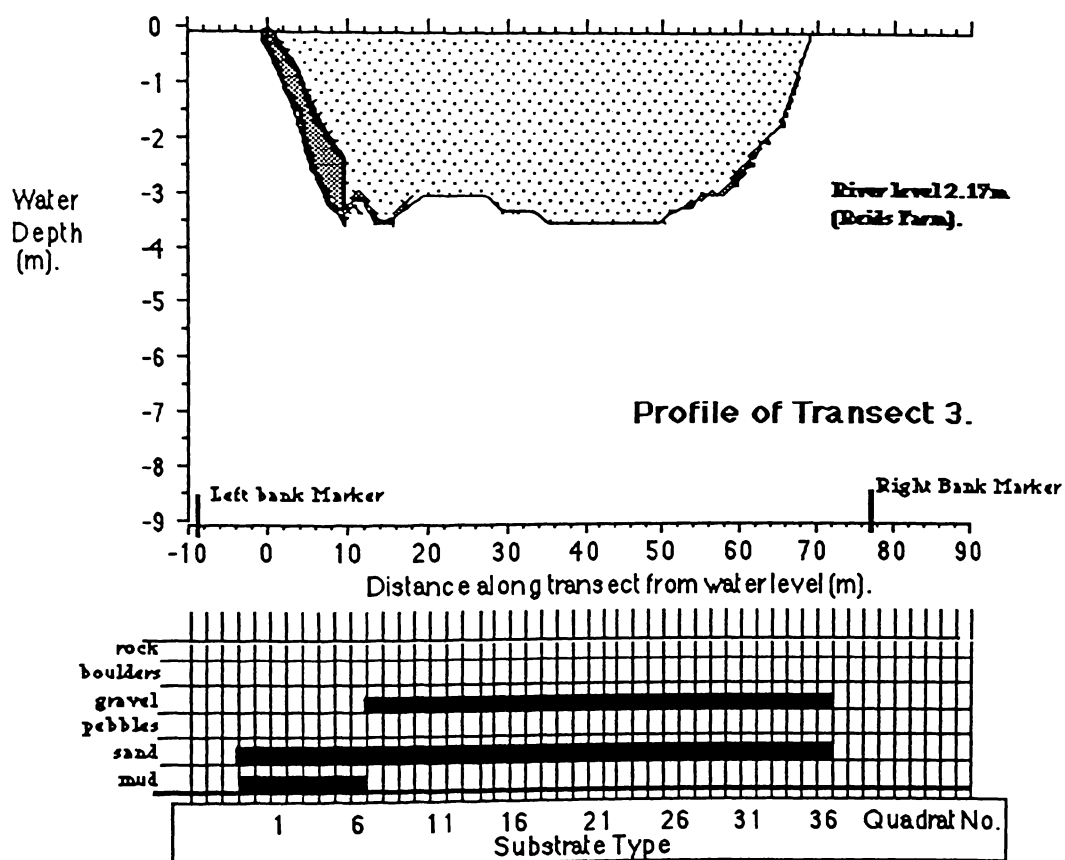
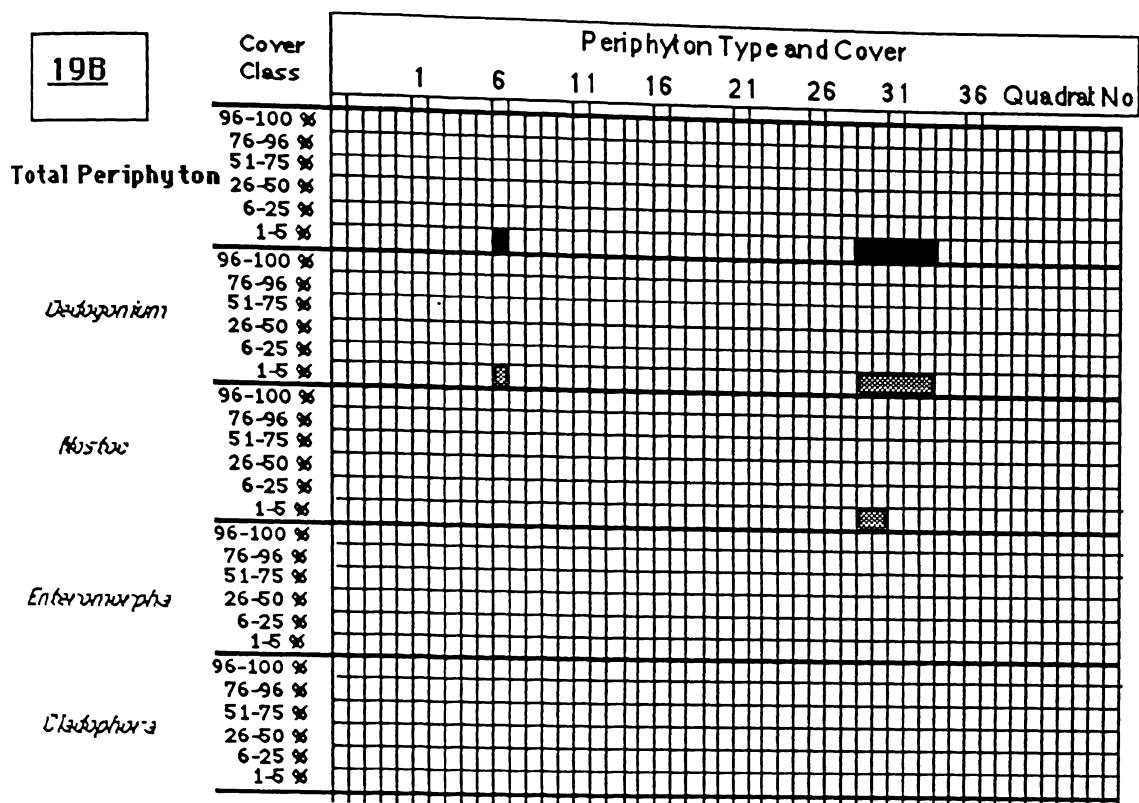
A low-mixed assemblage (mlsc 435g m⁻²) was present on the left bank both immediately upstream and downstream of Transect 3 in an area of low-moderate flow. This assemblage was dominated by *Glossostigma elatinoides* (mlsc 160g m⁻²), at the time of inspection. *Pilularia novae-zelandiae* formed a mlsc of 40g m⁻², *Isoetes Kirkii* formed a mlsc of 23g m⁻² from this association.

Figure 19. Permanent Transect 3, Upper Waikato River, March 1989.

19A. Total Benthic Vegetation Composition - Summer Survey.

19B. Dominant Periphyton Composition -Summer Survey.





Additional Observations from Section 1

Water levels during the summer survey were low and provided the opportunity to score the distribution of both submerged macrophytes and low-mixed species when travelling between transect sites. The most extensive areas of these communities occurred along either bank between Transects 1 and 4. Figure 20 shows the location of the sites described below.

Sites a

Site a was on the left bank immediately upstream of the sheltered embayment.

A well developed *Lagarosiphon major* bed was present in 0-3 m of water (see *Lagarosiphon* monitoring results). A low-mixed species association was present directly above the *Lagarosiphon* on exposed sandy mudbanks. Quadrat scores and maximum local biomass for low-mixed species which were immersed at Site a at the time of this inspection were;

Site a/sample 1

species:	height (mm)	cover class	maximum local biomass (g m ⁻²)
<i>Eleocharis pusilla</i>	20	1	6.2
<i>Glossostigma elatinoides</i>	40		168.7
<i>Isoetes kirkii</i>	60	1	8.4
<i>Lilaeopsis ruthiana</i>	50	2	11.9
<i>Pilularia novae zealandiae</i>	30	1	14.5

Site a/sample 2

species:	height (mm)	cover class	maximum local biomass
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			(g m ⁻²)
<i>Eleocharis pusilla</i>	20	1	84.0
<i>Glossostigma elatinoides</i>	10	4	237.6
<i>Isoetes kirkii</i>	60	1	3.4
<i>Lilaeopsis ruthiana</i>	60	2	23.8

Site b

Site b was on the right bank 200 m downstream of Transect1 where local patches of low-mixed species occurred on muddy substrate on rock surfaces (emersed at the time of this inspection). Species recorded as present were:

Species:	height (mm)	cover class
<i>Elatine gratioloides</i>	10	1
<i>Eleocharis pusilla</i>	20	2
<i>Glossostigma elatinoides</i>	10	1
<i>Glossostigma submersum</i>	10	3
<i>Isoetes kirkii</i>	60	1
<i>Lilaeopsis ruthiana</i>	50	1
<i>Myriophyllum pedunculatum</i>	90	1
<i>Myriophyllum votschii</i>	10	1
<i>Pilularia novae zealandiae</i>	30	1
<i>Ranunculus limosella</i>	40	2

Site c

A sheltered embayment lies on the left bank of the river between Transect 1 and 2 (site C on Fig. 1) which was the original channel of the river before the construction of the Lake Taupo Gates.

Nostoc spp. (*Nostoc verrucosum* type) was found growing at high densities in association with *Pilularia novae-zelandiae*. A quadrat was cut of this association type and *Nostoc* formed 93% of the local biomass (70.7g m⁻²). It is suggested that part of the local biomass observed accumulates in sheltered areas, like this embayment, from upstream drift of *Nostoc*. Due to the sheltered conditions in this embayment large unattached growths of *Nostoc* occurred (mlsc 558.4g.m⁻²). *Nostoc* spp. was also found at lower densities growing in association with low mound plants. Inspection of this embayment in January, 1990 confirmed the previous summer's observations.

The emergents *Schoenoplectus validus* and *Typha orientalis* were present at the head of the embayment. Well developed low-mixed communities were present around the periphery of the bay. The following quadrat dissection yielded the maximum local biomass for *Pilularia*.

species:	height (mm)	cover class	maximum local biomass (g m ⁻²)
<i>Elatine gratioloides</i>	10	3	130
<i>Eleocharis pusilla</i>	20	1	88
<i>Isoetes kirkii</i>	60	1	4
<i>Lilaeopsis ruthiana</i>	50	1	0.26
<i>Myriophyllum pedunculatum</i>	60	1	1
<i>Pilularia novae zealandiae</i>	30	2	192

A stormwater drain entered the embayment on the southern margin. Inspection of submerged plant associations in the vicinity of

this previously unrecognised inflow showed no visually obvious impact and discharge at this site was not considered further.

Inspection of river margins in this embayment showed occasional small populations of *Enteromorpha*, presumably associated with localised nutrient enrichment. *Cladophora* and *Enteromorpha* were infrequently observed, (most often as drift populations), at low cover in the main channel area. Plants of both species appeared chlorotic compared to populations downstream of the sewage discharge.

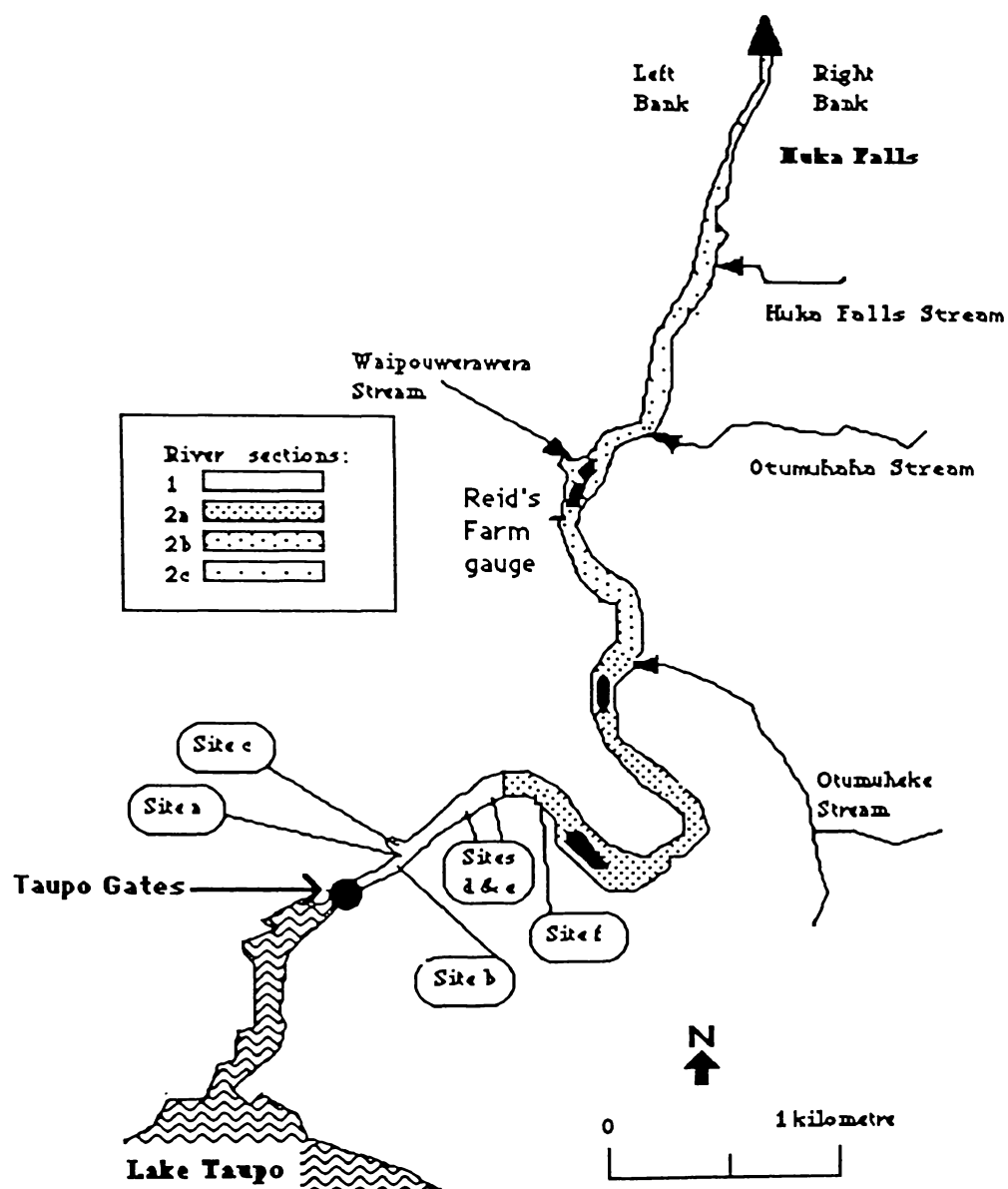


Figure 20. Map of the Upper Waikato River showing additional observation sites not located directly on transect, March 1989.

2:3.1.2**SECTION 2a**

An abrupt change in the composition of benthic vegetation was observed downstream of the sewage discharge. This was reflected by extensive periphytic algal proliferations in Transects 4 and 5.

TRANSECT 4

(ref. Figures 21A, B, C and D)

Physical Environment

This transect was 76m wide and formed a deep (maximum depth 7.5m (summer survey), 9.0m (winter survey)), steep-sided bedrock/boulder lined channel on the left bank that graded into a gravel/sand bed from mid-channel to the right bank. Neither riverbed profile nor substrate composition at Transect 4 changed significantly from comparison of summer and winter data. Bank erosion on the right bank may account for minor changes observed in this area. Slight differences in the length of chain and hence actual path followed may also account for minor differences.

Benthic Vegetation

Conspicuous growths of attached algae, notably *Cladophora glomerata* and *Enteromorpha nana*, dominated the submerged vegetation observed on Transect 4 during both summer and winter. *Enteromorpha* was found growing mainly as an epiphyte on mosses in moderate to high flow environments and directly on substrata in low flow environments. *Enteromorpha* was recorded in 51% of quadrats with a maximum cover class of 5 and median cover class of 3 recorded. A mlsc of 435g m⁻² was

recorded for *Enteromorpha* in low flow environments (100% of total local biomass), and a mlsc of 140g m⁻² when growing in association with mosses in the main channel (14% of total local biomass). Generally, filaments appeared poorly attached to the substrate and it is estimated that there would be a high 'slough-off' rate for this alga.

Cladophora was observed in 71% of quadrats with a maximum cover class of 4 and median cover class of 1 and was found growing epilithically. A mlsc of 83g m⁻² was sampled from quadrat 28 which reflected maximum observed biomass in the fast flowing main channel. Maximum local standing crop was measured from more flow sheltered locations was 1,226g m⁻². Low density epiphytic cover of diatoms were found on *Cladophora* filaments.

Nostoc was recorded at low cover in 21% of quadrats described. *Oedogonium* was found in only one quadrat during the summer survey, at a high cover (5), corresponding to 320g m⁻².

Both *Tridontium* and *Fissidens* were found infrequently on this transect (31 and 21 % quadrat frequency respectively), at low cover during the summer survey. Above water level (summer survey) on the left bank, a closed cover of low-mixed species was present on muddy sediments. *Eleocharis pusilla* formed 58% of mlsc (224g m⁻²) at this site. This high biomass for a low cover species was attributed to the extensive root mass present.

No submerged macrophytes were recorded on this transect in either the summer or winter surveys, although beds of *Lagarosiphon major*, *Myriophyllum triphyllum* and *Ranunculus fluitans* (mlsc 48g m⁻²) were present in the vicinity of the transect on the right bank side. *Enteromorpha* was found as an abundant epiphyte on *Lagarosiphon*

immediately upstream of Transect 4 (see *Lagarosiphon* monitoring results).

The winter survey of Transect 4 showed a similar benthic vegetation pattern to that observed in summer. Total vegetation cover was similar but with comparatively higher covers recorded in the vicinity of quadrats 20-30. Low-mixed species were present at low cover and low species diversity on the right bank.

Mosses (*Tridontium* and *Fissidens*) were more frequently encountered in the main channel (cover classes 2-3), and were heavily epiphytised by *Enteromorpha*. Maximum local standing crop of *Enteromorpha* was 414g m⁻², which formed approximately 90% of the biomass of this association.

The winter survey of Transect 4 recorded two new species of algal periphyton, these were *Vaucheria* sp. and *Ghomphonema* species. *Vaucheria* was present as dense cushion-like tufts at low cover in three quadrats. *Ghomphonema* sp. was present only in quadrat 7. More extensive development of these two species was observed at Transect 5.

As in the summer survey, periphyton dominated the phytobenthos (*Cladophora* and *Enteromorpha*) found on Transect 4. In the fast flowing main channel area *Enteromorpha* was commonly found as an epiphyte on mosses, *Cladophora* was found growing epilithically at all sites on this transect. Maximum local standing crop of *Cladophora* was 143g m⁻², with an average filament length of 100mm in the fast flowing area of the main channel and 200mm average filament length in areas of more moderate water flow.

As an epiphytic population on *Fissidens*, *Enteromorpha* formed a mlsc of 33.5g m⁻², which constituted approximately 8% of total local biomass.

Figure 21. Permanent Transect 4, Upper Waikato River, March 1989.

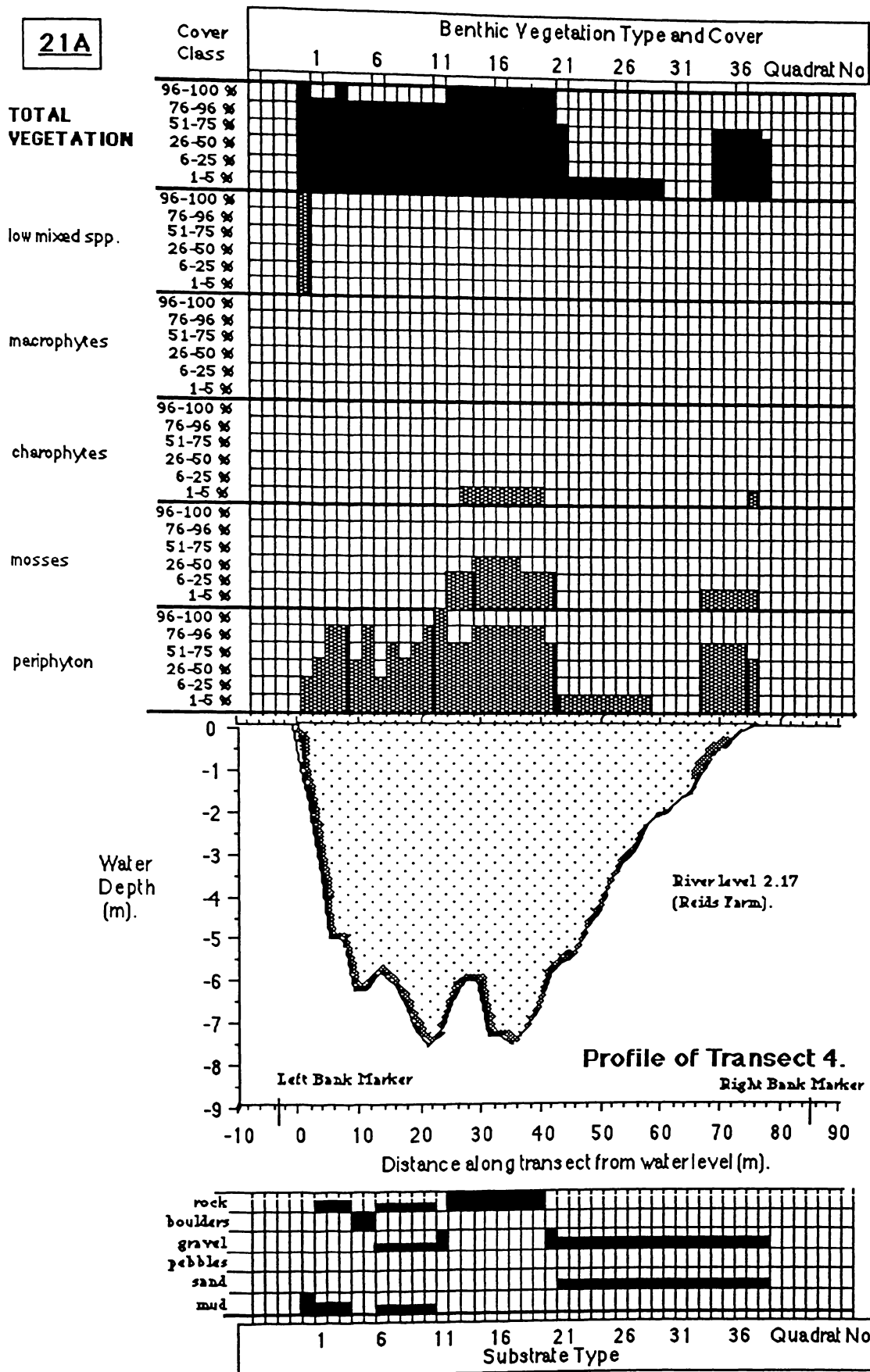
21A. Total Benthic Vegetation Composition - Summer Survey.

21B. Dominant Periphyton Composition -Summer Survey.

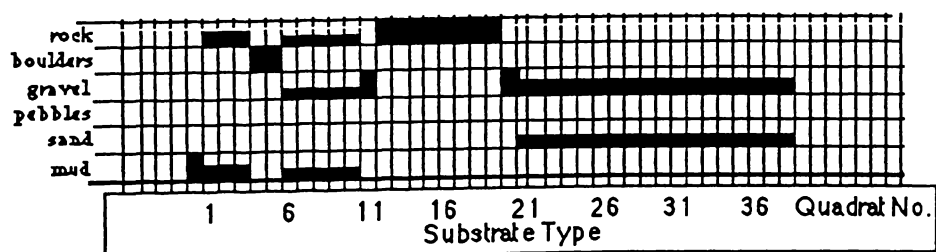
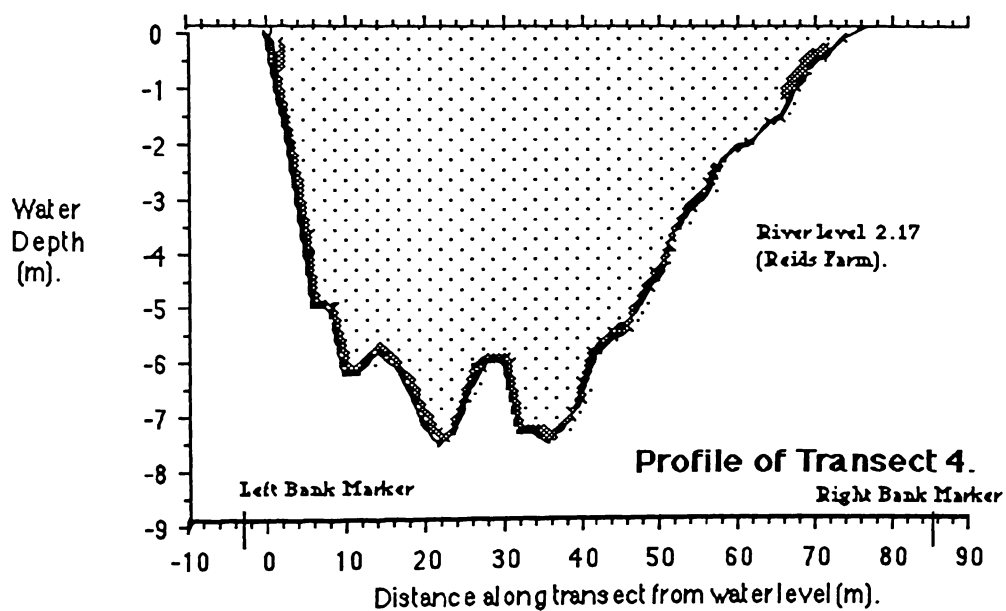
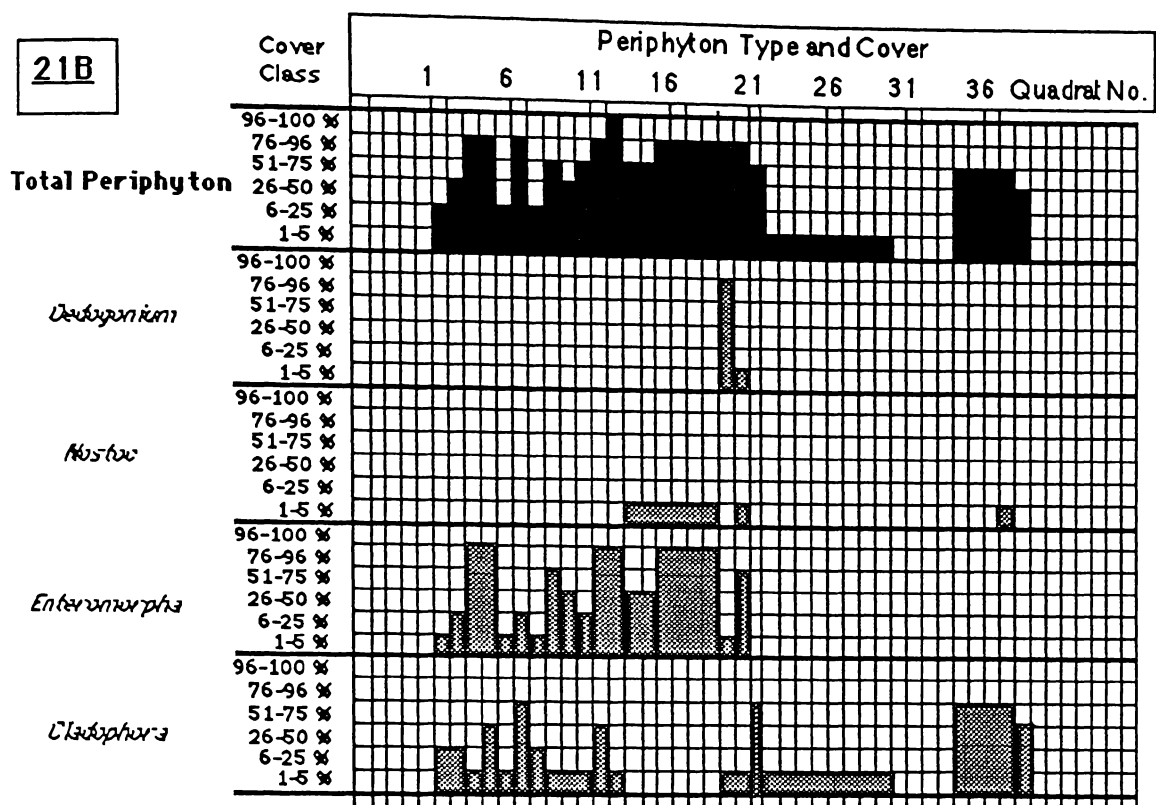
21C. Total Benthic Vegetation Composition - Winter Survey.

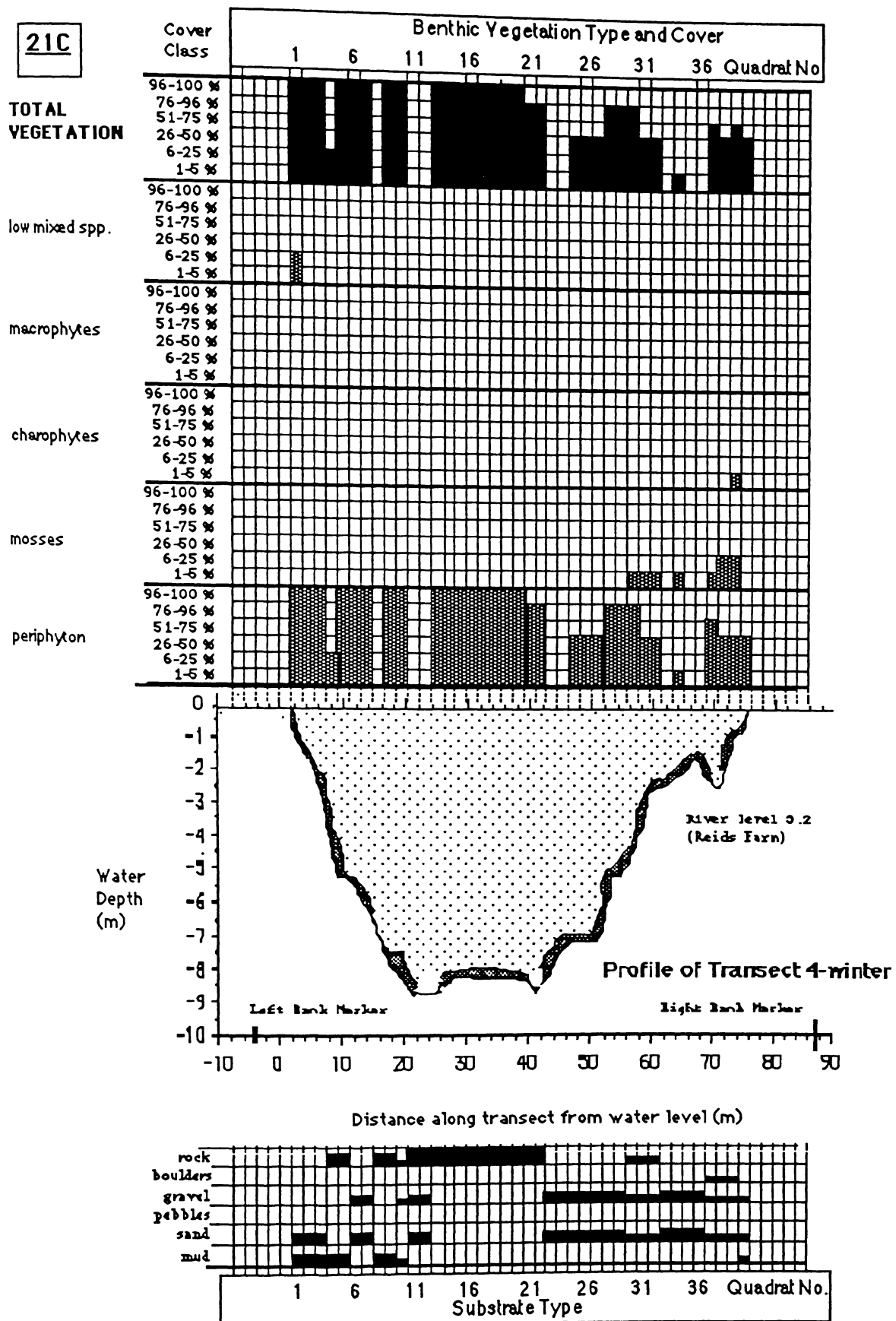
21D. Dominant Periphyton Composition -Winter Survey.

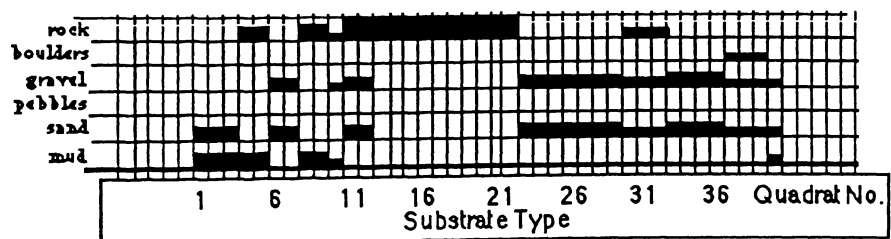
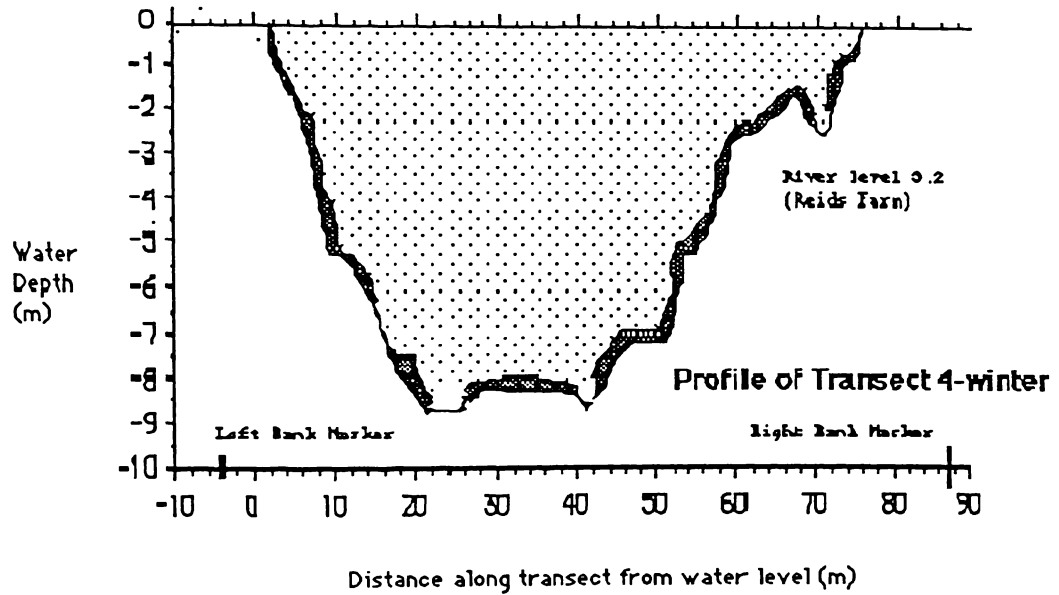
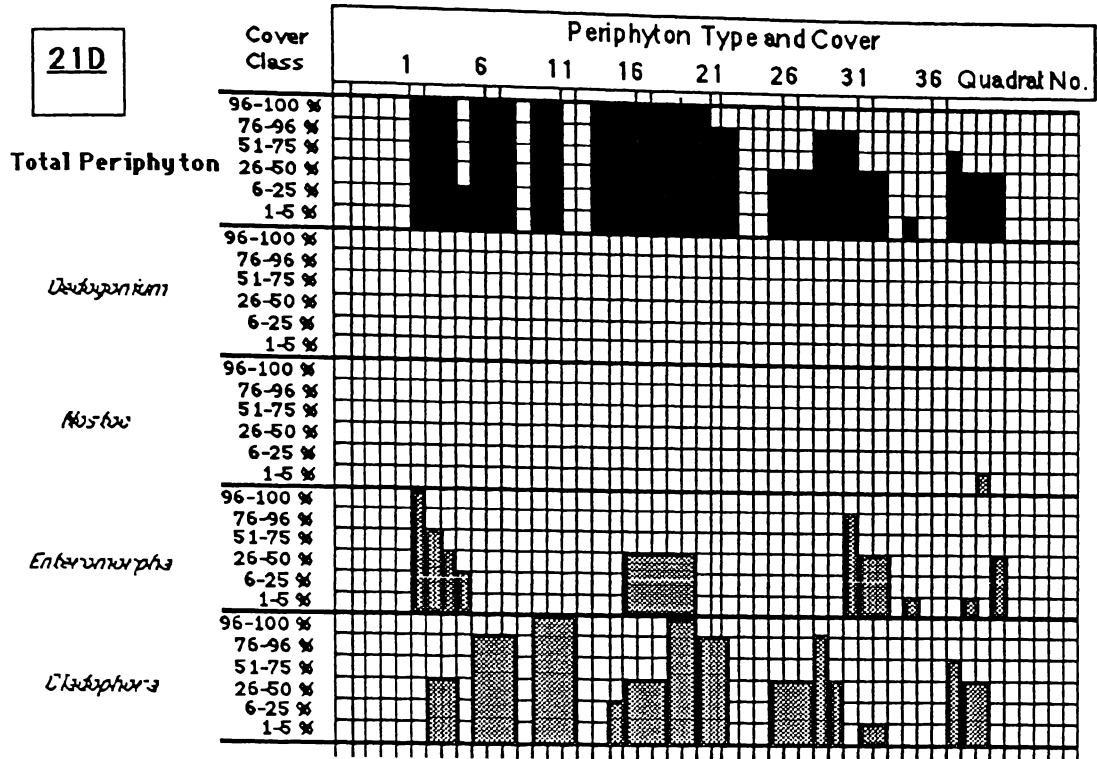
21A



21B







Transect 5

Physical Environment

(ref. Figures 22A, B, C and D)

Transect 5 dropped steeply on the left bank to a 6m wide gravel/sand transport-scour channel at a maximum depth of 6 metres (summer survey). As in other transects this channel was devoid of macroscopic vegetation due to substrate mobility. The right bank of this profile formed a shallow shelf (ca. 2.5m water depth at the time of survey), and consisted of a mixture of exposed bedrock, boulders, gravel and sand. Current flow was fast from the left bank through to near quadrat 26 where moderate flow was experienced. Transect 5 was 70 metres wide. The re-survey of Transect 5 in winter showed little change in either riverbed profile or substrate composition. Any minor changes recorded may be accounted for by reasons outlined in Transect 4's description.

Benthic Vegetation

The submerged benthic vegetation in Transect 5 was dominated by *Cladophora glomerata*. Epilithic growths of *Cladophora* were found in 86% (summer) and 75% (winter) of quadrats and was only absent from mobile sand/gravel channels and the low flow environment on the right bank. *Cladophora* scored a median cover class of 5 (summer and winter) and a maximum cover class of 6 (summer and winter) on this transect. Filaments grew to a maximum recorded length of 200mm in this high flow environment with an average length of 100-150mm. Maximum local standing crop of *Cladophora* was measured at 430 (summer) and 553 g m⁻² (winter). Epiphyte density on a representative sample of filaments was low.

Enteromorpha was also commonly found on this transect, where it grew predominantly as an epiphyte on mosses in moderate to high flow environments. Filaments of *Enteromorpha* grew to a maximum and average length of approximately 200mm (summer) and were observed up to a metre long in the winter. *Enteromorpha* was found in 56% (summer) and 22% (winter) of quadrats and scored a median cover class of 2 (summer), 3-4 (winter) with a maximum cover class of 4 (summer) and 6 in winter. A quantitative sample was made at quadrat 36 (summer). *Enteromorpha* formed 22% of the biomass (30g m⁻²) as an epiphyte on the low mound association. Similar samples made during the winter this site recorded 43 g m⁻² which formed 66% of total biomass. Maximum *Enteromorpha* biomass observed when growing epiphytically on mosses was much greater at 171g m⁻² (winter) which constituted 90% of the standing crop of this association.

Two 0.25 x 0.25m quadrats were cut above Transect 5 on the right bank (summer). These quadrats reflected maximum local standing crop of epilithic *Enteromorpha* in this vicinity. *Enteromorpha* formed 88 and 166g m⁻² in these two quadrats. Maximum local standing crop in this area was 205g m⁻² in winter.

Microscopic inspection of samples of *Enteromorpha* and *Cladophora* were largely free of conspicuous epiphytes in the summer, some relative increase in epiphytes (mainly diatoms) on *Cladophora* was observed upon inspection of winter samples. This may indicate a slower growth rate in winter. No such change was observed for *Enteromorpha*. *Cladophora* was occasionally observed to grow epiphytically on *Enteromorpha* in moderate flow environments in both summer and winter.

Vaucheria formed dense cushion-like mounds on rock substrate in both fast and moderate flow environs on the right bank side of this transect in winter. A maximum cover class of 5 with a median cover class of 3 was recorded and plants examined had few epiphytes. Maximum standing crop of *Vaucheria* was 342.8g m⁻². This species occupies similar habitat known from the summer survey to support *Cladophora* growth.

Ghomphonema was observed growing both epilithically on substrates in moderate to fast flowing areas and epiphytically on both *Cladophora* and *Enteromorpha* in the vicinity of this transect. This species was recorded as present on Transect 5 only at quadrat 34 at a cover class of 3. Maximum local standing crop of this species at this site was 25g m⁻² for epilithic populations.

Drift diving observations made during August-November showed extensive development of both *Ghomphonema* and *Vaucheria* in this Section of river.

Both *Tridontium* and *Fissidens* were commonly found growing epilithically in mid-channel in high flow environments on Transect 5. However they were not found to have covers greater than 2 in any quadrat and were heavily epiphytised by *Enteromorpha*. The maximum local standing crop was 98g m⁻² for *Tridontium* (quadrat 10) and 130 g m⁻² (quadrat 17) for *Fissidens* in the summer and 20g m⁻² in the winter for *Tridontium*.

The other major vegetation types were largely absent from this transect. No charophytes were observed and *Lagarosiphon major* was the only macrophyte recorded on this transect. *Lagarosiphon* was recorded from quadrat 3 as a localised growth in the lee of boulders with a maximum local standing crop of 61.3g m⁻² (summer).

A low-mixed association dominated by *Glossostigma elatinoides* with *Eleocharis pusilla* and *Myriophyllum pedunculatum*, was present in the shallow, low flow environment on the right bank. The maximum local standing crop of *Glossostigma* was 88 g m⁻². *Eleocharis* and *Myriophyllum* scored 16 and 3g m⁻² respectively from this quadrat. *Enteromorpha* was a common epiphyte on this association and was also observed to grow epilithically on exposed limestone in the area

Additional observations

Sites d, e and f

(ref. Figure 20)

All submerged macrophytes and low-mixed species recorded in this survey occurred at one of these three localities. *Ceratophyllum demersum* was recorded at Site f.

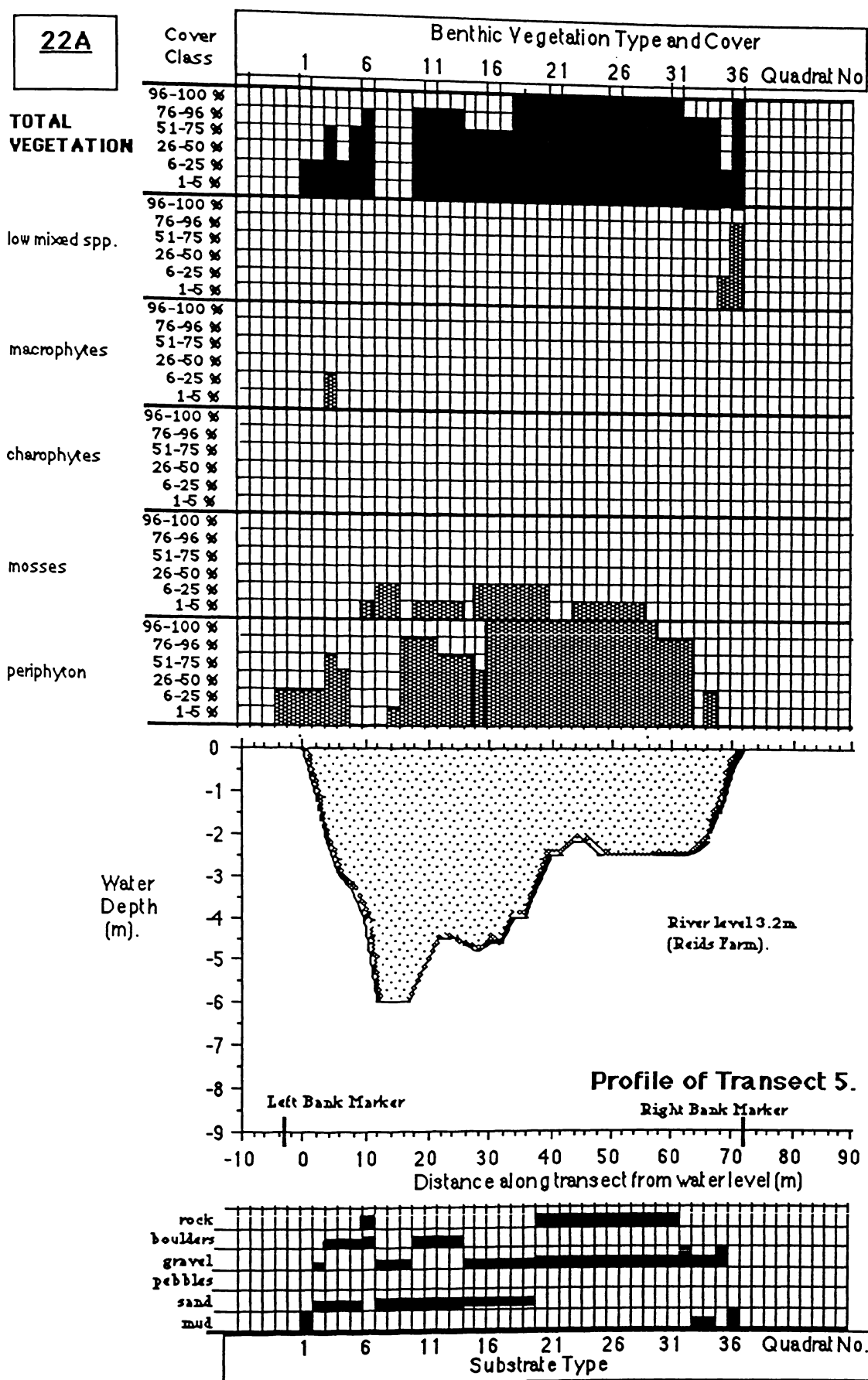
Figure 22. Permanent Transect 5, Upper Waikato River, March 1989.

**22A. Total Benthic Vegetation Composition
Summer Survey.**

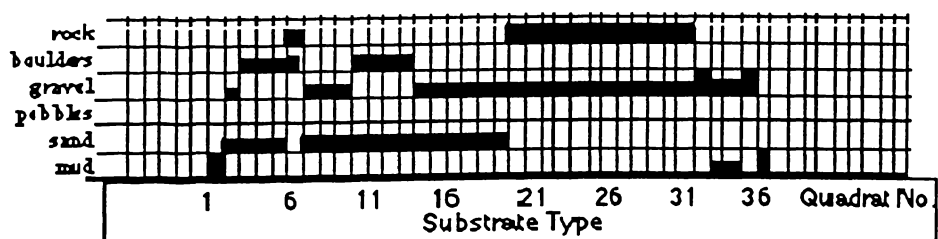
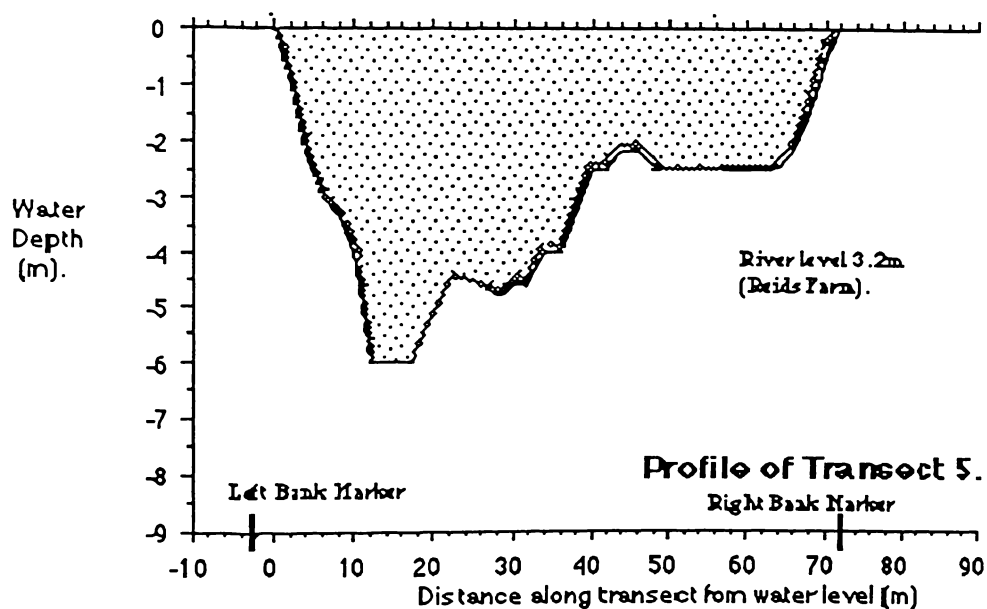
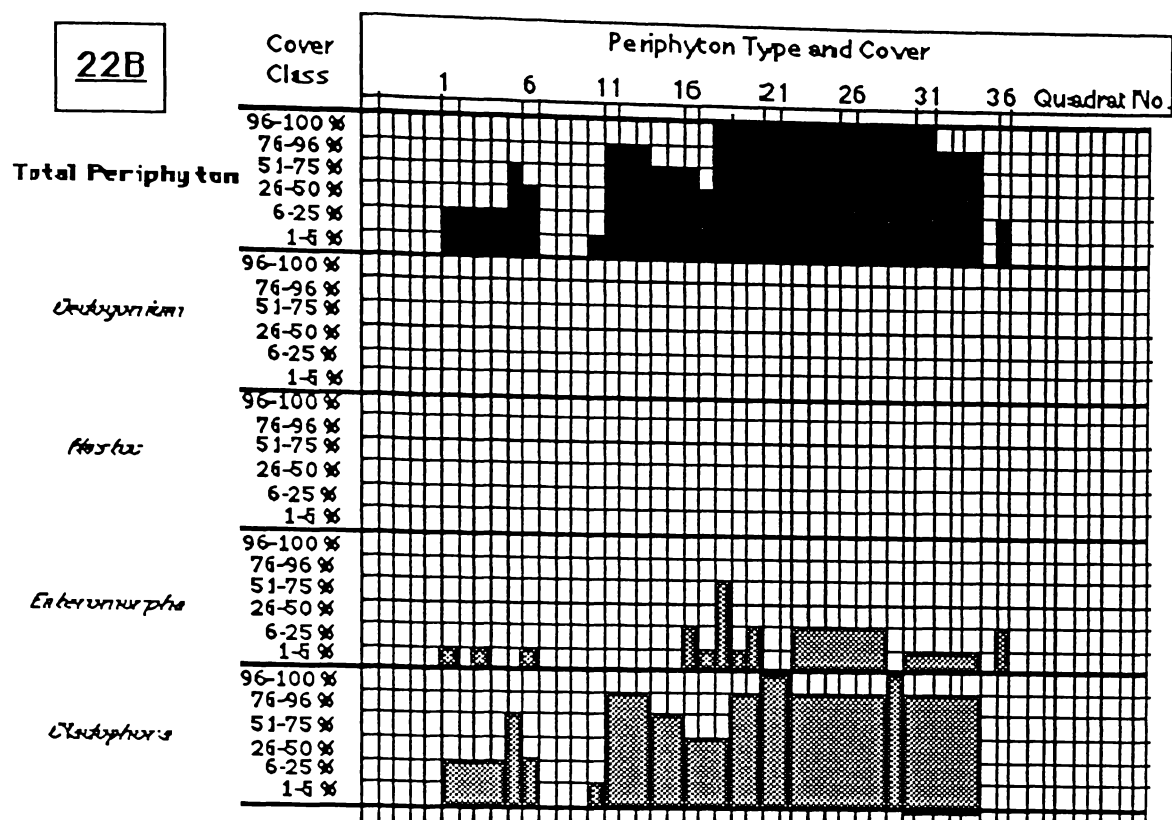
**22B. Dominant Periphyton Composition -Summer
Survey.**

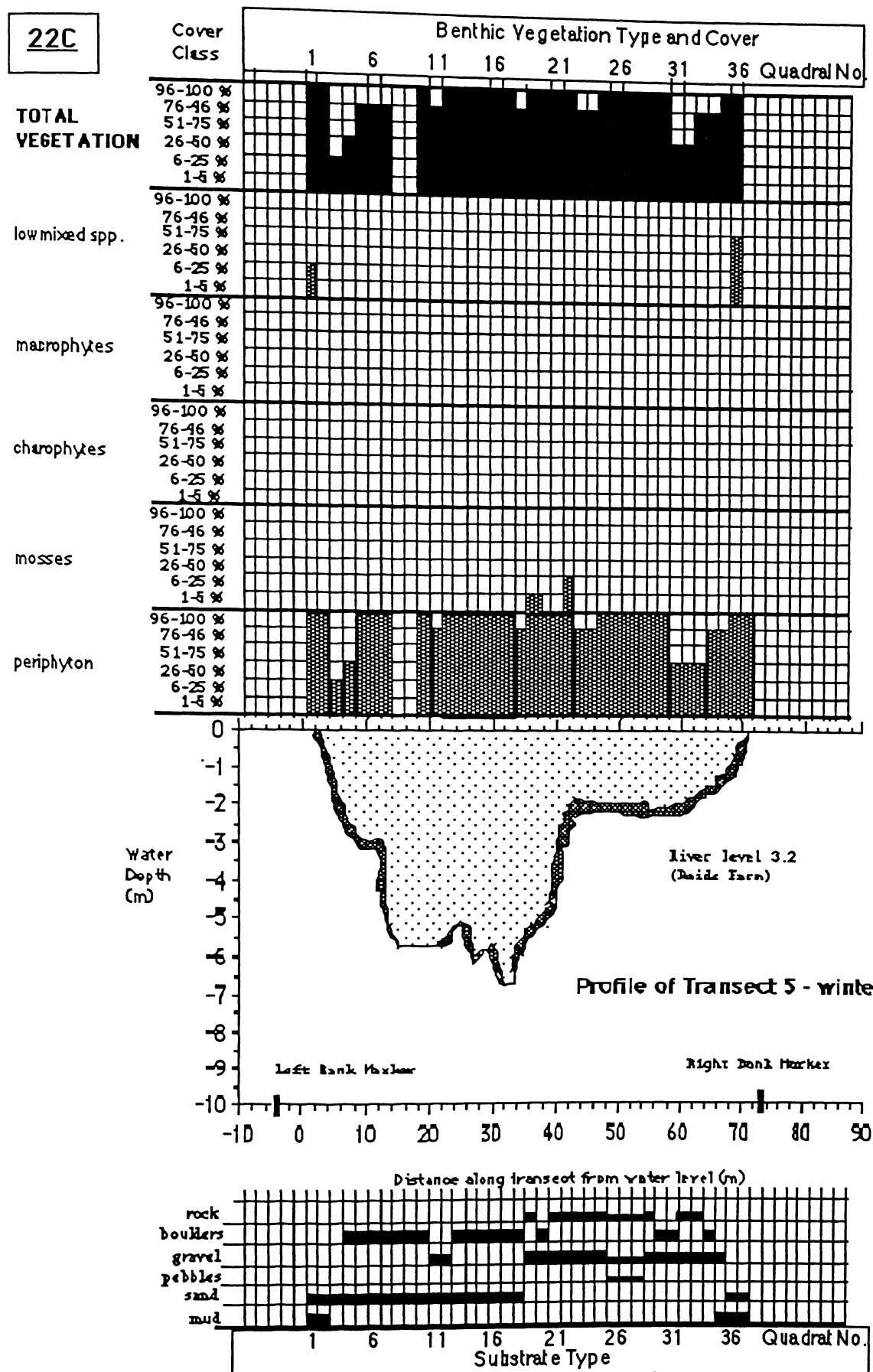
**22C. Total Benthic Vegetation Composition
Winter Survey.**

**22D. Dominant Periphyton Composition -Winter
Survey.**

22A

22B





2:3.1.3**SECTION 2b**

The same trend of *Cladophora* and *Enteromorpha* domination of phyto-benthos was observed in Section 2b as found in Section 2a.

TRANSECT 6

(ref Figures 23A and B)

Physical Environment

Transect 6 (80m wide) was located immediately below the discharge from the Otumuheke Stream. Large rocks and boulders dominated the riverbed on the left bank and graded into a gravel/pebble/sand main channel with a maximum depth of 4 metres. Water flow was fastest immediately adjacent to the left bank and moderate through the shallow main channel grading to a low flow near the right bank.

Benthic Vegetation

Benthic vegetation was dominated by attached algal associations in Transect 6. As in Transect 5 epilithic *Cladophora glomerata* dominated these associations with a maximum cover of 5 and a median cover class of 4 and was found in 86% of quadrats. Filaments grew to a maximum length of 200mm and were free of conspicuous epiphytic growths. Maximum local standing crop was 820g m⁻² measured at quadrat 35.

Enteromorpha was found predominantly as an epiphyte on mosses in moderate to high flow environments, but was also observed to also grow epiphytically in low flow areas. Filaments of *Enteromorpha* reached a maximum length of 50cm in these low flow environments. *Enteromorpha* was only found in 22% of quadrats at low cover (median cover class of 1, maximum cover class of 2). Maximum local standing crop was 135g m⁻² at quadrat 7.

Nostoc spp. was recorded sporadically through the transect at low cover, (maximum cover class 1, median cover class 1).

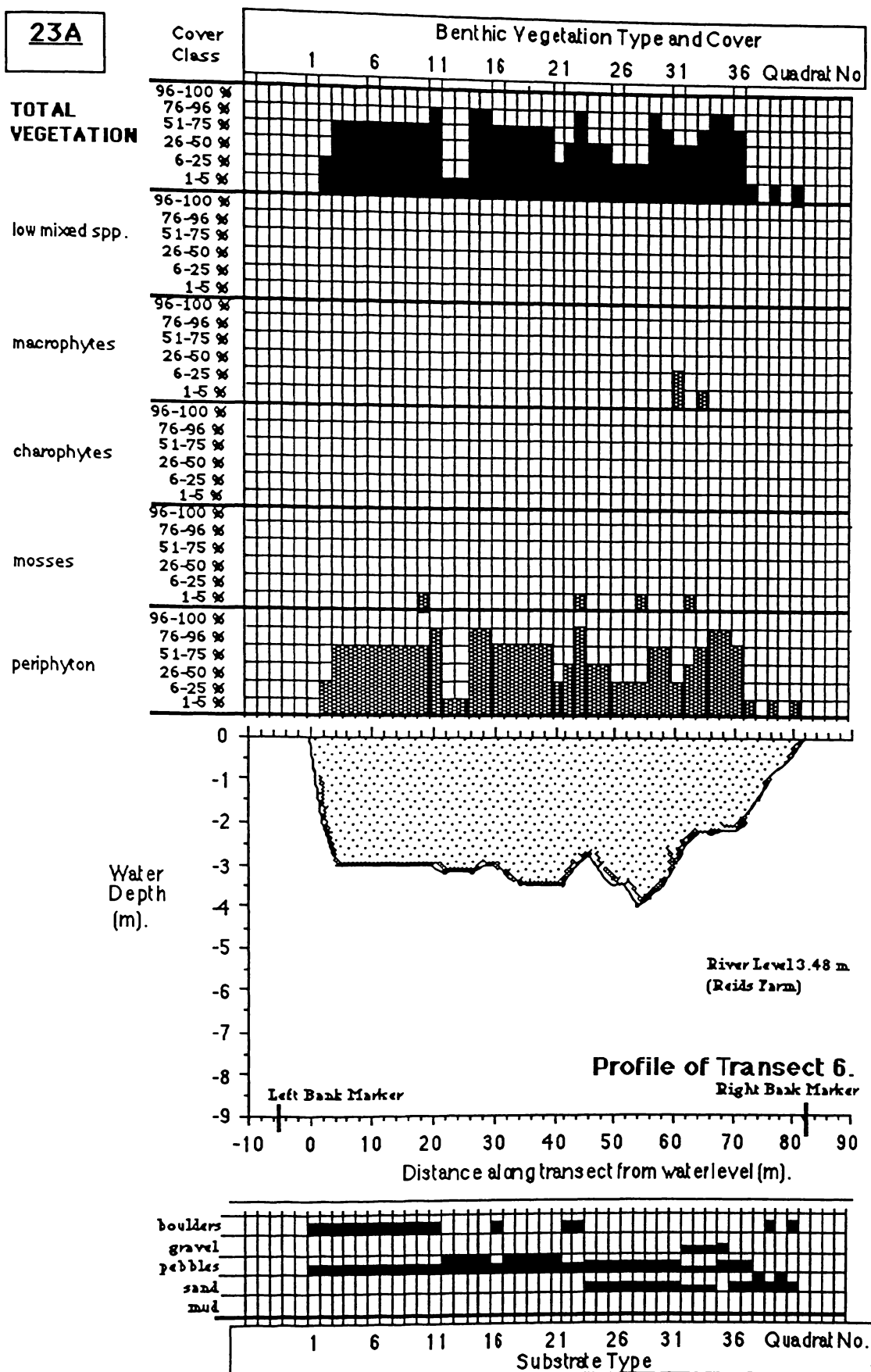
The impact of a geothermal discharge on the right bank was reflected by elevated water temperatures in a mixing zone extending approximately 10m from the right bank. Periphyton in this area was dominated by cyanophytes (*Oscillatoria* spp , *Microcoleus* sp and *Phormidium* sp.) and diatoms.

Tridontium was present in only 10% of quadrats with a maximum cover class of 1. *Fissidens* occurred only in quadrat 33. No charophytes or low-mixed species were recorded on this transect. *Lagarosiphon major* was recorded only from quadrat 31 and *Myriophyllum triphyllum* was recorded only from quadrat 33.

Figure 23. Permanent Transect 6, Upper Waikato River, March 1989.

23A. Total Benthic Vegetation Composition - Summer Survey.

23B. Dominant Periphyton Composition -Summer Survey.



Transect 7

(ref. Figures 24A and B)

Physical Environment

The Upper Waikato River narrowed (56m wide) in the vicinity of Transect 7 to form a deep (maximum depth 7.4m), fast-flowing rock and boulder lined channel. A sand/gravel transport-scour channel devoid of macroscopic vegetation passed through quadrats 19, 20 and 21 at a depth of 5.3m to 5.6m at the time of survey.

Benthic Vegetation

Cladophora glomerata dominated the benthic submerged vegetation of Transect 7 (86% quadrat frequency), in a similar fashion to that observed in Transects 4,5,and 6. *Cladophora* was the only submerged vegetation recorded from the right bank side of this transect and was the only macroscopic vegetation type observed in 44% of the quadrats. Filaments grew to a maximum length of 120mm, with an average length of 50mm. Maximum cover class was 5 with a median cover class of 4 recorded. Maximum local standing crop was 820g m⁻² from quadrat 23.

Nostoc was present in 36% of Transect's 7 quadrats, with a maximum of 2 and median cover class of 1. Maximum local standing crop of *Nostoc* was 40g m⁻².

Enteromorpha was recorded as an epiphyte only on mosses mid-channel only. Maximum cover class was 4 in quadrat 9 however median cover class was only 2. *Enteromorpha* was observed in only 4 out of 29 (14%) quadrats from this transect.

Both *Tridontium* and *Fissidens* were present at low covers (median cover class of both species was 1) in the mid-channel(quadrats 7-15). *Fissidens* had a maximum local standing crop of 190g m⁻² in quadrat 7,

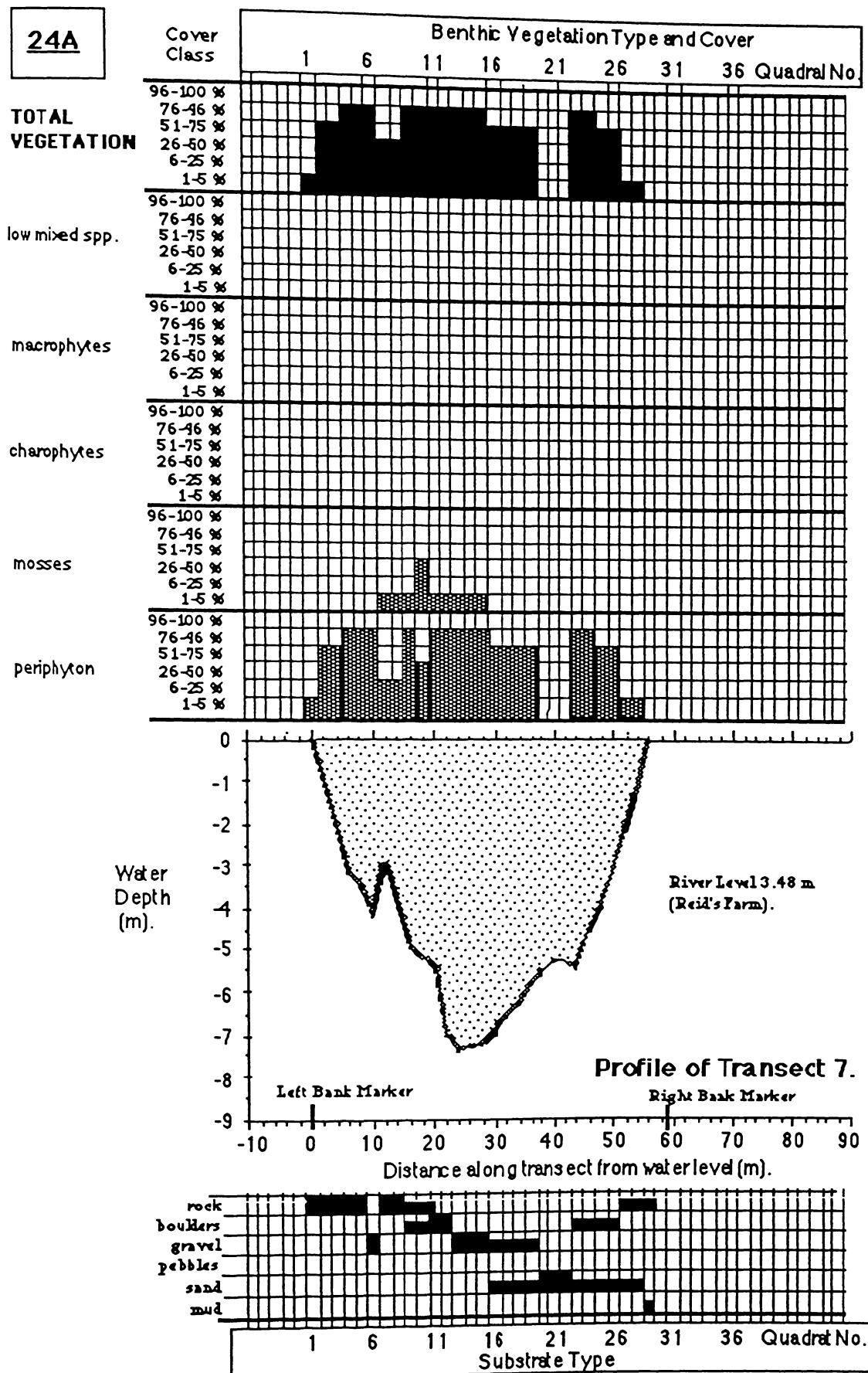
and *Tridontium* had a maximum local standing crop of 120g m⁻² in quadrat 14.

No macrophytes, charophytes or low-mixed species associations were observed on this transect.

Figure 24. Permanent Transect 7, Upper Waikato River, March 1989.

24A. Total Benthic Vegetation Composition - Summer Survey.

24B. Dominant Periphyton Composition -Summer Survey.

24A

2:3.1.4**SECTION 2c****Transect 8**

(ref. Figures 25A and B)

Physical Environment

The right bank of Transect 8 was located at the mouth of the Otumuhaha Stream (site of Fletcher Panel's Ltd. discharge). A gravel substrate dominated the riverbed at this transect except for the sandy mudbanks on either side. Transect 8 was 72m wide with a maximum depth of only 3.5 metres. Current low was swift through the main channel of this transect. A gravel/sand-transport-scour channel passed through quadrats 20-23, and was devoid of macroscopic vegetation.

Benthic Vegetation

Benthic vegetation cover in the main channel of Transect 8 was dominated by the moss *Tridontium tasmanicum* and *Cladophora glomerata*.

Tridontium was recorded as present in 38% of quadrats, with a maximum cover class of 5 and a median cover class of 4. Maximum local standing crop was 1,260g m⁻² from quadrat 16. *Fissidens* was also observed in 40% of quadrats, however although the maximum cover class recorded was 4, the median cover class for *Fissidens* was only 1. The maximum local standing crop measured for *Fissidens* was 90g m⁻² at quadrat 8. *Enteromorpha* was commonly found as an epiphyte on mosses on this transect.

Cladophora glomerata dominated periphytic algal associations in Transect 8. This alga formed a maximum cover of 5 with a median cover class of 1. *Cladophora* was found growing both epilithically and

epiphytically on mosses. A quantitative sample reflecting maximum local standing crop observed for *Cladophora* was made at quadrat 31. *Cladophora* formed 800g m⁻² at this site.

Nostoc spp was observed in 35% of quadrats described with a maximum and median cover class of 1. *Nostoc* was found growing in association with mosses (*Tridontium* and *Fissidens*) and formed approximately 2% of biomass (corresponding to 23g m⁻² at mlsc from quadrat 8).

Enteromorpha was present in 22% from Transect 8 and was observed mainly as an epiphyte on mosses in the main channel and epiphytically on willow roots on the left bank. Two 0.25 x 0.25m² quadrats were cut on the left bank which gave a maximum local standing crop of 133 and 286g m⁻² for *Enteromorpha*. A maximum cover class of 2 and a median cover class was 1-2 was scored for this algae on Transect 8. The river bed of Transect 8 was predominantly gravel lined with a fast water flow which appeared to favour *Cladophora* development where substrate was stable.

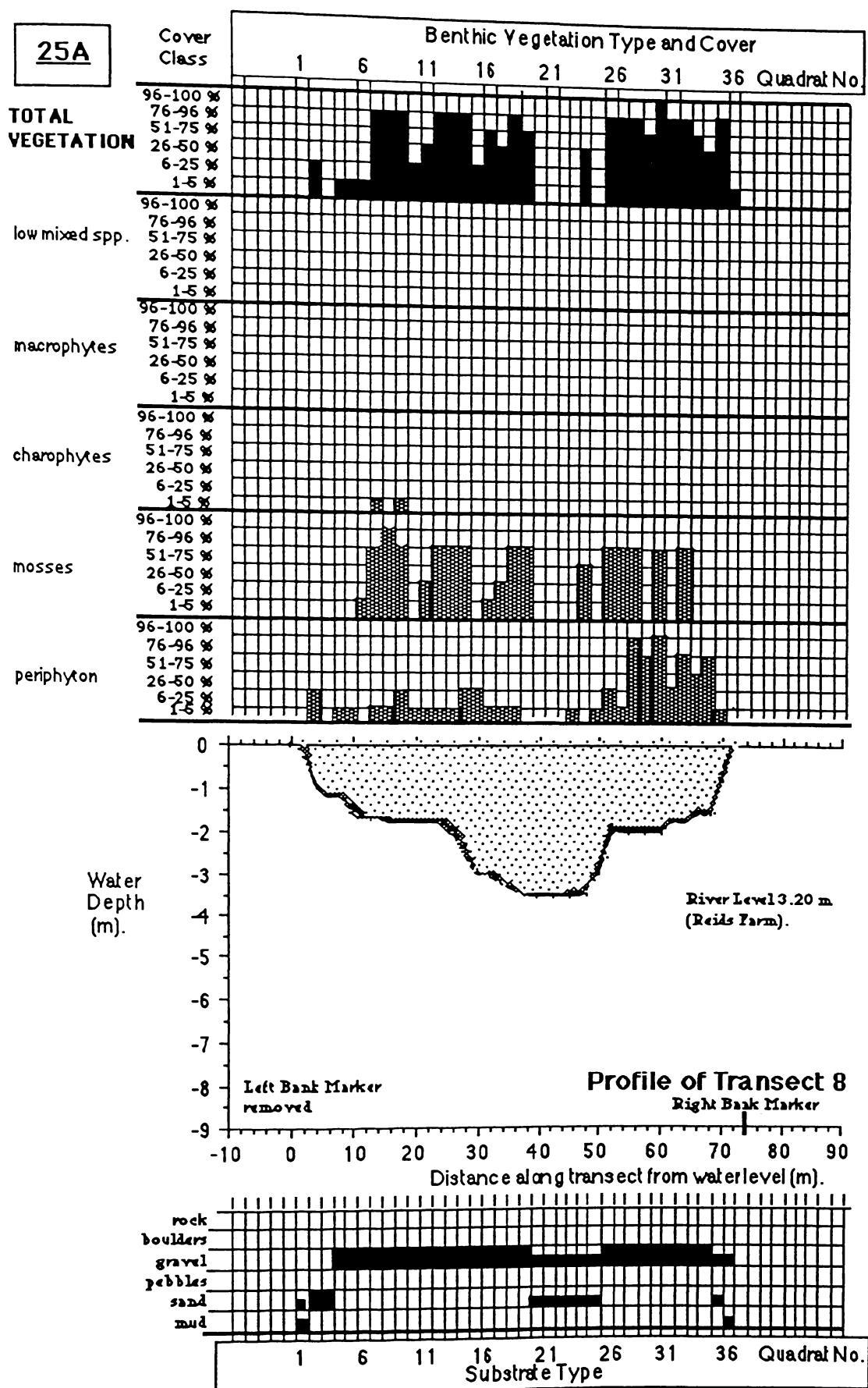
An epipelagic periphyton association dominated by *Oscillatoria* spp and diatoms was found on the right bank side of Transect 8. This corresponded to a mixing zone of discharge from Fletcher Wood Panels Ltd. with the Upper Waikato River.

No macrophytes or low-mixed species were recorded on this transect. Charophytes were represented only by *Nitella hookeri* at low cover in quadrats 7 and 9.

Figure 25. Permanent Transect 8, Upper Waikato River, March 1989.

**25A. Total Benthic Vegetation Composition
Summer Survey.**

**25B. Dominant Periphyton Composition -Summer
Survey.**



Transect 9

(ref. Figures 26A and B)

Physical Environment

The left bank of Transect 9 formed a shallow sandy mud bank that dropped to a fast flowing bedrock and boulder lined side channel. Transect 9 was 64m wide and deepest (5m) in a gravel lined mid-channel. The right bank dropped steeply to a depth of 4m and consisted of a large sand bank with occasionally protruding boulders. Water flow was moderate to low on this side of the transect.

Benthic Vegetation

A raupo (*Typha orientalis*) swamp was present on the right margin of Transect 9. Beneath the raupo a significant cover of *Nostoc* and low-mixed species was observed.

The sand bank on the right side of this transect was dominated by macrophytes (*Elodea canadensis*, *Potamogeton crispus* and *Lagarosiphon major*). *Glossostigma* was found at low cover in the shallows on this side. *Elodea*, *Lagarosiphon* and *Potamogeton* all had maximum local standing crop at a depth of 3.5m which corresponded to 240, 280 and 160g m⁻² respectively. Conspicuous epiphytic growths of both *Enteromorpha* (95 g m⁻²) and *Cladophora* (15g m⁻²) were found on these macrophytes.

Enteromorpha was scored as present in 82% of quadrats. This alga was observed to grow both epiphytically and epilithically, although the latter two substrates were covered by this alga in low flow environments only. A maximum cover class of 4 with a median cover class of 1 was scored for this alga across the riverbed profile. Filaments were observed

to grow to a maximum length of 120mm and *Enteromorpha* formed a maximum local standing crop of 800g m⁻² from quadrat 5.

Cladophora was present in 82% of quadrats with a maximum cover class of 4 and median cover class of 1. *Cladophora* was commonly found growing in association with *Enteromorpha*, *Tridontium* and *Nostoc spp* and formed in excess of 190g m⁻² in this transect .

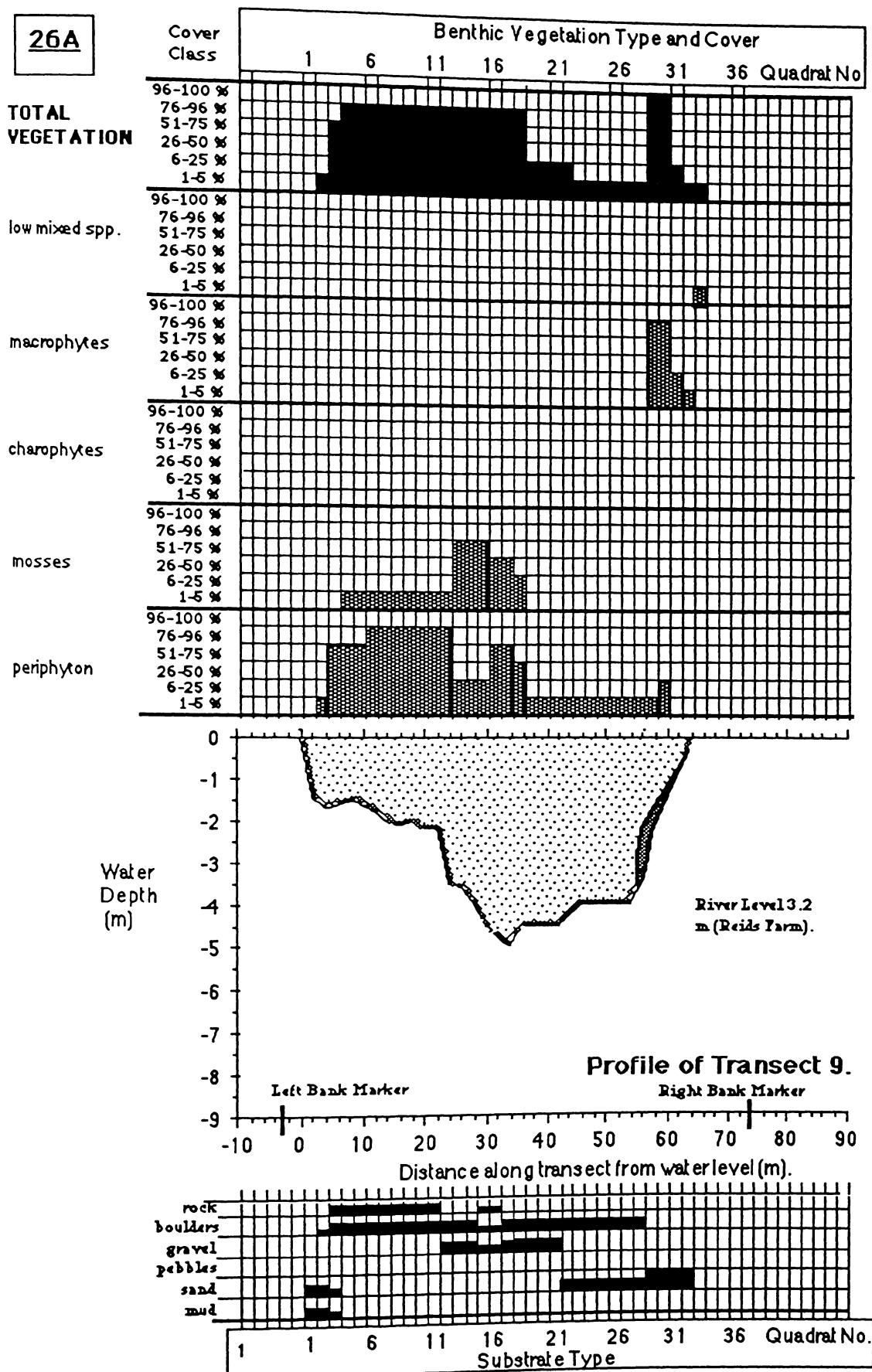
Nostoc was present in (75%) of quadrats from Transect 9 with a maximum cover class of 3 and median cover class of 1. As with Transect 8, *Nostoc spp.* formed approximately 2% of total biomass at mlsc (15g m⁻²) when found growing with mosses.

Mosses dominated by *Tridontium tasmanicum* were common only in the mid-channel area. Maximum local standing crop was measured at 700g m⁻² in this area. *Enteromorpha* was commonly found as an epiphyte on mosses in the high flow mid-channel.

Figure 26. Permanent Transect 9, Upper Waikato River, March 1989.

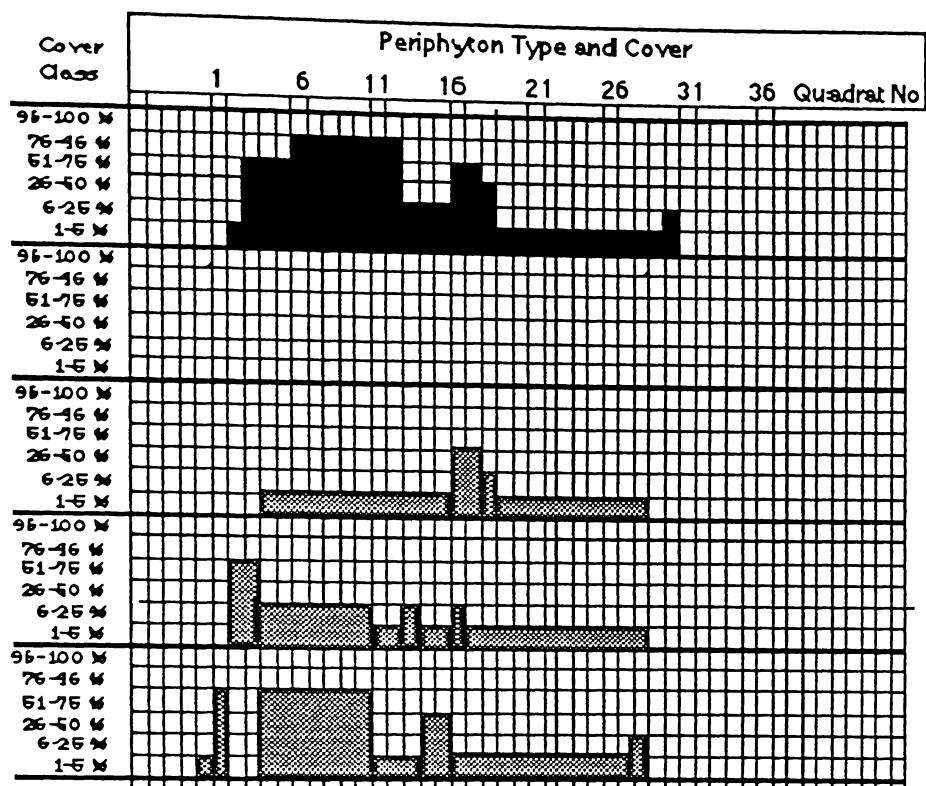
**26A. Total Benthic Vegetation Composition
Summer Survey.**

**26B. Dominant Periphyton Composition -Summer
Survey.**

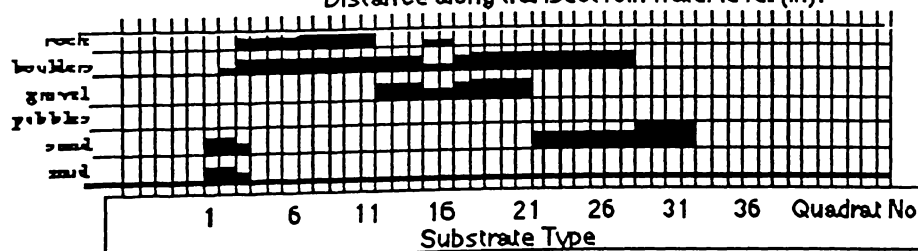
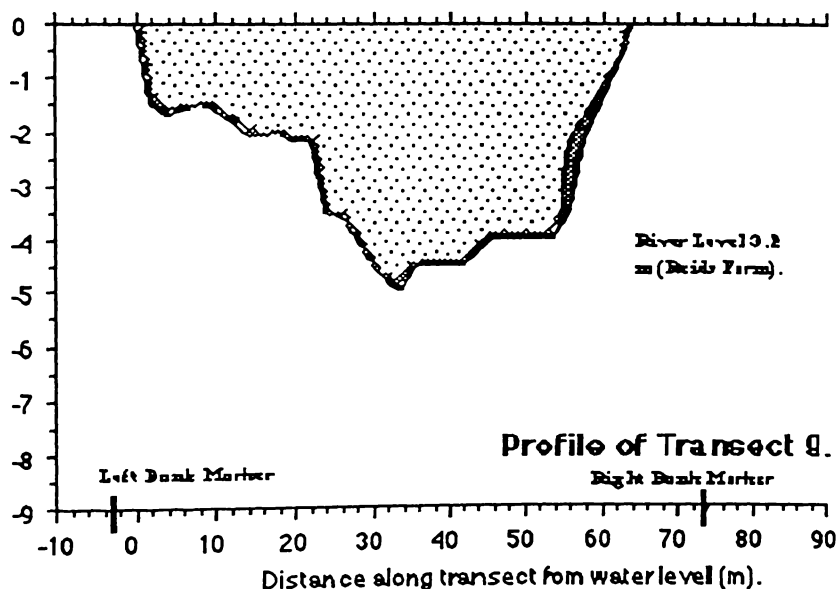


26B

Total Periphyton

*Unidentified**Algae**Enteromorpha**Chlorella*

Water Depth (m)



Transect 10

(ref. Figures 27A and B)

Physical Environment

Transect 10 was 72m wide and crossed a deep river section (maximum depth 8.5m). The left bank dropped from a mud substrate to boulder/bedrock bottom interspersed with gravel and sand which continued through to mid-channel. Water flow was fastest in this section of the transect. A 16m wide sediment-transport-scour channel which ran through quadrats 24-31, formed a large sandbank on the right bank side of mid-channel. Rock outcrops protruding from a sand bank on the right bank, caused this area to experience a low upstream eddy flow.

Benthic Vegetation

Periphyton, notably *Cladophora glomerata* dominated suitable substrates in Transect 10. *Cladophora* was present in 85% of quadrats with a maximum cover class of 5 and a median cover class of 3. Maximum local standing crop was 560g m⁻² measured at quadrat 16.

Enteromorpha scored a maximum and median cover class of 1 from Transect 10 and was present in 32% of quadrats. Two 0.25m x 0.25m quadrats of *Enteromorpha* were cut from a mud/sand bank on the left bank immediately upstream of Transect 10. A mlsc of 855 and 1008g m⁻² was measured at this site.

Nostoc spp. formed a maximum and median cover class of 1 and was scored as present in 24% of quadrats described. This corresponded to a maximum local standing crop of 12g m⁻², which was approximately 1% of

total biomass when found growing in association with mosses, *Cladophora* and *Enteromorpha*.

Growths of epipellic *Tolypothrix* spp and diatoms, were found on the right bank of Transect 10.

Mosses, mainly *Tridontium tasmanicum* were present only in mid-channel (quadrats 13-23, 24% frequency) on exposed rock outcrops and boulders. Maximum local standing crop was 680 g m⁻² measured at quadrat 16 for *Tridontium*. *Fissidens* was recorded as present only in quadrat 13.

No macrophytes or charophytes were recorded from Transect 10, Low mixed species, (*Glossostigma elatinoides*) only occurred on the left bank. *Enteromorpha* was a conspicuous epiphyte on *Glossostigma* at this site.

Figure 27. Permanent Transect 10, Upper Waikato River, March 1989.

27A. Total Benthic Vegetation Composition - Summer Survey.

27B. Dominant Periphyton Composition -Summer Survey.

2:3.2 Aerial Photography

Preliminary examination of photos confirmed that the transects were representative of habitats available in each section of the river and the number of transects surveyed covered all habitat types. Drift diving observations and inspection of photos confirmed transect observations that the development of phytobenthos in the Upper Waikato River is primarily limited by substrate availability. Gravel and sand beds are not stable long enough for the development of macroscopic vegetation. A continuous sediment (sand and gravel) transport-scour channel was present throughout the length of the Upper Waikato River.

2:3.3. *Lagarosiphon major* Monitoring

Figure 20 gives the location of the *Lagarosiphon* beds monitored upstream (site a) and downstream (site f) of the TB-PCP discharge. Table 6 gives the maximum local standing crops of *Lagarosiphon* and *Enteromorpha* at the up- and downstream of TB-PCP discharge monitoring sites in both summer and winter. *Lagarosiphon* growing upstream of the sewage discharge had no macroscopic epiphyte growth. Microscopic inspection of selected stems from the upstream site showed low densities of diatoms and blue-green algae (mainly *Oscillatoria* spp). Downstream populations of *Lagarosiphon* had dense epiphytic growths of *Enteromorpha*. Erosion of the downstream bed of *Lagarosiphon major* was responsible for the lower standing crop measured in winter which at the time of sampling (August) was in a re-establishment phase. Table 6 shows Tissue Nitrogen and $\delta^{15}\text{N}$ values for the *Lagarosiphon* monitoring sites in summer and winter. Overall mean TN for upstream plants was higher than

that measured for *Lagarosiphon* downstream of the sewage discharge, whilst the reverse was found for $\delta^{15}\text{N}$ values which were significantly greater $p < 0.002$ in downstream plants.

Table 5. Standing crops of *Lagarosiphon* and *Enteromorpha* measured up- and downstream of the TB-PCP sewage discharge in summer (March), and winter (August), Upper Waikato River, 1989. Units are g m⁻² dry weight and quadrat size was 0.25 x 0.25m .

Species	Upstream		Downstream	
	summer	winter	summer	winter
<i>Lagarosiphon major</i>	640, 984, 1340	396, 406 481	273, 249, 416	20, 15, 20
<i>Enteromorpha nana</i>	0, 0, 0	0, 0, 0	64, 97, 470	37, 25, 43
Total	640, 984, 1340	396, 406 481	337, 346 886	57, 40, 63

Table 6. Tissue Nitrogen (%N) and $\delta^{15}\text{N}$ values for *Lagarosiphon major* Upstream and Downstream of the TB-PCP discharge in summer (March) and winter (August), Upper Waikato River, 1989.

	Tissue Nitrogen (%N)	$\delta^{15}\text{N}$
UPSTREAM		
Summer	1.3843	3.35
	1.4387	3.57
	1.3356	4.09
	1.3254	1.82
	mean	1.37
	stdev	0.05
		3.21
		0.98
Winter	1.5081	2.70
	1.4027	2.50
	1.4870	3.82
	1.3747	4.04
	1.4897	3.00
	mean	1.45
	stdev	0.06
		3.21
		0.68
DOWNSTREAM		
Summer	1.2646	1.86
	1.1483	6.22
	1.1786	6.17
	1.1563	6.11
	mean	1.19
	stdev	0.05
		5.09
		2.15
Winter	1.2393	8.08
	1.0933	4.37
	1.1239	6.50
	1.1506	4.80
	1.2505	5.02
	mean	1.17
	stdev	0.07
		5.75
		1.53
overall means and (stdev)		
-Upstream	1.41 (0.04)	3.21 (0.0)
-Downstream	1.18 (0.01)	5.42 (0.33)
Sewage		12.2-18.8

2:3.4 *Oedogonium*, *Enteromorpha* and *Cladophora* Species
Descriptions.

The three dominant periphytic algal species found in the Upper Waikato River are described below. Mean cell measurements are reported from approximately 50 individual cell measurements for each species taken at various times throughout the study.

2:3.4.1 *Oedogonium* sp.

see Plates 6, 7, 8 and 15.

Division: Chlorophyta

Class: Chlorophyceae

Order: Oedogoniales

***Oedogonium* Link**

Oedogonium could only be identified to genus level as no fertile material was observed. Identification was from Prescott (1970). Cells averaged 72 μ long x 41.6 μ wide.

Oedogonium species are commonly recorded from New Zealand's freshwaters (Cassie, 1984), but do not form nuisance accumulations.

**2:3.4.2 *Enteromorpha nana* (Sommerf.) Bliding-
var *minima* ecad *rivularis* Collins**

see Plates 2, 4, 10, 11, 12, 13, 16 and 17.

Division: Chlorophyta
Class: Chlorophyceae
Order: Ulvales

***Enteromorpha* Link**

***Enteromorpha nana* (Sommerf.) Bliding var *minima* ecad
rivularis Collins**

Identification was from Chapman (1954). Thallus was larger than that observed by Chapman (1953), up to 1 metre long. Cells were irregularly arranged, rounded and 3-8.5 μ in diameter.

2:3.4.3 *Cladophora glomerata* (L.) Kuetzing

see Plates 14, 18 and 19.

Division: Chlorophyta

Class: Chlorophyceae

Order: Cladophorales

***Cladophora* Kuetzing**

***Cladophora glomerata* (L.) Kuetzing**

Identification was from Prescott (1970). Main axis cells averaged 81 μ in diameter and were 5-7 times the diameter in length. Branch cell dimensions were more variable and averaged 40 μ in diameter and were 3-4 times the diameter in length. See discussion for growth form descriptions above and below the sewage discharge.

2:4 Discussion

Aerial photography, drift diving and transect surveys revealed that phytobenthos development in the Upper Waikato River was primarily limited by substrate availability. Areas of gravel/pebble/sand are not immobile long enough in current flow to allow development of macroscopic vegetation (see Plates 6, 7, 9 and 14). In addition, active transport of these substrates along the channel has a significant scour action on benthic vegetation. However, in each river section identified in this study there were similar proportions of stable substrate (rocks, boulders, mudbanks etc) available for phytobenthos development (see Plate 3, 4, 5, 12, 13).

2:4.1 Biological Impact of the TB-PCP sewage discharge on Phytobenthos.

2:4.1.1 Main Channel Phytobenthos Changes

A dramatic change in dominant main channel benthic vegetation type occurred downstream of the inflow of the TB-PCP sewage discharge to the Upper Waikato River. Extensive growths of epilithic *Cladophora glomerata* and predominantly epiphytic *Enteromorpha nana* were found in all

transects surveyed downstream of this discharge in both summer and winter.

This contrasted with the moss assemblage that dominated the main channel phytobenthos upstream of the sewage discharge. *Tridontium tasmanicum* and *Fissidens rigidulus* variously constituted this epilithic moss association in Section 1. These moss species are commonly found in the high water quality rivers of the Tongariro National Park (Michaelis, 1981), and their presence in Section 1 of the Upper Waikato River is in keeping with the oligotrophic nature of the water leaving Lake Taupo.

Although numerous interactive physical, chemical and biological factors influence the development of submerged vegetation, in any given river/stream or section there of, one or a definitive combination of a few of these factors may exert an over-riding influence. Water quality, water flow (mechanically acting through current velocity), and substrate availability are often implicated as primary influencing factors (Whitton, (1975); Round, (1981)). The impact of point-source discharges, including natural tributaries, downstream of a river source may cause changes in these primary factors.

Ttransect surveys, drift diving and aerial photographic assessment in the Upper Waikato River, showed that point-source discharges did not affect substrate composition except in small, localised mixing zones. Bulk water flow and flow pattern in this river is dominated by the setting of the Lake Taupo Control Gates and only very localised changes in water flow are caused by point source discharges. Thus, neither water flow or substrate availability can account for the observed changes in

phytobenthos downstream of the sewage discharge. Lack of available inocula for growth of either *Enteromorpha* or *Cladophora* upstream of the sewage discharge is not a plausible explanation for observed changes as both species occur in Lake Taupo (Forsyth and Howard-Williams, (1983) and pers observation). Surveys and drift diving through the study period showed only low densities of grazers (mainly *Potamopyrgus* sp and caddis flies) in the main channel area, presumably due to high flow, and it is assumed that grazing does not have a significant impact on submerged vegetation in this river reach.

Changes in water quality due to the input of treated sewage is therefore likely to be the primary causative factor in observed benthic vegetation changes. Proliferations of *Cladophora* and *Enteromorpha* species are often attributed to increases in P and/or N loads in both New Zealand and overseas (Freeman, (1986); Whitton, (1970)). Marked changes in N and P loads in this reach of river due to the TB-PCP discharge have been described in Chapter One. The most significant change in nutrient components occurs for $\text{NH}_4\text{-N}$ (relative significance to all loads of 61.5%) and DRP (relative significance to all loads of 55.6%). No significant change in other water quality parameters were found and thus these factors can not be invoked as causative of observed vegetation changes. It is acknowledged that the input of trace elements, vitamins and other minor constituents from the sewage discharge could have some effect in this river, however they were not quantified in this study.

Increases in N and/or P nutrients alone may not necessarily cause marked changes in periphytic algal species incidence as many algae can have wide tolerances to these nutrient concentrations (Lewis and

Bannister, 1980). The processes that enable these species changes eg. through changes in settling/establishment success have not been investigated in this study. Only observable, overall effects of the impact of the TB-PCP discharge have been described. However, increases in $\text{NH}_4\text{-N}$ and/or DRP are proposed as the primary causative factors in the proliferation of periphytic algae downstream of the TB-PCP discharge. The relative importance of these two nutrient species in the proliferation of periphytic algae is investigated in Chapter 3.

The exact nature of species changes up- and downstream of the sewage discharge can be elucidated from consideration of vegetation structure. The physical habitats of hard rock substrate and high current flow that mosses occupied upstream of the discharge were dominated by *Cladophora glomerata* downstream of the sewage discharge, indicating species replacement. Displacement of rooted macrophytes by *Cladophora glomerata* downstream of sewage discharges has been reported by Wharfe et al (1984) which was correlated to increases in available P nutrients.

Significant moss cover did occur below the TB-PCP discharge, however maximum/median cover and mlsc were noticeably lower. A significant change in the species composition of this moss community occurred downstream of the sewage discharge. Epiphytic growths of *Oedogonium* and *Nostoc* were characteristic of the moss cover in Section 1 of the river (Plates 7 and 8). Although quadrat frequencies were high for these two species of algae (Figure 28), maximum/median cover (Figure 29) and mlsc (Figure 30) were low compared to *Enteromorpha* and *Cladophora* growths downstream of the sewage discharge (Plates 4, 10, 11, 12, 13 and 14). Epiphytic growths of *Enteromorpha* replaced the

Oedogonim/Nostoc growths on mosses downstream of the sewage discharge. *Enteromorpha* was only found growing in moderate to high flow environments when in association with mosses, (Plate 12), and epilithic growths were only found in areas of low flow (Plate 13). *Enteromorpha nana* attaches to substrate via rhizoids from a basal portion of the plant (Chapman, 1973). This means of attachment is not strong and plants are easily dislodged. Compared to rock substrate, the moss cover likely provides a sheltered habitat from main current velocity which allows establishment of *Enteromorpha* in high flow environments as entanglement of filaments around moss stems would increase the strength of attachment.

It seems initially surprising that a poorly attached species like *Enteromorpha* should be recorded from such high flow environments, however it is important to note that within a river there are two different zones of water velocity; the free water velocity of open water and the local velocity at substrate surfaces. Reiter and Carlson (1986) found that the local velocity near algal mats developed under a range of low to high open water velocities markedly diminished and eventually become equal under all ranges of open water velocities, while the free open water velocities remained different. Thus, with the development of moss cover a habitat becomes available for the establishment of epiphytic algae which may not be subject to the free open water velocity of the river during critical settling and establishment phases.

Some increase in *Nostoc* and *Oedogonium* was noted in the final sections of the river and were correlated to observed increases in moss cover. However quadrat frequencies, covers (maximum and median) and

mlsc were significantly lower compared to those observed for both *Enteromorpha* and *Cladophora*. The significance of these changes is probably not great as investigation of the Waikato River downstream of the Huka Falls to Lake Aratiatia in late summer 1989 revealed extensive growths of both *Enteromorpha* and *Cladophora*. In addition no marked changes in either DRP or $\text{NH}_4\text{-N}$ were observed from Cherry Island to Huka Falls in either summer or winter during diurnal water quality studies (Figures 13 and 14 , Chapter One). Coffey (1975) described the submerged macrophyte species composition in Lake Aratiatia. Significant epiphytic algal populations were found on macrophytes at this time and these were dominated by *Spirogyra* and *Ulothrix* species (Coffey, 1975). *Enteromorpha* and *Cladophora* presently dominate these epiphytic populations in Lake Aratiatia (Howard-Williams pers comm). This change makes Coffey's (1979) oligotrophic plant assemblage classification of the Waikato River from Lake Taupo to the upstream end of Lake Ohakuri no longer applicable.

Thus there are two different kinds of species replacement are occurring in main channel phytobenthos downstream of the sewage discharge; an epilithic association change, (mosses to *Cladophora*), and an epiphytic species change from *Oedogonium/Nostoc* to *Enteromorpha* where mosses are found downstream of this discharge.

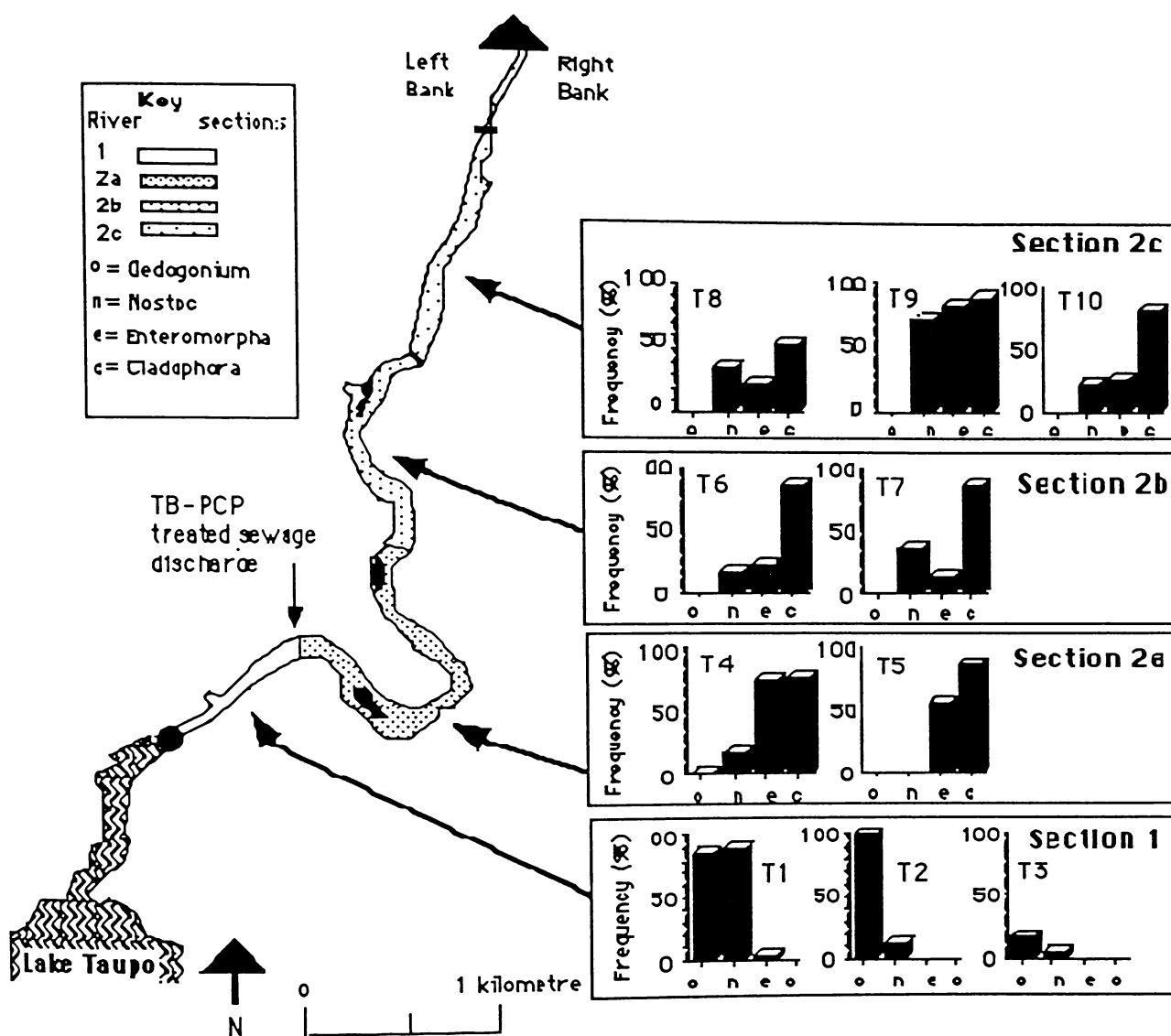


Figure 28. Mean quadrat frequency of *Oedogonium*, *Nostoc*, *Enteromorpha* and *Cladophora* from Transects 1-10 (summer survey), Upper Waikato River, March 1989. See Appendix 4 for data.

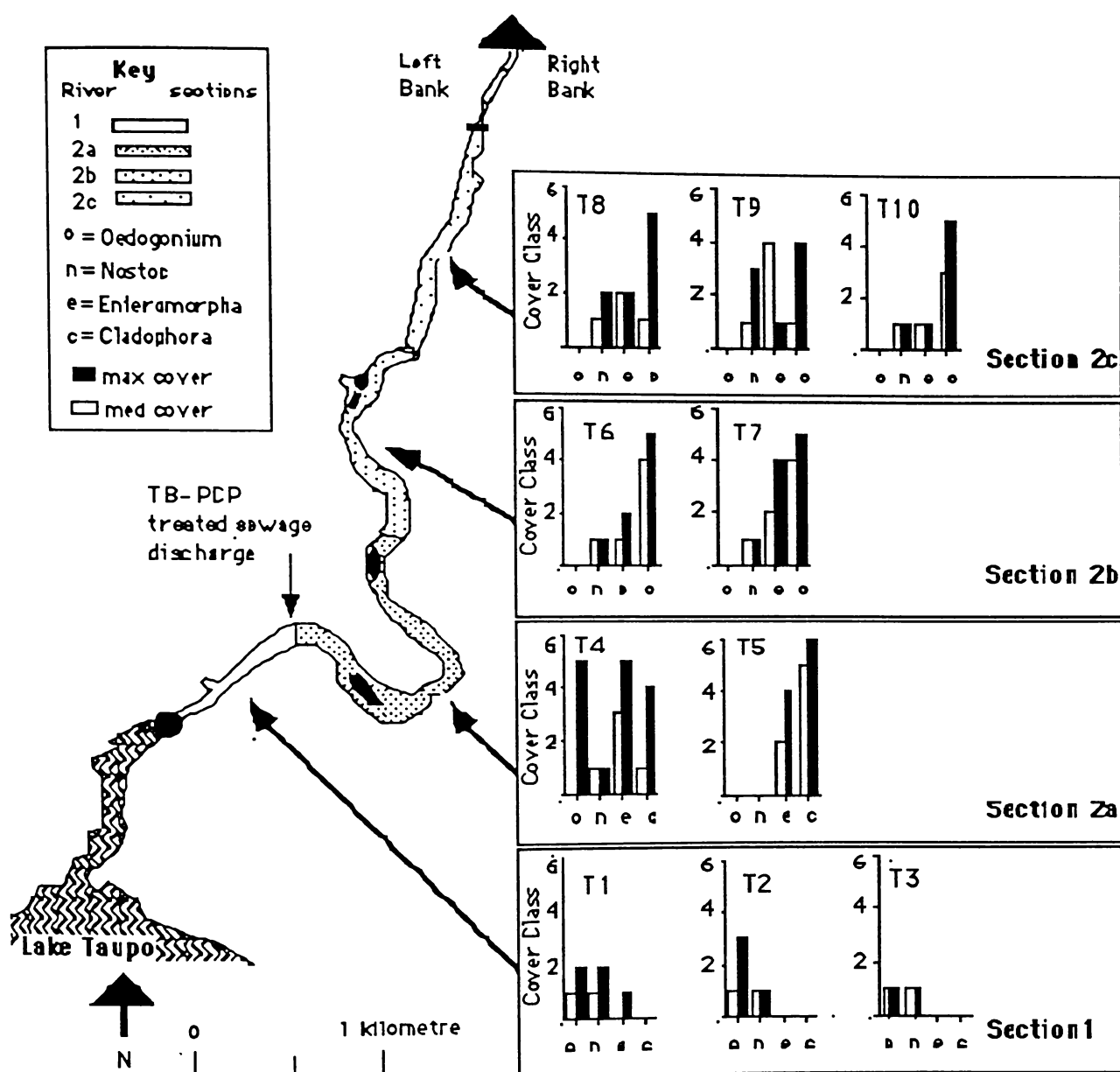


Figure 29. Maximum and Median cover of *Oedogonium*, *Nostoc*, *Enteromorpha* and *Cladophora* from Transects 1 to 10 (summer survey), Upper Waikato River, March 1989. Note that high maximum cover of *Oedogonium* from transect 4 is due to one spot record only. See Appendix 4 for data.

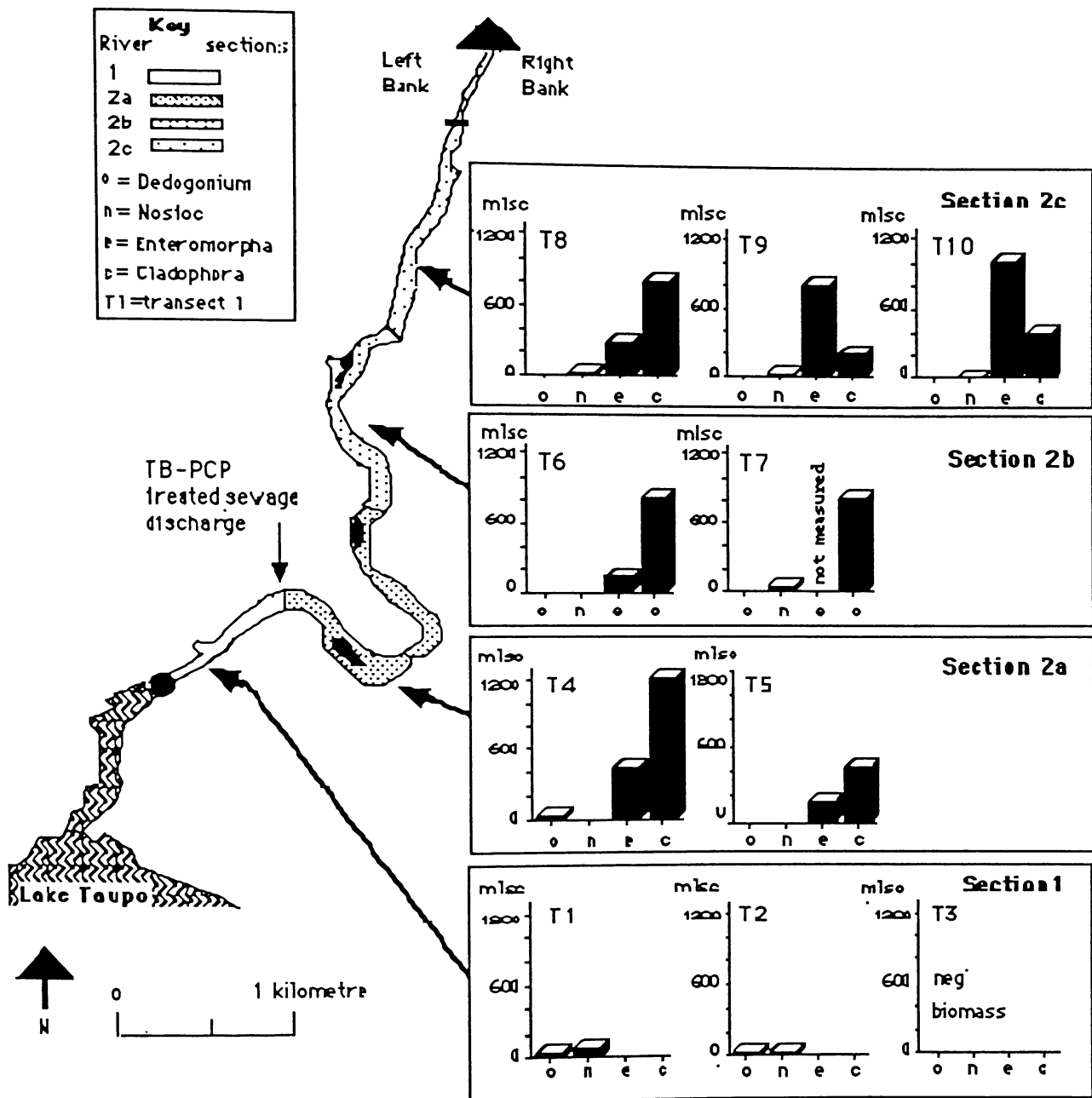


Figure 30. Maximum local standing crop (mlsc) of *Oedogonium*, *Nostoc*, *Enteromorpha* and *Cladophora* from Transects 1 to 10 (summer survey), Upper Waikato River, March 1989. Units = g m⁻² dw. See Appendix 4 for data.

2:4.1.2 Riverbank Phytobenthos

Riverbank submerged vegetation was dominated by low-mixed and tall-growing macrophyte associations. Trends of increase in epiphytic algae downstream of the sewage discharge as described for main channel phytobenthos, were also apparent in riverbank submerged vegetation.

Upstream of the sewage discharge *Oedogonium* and *Nostoc* were commonly found as epiphytes on low-mixed communities. Downstream of the discharge extensive epiphytic growths of *Enteromorpha* were observed. Decreases in species diversity of low-mixed species associations were observed downstream of the sewage discharge, with the most noticeable change being the absence of *Pilularia*.

Lagarosiphon major was the dominant tall-growing macrophyte in the Upper Waikato River, confirming previous observations by Miller et al, (1988), of change from *Elodea* dominance in the mid-1970's (Coffey, 1975), and reflecting the same succession reported by Howard-Williams and Davies (1988).

Beds of *Lagarosiphon* upstream of the sewage discharge were free of macroscopic epiphyte growths (Plate 5), whilst beds downstream of this discharge supported significant growths of epiphytic *Enteromorpha* (Plate 11). Figure 31 compares winter/summer standing crop of *Lagarosiphon* and *Enteromorpha* up- and downstream of the sewage discharge. Although this is a limited data set, standing crop of *Lagarosiphon* was noticeably higher upstream of the sewage discharge and

Enteromorpha could form up to 68% of biomass in quadrats downstream of the discharge.

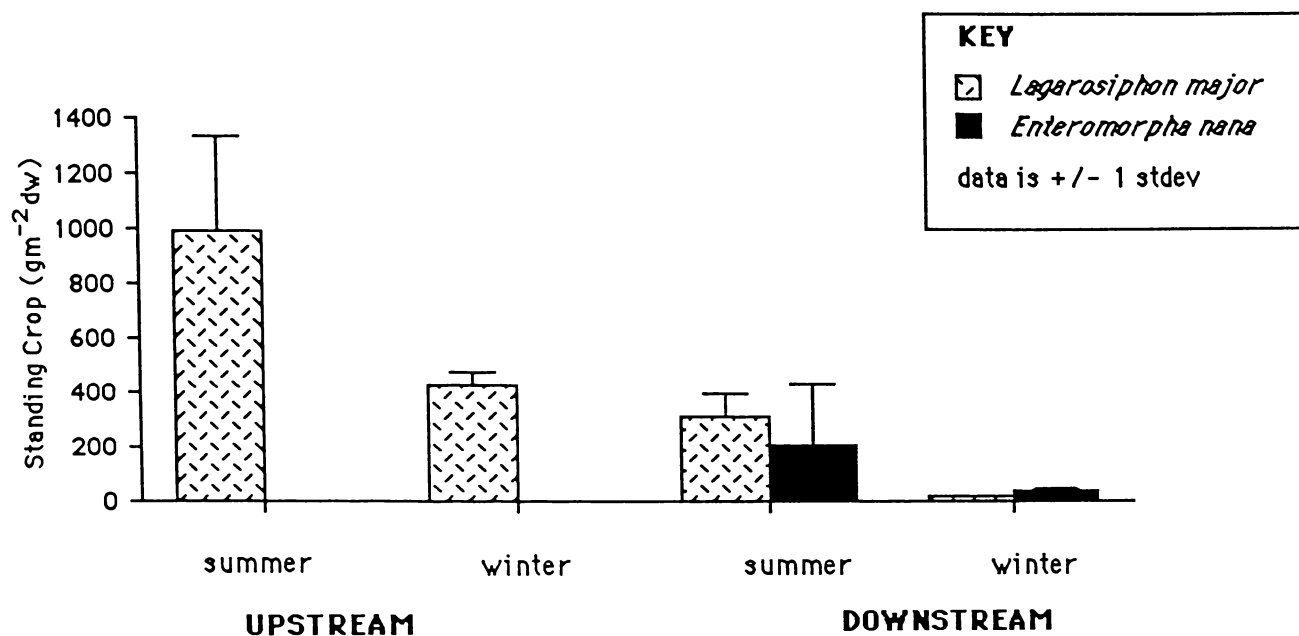


Figure 31. Standing crop of *Lagarosiphon* and *Enteromorpha* at the *Lagarosiphon* monitoring sites above and below the TB-PCP discharge in summer (March) and winter (August), Upper Waikato River, 1989; (see Figure 20 for site location).

Periods of extended low flow in winter caused desiccation of marginal riverbank vegetation and significant erosion of these macrophyte beds and low-mixed associations. Seasonal changes in standing crop of *Lagarosiphon* and *Enteromorpha* at these sites are likely masked by the erosive influence of flow fluctuations.

Lagarosiphon was one of the few submerged species present throughout the year at appreciable standing crop both above and below the TB-PCP discharge. This distribution makes *Lagarosiphon* a suitable monitoring species for ^{15}N studies. *Lagarosiphon* plants downstream of the TB-PCP sewage discharge were significantly ($p < 0.002$) enriched with ^{15}N compared to plants growing upstream, reflecting utilisation of N nutrients from the effluent which was highly enriched in ^{15}N . No significant seasonal difference in Tissue Nitrogen or $\delta^{15}\text{N}$ values was found at either the upstream or downstream monitoring sites. Lower tissue N values for *Lagarosiphon* plants downstream of the sewage discharge was unexpected, but may be due to the influence of epiphytic growths of *Enteromorpha*.

Assuming that substrate sources of N nutrients were the same for *Lagarosiphon* up- and downstream of the discharge, the percentage of N nutrients gained directly from the effluent can be estimated by the difference in $\delta^{15}\text{N}$ values. Using overall means from summer and winter, the percentage of N nutrients in *Lagarosiphon* tissue directly attributable to the sewage discharge can be calculated as follows:

$$\begin{aligned}
 & (1 - (\text{Upstream mean } s^{15}\text{N} / \text{Downstream mean } s^{15}\text{N})) \times 100 \\
 & = (1 - (3.21 / 5.42)) \times 100 \\
 & = 40\%
 \end{aligned}$$

This is likely to be a conservative estimate of N nutrient source utilisation due to the presence of high biomass of epiphytic *Enteromorpha* present on *Lagarosiphon* plants downstream of the sewage discharge. Assessment of ^{15}N in plants up- and downstream of discharges has considerable potential as a monitoring technique for the biological impact of N nutrients from discharges, and warrants further investigation.

A general inspection of the literature showed that species of *Enteromorpha* are more commonly found in marine and brackish water compared to freshwater environments, and often form nuisance growths in harbours and estuaries. Round (1984) described the increase of nuisance level *Enteromorpha* growths in freshwater as being correlated to salinity increases of these environments. In a survey of summer proliferations of periphytic algae in New Zealand Biggs and Price (1987) did not record any *Enteromorpha* species. *Enteromorpha nana* was first recorded in Waikato River catchment by Hill (1969) and forms nuisance growths in many of the hydroelectric dams in the Waikato River as well as in Lake Taupo (Howard-Williams pers comm). Growths in Lake Taupo are associated with groundwater contamination by sewage and agricultural run-off. *Enteromorpha* growth in Lake Taupo is highly variable as can be seen from monitoring data by Howard-Williams (pers comm);

Year	Maximum Standing Crop (g m ⁻²)
1985	10-25
1986	160
1987	55
1988	25
1989	62

These maximum standing crops are less than that observed for *Enteromorpha* in the Upper Waikato River. The summer transect survey reported maximum local standing crops on Transects 4-10 of 135 - 1008 g m⁻³, and on the winter transect survey maximum local standing crop was 205 (Transect 5) and 414 g m⁻³ (Transect 4).

2.4.2 Biological Impact of Tributaries

No observable changes in main channel phytobenthos were associated with inflows from the four streams. This was not unexpected as inputs from the four stream inflows were shown in Chapter One to contribute only minor N and P loads relative to the combined upstream loads from Lake Taupo and the TB-PCP sewage discharge. Only localised mixing zones of stream water with the Upper Waikato River reflected noticeable changes in benthic vegetation. The abundance of cyanophytes and diatoms

found in the mixing zone of the Otumuheke Stream and the river are likely due to both elevated water temperatures and nutrients from geothermal fluids. The low cover of epipellic *Oscillatoria spp* and diatoms associated with the discharge from the Otumuhaha Stream are more likely to be attributable to the influence of the Fletcher Wood Panel's discharge than the ephemeral baseflow of the stream itself.

2.4.3 Seasonal Changes

Re-survey of transects 4 and 5 and drift diving throughout the year showed no marked seasonal change in the distribution and abundance of *Enteromorpha*. Growth rates may decrease in winter, however this would be reflected in a decreased 'slough-off' rate as standing crops and covers measured in summer and winter showed no significant change.

No significant changes in the distribution and abundance of either *Oedogonium* or *Nostoc* were also observed either upstream or downstream of the sewage discharge. However, decreases in both of these species was observed during September-November from drift diving observations.

Distinct seasonal changes in the distribution and abundance of *Cladophora* were however observed. From late winter through to spring (1989) replacement of *Cladophora* populations by epilithic growths of *Vaucheria*, *Ghomphonema* and to a lesser extent *Batrachospermum* were observed. In addition, *Cladophora* present during this time was heavily epiphytised by diatoms, including *Ghomophnema*. Weekly drift diving

observations in January, 1990 found the growths of *Cladophora* similar to that described in the 1989 summer survey. No visually obvious growths of *Ghomphonema*, *Vaucheria* or *Batrachospermum* were recorded in summer 1989 or 1990. Although these species were only found downstream of the sewage discharge, the apparent seasonal trend can not be attributed to changes in nutrient loadings as there were no marked changes in the discharge during this period.

2.4.4 Effects of Flow Regulation

In non-regulated rivers flow regime can be an equally important factor in the accumulation of periphyton as nutrient availability (Biggs and Close, in press). Freeman (1986) found that floods prevented significant accumulation of *Cladophora* in the Manawatu River and Biggs and Close (in ¹⁹⁸⁹ press) identified that hydrological factors contributed at least equally to the differences in periphyton biomass between gravel-bed rivers studied.

No records of benthic vegetation pre-flow regulation of the Upper Waikato River exist, restricting assessment of flow regulation on submerged vegetation. Flow regulation in this reach of river increases the frequency of oscillation between low and high water flow due to the imposed marked diurnal regime. However, the maximum amplitude of high flow in the regulated regime is likely to be significantly less than that experienced by the river during flood conditions pre-regulation. Phytobenthos associations present can obviously tolerate the magnitude

and frequency of changes in the artificial flow regime and it is likely that maximum benthic vegetation standing crop is higher in this regime than it would be without flow regulation. In non-regulated rivers the flood events which clear out major areas of phytobenthos are absent in the Upper Waikato River.

Extended periods of low flow, as observed in winter 1989, cause desiccation of riverbank vegetation and subsequent removal upon return to higher flows creating a significant erosive effect.

2:4.5 Chain Transect Technique Evaluation

Drift diving and aerial photographic assessment confirmed that transect sites in each designated section of river were representative of these river sections, and the number of transects surveyed (ten) gave a good representation of phytobenthos composition given the time and resources available.

The use of a marked chain as a transect line to assess phytobenthos in a deep, fast flowing river, the Upper Waikato River, worked extremely well. A minimum of two people is required to lay and survey the chain transect from a medium size speedboat. A high degree of diver skill is required to work in these high flow environments and SCUBA gear modifications described in the methods section are necessary. Quantitative sampling in high current flow is difficult, however the plastic vial technique gave reasonably accurate estimates of standing

crop compared to quadrat techniques. Recognition of macrophytes and some macrophytic algal species is relatively easy in these environments, herbarium samples of all vegetation types observed should be made especially for final identification of algal species. Vegetation structure of recognised plant associations should be described accurately, especially for the nature of substrate occupied eg. epilithic/epiphytic algae.

Comparison of riverbed profiles of re-surveyed Transects 2, 4 and 5 in winter with the summer survey of these transects gave acceptable repeat passage of the riverbed profile and justifies further application of this technique in surveillance of point source discharges into lotic environments.

2:5 SUMMARY

Proliferation of periphytic algae, notably *Enteromorpha* and *Cladophora*, occurred downstream of the TB-PCP sewage discharge. In essence this situation is a classic species replacement series in response to a changing water quality gradient due to the inflow of treated sewage which may be summarised diagrammatically (Figure 32 and 33). Investigation of water quality of the Upper Waikato River and sewage effluent indicated that the most significant changes attributable to this discharge is in the form of increase $\text{NH}_4\text{-N}$ and DRP loads. The proliferation of periphytic algae is likely due to these N and/or P inputs. However, the overall concentrations of N and P nutrients below the sewage discharge were still consistent with an oligotrophic classification, investigation into the relative importance of these nutrient species is considered in Chapter 3.

In the Upper Waikato River phytobenthos associations found below the TB-PCP sewage discharge are not consistent with the 'oligotrophic plant assemblage' described by Coffey (1979). A major habitat degradation in the Upper Waikato River has occurred and is attributable to the inflow from the Taupo Borough-Pollution Control Plant. No change in Coffey's (1979) classification of 'oligotrophic plant assemblage' of the Waikato River from the Lake Taupo Control Gates to the upstream end of the point of inflow of the TB-PCP sewage discharge was concluded from this study.

Two new techniques have been trialled in this part of the study;

the use of a chain transect to survey phytobenthos of a deep, swift flowing river,

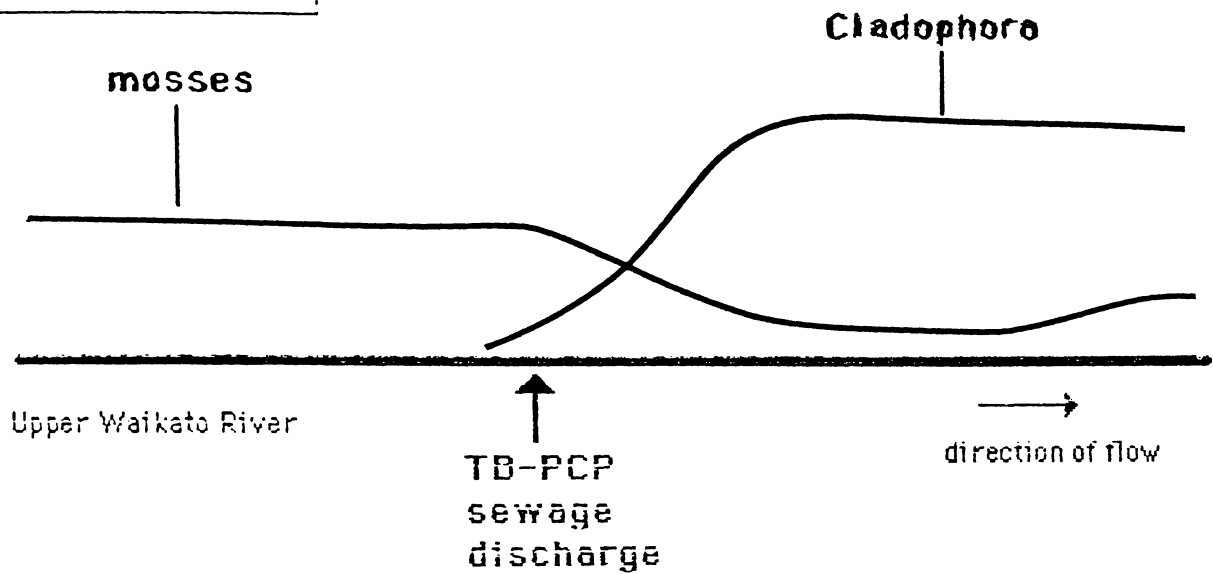
use of $s^{15}\text{N}$ signatures of plants growing up- and downstream of the discharge to ascertain the extent of effluent N nutrient utilisation by plants growing downstream of the sewage discharge.

Preliminary application of these techniques have been successful in the Upper Waikato River and warrant their further development and application for the assessment of the biological impact of point-source discharges.

Figure 32. Major Epilithic and Epiphytic changes in Main Channel
Phytobenthos observed in the Upper Waikato River in relation to the inflow of
treated sewage from the TB-PCP, 1989/90. Note the vertical scale is a
qualitative assessment of overall abundance based on drift diving observations
and transect cover, quadrat frequency and maximum local standing crop found.

MAIN CHANNEL PHYTOBENTHOS

Epilithic Species Changes



Moss epiphyte species changes

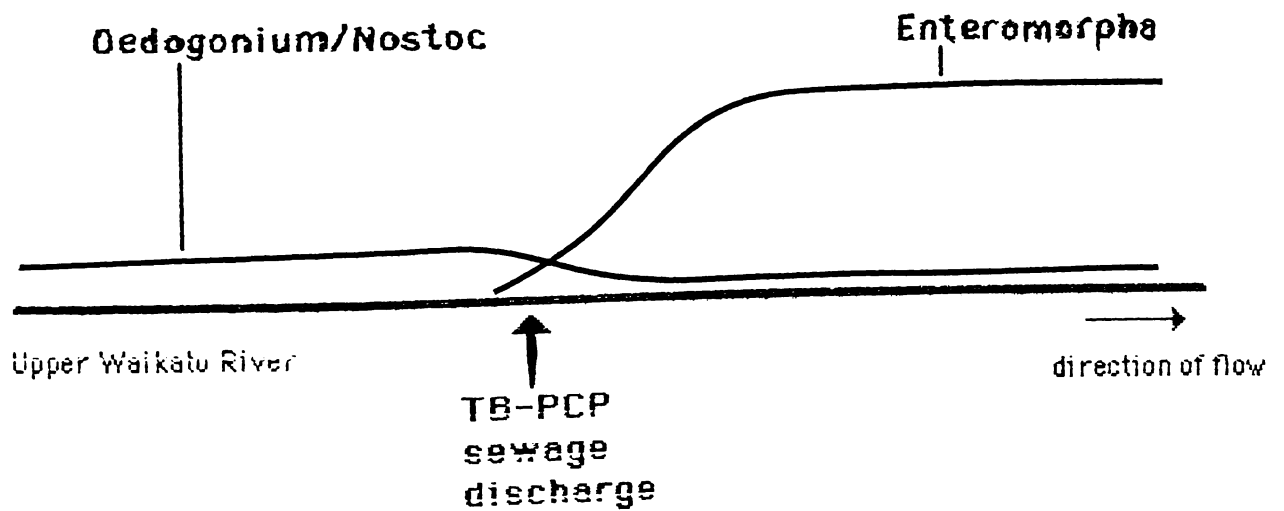
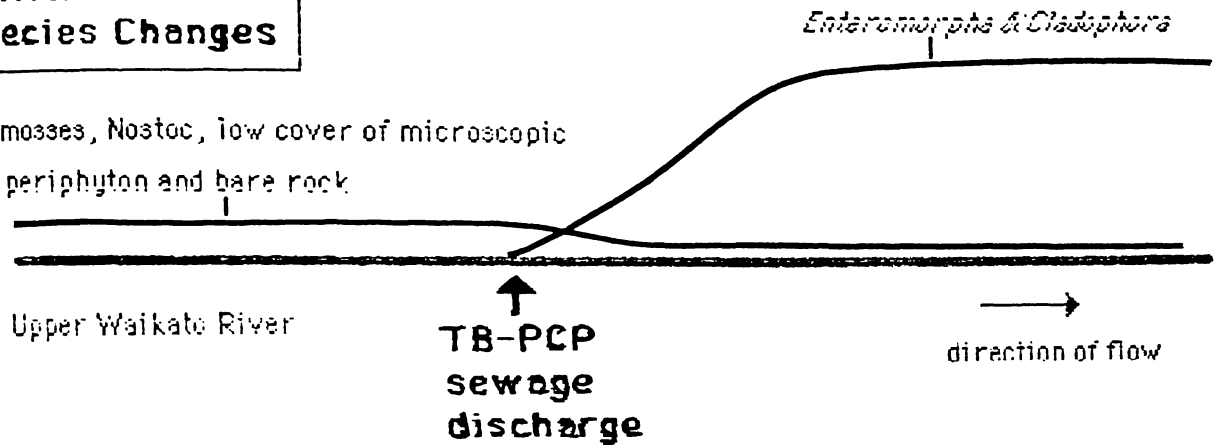


Figure 33. Major Epilithic and Epiphytic changes in Riverbank Phytobenthos observed in the Upper Waikato River in relation to the inflow of treated sewage from the TB-PCP, 1989/90. Note the vertical scale is an qualitative assessment of overall abundance based on drift diving observations and transect cover, quadrat frequency and maximum local standing crop found.

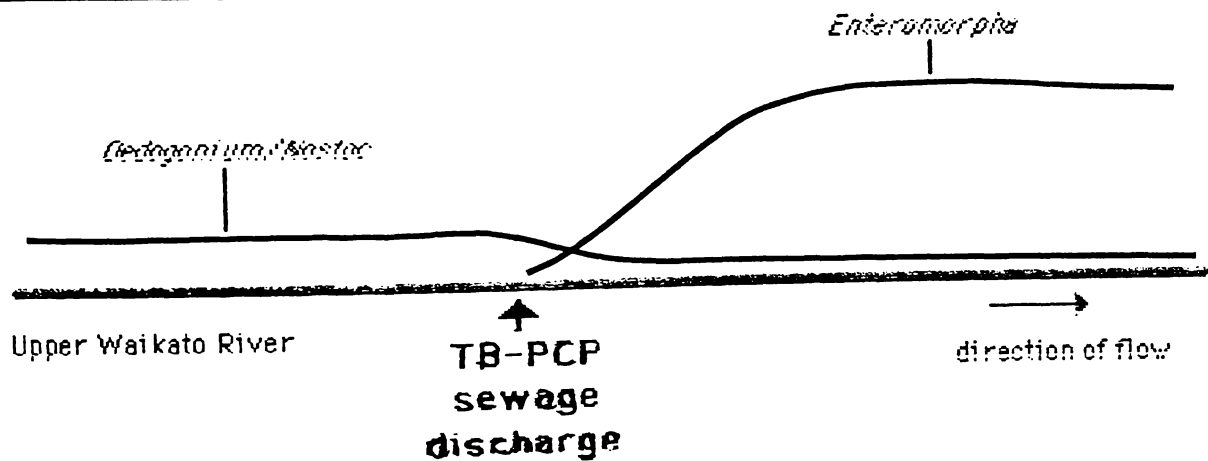
RIVERBANK PHYTOBENTHOS

Epilithic Species Changes

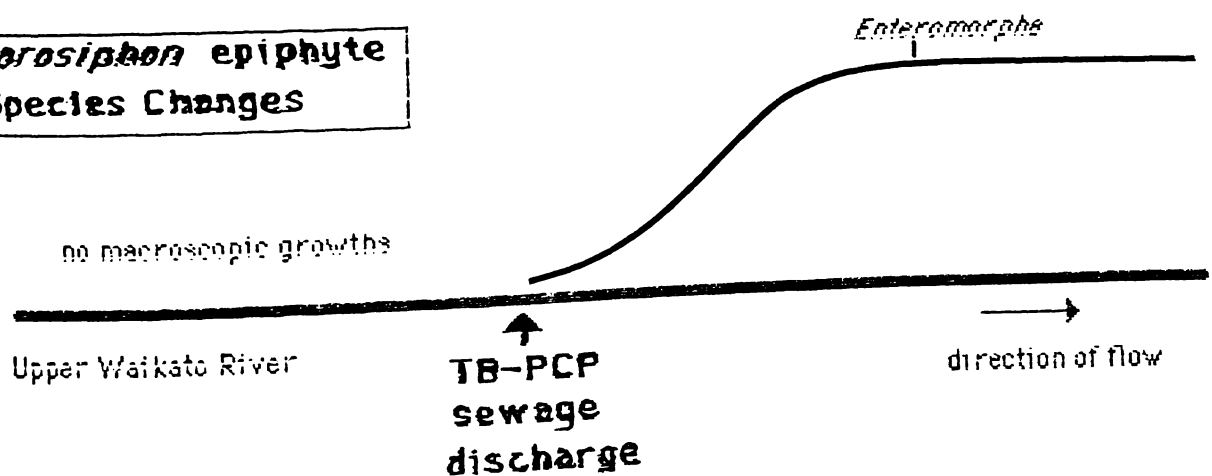
mooses, Nostoc, low cover of microscopic
periphyton and bare rock



Low-mixed epiphyte Species Changes



Logrosiphon epiphyte Species Changes



Chapter Three: Nitrogen and Phosphorus Nutrition Studies of
Enteromorpha, *Cladophora* and *Oedogonium*.

3.1. Introduction

In the Upper Waikato River marked changes in phytobenthos occur downstream of the TB-PCP sewage discharge. Displacement of epiphytic *Oedogonium/Nostoc* assemblages by *Enteromorpha*, and of epilithic moss associations by *Cladophora*, have been described downstream of this discharge (Chapter Two). The greatest change in water quality attributable to the TB-PCP discharge was increase in both $\text{NH}_4\text{-N}$ (relative significance to all loads 61.5%) and DRP (relative significance to all loads 55.6%). However, even below the TB-PCP discharge average concentrations of $\text{NH}_4\text{-N}$ (ca. 10mg m^{-3}) and DRP (ca. 4mg m^{-3}) were still low and water may still be classified as oligotrophic. From Chapter One it was seen that the ratio of TN-DON:TP-DOP is low in water leaving Lake Taupo (10.4), the inflow from the TBB-PCP sewage discharge further decreases this ratio to 6.2, measured at Reid's Farm.

It was hypothesized from these low ratios that nitrogen may be limiting *Oedogonium* populations found upstream of the sewage discharge. It was also hypothesized that while increased N and/or P loads may support the proliferation of *Enteromorpha* and *Cladophora* below the sewage discharge, the overall reduction in N:P ratios suggest that further growth of these algae may be limited by nitrogen. It also follows that N levels upstream of the TB-PCP sewage discharge may be too low to support significant *Enteromorpha* and *Cladophora* in Section One and that therefore the observed mean change in ammonia from 4mg m^{-3} to 10mg m^{-3} (see Chapter One), may represent a critical change for algal growth in this river and may also play a role in the observed species changes.

A preliminary examination of these hypotheses was carried out by investigation of the following specific objectives:

#to identify whether in-situ *Oedogonium* populations were limited by N and/or P upstream of the TB-PCP sewage discharge,

#to identify whether in-situ *Enteromorpha* and *Cladophora* populations were limited by N and/or P downstream of the TB-PCP sewage discharge,

#to investigate the relative importance to algal proliferations of the N and P inputs from the TB-PCP sewage discharge.

These last two objectives have important management implications if, as predicted (Table 2, Chapter One), further increases in N and P loads from the sewage plant are discharged to the Upper Waikato River in the future.

To investigate the above hypotheses and achieve the outlined objectives a monitoring programme of the nutritional status of the three dominant periphytic algae (*Oedogonium*, *Enteromorpha* and *Cladophora*) was carried out. In addition an algal transplant experiment was specifically designed to investigate the relative importance of N and P inputs from the TB-PCP sewage discharge to *Cladophora* and *Enteromorpha* nutrition. Standard techniques used for estimation of growth rates are difficult to apply in the Upper Waikato River, due to its deep, fast^{flowing} nature and the described diversity of phytobenthos associations. The transplant experiment was also designed to measure growth rates of transplants and to use these to estimate growth rates of in-situ populations.

A variety of Nutrient Availability Tests (NATS) can be used to directly assess the N/P nutritional status of in-situ algae and therefore used to test hypotheses of nutrient limitation/surplus made on the basis of water nutrient concentrations. These assays rely on comparisons of observed values to accepted critical and minimum viable values. The

critical level or growth controlling level is defined as the minimum level of an element in a particular species necessary for maximum growth, (Gerloff and Krombolz, 1966), whilst the minimum viable level is that concentration associated with little or no growth (Gordon et al, 1980). The use of these NATS has distinct advantages over the alternative approach of relating nutrient concentrations in water to potential for supporting plant growth as this latter approach has several complicating factors including;

- # the difficulty of analyzing for very low concentrations of elements in natural waters,

- # the problem of distinguishing between available and non-available forms of an element,

- # the fact that the volume of water from which an organism withdraws a nutrient element as well as the concentration of the element determines the total available supply, and

- # and the often large variation in nutrient levels over a short period of time (Gerloff and Krombolz, 1966).

Plants integrate many of these factors over the response time of the NAT being tested. Bioassays with in-situ plants demonstrate whether the environment has supplied limited or surplus quantities of those nutrients tested under ambient conditions. The interpretation of these NATS relies on the assumption that the result is not affected by other nutritional and environmental variations. It has been demonstrated that these NATS are reliable indicators of nutrient limitation/surplus, but the magnitude of values can be affected by other factors such as temperature, light intensity and concentrations of other nutrients (Freeman, 1983). NAT interpretation also relies on assuming that the washed algal sample (ie removal of epiphytes), gives a NAT response indicative of its river situation as epiphytes may significantly influence the nutritional status of the underlying algal filaments (Freeman, 1983). The theoretical basis and extent of application of these NATS has been reviewed by Freeman (1983) for *Cladophora glomerata* and is briefly outlined below for each test used in this study. The critical values of each NAT, the degree of applicability of these NATS to species of filamentous green algae found in the Upper Waikato River, and consideration of response times of tests are discussed after the theoretical basis of test has been described .

3:1.2. Phosphorus Nutrient Availability Tests

3:1.2.1. Total Tissue Phosphorus (TTP)

The total amount of phosphorus (P) contained in plant tissue is an indicator and integrator of the external available P over the generation time of the individual under investigation. Under P limited conditions the growth rate of the alga is dictated by the levels of internal P (Auer and Canale, 1982). The quantity of P present in internal pools is a result of the balance between input through uptake and loss through demand for growth and respiration. There are three functional components of TTP (Freeman, 1983).

#Structural Components - are necessary to maintain the integrity and viability of the plant and include DNA-P and membrane lipid-P. If internal P consists of structural P only, the growth rate will be zero, this is defined as the critical TTP concentration.

#Functional Components - are involved in the cells metabolic activities and include phosphorylated intermediates and RNA-P. The size of this functional P component will have the major influence on the plant's growth rate.

#Storage Compounds - are formed when there is excess P relative to the structural and functional requirements and P is stored as polyphosphate grannules.

The relationship between the TTP components and the growth rate of the plant is illustrated in Figure 34. The Droop function describes the storage hyperbolic curve (Droop, 1973) :

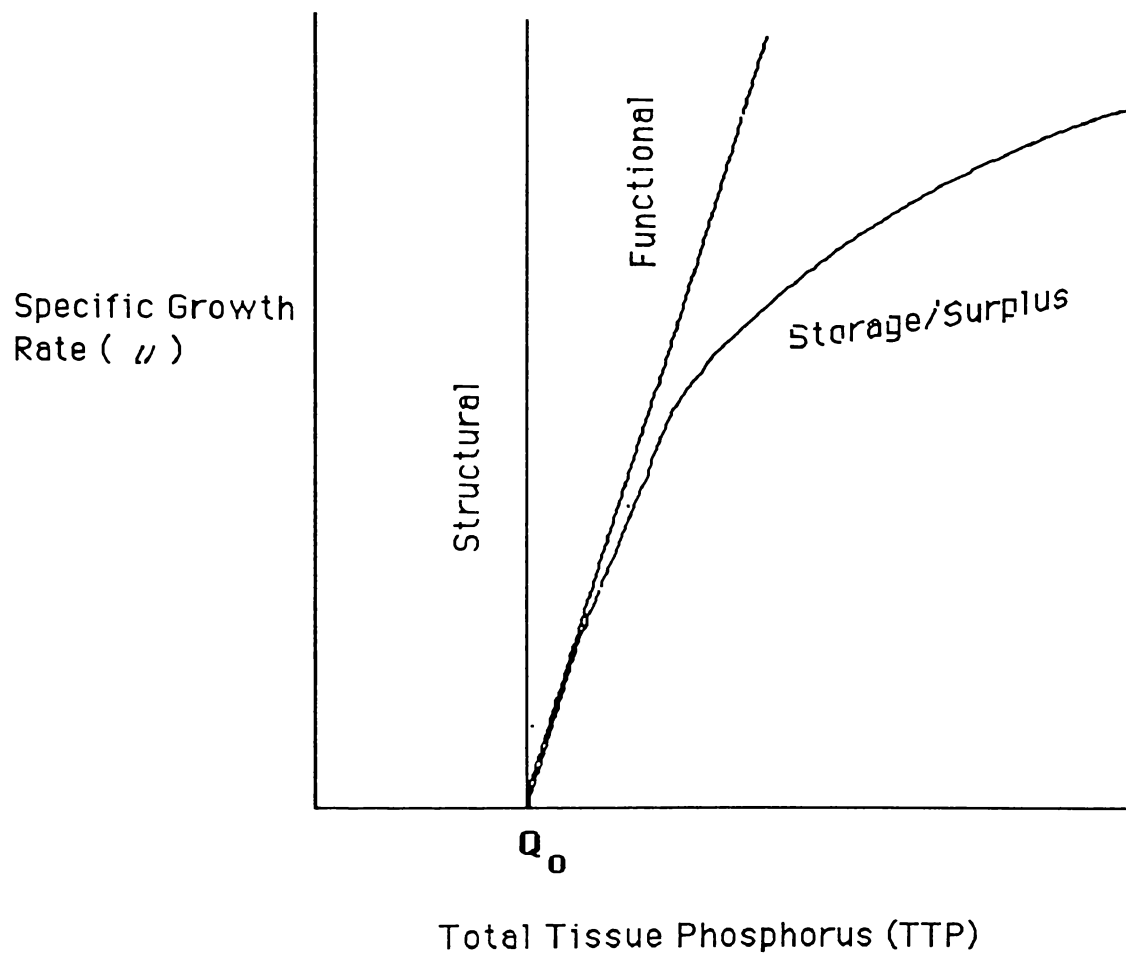
$$u = u_m (Q - Q_0) / Q \quad u = \text{specific growth rate (day}^{-1}\text{)}$$

$$u_m = \text{maximum specific growth rate (day}^{-1}\text{)}$$

$$Q = \text{Total Tissue Phosphorus (TTP) (\%P)}$$

$$Q_0 = \text{Critical TTP (\%P)}$$

The growth rate will effectively drop to zero when Q approaches Q_0 and approach the maximum growth rate when Q increases beyond Q_0 . The ecological consequence of the hyperbolic shape of the storage curve is that a high growth rate is maintained for as long as possible in the face of dwindling TTP caused by a lack of available external P (Freeman, 1983).



* Q_0 = minimum or critical value when $\mu = 0$

Figure 34. The relationship between Total Tissue Phosphorus (TTP) and the Specific Growth Rate (μ)* (from Freeman (1983) after Fuhs (1969)).

3:1.2.2. Extractive Phosphorus (EP)

Algae can store P beyond the immediate nutritional requirements of the plant (Fitzgerald and Nelson, 1966). This is often denoted as luxury consumption or over-compensation, and the excess P is stored as polyphosphate compounds. This internal P store is drawn upon during basic metabolic activities as well as being an internal supply when external P is scarce (Kuhl, 1974). Generally, polyP bodies occur in cells whose metabolism is limited by a growth factor other than P and are less abundant during exponential growth (Stevenson and Stoermer, 1982). Correlations between EP and ambient P concentrations have been reported by Fitzgerald and Nelson (1966); Wong and Clark (1976) and Lin (1971).

Surplus or stored P can be measured by a standard boiling water extraction technique (Fitzgerald and Nelson, 1966). The resulting EP measurement will include some functional and structural P components, but is a reliable estimation of surplus P and a reliable quantitative measure for assessing P limitation (Fitzgerald and Nelson, (1966); Gotham and Rhee, (1981); Gerloff and Mathu, (1984)). Extractive P is usually reported as a percentage. The minimum EP (EP₀) is generally accepted to be 0.02% P (Fitzgerald and Nelson, (1966); Lin, (1971); Mantai et al, (1982); Gerloff and Mathu, (1984)).

3:1.2.3. Alkaline Phosphatase Activity (APA)

Algae that are P limited have been found to have 25-30 times more Alkaline Phosphatase Activity (APA) than algae with surplus external P available (Fitzgerald and Nelson, 1966). A high APA measurement is indicative of a past P shortage which can persist for 1-3 days after a P limiting situation has been relieved (Healey 1973; Mantai, 1978). Analysis of APA levels can be used to confirm that plants with low EP levels are alive and limited by P (Fitzgerald, 1969).

It is important to note that the APA is not under the control of any internal P component. "Any relationship between TTP, EP or PUR (phosphate uptake rate), and APA is only due to all the parameters being linked to the supply of external available P" (Freeman, 1983). Thus APA may act as an independent test to confirm either P surplus or limitation conditions. Also, the phosphomonoesterase enzyme synthesis is inhibited by addition of external P but high APA will only be decreased as the growth of the alga dilutes the enzyme concentration (Fitzgerald and Nelson, 1966). This phenomenon results in a slow response of the APA to a change from a P limiting to a P surplus situation which must be taken into account in the interpretation of APA field data (Freeman, 1983).

Both EP and APA assays have been widely applied to detect long term nutritional changes, such as seasonal changes in P availability or the impact of recent additions of phosphorus nutrients (Fitzgerald, 1969).

3:1.2.4. Phosphorus Uptake Rate (PUR)

Decreasing P in algal tissue is correlated with increases in the phosphorus uptake rate (Auer and Canale, 1982). This study elucidated the governing factors controlling the PUR. These are the external available P (estimated by DRP) and the internal P pool and their effect on the PUR may be illustrated as in Figure 35 from Freeman (1983). As the level of internal P increases the PUR is reduced through negative feedback. This phenomenon resembles non-competitive enzyme inhibition. A net release of reactive P from the alga after the maximum cell quota has been reached has been observed (Freeman, 1983), giving rise to negative phosphate uptake rates.

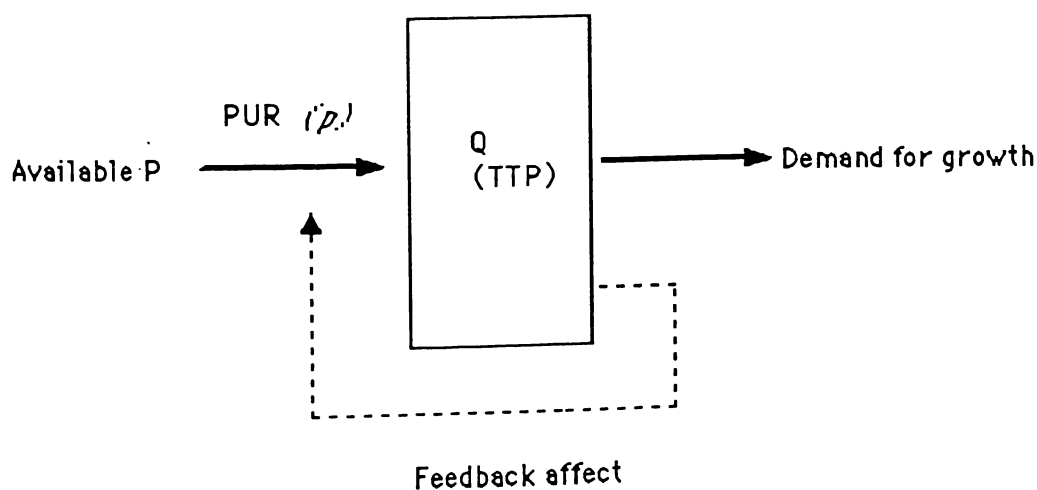


Figure 35. The factors controlling phosphorus uptake kinetics (from Freeman, 1983 after Auer and Canale, 1982).

3:1.3. Nitrogen Nutrient Availability Tests

3:1.3.1. Total Tissue Nitrogen (TTN)

The total amount of nitrogen (TTN) contained in algal tissue is an indicator and integrator of the external available N over the generation time of the individual under investigation in the same way as total tissue phosphorus. Nitrogen in algal tissue is found in free amino acids and the amino acid composition of algal peptides/proteins, the latter forming the structural/functional components of total tissue nitrogen.

Under N limitation the majority of the TTN is contained in the structural and functional components. The Droop function describes the growth rate as a function of the TTN (analogous to TTP). Luxury storage of N by algae has been reported by Fitzgerald and Nelson, (1966); Ho, (1979); Gordon et al (1981) and Soulsby et al (1985).

3:1.3.2. Ammonium Absorption Rate (AAR)

There are two main sources of readily available N in water supplies; ammonia and nitrate. Preferential uptake of $\text{NH}_4\text{-N}$ by algae has been reported by Whitton (1970) and Gordon et al (1981). In the Upper Waikato River, water quality investigations revealed that overall concentrations of $\text{NO}_3\text{-N}$ are low. Inputs from the TB-PCP discharge are minor ^{for $\text{NO}_3\text{-N}$} relative to total loads to this river, while the reverse is true for $\text{NH}_4\text{-N}$ (see Figure 13 in Chapter One). Ammonia uptake rates and not nitrate uptake rates were therefore investigated. In algae that are N limited, the rate of ammonium N assimilation is 4-5 times greater than that of algae growing with a sufficient N supply (Fitzgerald, 1968). The Ammonium Absorption

Rate (AAR) is analogous to the PUR and similar relationships between AAR and ammonium N and PUR and external available P have been described (Freeman, 1983).

3:1.4. CRITICAL LEVELS of NATS

Table 8 summarises critical levels for each NAT reported for various species in the literature. Values of NATS have been well calibrated for *Cladophora* from both lake and riverine environments, reflecting the widespread distribution of this alga and its often nuisance forming growths. In New Zealand Freeman (1983) calibrated *Cladophora glomerata* growing in the Manawatu River using standard batch culture techniques. Values obtained from this study agreed well with those reported from overseas (Table 8) and were used in the present study to evaluate the nutritional status of *Cladophora glomerata* growing in the Upper Waikato River. It is noted that any value obtained from laboratory studies must be used with caution as batch culture set ups may not adequately simulate in-situ conditions.

There is limited application of NATS to other species of filamentous green algae or to other species of algae in general. Most studies assume that critical levels are relatively similar for all species. Application of critical levels of NATS to other species of algae and to populations of calibrated species like *Cladophora glomerata* from different areas needs to be considered from the basis of the functional nature of the NATS employed. The NATS used in this study were enzymatic based (APA, PUR and AAR) and tissue component based (TTP, TTN and EP), (Freeman, 1983). The distinction between a surplus and a limiting situation for the enzymatic NATS is gradual, as opposed to the precise concentrations

defined for the tissue components. In the Upper Waikato River, three species of filamentous green algae are of interest; *Oedogonium* sp, *Cladophora glomerata* and *Enteromorpha nana* var *minima* ecad *rivularis*.

Table 7. Reported Critical levels of Nutrient Availability Tests (NATS) associated with N and P limitation/surplus conditions.

	<u>Level associated with</u>			reference
	Limitation	Surplus	environment	
TTN (%N)				
<i>Cladophora glomerata</i>	<1.1	>1.1	lake	Gerloff & Fitzgerald (1976)
" "	<2	>2	river	Freeman (1983)
" "	<1.2-1.5	>1.2-1.5	river	Wong & Clark (1976)
<i>Cladophora aff. albida</i>	<2.1	>2.1	estuary	Gordon et al (1981)
aquatic plants in general	<1.3	>1.3	-	Gerloff & Krombolz (1966)
<i>Cladophora</i>	<2.1	>2.1	estuary	Birch et al (1981)
TTP (%P)				
<i>Cladophora glomerata</i>	< 0.06	>0.06	lake	Gerloff & Fitzgerald (1976)
" "	<0.07	>0.07	river	Freeman (1983)
" "	<0.16	>0.16	river	Wong & Clark (1976)
<i>Cladophora aff. albida</i>	<0.05	>0.05	estuary	Gordon et al (1981)
angiosperm aquatic plants	<0.13	>0.13	-	Gerloff & Krombolz (1966)
EP (%P)				
range of algae species	<0.08	>0.08	-	Fitzgerald & Nelson (1966)
<i>Cladophora glomerata</i>	<0.02	>0.02	lake	Mantai et al (1972)
" "	<0.02	>0.02	river	Freeman (1983)
" "	<0.06	>0.06	lake	Auer and Canale (1980)
" "	<0.08	>0.08	lake	Gerloff and Muth (198?)
range of green algae	<0.06-0.08	>0.06-0.08	lakes/streams	Sladick and Coleridge (1978)

Table 8 cont.

APA (enz. units/mg) ⁻¹) range of green phytoplankton <i>Cladophora glomerata</i> "	>2400	<75	Fitzgerald & Nelson (1966)
	>200	<20	Mantai (1978)
	>150	<50	Freeman (1983)
PUR (ugP(10mg) ⁻¹ h ⁻¹) <i>Cladophora glomerata</i> " <i>Ceratophyllum</i>	>6 >3 >15	<3 <1 <5	Auer & Canale (1982) Freeman (1983) Fitzgerald (1969)
AAR (ugN(10mg) ⁻¹ h ⁻¹) <i>Cladophora glomerata</i> "	25 >6	5 <6	Fitzgerald (1969) Freeman (1983)

Ideally, each species of algae should have these NATS calibrated through standard batch culture techniques, however given the time frame of this study such an undertaking was not possible. While there is no great problem in applying accepted critical values of NATS to the *Cladophora* found in this study the degree of applicability of using these levels for assessing the nutritional status of *Oedogonium* and *Enteromorpha* needs to be considered carefully.

3:1.4.1. Tissue Component NATS:- TTN, TTP and EP

As tissue component tests measure the amount of an element per dry weight, it is likely that the critical levels of these types of test should be fairly similar for those species of algae that have similar form eg. filamentous green algae. Table 8 shows that there is generally good agreement on the critical level of tissue component based tests between different species of algae from both lentic, lotic and marine environments. In addition, Sladick and Coleridge (1978) found that EP levels for *Cladophora*, *Oedogonium* and *Hydrodictyon* were similar from similar environments of soluble reactive phosphate (SRP) concentrations and more importantly that the slope of SRP versus EP graphs were not significantly different, indicating a comparable response to P limiting and P surplus conditions.

In this study incorporation of Freeman's critical TTN level of 2%N gives a conservative estimate of N limitation compared to the 1.3%N level obtained from early studies by Gerloff and Krombolz (1966). In the same way using Freeman's critical level of TTP calibrated for *Cladophora* gives a conservative critical level of P limitation compared to other

investigations of filamentous green algae.

For EP values the more conservative estimate of 0.06-0.08%P from Fitzgerald and Nelson (1966) and Saldick and Coleridge (1978) is probably a 'safer' critical level to apply to other green filamentous algae than the 0.02%P used by Freeman, (1983).

3:1.4.2. Enzymatic based NATS:- AAR, PUR and APA

As opposed to the tissue based NATS, inspection of the literature shows that *Cladophora* critical levels for these enzymatic tests should not be applied liberally. In studies of *Enteromorpha*, Fujita (1985) noted that AAR rates differed markedly for many species and that within a species ammonium uptake rates may vary with the nutritional history of the individual. Gerloff and Mathu (1984) also reported this high degree of variability of AAR for *Cladophora glomerata* from the Great Lakes area. Fujita also postulated the existence of species of macroalgae like *Enteromorpha* spp. to have extremely rapid ammonium uptake as an adaptation to episodic N nutrient supply. Auer and Canale (1982) showed the influence of cell size on the maximum PUR. Maximum possible PUR for *Cladophora* was 4.5% day⁻¹(= ca 18 ugP (10mg)⁻¹h⁻¹, assuming linear uptake), whilst for smaller celled planktonic algae maximum possible PUR ranged up to 148.8% day⁻¹(= ca 595 ugP (10mg)⁻¹h⁻¹, assuming linear uptake).

In view of this variability no critical values are set for PUR and AAR for *Enteromorpha* and *Cladophora*. The critical levels reported by Freeman, (1983) for *Cladophora glomerata* in the Manawatu River were used with caution for this species in the Upper Waikato River as there may be a significant degree of ecotypic adaptation by *Cladophora* to ambient supplies of these nutrients.

APA is the most widely applied enzymatic NAT and the large difference between P limiting and P surplus levels makes interpretation of APA levels relatively straightforward (Table 8). In this study Freeman's values for *Cladophora* were used as they provided a more conservative estimate of P limitation assessment.

The following relatively conservative NAT critical levels were used as a guide to limitation/surplus conditions for *Oedogonium* and *Enteromorpha*.

NAT	Critical level used in this study	Source
TTN	limitation <2%N>surplus	Freeman (1983)
TTP	limitation <0.07%P>surplus	Freeman (1983)
EP	limitation <0.08%P>surplus and compared to Freeman's level of 0.02%P	Fitzgerald & Nelson (1966)
APA	limitation >150, surplus < 50 enz. units mg ⁻¹	Freeman (1983)
PUR	none set, see text	
AAR	none set, see text	

It is important to note that interpretation of the nutritional status of in-situ algae must rely on the employment of more than one type of NAT for each nutrient under consideration until the variation of critical levels both within and between species has been more fully investigated.

There are only few reports of monitoring more than one species field population at the same site. An interesting facet of this study is that there is such marked species replacement below the sewage discharge and provides a test case for nutrient based competition between filamentous green algae.

3:1.5. NATS RESPONSE TIMES

Investigations into the response times of NATS by Freeman (1983) showed that the different assays have significantly different response times (Table 8). Freeman (1983) showed that the speed of NAT response has important consequences for data interpretation, as, a result indicative of nutrient limitation could represent a recent situation (hours) or be a relic of some historic event (days). Freeman's study forms the only complete assessment of response times carried out on all NATS at the same time and the results compare fairly well with response times reported for NATS from other studies. Sladick and Coleridge (1978) found similar EP (24 hours), response times in field populations of *Cladophora* when transplanted to surplus/limiting P environs. Mantai et al (1982) found approximately a days delay in AAR response from N limiting to N surplus environs for *Cladophora*. Fitzgerald (1969) also found similar response times of both APA and EP to Freeman's values.

Table 8. A summary of laboratory Nutrient Availability Tests (NATS) response times for *Cladophora glomerata* from the Manawatu River, New Zealand, (from Freeman, 1983).

Response from Surplus to Limiting Situation

Nutrient	NAT
Phosphorus	
very slow	APA
slow	TTP, EP
fast	PUR
Nitrogen	
slow	TTN
fast	AAR

Response from Limiting to Surplus Situation

Nutrient	NAT
Phosphorus	
slow	APA
fast	TTP, EP, PUR
Nitrogen	
fast	AAR, TTN

Key: very slow=>4 days

slow= 2-4 days

fast= 2-12 hours

3:1.6. *Oedogonium*, *Enteromorpha* and *Cladophora*
NATS Monitoring Programme

These six nutrient availability tests (TTN, TTP, APA, EP, AAR and PUR), were applied to *Oedogonium*, *Enteromorpha* and *Cladophora* in-situ populations in the Upper Waikato River from May, 1989 to January, 1990. Previous applications of NAT monitoring of in-situ algal populations have almost exclusively been carried out in the summer months which coincided with periods of maximum growth. In this study it was decided to include winter monitoring as studies carried out on phytoplankton in Lake Taupo, (the main source of water for the Upper Waikato River), had shown a winter maximum of biomass and fluctuating N/P nutrient limitation between winter and summer (White and Payne, 1977). Nitrogen was reported as more likely to limit the growth of phytoplankton in the winter with phosphorus taking over this role in summer. This strategy was confirmed in hindsight as results from the resource assessment part of this study showed that cover and standing crops of *Enteromorpha* did not appreciably change throughout the entire study period, (summer, 1989 to summer 1990), and cover and standing crops of *Cladophora* did not appreciably change from summer through to late winter-early spring (Chapter Two).

3:1.7. Algae Transplant Experiment

An algal (*Enteromorpha* and *Cladophora*) transplant experiment was also designed and carried out in this study in order to gauge the relative importance of N and P inputs from the sewage discharge and to provide a means of assessing *Enteromorpha* and *Cladophora* growth rates. *Cladophora* and *Enteromorpha* did not form significant growths in main channel environs upstream of the TB-PCP discharge, only drift material and occasional small growths of these two species were observed in Section 1 (Chapter One). Some limited marginal growth of *Enteromorpha* was observed in the embayment area, presumably associated with small, localised nutrient inputs. It was proposed to carry out NATS at each harvest of *Enteromorpha* and *Cladophora* from up- and downstream transplants with the hypothesis being that comparison of relative changes in either N or P NAT levels would indicate which input from the sewage discharge was of greater relative importance to these species growths downstream of the sewage discharge. In the literature only one case of algae transplant technique could be found; Saldick and Coleridge (1978) transplanted *Cladophora* to both P-poor and P-rich lentic environments as part of an assessment testing the validity of using EP measurements as a reliable indicator of P-limitation/surplus. The transplant experiment designed in this experiment is reported as a new technique that may be useful in assessing the relative importance of nutrient loads to lotic environments.

3:2. Methods

3:2.1. *Oedogonium*, *Enteromorpha* and *Cladophora* **NATS Monitoring Programme**

The three monitoring sites for algal filament collection are shown in Figure 36. *Oedogonium* was collected from the left bank side of Transect 2, located upstream of the treated sewage discharge. Filaments of *Enteromorpha* and *Cladophora* were collected from the right bank side approximately 100m below Transect 4, and from the right bank side 5m above Transect 5.

Collections of filaments were made approximately weekly from late May through to August, with some sampling runs in September and October 1989, and three summer sampling runs in January 1990. Due to limited time available, only the assays of TTN, TTP, APA, and AAR were carried out in the 1990 summer runs. In late winter the lack of sufficient material of *Oedogonium* prevented some analyses. The collection site at Transect 4 was indicative of immediate post-discharge while the collection site at Transect 5 was indicative of post-discharge further downstream (approximately 2.8km), but upstream of any other point source discharge. The precise location of these sites was made on the basis of similar, water depth, flow regime and lack of over-hanging terrestrial vegetation.

Oedogonium was collected from epiphytic populations that grew on the moss and the low-mixed species associations. Filaments of *Enteromorpha* were collected from predominantly epiphytic populations, *Cladophora* was collected from epilithic populations.

At each site samples of algae were collected in triplicate using SCUBA and washed in river water. Collections were made at approximately the same time on each sample run, between 8:30am and 10:30am, and transported chilled to the laboratory with a maximum delay before processing of 4 hours.

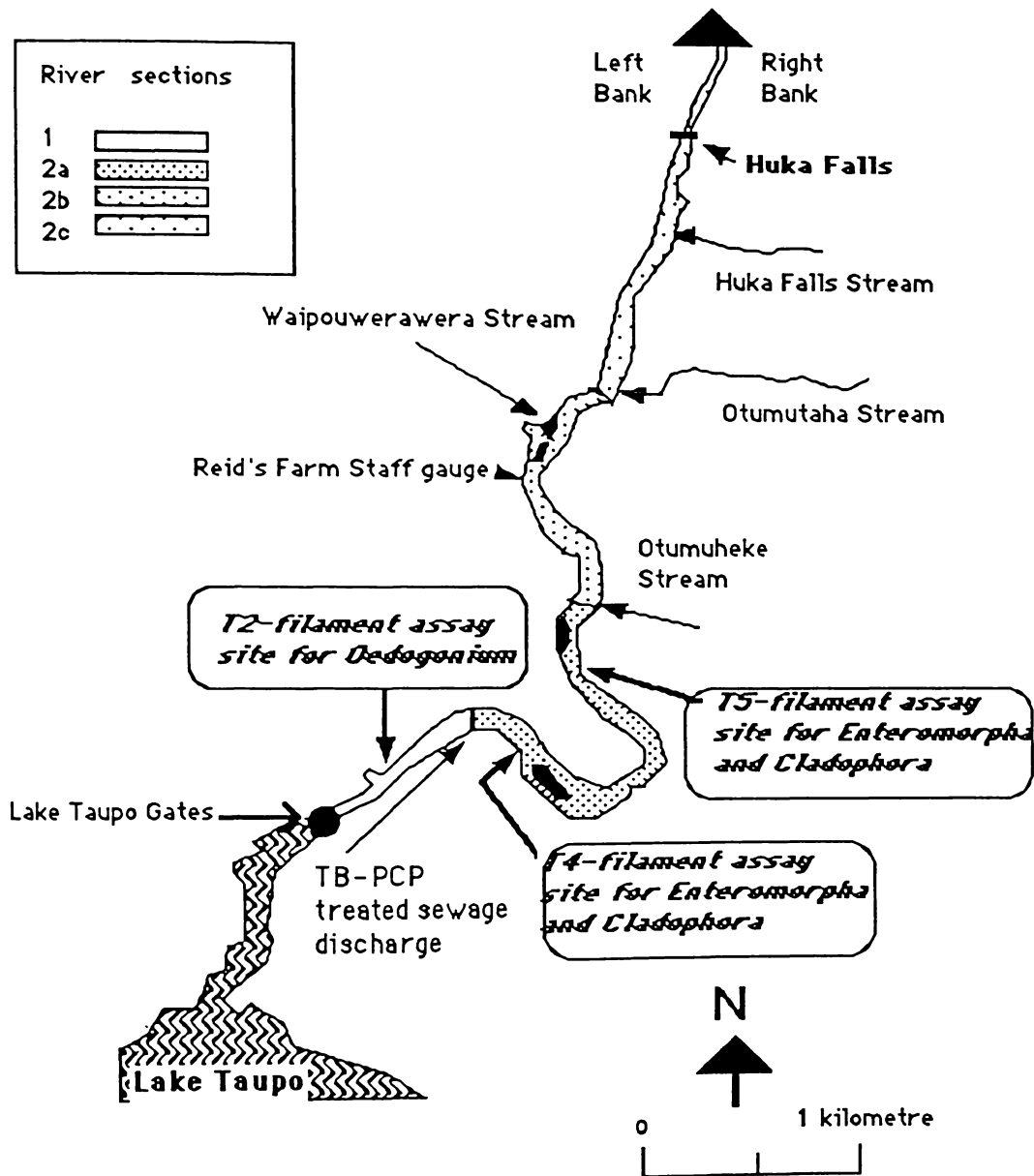


Figure 36. Map of the Upper Waikato River showing algal collection sites for Nutrient Availability Tests.

Water temperature and conductivity were measured at each site using a Yellow Springs Instruments Model No. 33 S.C.T. meter. Water flow was measured directly above the algal growths using a Gurly meter, and was an averaged reading from three consecutive readings. A water sample was collected directly above the algal growths at each site using an acid-cleaned 2 litre container. Water samples were analysed by Mr. M. Gibbs, D.S.I.R, Taupo for nitrate (Downes, 1978), ammonia (modified from Crooke & Simpson, 1971) and dissolved reactive phosphorus (Downes, 1978) concentrations.

3:2.2 Nutrient Availability Tests (NATS)

Tests for alkaline phosphatase activity, extractive phosphorus, ammonia absorption rate and phosphate uptake rate were completed on the same day of sample collection. Total tissue nitrogen and phosphorus tests were made on dried algal material at the end of the winter and summer sampling period. Algal samples were dried at 64°C to avoid the loss of volatile organics (Freeman, 1986).

Each algal sample was washed in river water to remove sediment and epiphytes on filaments. Filaments were also washed in Gorhams (minus P) medium (Appendix 6) for the assays of alkaline phosphatase activity, extractive phosphorus and phosphate uptake rate. Algal samples used for the ammonia absorption assay were washed in Gorhams (minus N) medium. Three samples were collected of each species at their respective sampling site and these samples were analysed in triplicate for each assay.

Where possible only the terminal portions of algae filaments were used in the assays, as Fitzgerald, (1969) noted that there can be significant differences between basal and terminal portions of plant species. However this difference seemed to be significant only for higher plants eg. *Myriophyllum* sp.

All glassware used in assays was soaked overnight in 50% sulphuric acid followed by three rinses in distilled water. Milliquat grade water was used to make up solutions/media used in the assays.

3.2.2.1. ALKALINE PHOSPHATASE ACTIVITY -APA^S

The methods of this analysis follow that of Fitzgerald and Nelson (1966). Freshly collected samples (1-20mg) of washed algae (*Oedogonium*, *Enteromorpha* and *Cladophora*), were suspended in 100ml conical flasks containing 32ml of Gorham's (minus P) medium. Four mls of buffer solution (1M Tris, 0.01M MgCl₂ adjusted to pH 8.5 with acetic acid), and four mls of *p*-nitrophenol-phosphate solution (30mg (100ml)⁻¹) was then added.

The resulting solutions, including a minus-algae control, were placed in a monitored temperature water bath (35-37°C), in natural light for 1 hour. Flasks were shaken each 1/4 hour to ensure homogeneity of the solutions. After 1 hour the samples were removed from the water bath and immediately filtered through pre-washed/dried and weighed Whatman

Glass microfibre filters (47mm diameter) to remove the algae. Algal samples were dry-weighted at 64°C for six days in a hot air oven.

The optical density of the remaining solution was read at 395nm using a Cecil Instruments CE 29Z Digital UV Spectrophotometer. The optical density of *p*-nitrophenol was calibrated using standard solutions.

Alkaline phosphatase activity was reported as units of enzyme mg⁻¹ (dry weight) of algae in 40ml. A unit of alkaline phosphatase is defined as the amount of enzyme which liberates 1nm of *p*-nitrophenol per hour under the prescribed conditions (Fitzgerald and Nelson, 1966).

3:2.2.2

EXTRACTIVE PHOSPHOROUS - EP

The method employed for this analysis followed that described by Fitzgerald and Nelson (1966). Washed algal samples (approximately 10-30mg) were placed in 20ml test-tubes containing 10mls of Gorham's (minus-P) medium. Tubes were stoppered and placed in a boiling water bath for one hour. Algal material was removed from the resulting solution by filtration and dry-weighted as described above. It is noted that dry weights of samples after extraction with boiling water are not equal to the total dry weight of the original sample, but are accurate enough for comparative purposes (Fitzgerald, 1969).

The remaining solution was analysed for orthophosphate concentration using a Malachite green - molybdate assay (Appendix 7).

Extractive phosphorus results are reported as %P on a dry weight basis.

3:2.2.3PHOSPHORUS UPTAKE RATE - PUR

This method was based on Healy (1973) with modification for a filamentous algae by Freeman (1983). Approximately 10-30 mg of washed algae was placed in 50 ml of Gorham's (minus P) medium, with 10 ml of $K_2H_2PO_4$ (2 $mg\ l^{-1}$) added. Solutions, including a minus-algae control, were incubated, with occasional shaking, in the dark for two hours at 25 °C in a Contherm Series 5 incubator. The algal material was filtered from the solution and dried as described above. The supernatant was analysed for reactive phosphate by the malachite green-molybdate method (Appendix 7).

Phosphorus uptake rates are reported as ($\mu g\ P(10mg)^{-1}\ h^{-1}$) on a dry weight basis.

3:2.2.4AMMONIUM ABSORPTION RATE - AAR

The method employed for this analysis followed that of Fitzgerald (1969). Samples of algae (1-30 mg), were placed in 100ml conical flasks containing 50ml Gorham's (minus N) medium and 10ml of 10 $mg\ l^{-1}$ ammonium chloride solution. Replicate samples were incubated, including a minus algae control, in the dark at 25°C in a Contherm Series 5 incubator for a two hours.

Ammonium absorption rates are reported as $\mu g(10mg)^{-1}\ h^{-1}$ on a dry weight basis.

Algal material was removed from the resulting solution by filtration and dry-weighted as described previously. The ammonium concentration of the remaining solution was assayed using a manual modification of the

nitroprusside/phenol hypochloride method from Brown (1973), see Appendix 8.

3:2.2.5 TOTAL TISSUE NITROGEN (TTN) and PHOSPHORUS (TTP)

The method employed for this analysis follows that of the Ministry of Agriculture and Fisheries-Ruakura Research Station Plant Analysis Laboratory, and is based on a Kjeldahl digest.

Approximately 0.1g of washed (river water) and dried (64°C) algal material was placed in digestion tubes (75 ml volume). Replicate samples of known standards were also analyzed (Ruakura Plant Analysis Laboratory Standard No. 86P). To each tube a Kjeldahl Catalyst Tablet and 4.5 ml H₂SO₄ was added. Tubes were placed on pre-heated blocks (300°C) and following stabilisation checks the temperature was raised to 325°C. Replicate tubes containing no algal material were also processed as controls.

Samples were removed after 1.5 hours, cooled and sample volume was made up to 50 ml with distilled water. After samples had cooled to room temperature they were analysed for TTN and TTP simultaneously using a Auto-Analyser (Cadmium Column Reduction).

3:2.3. Algae Transplant Experiment

A pilot scale transplant experiment was carried out during September, 1989. Baskets were designed to hold the algae transplants and were made out of plastic "gutter-guard" (mesh size 1cm²) with a whitebait netting (mesh size 4 mm²) draw-string top (see Figure 37). Baskets ranged from approximately 200-300mm diameter and were ranged from 300-400mm high. Six randomly placed baskets (3 containing *Cladophora* and 3 containing *Enteromorpha*) were shackled to a rope suspended from a supporting rod (electrical conduit piping). Three 2 litre buoys were fixed to the supporting rod to ensure buoyancy of the structure. The buoyancy of these could be altered by filling with water. The basket structures were anchored into the riverbed using steel stakes (waratahs) where no suitable anchoring structure was already present. A sufficient length of rope was used to fix the buoyed unit to ensure that the baskets remained submerged with changing water levels in the river.

Rocks of suitable size (ca. 100-200mm diameter) supporting high cover of *Cladophora* and epiphytic populations of *Enteromorpha* were collected, using SCUBA, from Transect 5 and held in plastic containers of river water (approximately 0.25 hours) before transfer to the baskets. To enable growth rate measurements replicate quadrats were harvested for standing crop estimates of in-situ *Cladophora* and *Enteromorpha* at the start of the experiment. It is noted that slough-off rates are not estimated in the growth rates but are assumed to be minimal in the basket containers. Only preliminary growth rate observations are reported in this study.

Two duplicate sets of baskets were placed upstream, (near Transect 2), and downstream, (Transect 5), of the TB-PCP discharge, designed for two harvests, after one, (8/9/89), and two weeks, (15/9/89), see Figure 37. A minimum period of one week was used for harvest frequency as from consideration of NATS response times the slowest assay response time was reported for APA (ca. 4 days). Thus, by one week all NATS should have stabilised and after two weeks, if transplants survive, results should be indicative of the transplant site and not a relic response from the original in-situ collection site downstream of the sewage discharge. Sites were chosen for similar water depth, flow regime and lack of overhanging terrestrial vegetation. The supporting structure was designed to suspend the baskets at approximately 0.5m water depth. Table 8 illustrates the replicated experimental design.

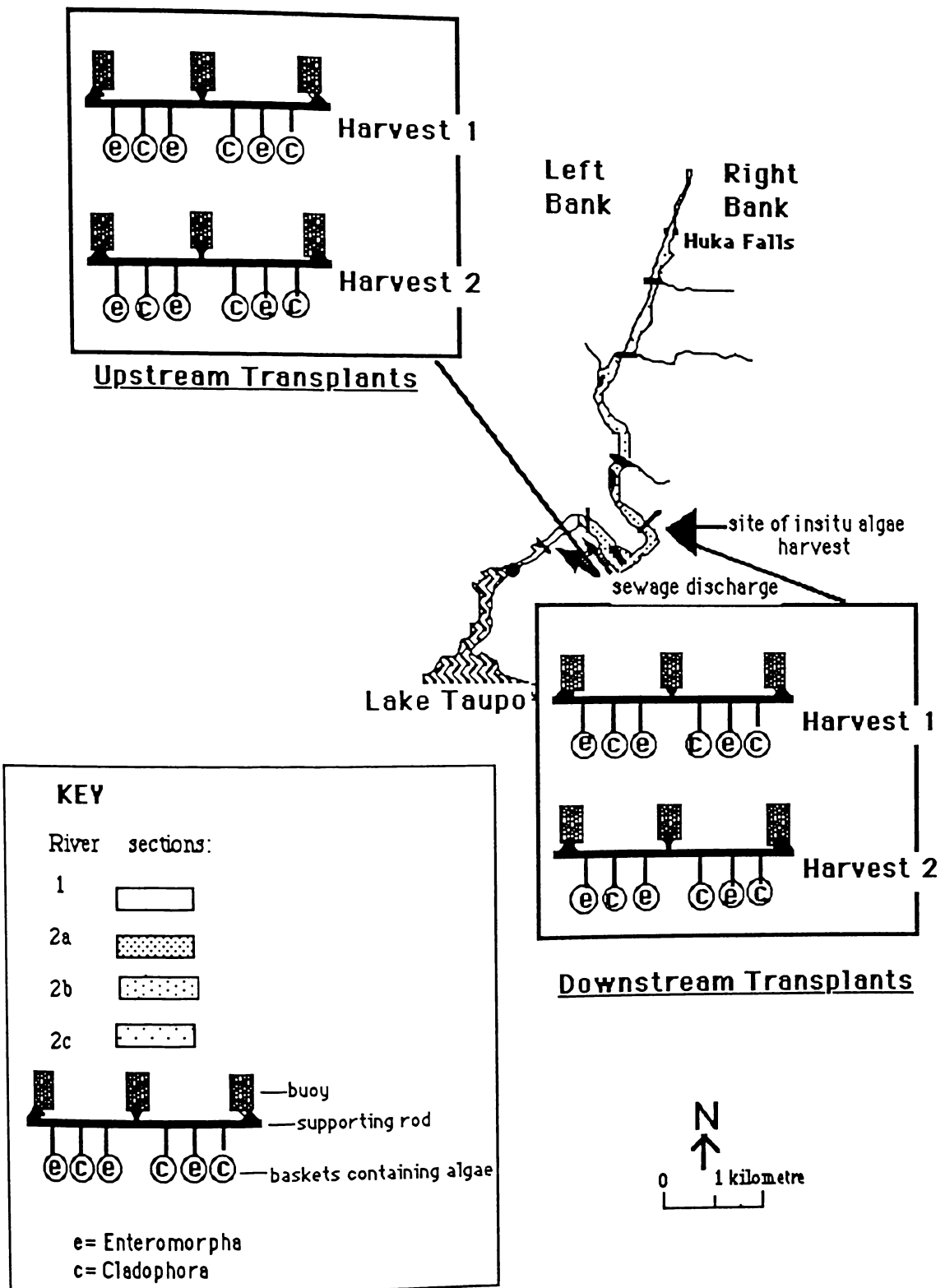
At each harvest three samples (baskets) of *Cladophora* and three samples (baskets) of *Enteromorpha* were collected from both upstream and downstream of the discharge. Three samples of in-situ populations of both *Cladophora* and *Enteromorpha* were collected from original transplant collection sites (near Transect 5), to enable assessment of the effect, if any, of the basket structures on growth of the algae, and thus permitted evaluation of this experimental design in simulating the natural environment.

Samples were transported chilled to the laboratory. The physiological indicator tests of; alkaline phosphatase activity, extractive phosphorus, ammonium absorption rate and phosphorus uptake rate were carried out in triplicate on each sample on the same day of harvest. Total Tissue Nitrogen and Phosphorus assays were carried out on dried algal material. Critical levels used for each NAT were the same values used for the monitoring programme.

Table 9. Algae Transplant Experimental Design, Upper Waikato River, September, 1989.

Species	Upstream Transplants near (T2)	Downstream Transplants near (T5)	In- situ populations near (T5)
<i>Enteromorpha</i>	E-US-A	E-DS-A	5E-A
	E-US-B	E-DS-B	5E-B
	E-US-C	E-DS-C	5E-C
<i>Cladophora</i>	C-US-A	C-DS-A	5C-A
	C-US-B	C-DS-B	5C-B
	C-US-C	C-DS-C	5C-C

Figure 37. Algal (*Enteromorpha* and *Cladophora*) Transplant Experimental Design. Replicate samples of *Enteromorpha* and *Cladophora* collected from near Transect 5 were placed in baskets and suspended in the river near Transect 2, (right bank, upstream of the sewage discharge), and at Transect 5, (right bank, downstream of the sewage discharge). The experiment was designed for two harvests, at one and two weeks. Samples of in-situ *Enteromorpha* and *Cladophora* were collected at each harvest from Transect 5.



3:3 Results

3:3.1 *Cladophora*, *Enteromorpha* and *Oedogonium* NATS Monitoring Programme.

Collections of algae were made approximately weekly from late May through to August, with some sampling runs in September and October, 1989, and three sampling runs in January, 1990. In the 1990 summer sampling runs the assays of TTN, TTP, APA and AAR only were carried out.

When the monitoring sites were chosen, it was believed that all diffuser outlets of the discharge structure were operable. It was subsequently found that the inner diffuser outlets had not been working for some time, thus restricting mixing of the effluent. This is likely to have affected effluent mixing in the vicinity of the Transect 4 monitoring site, resulting in a lower effluent concentration in the river water at this site than if all diffusers were working. Results from the Transect 5 monitoring site are considered to give more reliable indications of possible nutrient limitation/surplus conditions. *Enteromorpha* and *Cladophora* results described in the NATS results are therefore restricted to trends at Transect 5 unless otherwise stated.

3:3.1.1Site Monitoring Data

Water temperature did not vary significantly between the three monitoring sites (see Figure 36 for site location). A minimum water temperature of 11.2°C was recorded in July and August sampling runs with a maximum water temperature of 18.9°C in summer (January). No marked seasonal or between site trends were found in conductivity measurements with an overall mean conductivity of 12.1mSm⁻³ for the sampling period from May to October (conductivity was not measured in the summer sampling runs). Flow measurements recorded at each site were correlated (not linear) to river flow. Ranges and mean current velocities at the three monitoring sites is given in Table 11.

Table 10. Mean and Range of Current Velocities measured at Algal Monitoring Sites.

<u>Monitoring Site</u>	<u>Current Velocity</u>	
	(ms ⁻¹)	
	<u>Mean</u>	<u>Range</u>
Transect 2	0.50	0.46-0.57
Transect 4	0.52	0.43-0.75
Transect 5	0.65	0.40-0.87

Sufficient material of *Enteromorpha* and *Cladophora* for NAT analyses was obtained on each sampling run and plants after washing, (see methods), were largely free of epiphytes. *Oedogonium* populations fluctuated throughout the study period which sometimes restricted the use of the full suite of analyses at this site. In addition the washing procedure failed to remove high densities of diatom epiphytes on *Oedogonium*.

Water quality site monitoring is presented after the NAT results.

3:3.1.2 Nutrient Availability Test Results

Results of Nutrient Availability Tests (NATS , TTN, TTP, AUR, PUR, APA and EP), are presented in Figures 38 to 43. Data can be referenced in Appendix 9 (Tables i to vi). Values denoting N/P limitation/surplus on the following graphs are for *Cladophora glomerata* from Freeman (1983) and some general EP levels from Fitzgerald and Nelson (1966), their degree of applicability for both the *Cladophora glomerata* found in the Upper Waikato River, and *Enteromorpha* and *Oedogonium* is discussed in the next section, thus the values are for reference only and do not necessarily imply N/P limitation or surplus.

Coefficients of variation were used to monitor the accuracy of each NAT test. Appendix 10 gives the overall mean coefficients of variation for each test. These compare well with the level of accuracy obtained by Freeman (1986).

Overall NAT response was similar for *Enteromorpha* and *Oedogonium* at both monitoring sites (below the TB-PCP sewage discharge), whilst *Oedogonium* (above the TB-PCP sewage discharge), often showed distinctly different trends.

Total Tissue Nitrogen (TTN)- Figure 38.

Total Tissue Nitrogen levels in *Oedogonium* were consistently well below Freeman's critical TTN level for *Cladophora* of 2% tissue nitrogen. *Cladophora* and *Enteromorpha* TTN values were generally above this 2% level indicating N sufficiency for *Cladophora*, and likely N sufficiency for *Enteromorpha*.

Total Tissue Phosphorus (TTP)- Figure 39.

Oedogonium's TTP level fluctuated between the accepted P limitation and P surplus values and were low for all three summer monitoring runs. Both *Enteromorpha* and *Cladophora* TTN values were generally well above Freeman's critical 0.07%P level, indicating P sufficiency in these populations downstream of the sewage discharge.

Alkaline Phosphatase Activity (APA)- Figure 40.

APA results from *Oedogonium* populations showed fluctuating P limitation in the winter, with all three summer values well within accepted P surplus levels.

Enteromorpha and *Cladophora* populations exhibited low APA values indicative of P surplus conditions. P limitation in *Cladophora* was indicated in only one APA analysis on the 18/7/89. However, this was not confirmed by either TTP or EP results and reflects the importance of using more than one NAT to test the possibility of limitation/surplus conditions.

Alkaline phosphatase assays confirmed that algae were alive and provide independent confirmation of P limitation/surplus conditions (see introduction).

Ammonium Absorption Rate (AAR)- Figure 41.

All species (*Oedogonium*, *Enteromorpha* and *Cladophora*), at all sites (Transect 2, 4 and 5 monitoring locations), exhibited high AARs, with an apparent trend of decrease in the magnitude of AAR summer values compared to winter levels.

A small population of *Cladophora* was found growing in-situ near the Transect 2 monitoring site on the 18/10/89. Enough material was present for AAR, PUR and EP analyses (see Appendix 9, Tables iii, iv and vi). *Cladophora* at this site did not appear to be limited P from tissue NATS but had an AAR indicative of N limitation. The growth form of this population was chloritic with relative cell elongation compared to *Cladophora* growth downstream of the sewage discharge.

Phosphate Uptake Rate (PUR)-Figure 42.

Cladophora PUR levels were generally less than the critical P limitation value defined by Freeman (1983). *Enteromorpha* populations at both monitoring sites (Transect 4 and 5), exhibited both similar magnitude and overall trends in PUR as that shown by *Cladophora*.

Oedogonium populations had comparatively higher phosphate uptake rates. The sampling run on the 11/7/89 showed a negative PUR, indicating possible lack of P limitation.

Extractive Phosphorus (EP)- Figure 43.

Extractive phosphorus tissue concentrations of *Cladophora* samples were consistently above the 0.02%P critical level, indicating a lack of P limitation. A more conservative critical level was used for *Enteromorpha* and *Oedogonium* populations (see introduction), which showed possible fluctuating P limitation for both species. However, EP results were above the *Cladophora* critical EP values for both *Enteromorpha* and *Oedogonium* populations.

Water quality, (DRP, NH₄-N, NO₃-N), monitoring data at each algal collection site for the period from May through to October are graphically presented in Figure 44. Raw data for these analyses are given in Table vii (Appendix 9). Correlations of water quality levels to NAT parameters was generally low. Highest correlations were shown for DRP and *Enteromorpha* and *Cladophora* populations at Transect 5 ($r^2 = 0.77$ and 0.62 respectively). Similar levels of correlations were found for these species at Transect 5 for EP, reflecting the similar nature of these assays. High variability in these parameters, lack of correlation to NATS and cost of analyses resulted in ceasing these monitoring parameters in August. Lack of correlation for either *Enteromorpha* and *Cladophora* at the Transect 4 monitoring site may be partially explained by lack of complete mixing of the effluent with the river.

General trends in water quality for the entire period is given by the monthly monitoring data at the Taupo Gates and Huka Falls, and the TB-PCP discharge monitoring data for the entire study period (Figures 4, 13 and 14, Chapter One).

Figure 38. Total Tissue Nitrogen (%N) Monitoring Data for *Oedogonium*, *Enteromorpha* (Transect 4 &5) and *Cladophora* (Transect 4 & 5) from May, 1989 - January, 1990. Values denoting N/P limitation/surplus on these graphs are for *Cladophora glomerata* from Freeman (1983), their degree of applicability for both the *Cladophora glomerata* found in the Upper Waikato River, and *Enteromorpha* and *Oedogonium* is discussed in the text, thus the values are for reference only and do not necessarily imply N/P limitation or surplus.

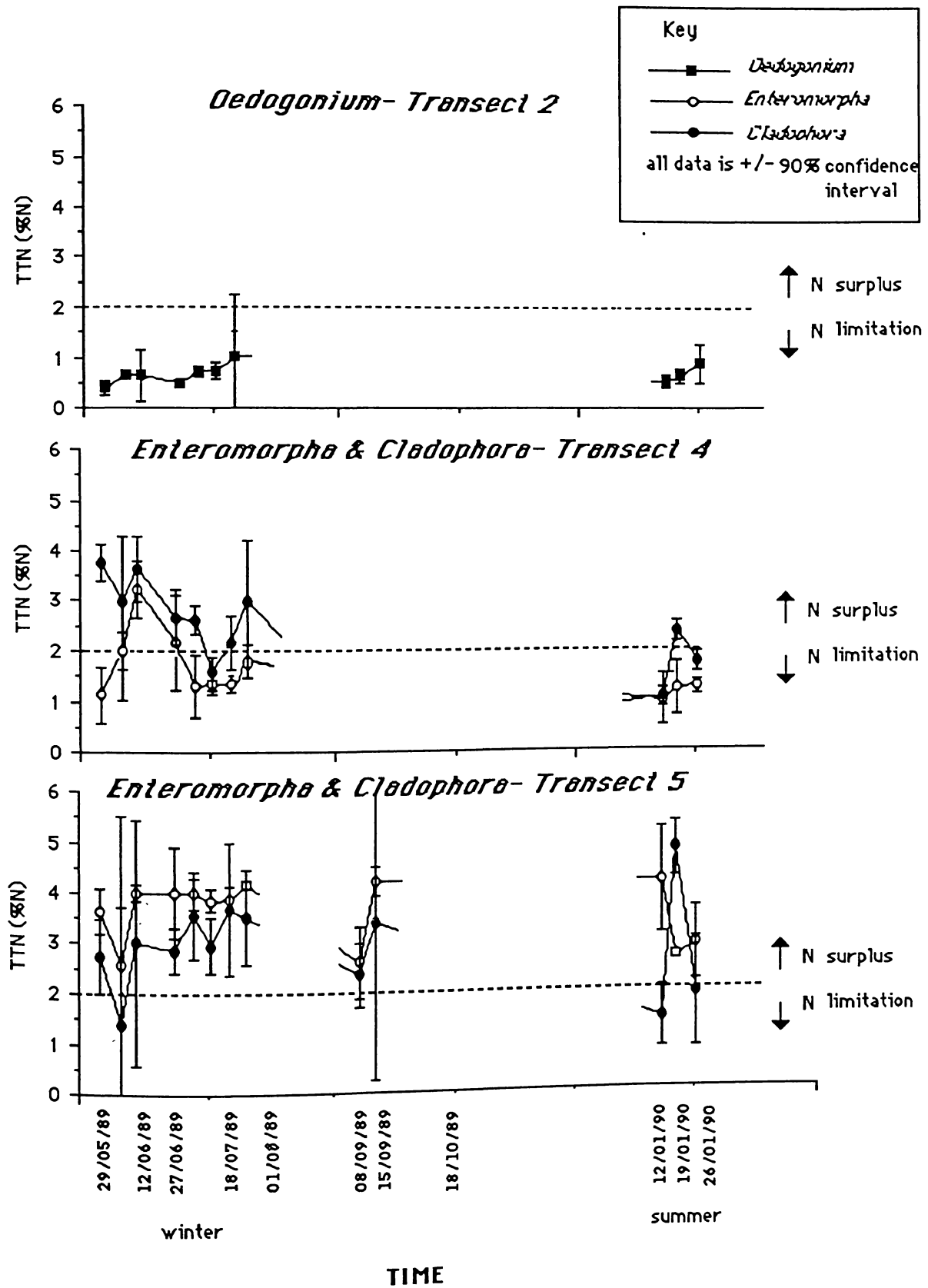


Figure 39. Total Tissue Phosphorus (%P) Monitoring Data for *Oedogonium*, *Enteromorpha* (Transect 4 &5) and *Cladophora* (Transect 4 & 5) from May, 1989 - January, 1990. Values denoting N/P limitation/surplus on these graphs are for *Cladophora glomerata* from Freeman (1983), their degree of applicability for both the *Cladophora glomerata* found in the Upper Waikato River, and *Enteromorpha* and *Oedogonium* is discussed in the text, thus the values are for reference only and do not necessarily imply N/P limitation or surplus.

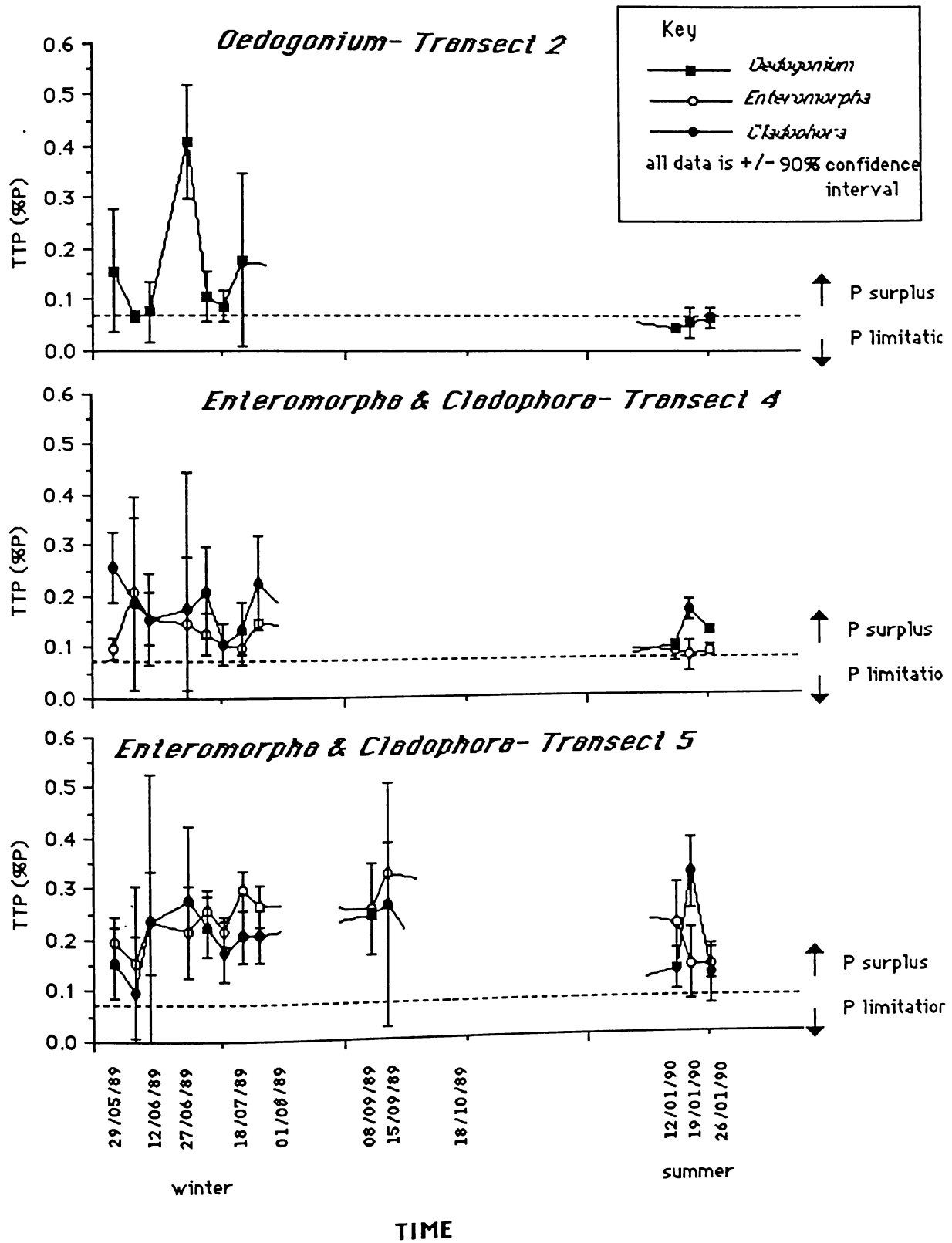


Figure 40. Alkaline Phosphatase Activity (APA) Monitoring Data for *Oedogonium*, *Enteromorpha* (Transect 4 &5) and *Cladophora* (Transect 4 & 5) from May, 1989 - January, 1990. APA units = enz. units mg⁻¹. Values denoting N/P limitation/surplus on these graphs are for *Cladophora glomerata* from Freeman (1983), their degree of applicability for both the *Cladophora glomerata* found in the Upper Waikato River, and *Enteromorpha* and *Oedogonium* is discussed in the text, thus the values are for reference only and do not necessarily imply N/P limitation or surplus. Note different scale used for *Oedogonium* samples.

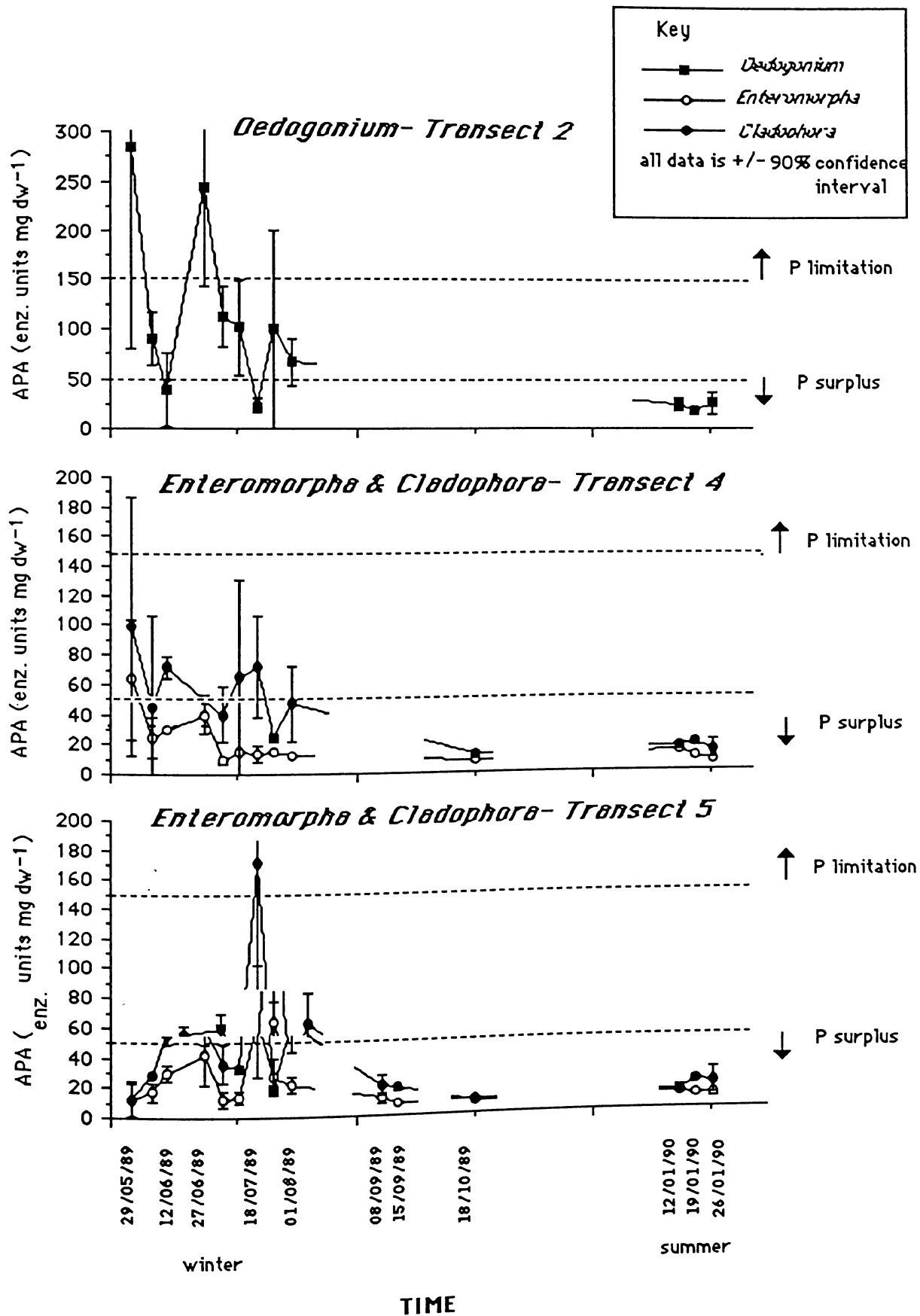
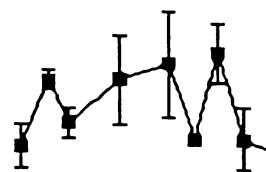




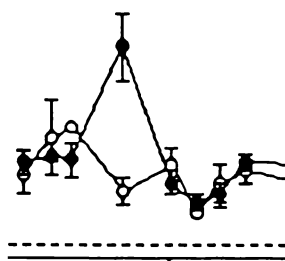
Figure 41. Ammonium Absorption Rate (AAR) Monitoring Data for *Oedogonium*, *Enteromorpha* (Transect 4 & 5) and *Cladophora* (Transect 4 & 5) from May, 1989 - January, 1990. AAR units = $(\mu\text{gN}(10\text{mg})^{-1}\text{h}^{-1})$. Values denoting N/P limitation/surplus on these graphs are for *Cladophora glomerata* from Freeman (1983), and thus do not imply N limitation or surplus for *Enteromorpha* (see discussion).

Oedogonium- Transect 2

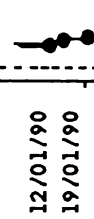
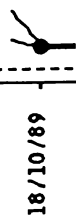
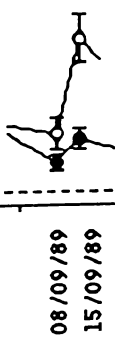
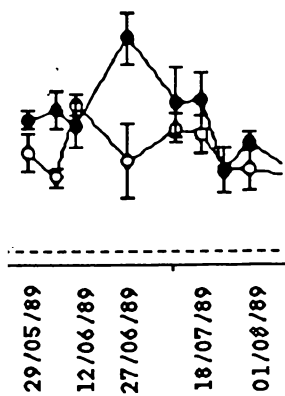
Key

- *Oedogonium*
- *Enteromorpha*
- *Cladophora*

all data is +/- 90% confidence interval

*Enteromorpha & Cladophora- Transect 4*

↑ N limitation
↓ N surplus

Enteromorpha & Cladophora- Transect 5

↑ N limitation
↓ N surplus

29/05/89

12/06/89

27/06/89

18/07/89

01/08/89

08/09/89

15/09/89

18/10/89

12/01/90

19/01/90

26/01/90

winter

summer

TIME

Figure 42. Phosphorus Uptake Rate (PUR) Monitoring Data for *Oedogonium*, *Enteromorpha* (Transect 4 &5) and *Cladophora* (Transect 4 & 5) from May, 1989 - January, 1990. PUR units = $\mu\text{gP (10mg)}^{-1}\text{h}^{-1}$. Values denoting N/P limitation/surplus on these graphs are for *Cladophora glomerata* from Freeman (1983), and thus do not imply N limitation or surplus for *Enteromorpha* (see discussion).

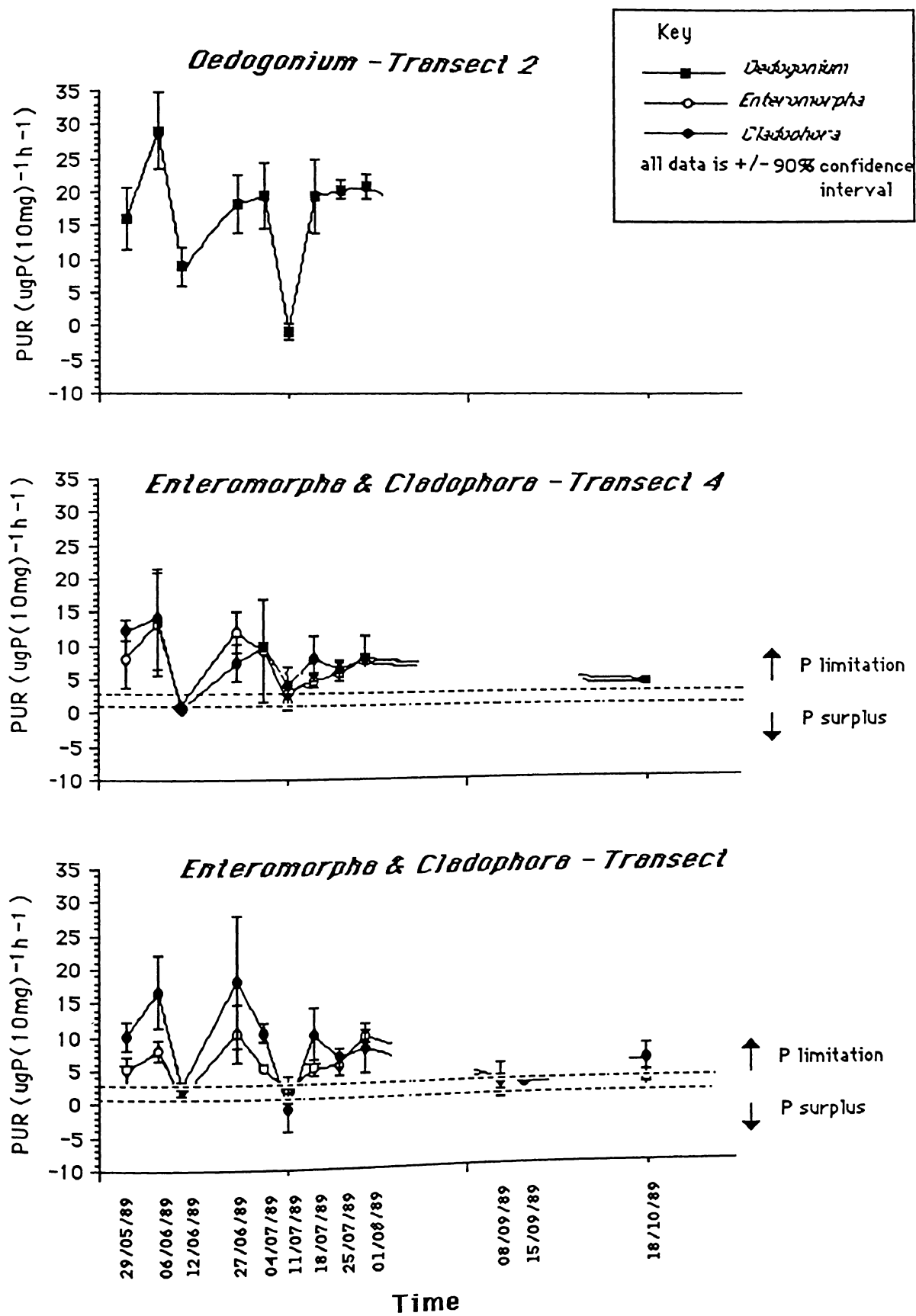
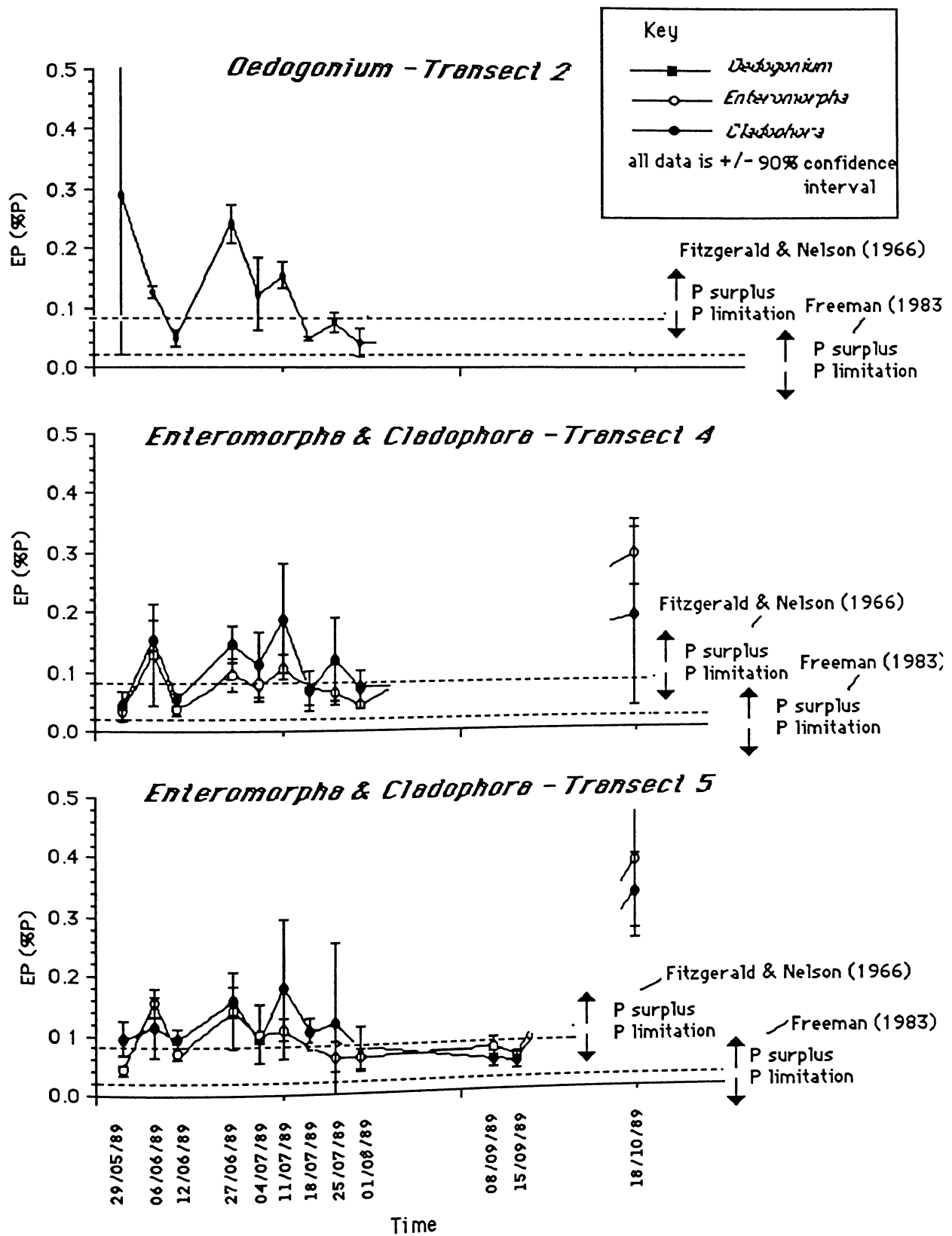


Figure 43. Extractive Phosphorus (EP) Monitoring Data for *Oedogonium*, *Enteromorpha* (Transect 4 &5) and *Cladophora* (Transect 4 & 5) from May, 1989 - January, 1990. EP units =%P. Two sets of values denoting N/P limitation/surplus on these graphs are for *Cladophora glomerata* from Freeman (1983) and from Fitzgerald and Nelson (1966) as a general level (see discussion).



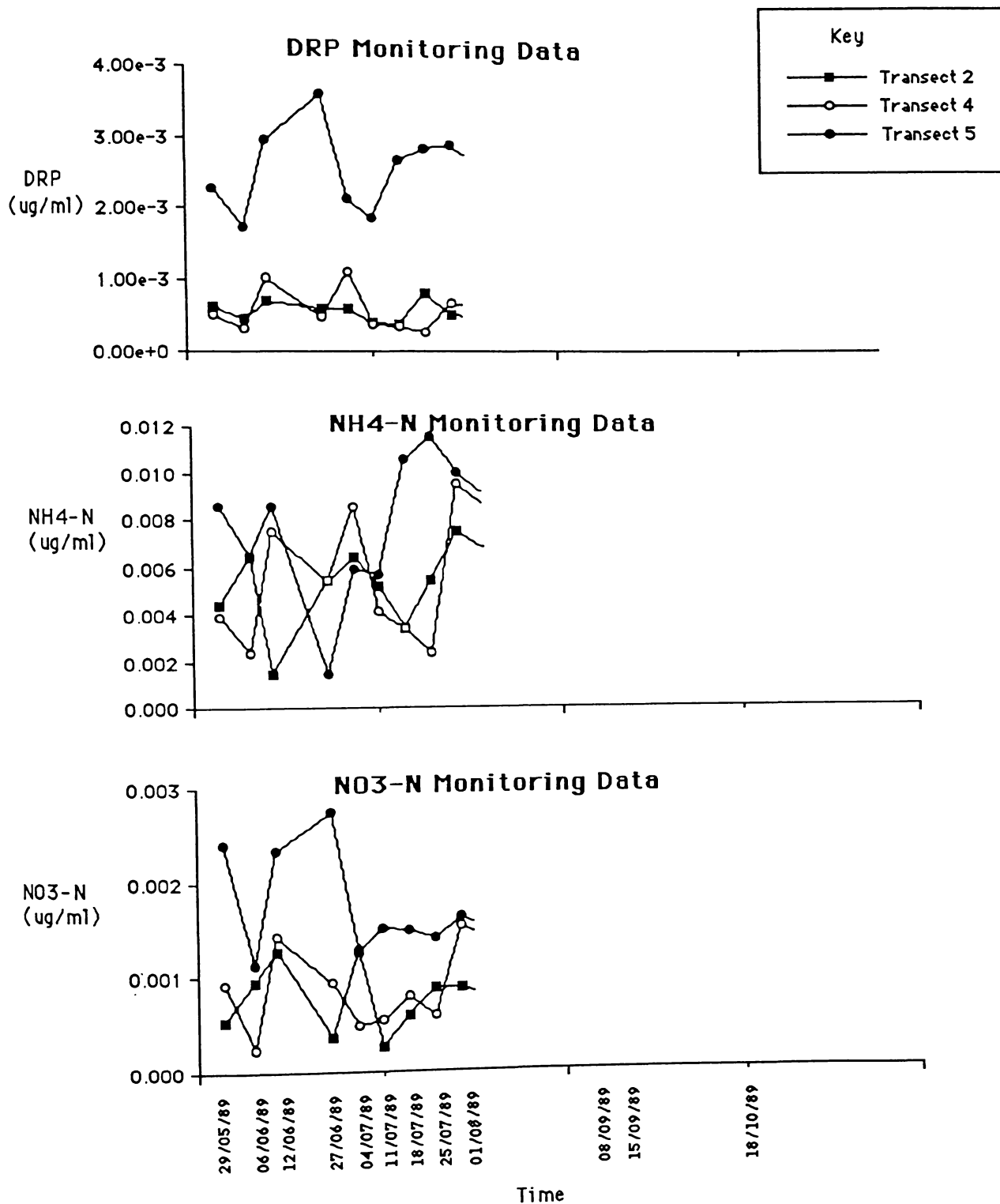


Figure 44. Water Quality Monitoring Data (DRP, NH₄-N and NO₃-N) from Algal Collection sites (near Transect 2, 4 and 5, see methods), Upper Waikato River.

3:3.2 Algae Transplant Experiment

The transplant experiment was set up on the 1/9/89 and harvested on the 8/9/89 and 15/9/89. Nutrient Availability Test results for transplant (up- and downstream) and in-situ *Cladophora* and *Enteromorpha* populations are graphically presented in Figures 45 (TTN and AAR), 46 (TTP and PUR) and 47 (EP and APA) for both harvests. Data can be referenced in Table vii (Appendix 9). Significant levels of variation occurred in NAT responses in this experiment, however, it must be noted that this technique was trialled at a 'pilot study' scale only. Despite variation, overall trends can be distinguished from the data. The physical effect of transplanting algae can be seen from comparison of downstream transplants to in-situ populations in these figures for each NAT tested. No consistent difference between naturally occurring populations of either *Enteromorpha* or *Cladophora* and downstream transplants was observed.

Preliminary investigation of growth rate data showed no consistent trends, however, a marked change in the growth form of *Cladophora* upstream transplants was observed. Plants at this upstream site became chlorotic (Plate 19) after one week, whilst plants in downstream transplants retained the vivid green colour characteristic of in-situ populations below the sewage discharge (Plate 18). Greater relative increase in total thallus length occurred in upstream transplants. At the start of the experiment plants were approximately 50-100mm long, at the end of two weeks thallus length of upstream transplants was ca. 300-400mm compared to 10-20mm for downstream transplants. However this increase in thallus length was not accompanied by comparable increases in dry weight. It is noted however, that slough-off rates have not been

taken into account. No changes in the growth form of experimental populations (up- and downstream transplants and in-situ) of *Enteromorpha* were observed.

3.3.2.1 Nutrient Availability Test (NATS) Results

Total Tissue Nitrogen (TTN) results -(Figure 45)

Upstream transplants of both *Enteromorpha* and *Cladophora* showed marked decreases in tissue nitrogen compared to both downstream and in-situ populations. *Cladophora* upstream transplants were below Freeman's (1986) critical 2%N level, indicating possible N limitation. Tissue N levels of *Enteromorpha* upstream transplants also decreased to below 2%N indicating possible N limitation. Although variable, mean values of downstream transplant and in-situ populations of both species were above 2% nitrogen.

Ammonium Absorption Rate (AAR) results- (Figure 45)

Upstream *Cladophora* transplants showed a marked increase in AAR after two weeks compared to both downstream and in-situ populations. Transplanted (up- and downstream) and in-situ populations of *Enteromorpha* showed decreases in AAR after two weeks, however, the decrease was the least for upstream transplants.

Total Tissue Phosphorus (TTP) results- (Figure 46)

Upstream transplants of *Enteromorpha* and *Cladophora* generally had lower TTP values than that observed in either downstream or in-situ populations of these species at each harvest. However, values of both species at all sites was generally above accepted critical levels of P limitation derived for *Cladophora*.

Phosphate Uptake Rates (PUR) results-(Figure 46)

Phosphate uptake rates of upstream *Cladophora* transplants increased after two weeks to above critical levels, indicating possible P limitation. Downstream *Cladophora* transplants also showed increases in PUR to above Freeman's critical $3 \text{ ugP (10mg)}^{-1} \text{ h}^{-1}$ after two weeks. No significant change in PUR of in-situ populations was observed during this experiment.

All experimental populations of *Enteromorpha* (up- and downstream transplants and in-situ populations), showed increases in PUR after two weeks.

Extractive Phosphorus (EP) results (Figure 47)

Up- and downstream and in-situ *Cladophora* populations retained EP values greater than the accepted 0.02%P critical level, indicating a lack of P limitation of *Cladophora* growth. No significant difference in EP values of all experimental *Enteromorpha* populations was observed and these also remained above 0.02% phosphorus.

Alkaline Phosphatase Activity (APA) results (Figure 47)

Alkaline phosphatase activities of both species at all sites were well within accepted P surplus conditions. This test confirmed that transplant populations of both *Enteromorpha* and *Cladophora* were alive at the time of harvest. No significant difference between up- and downstream populations of both species was observed.

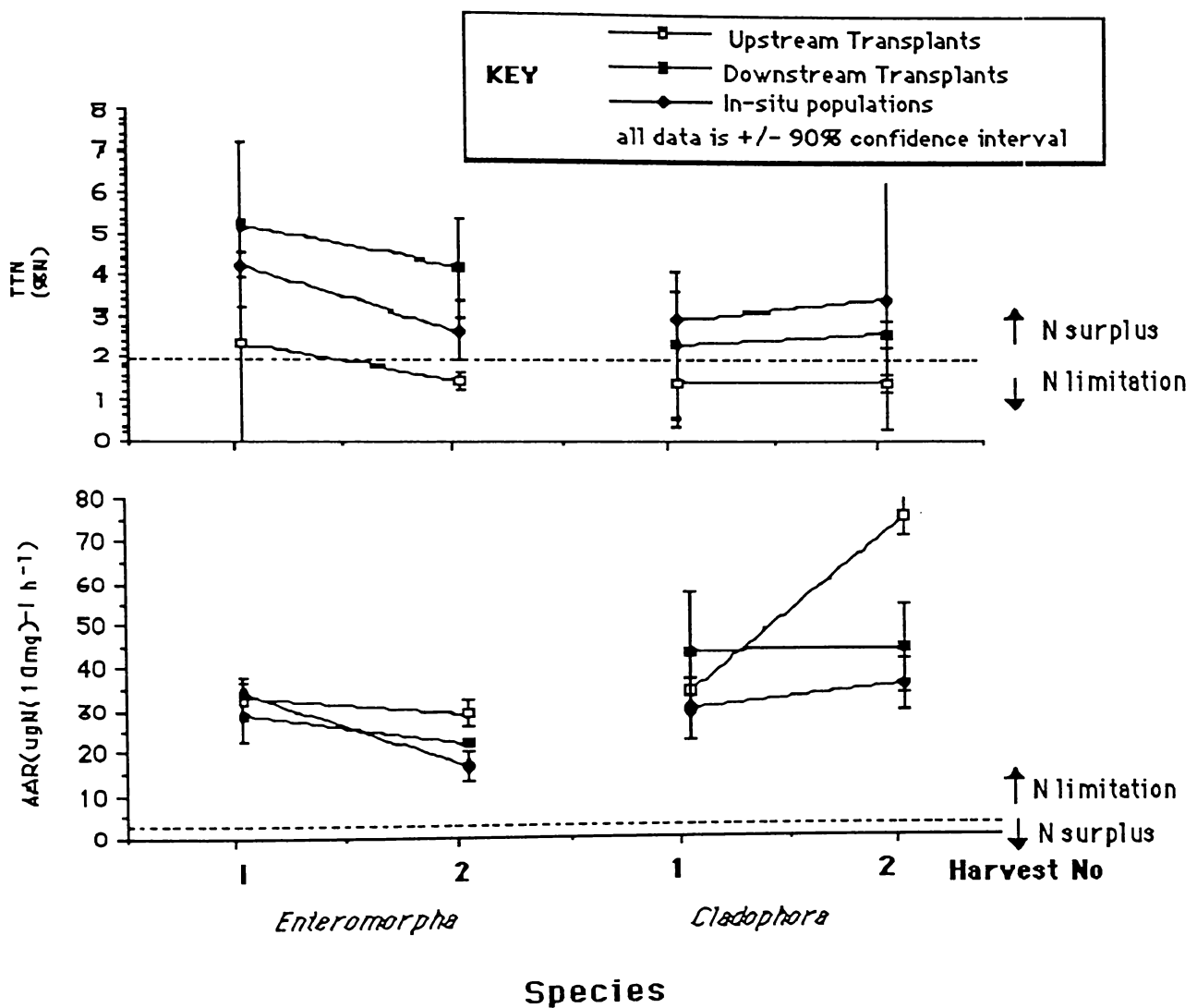


Figure 45. Total Tissue Nitrogen (TTN) and Ammonium Absorption Rate (AAR) results for *Enteromorpha* and *Cladophora* Transplants, Upper Waikato River, September, 1989. Critical levels given are for *Cladophora* from Freeman (1983) and do not necessarily imply N limitation/surplus for *Enteromorpha* (see discussion).

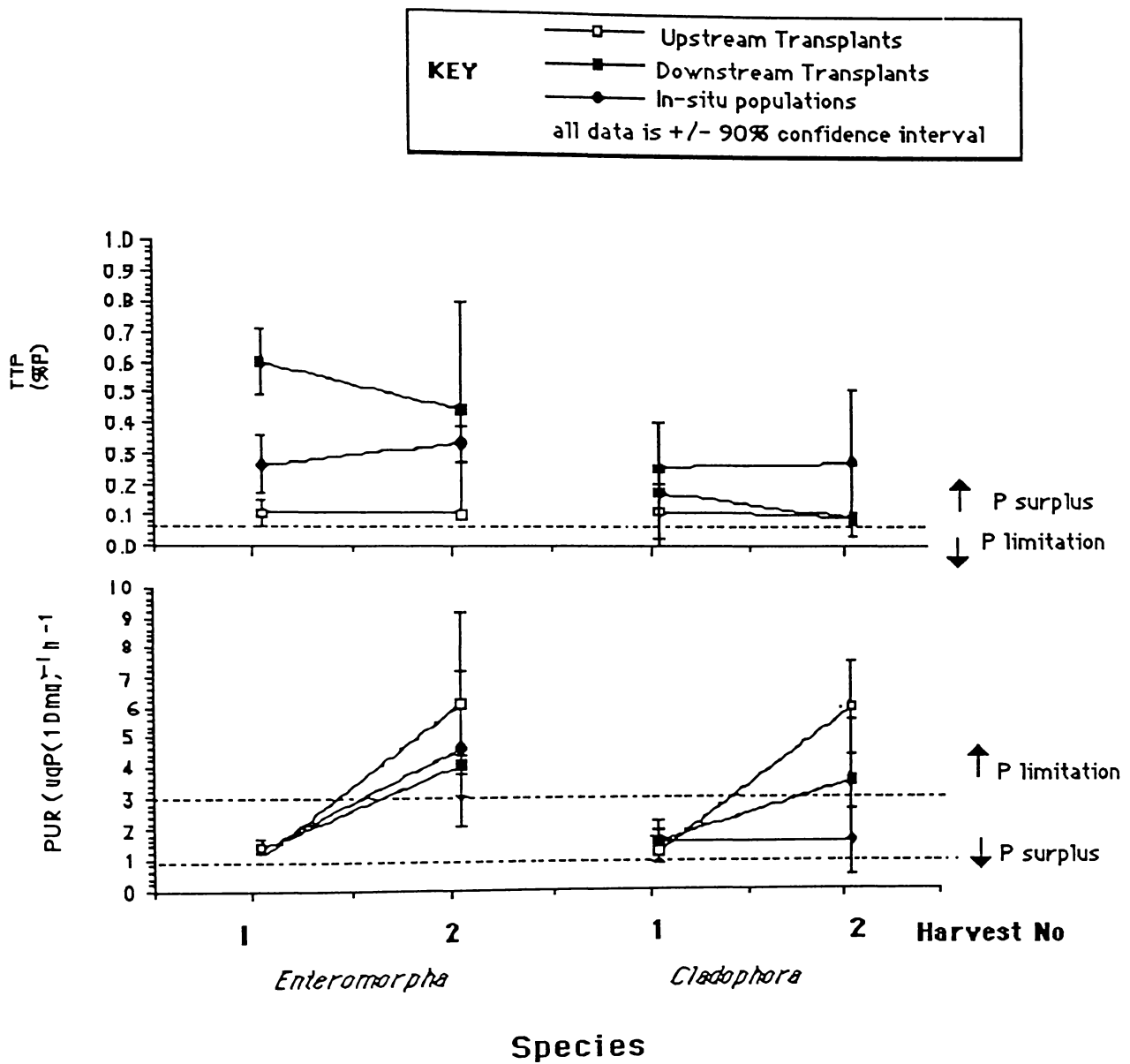


Figure 46. Total Tissue Phosphorus (TTP) and Phosphorus Uptake Rate (PUR) results for *Enteromorpha* and *Cladophora* Transplants, Upper Waikato River, September, 1989. Critical levels given are for *Cladophora* from Freeman (1983) and do not necessarily imply N limitation/surplus for *Enteromorpha* (see discussion).

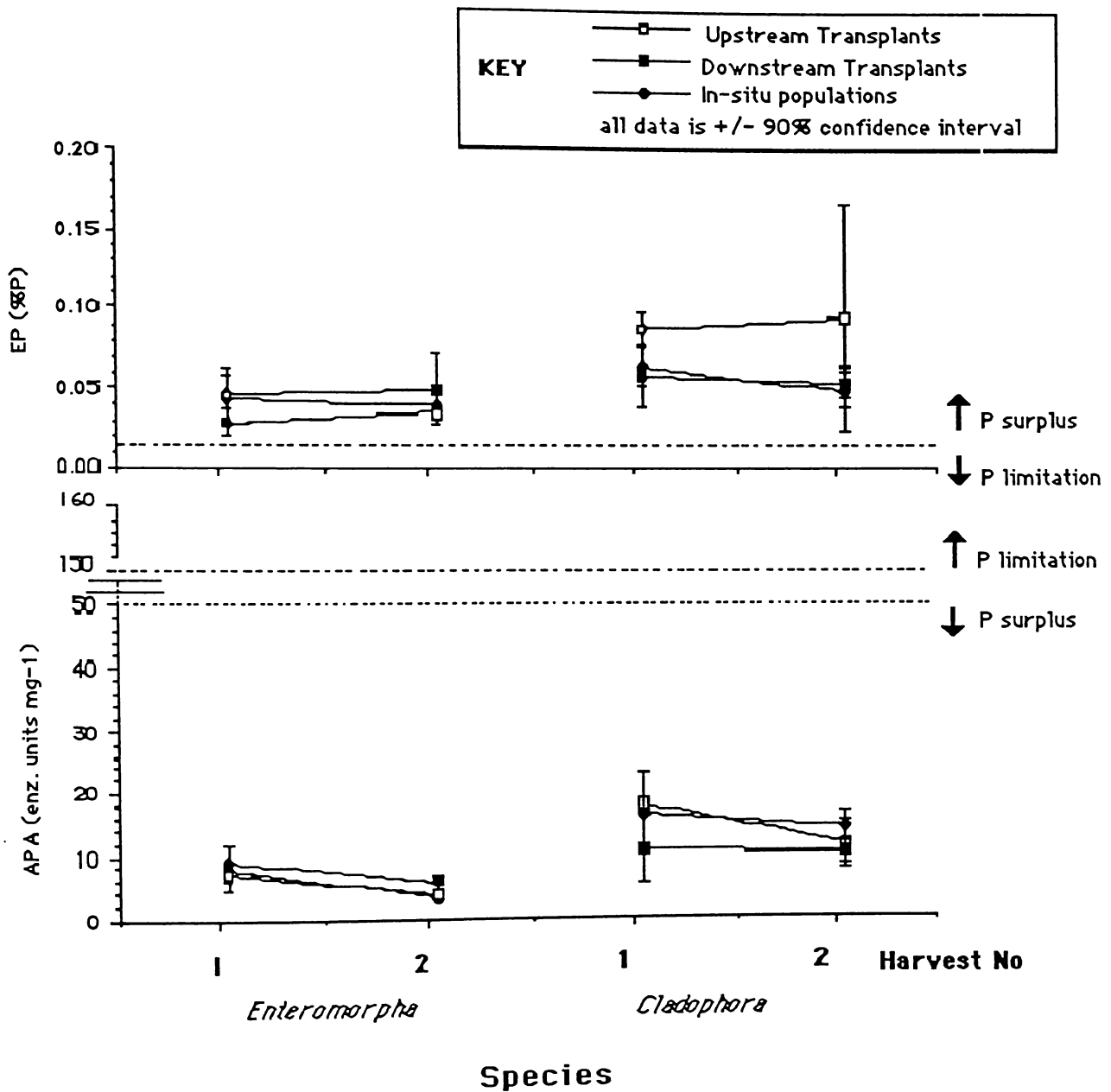


Figure 47. Extractive Phosphorus (EP) and Alkaline Phosphatase Activity (APA) results for *Enteromorpha* and *Cladophora* Transplants, Upper Waikato River, September, 1989. Critical levels given are for *Cladophora* from Freeman (1983) and do not necessarily imply N limitation/surplus for *Enteromorpha* (see discussion).

3:4 Discussion

Above the TB-PCP sewage epiphytic growths of *Oedogonium* dominated main channel periphytic algal associations (see Chapter Two). Monitoring of tissue component NATS (TTP, TTN and EP) of *Oedogonium* at Transect 2 indicated that growth of this species was limited by N and was susceptible to limitation by available P supply. Independent confirmation of sporadic P limitation was provided by APA analyses. Susceptibility to N limitation is consistent with TN-DON:TP-DOP ratios of 10.4 in Lake Taupo water (see Table 3, Chapter One), and reports by White and Payne (1977) of N limitation in winter phytoplankton populations. The presence of significant populations of *Nostoc* spp in this section of the river is also consistent with a hypothesis of N limitation as these species are known to fix N₂.

Below the TB-PCP sewage discharge there was a significant increase in N and P loads (see Chapter One). These increases caused a reduction in the TN-DON:TP-DOP ratio from approximately 10.4 to 6.2 in river water, indicating an increased likelihood of N limitation based on general N and P ratios of 10:1 - 30:1 required by most algae (Redfield, 1963 quoted from Rosemarin, 1985). Overall trends in tissue component NATS suggested that *Cladophora* and *Enteromorpha* growth downstream of the TB-PCP discharge was unlikely to be limited by levels of available P and may be only sporadically limited by nitrogen. As with *Oedogonium*, APA analyses confirmed lack of P limitation.

The lack of marked N limitation by either *Enteromorpha* or *Cladophora* seems initially surprising as average dissolved inorganic

nitrogen (DIN) concentrations were low below the sewage discharge and still consistent with an oligotrophic water classification (see Chapter One). Total dissolved inorganic nitrogen ($\text{DIN} = \text{NH}_4\text{-N} + \text{NO}_3\text{-N}$, $\text{NO}_2\text{-N}$ was negligible) concentrations averaged 14mg m^{-3} , whilst DRP averaged only 4mg m^{-3} in river water below the TB-PCP sewage discharge. Average DIN level below the TB-PCP discharge was much lower than the average of 80mg m^{-3} reported by Freeman (1986) to support prolific growths of *Cladophora glomerata* in the Manawatu River. Average DRP concentrations in the Manawatu River were similar to those below the sewage discharge in the Upper Waikato River. *Cladophora* N NATS never indicated nitrogen limitation in Freeman's study, whilst summer P limitation of *Cladophora* growth was reported. In addition the maximum biomass reported for *Cladophora* in the Manawatu River of approximately 90g m^{-2} is much lower than that found for this species below the TB-PCP discharge (maximum local standing crop on Transects 4 - 10 in the summer survey was $190 - 1,226\text{g m}^{-2}$).

In dealing with the growth of attached algae in lotic environments it is important to realise that the total available supply of nutrients to an organism is not just affected by concentration, but also by the volume of water from which supply is drawn. Whitton (1970) postulated that " the increase in the rate of water flow past *Cladophora* may permit it to make much more efficient use of mineral nutrients". This theory was based on the boundary layer studies of Whitford and Schumacher (1961). The importance of rate of water flow was shown by Zimmerman (1967, quoted from Whitton, 1970). Zimmerman studied the effect of flow and sewage on the growth of *Cladophora glomerata*. In the presence of the highest sewage concentration tested *Cladophora* grew at flow rates of 80cms^{-1} and 20cms^{-1} but not at 5cms^{-1} . At a lower concentration of sewage the alga would grow at only 80cms^{-1} , indicating the importance of water flow in determining total nutrient supply.

In a fast flowing river, like the Upper Waikato River, it^{was} postulated that observed algal growths (*Cladophora* and *Enteromorpha*) may be supported in an environment of low N and P concentrations if depletion of these nutrients in the alga's boundary layer is minimal due to constant replenishment by fast water flow. It is likely that given such conditions nutrient supply to these algae may be effectively unlimited, above a very low critical concentration in the surrounding water. If this hypothesis is correct, it follows that N and/or P concentrations above the TB-PCP discharge are below this critical concentration and therefore prolific growths of *Enteromorpha* and *Cladophora* observed downstream of the sewage discharge are not supported upstream of this inflow. Algae adapted to such an environment would require to exhibit certain adaptations such as the capacity for high nutrient uptake rates in order to sustain adequate tissue nutrient concentrations, and adaptation to high water flow conditions by having suitable attachment structures.

All three species at all monitoring sites in the Upper Waikato River exhibited high uptake rates of both ammonia and phosphate. However, these tests (PUR and AUR) rely on adding nutrient pulses that are much in excess of observed river concentrations. In addition, these tests are carried out under static conditions as opposed to the high flow environment observed in the river. Therefore, although these tests indicate that *Oedogonium*, *Enteromorpha* and *Cladophora* have the capacity for high nutrient uptake rates which is consistent with the above hypothesis, it is doubtful that such rates occur in-situ given the marked difference between test and in-situ environments.

The greater relative importance of N inputs compared to P inputs from the sewage discharge was illustrated by results from the transplant experiment. *Cladophora* and *Enteromorpha* transplants above the sewage discharge were limited by available N supply. Whilst there was adequate P

supply to support these species for at least two weeks in this river section as indicated P NAT results. The chloritic growth form (Plate 19) of *Cladophora* upstream transplants is also in line with a hypothesis of N limitation. The change in average $\text{NH}_4\text{-N}$ concentrations from approximately 4mgm^{-3} to 10mgm^{-3} may therefore represent a critical change in available N concentrations for periphytic algal growth in the Upper Waikato River, and may be a factor in the observed species changes up- and downstream of the sewage discharge. However, further work would be required to substantiate this hypothesis as it is important to note that observed changes in attached algal growth are responses to the total suite of inputs from the sewage discharge.

It is concluded from the pilot study transplant experiment that this technique warrants further development and investigation as a method for examining the relative importance of increased nutrient loads to changes in phytobenthos correlated to the inflow from point-source discharges.

3.5. Summary

Nutritional studies of *Oedogonium* upstream of the TB-PCP sewage discharge supported the hypothesis of N limitation derived from N:P ratios. *Oedogonium* consistently exhibited tissue nitrogen levels below critical values.

The same nutritional studies applied to *Enteromorpha* and *Cladophora* growths downstream of the TB-PCP sewage discharge showed that neither species was consistently limited by available N or P nutrients, and both species showed a greater susceptibility to N limitation. This was not expected from the predictions based on N:P ratios. *Enteromorpha* and *Cladophora* may be able to sustain adequate tissue N levels by maintaining high uptake rates. Both AAR and PUR rates were high for these species in the NATS monitoring programme. However, due to the high pulse concentration and the static nature of these techniques results are not likely to be indicative of in-situ conditions. These results merely indicate that the alga has the capacity for high uptake rates.

The algae transplant experiment indicated the greater relative importance of N compared to P inputs from the TB-PCP discharge for *Enteromorpha* and *Cladophora* growth. Phosphorus tissue NATS did not show P limitation of upstream transplants after one and two weeks, compared to decreases in N tissue tests below critical levels. Results from this transplant experiment support the hypothesis that N concentrations in the Upper Waikato River above the TB-PCP discharge may be too low to support significant *Enteromorpha* and *Cladophora* growths. The increase in ammoniacal nitrogen from the TB-PCP discharge

may represent a critical change for periphytic algal growth, given the physical environs of this river.

CHAPTER FOUR : Study Summary

Study Summary

The discharge of treated sewage from the Taupo Borough-Pollution Control Plant was associated with a dramatic change in downstream phytobenthos associations found in the Upper Waikato River. Displacement of epilithic moss assemblages by *Cladophora*, and domination of epiphyte habitats by *Enteromorpha* were observed downstream of this discharge. In essence, this situation was a species replacement series in response to a changing water quality gradient attributable to the inflow of treated sewage.

Aerial photographs, transect surveys and and drift diving showed that the extent of phytobenthos development through the entire length of the Upper Waikato River was primarily limited by substrate availability. Areas of gravel/pebble/sand were not immobile long enough in current flow to allow for the development of macroscopic vegetation either up- or downstream of the sewage discharge. However, there were similar stable habitats for phytobenthos development both up- and downstream of the sewage discharge. The greatest change in water quality attributable to the TB-PCP discharge was increase in both $\text{NH}_4\text{-N}$ (relative significance to all loads 61.5%) and DRP (relative significance to all loads 55.6%). However, even below the TB-PCP discharge average concentrations of $\text{NH}_4\text{-N}$ (ca. 10 mg m^{-3}) and DRP (ca. 4 mg m^{-3}) were still low and water may still be classified as oligotrophic. The ratio of TN-DON: TP-DOP is

low in water leaving Lake Taupo (10.4), the inflow from the TBB-PCP sewage discharge further decreases this ratio to 6.2, measured at Reid's Farm. A prediction of nitrogen limitation of algal growth was made from these low ratios.

Nutritional studies of *Oedogonium* upstream of the TB-PCP sewage discharge supported the hypothesis of N limitation derived from N:P ratios. *Oedogonium* consistently exhibited tissue nitrogen levels below critical values. The same nutritional studies applied to *Enteromorpha* and *Cladophora* growths downstream of the TB-PCP sewage discharge showed that neither species was consistently limited by available N or P nutrients, and both species showed a greater susceptibility to N limitation. This was not expected from the predictions based on N:P ratios. *Enteromorpha* and *Cladophora* may be able to sustain adequate tissue N levels by maintaining high uptake rates. Both A AR and PUR rates were high for these species in the NATS monitoring programme. However, due to the high pulse concentration and the static nature of these techniques, results are not likely to be indicative of in-situ conditions. These results merely indicate that the algae have the capacity for high uptake rates. A greater relative importance of N compared to P inputs from the TB-PCP discharge for *Enteromorpha* and *Cladophora* growth was concluded from the pilot algae transplant experiment. Phosphorus tissue NATS did not show P limitation of upstream transplants after one and two weeks, compared to decreases in N tissue tests below critical levels. Results from this transplant experiment support the hypothesis that N concentrations in the Upper Waikato River above the TB-PCP discharge may be too low to support significant *Enteromorpha* and *Cladophora* growths. The increase in ammoniacal nitrogen from the TB-PCP discharge may represent a

critical change for periphytic algal growth, given the physical environs of this river.

Three new techniques have been trialled in this study:

- # use of a chain transect to survey phytobenthos of a deep, swift flowing river,

- # use of $\delta^{15}\text{N}$ signatures of plants growing up- and downstream of a point-source discharge in order to ascertain the extent of effluent N nutrient utilisation by plants growing downstream of the sewage discharge,

- # algae transplant experiment as a method for examining the relative importance of increased nutrient loads to changes in phytobenthos correlated to the inflow from point-source discharges.

Preliminary application of these techniques has been useful in the Upper Waikato River to describe the biological impact of the TB-PCP discharge on benthic vegetation.

In the Upper Waikato River phytobenthos associations found below the TB-PCP sewage discharge during 1989-1990 are not consistent with the 'oligotrophic plant assemblage' described by Coffey (1979). A major habitat degradation in the Upper Waikato River has occurred and is associated with the inflow from the Taupo Borough-Pollution Control Plant. No change in Coffey's (1979) classification of 'oligotrophic plant assemblage' of the Waikato River from the Lake Taupo Control Gates to the upstream end of the point of inflow of the TB-PCP sewage discharge was concluded from this study.

PLATES

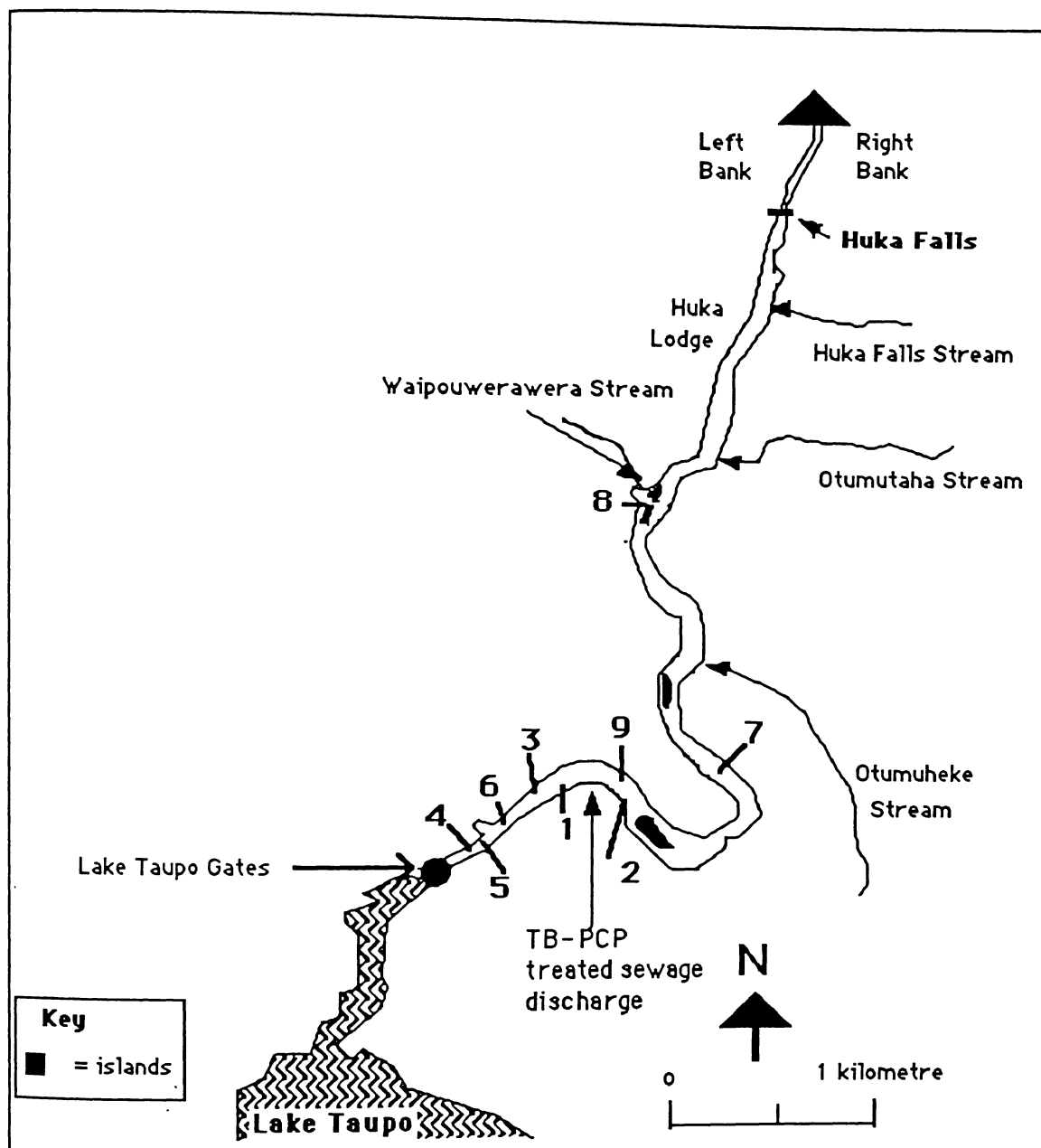


Figure 48. Locations of photographic sites in the Upper Waikato River.

Plate 3. Exposed low-mixed communities 100-200m above the TB-PCP sewage discharge, Upper Waikato River, November 1989 (site 1, Figure 48). Photo was taken facing upstream (right bank) when the river was lowered for the purposes of aerial photography, compare to Plate 4.

Plate 4. Epiphytic *Enteromorpha* growths on exposed low-mixed and *Lagarosiphon* beds approximately 300m below the sewage discharge. Photo taken facing downstream, right bank, Upper Waikato River, November 1989 (site 2, Figure 48).





Plate 5. *Lagarosiphon major* weedbeds and charophyte associations upstream of the TB-PCP sewage discharge. Photo was taken at the left bank looking upstream (site 3, Figure 48), Upper Waikato River, November 1989.



Plate 6. Streamlined development of low-mixed associations adjacent to the sediment-transport-scour main channel above the sewage discharge. Epiphytic algal growth is mainly *Oedogonium* sp. Photo was taken looking upstream, left bank (site 4, Figure 48), Upper Waikato River, November 1989.

Plate 7. Typical main channel vegetation/substrate composition near Transect 1, above the TB-PCP sewage discharge (site 5, Figure 48), Upper Waikato River, November 1989. Photo was taken facing across the river, vegetation present was dominated by mosses (*Tridontium* and *Fissidens*) with epiphytic cover of *Oedogonium/Nostoc*.

Plate 8. Close up of main channel moss assemblage illustrated in Plate 7, Upper Waikato River, November 1989. The total assemblage stands ca. 50-100mm high.

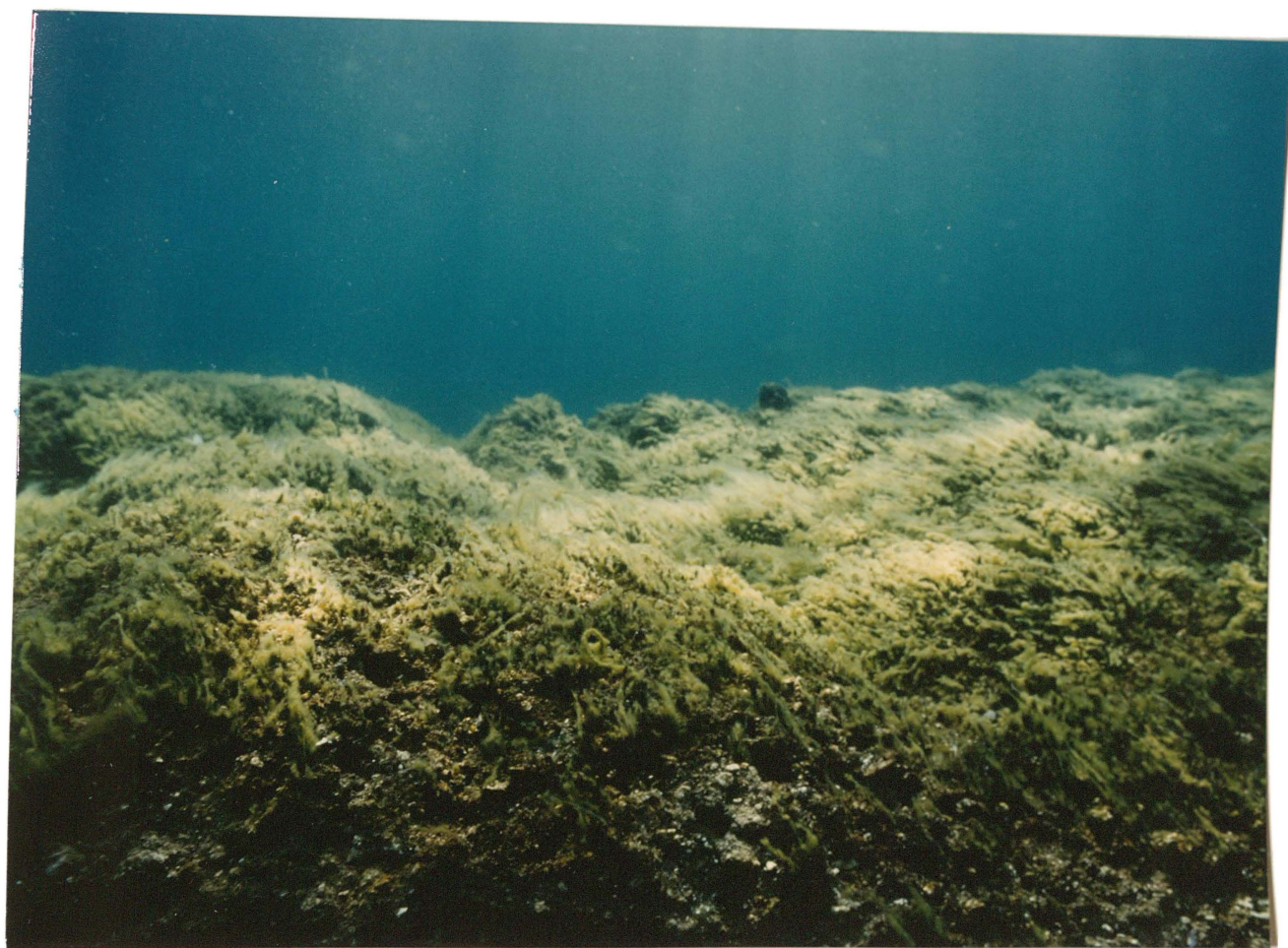
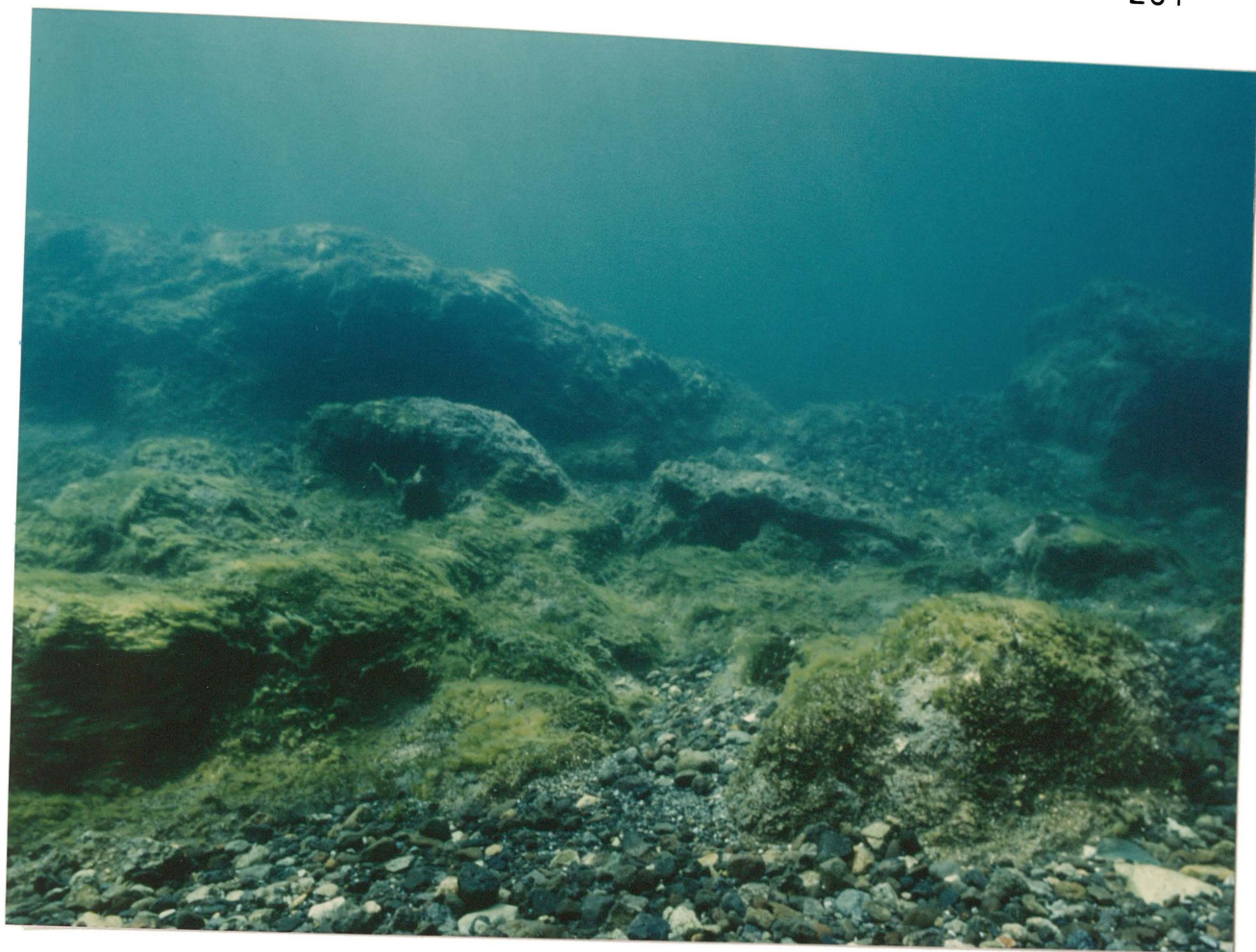
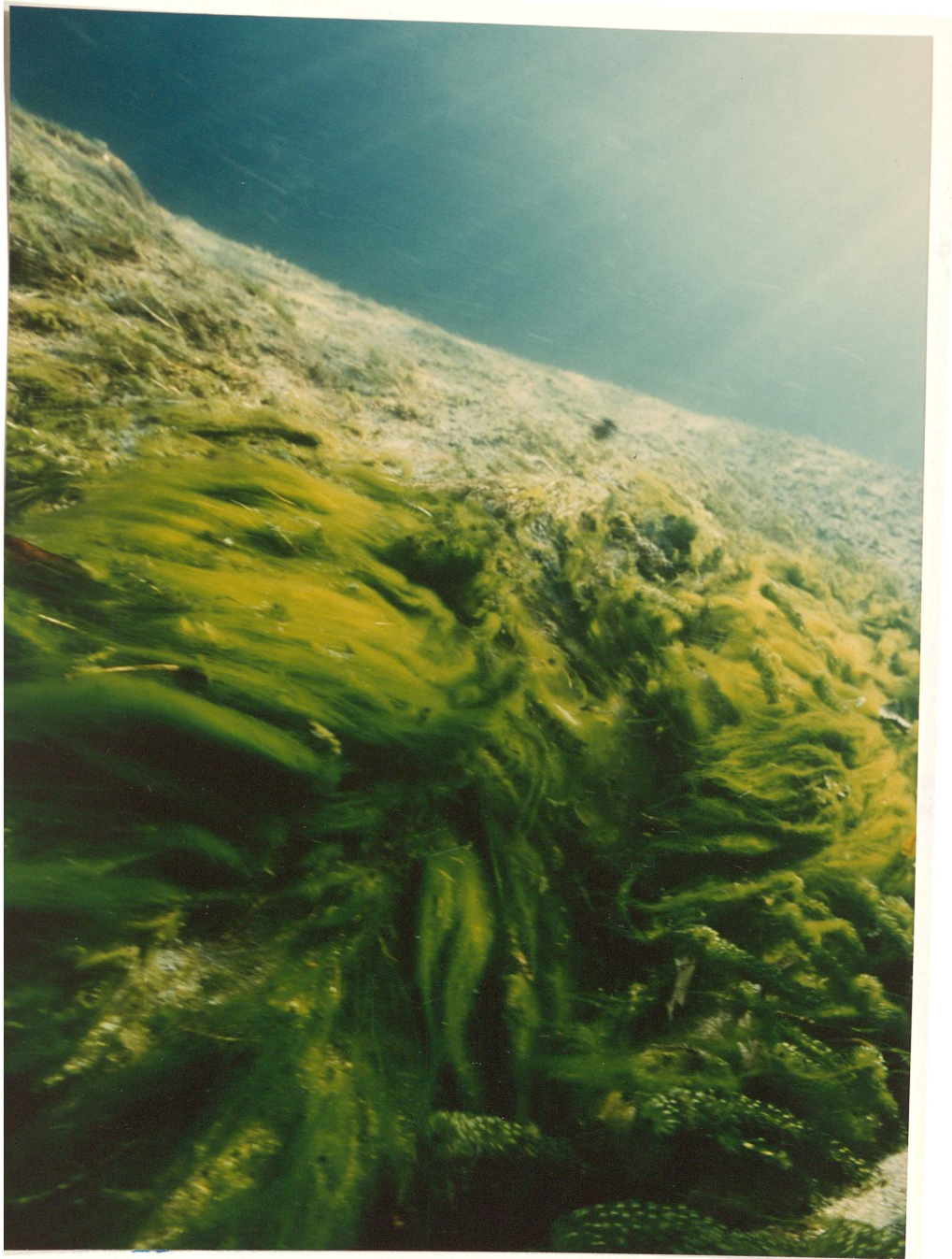




Plate 9. Typical substrate composition in the main channel near Transect 2-3, Upper Waikato River, November 1989. (see site 6, Figure 48). Moss development was only on larger rocks (rocks covered by mosses in the picture were approximately 20-30cm diameter).



J. Epiphytic *Enteromorpha* on low-mixed and *Lagarosiphon* beds
nately 300m below the TB-PCP sewage discharge (site 2, Figure
per Waikato River, March 1989.

Plate 11. Close up of epiphytic *Enteromorpha* growth on *Lagarosiphon* beds below the TB-PCP sewage discharge (site 2, Figure 48), Upper Waikato River, January 1990.

Plate 12. Main channel epiphytic growths of *Enteromorpha* on mosses (site 7, Figure 48), Upper Waikato River, November 1989. Filaments shown are approximately 0.1-1m long.

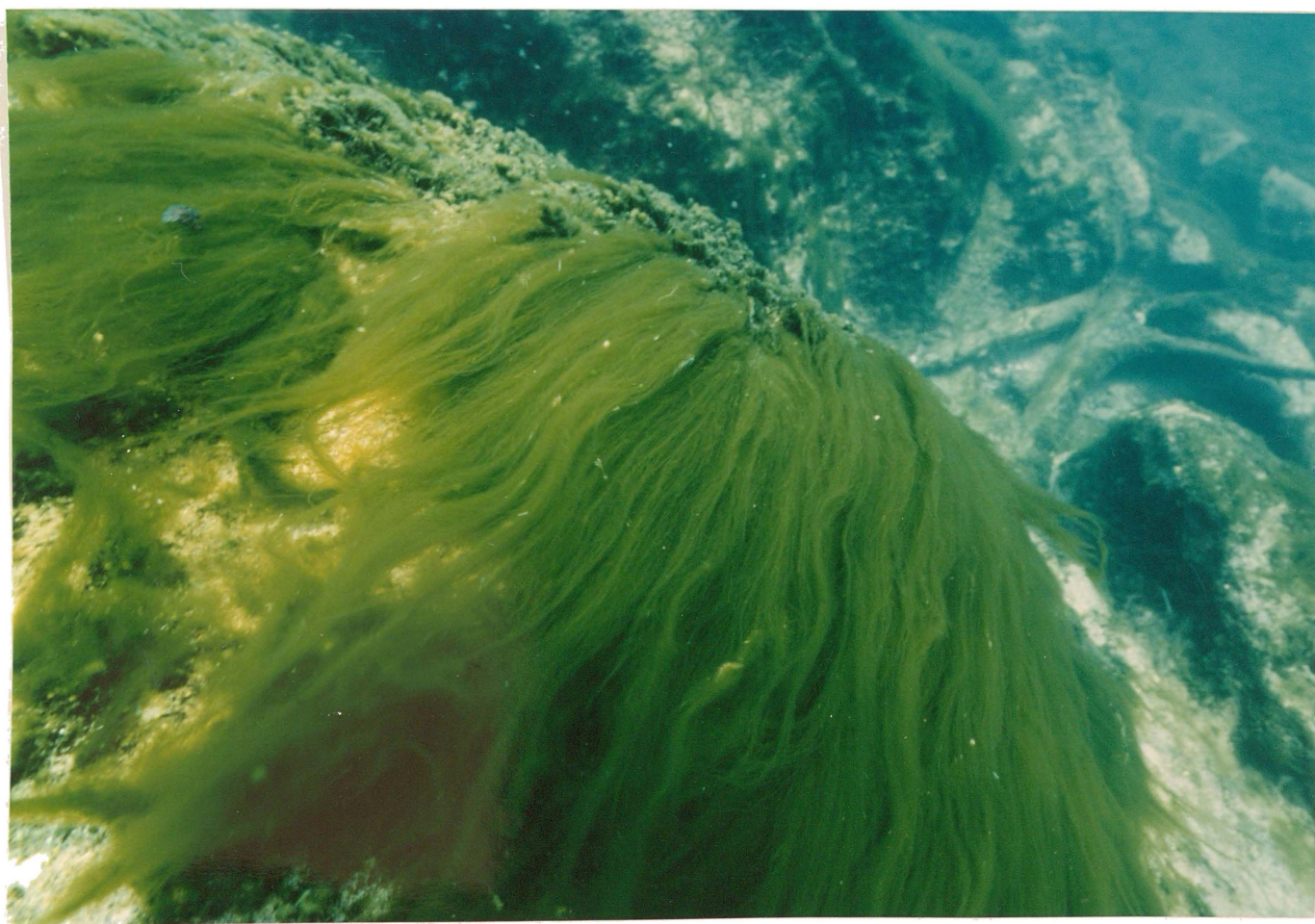




Plate 13. Epilithic growths of *Enteromorpha* (site 8, Figure 48), Upper Waikato River, November 1989. Note that 'white' appearance of some rocks is actually cover of desiccated *Enteromorpha*. Submerged rocks in this channel were dominated by epilithic *Cladophora* growth. Photo was taken when the river was lowered for the purposes of aerial photography.



Plate 14. Epilithic *Cladophora* growth below the Tb-PCP sewage discharge (site 9, Figure 48), Upper Waikato River, November 1989. Note that this would be equivalent to a cover score of 2 (6-25%) on a transect. Covers up to 6 (96-100%) were scored for *Cladophora* growths during transect surveys.

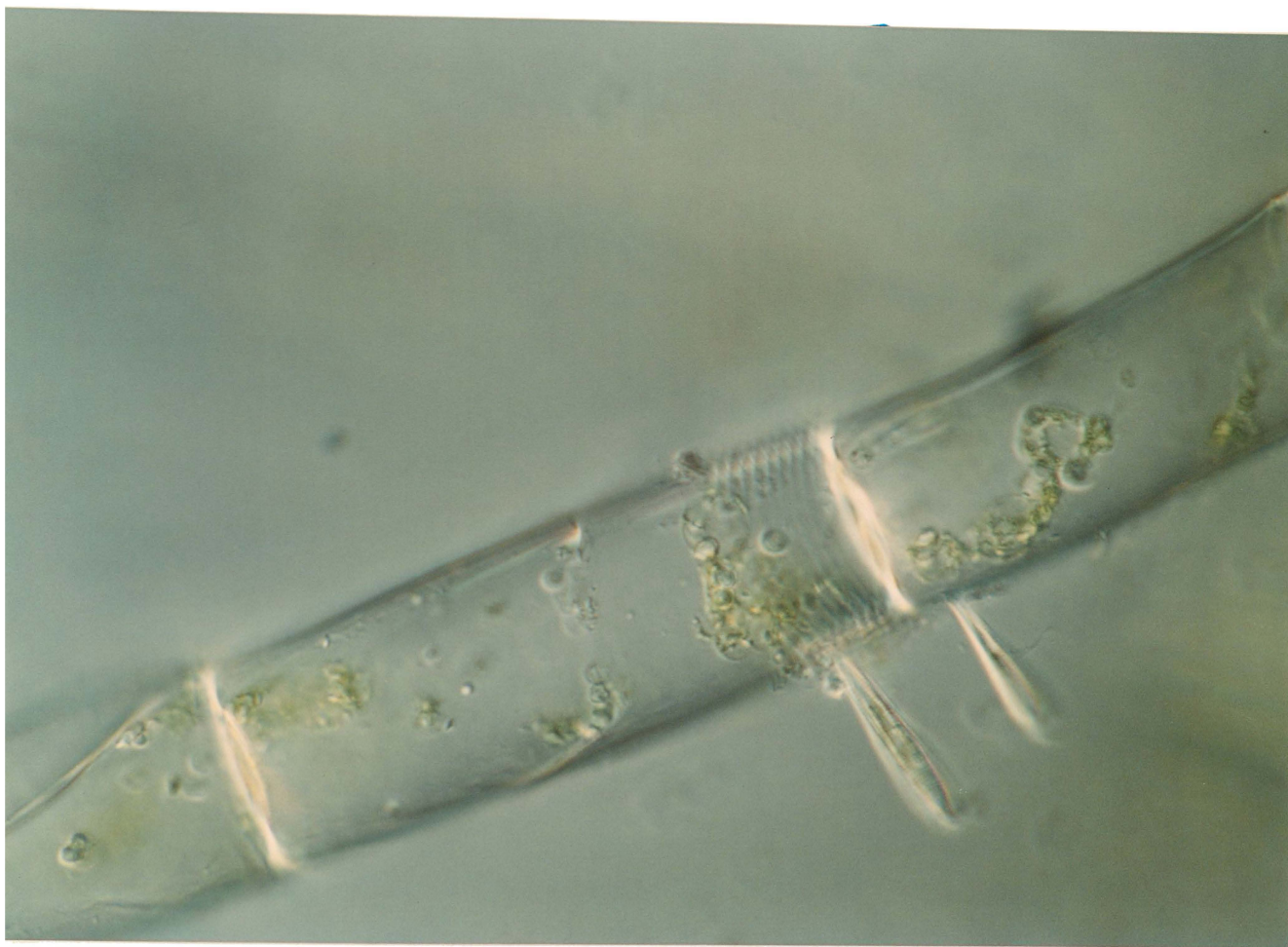


Plate 15. *Oedogonium* sp (Upper Waikato River), note the presence of cap cells. Cell in photo was 65 μ long x 31 μ wide.

Plate 16. *Enteromorpha nana* (Upper Waikato River), note the low density of epiphytes. The thicker filaments were approximately 5mm wide.

Plate 17. Close up of *Enteromorpha nana* (Upper Waikato River), showing the small cell thallus structure. Average cell dimensions were 3-8.5 μ in diameter.



Plate 18. *Cladophora glomerata*- typical growth form of plants found below the TB-PCP sewage discharge, Upper Waikato River. Cell dimensions in photo (branch cell) were: 30 μ wide x 96 μ long.

Plate 19. Chloritic growth form of *Cladophora glomerata* from upstream transplants. Cell dimensions in photo (middle cell) were 60 μ diameter x 251 μ long.



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APPENDICES

APPENDIX 1

Average water quality of major tributaries to the Upper Waikato River, from Huser (in prep). Results are presented as arithmetic means plus standard deviation and range.

Tributary	Flow m ³ /s	Temp. °C	pH	DO g/m ³	DO(sat) %	Cond. mS/m ³	Turb N.T.U	SS g/m ³	BOD ₅ g/m ³	Hdt g/m ³
Otumuheke Stream	0.1151	43.6 1.7 41-47	7.3 0.2 6.9-7.7	6.0 0.3 5.5-6.5	103.0 5.0 95-112	58.8 3.5 52-65	2.1 0.8 1.3-3.4	3.3 1.9 2-7	1.5 1.2 0.5-4.2	65.5 2.1 64-67
Otumutaha Stream	0.0217	19.0 2.6 12-25	7.0 0.4 6.2-7.5	8.1 0.7 7.0-10.1	89.8 7.5 81-114	23.2 6.0 16-40	7.2 4.3 14-17	15.8 10.6 6-43	6.3 3.5 2.2-14	32.0 2.8 30-34
Huka Falls Stream	0.0303	17.0 2.6 12-21	7.0 0.4 5.7-7.5	9.2 1.2 6.7-11.9	98.5 11.5 73-123	53.4 6.1 42-60	6.7 4.5 3.4-21	29.5 37.0 3-110	1.2 0.4 0.6-0.7	40.8 3.9 38-44
Waipouwerawera Stream	0.0355	25.7 2.3 21-29	7.8 0.3 6.8-8.2	7.7 0.6 6.7-8.8	98.7 6.7 83-111	21.5 1.4 19.3-25	2.0 1.4 0.4-0.5	10.0 8.5 2.1-27	1.0 0.7 2.6	28.5 3.5 26-31

Table 1. continued.

Tributary	NO ₃ -N*	NH ₄ -N*	TKN	DRP*	TP*
Otumuheke Stream	360	378	657	547	631
	164	88	80	62	102
	201-694	223-544	510-800	439-658	438-810
Otumutaha Stream	2510	6870	10800	192	283
	2620	7450		9780	55
	670-	1153-	1150-	97-292	132-630
	10300	22500	29200		
Huka Falls Stream	270	30	299	68	95
	53	37	212	38	37
	196-362	10-146	35-770	36-192	21-144
Waipouwerawera Stream	405	27	216	180	212
	167	24	181	30	33
	259-814	8-80	80-500	118-217	166-287

Note: * all nutrient concentrations in mg/m³.

APPENDIX 2

The following table is summary data of two diurnal water quality surveys of the Upper Waikato River from Huser (1989 in prep).

Synoptic surveys of nutrient concentrations at various sites in the Upper Waikato River. Results of two 24 hour surveys at constant river flow of 210 m³/s. Arithmetic means of 4 hourly samples (n=7) for NO₃-N, NH₄-N and DRP and of 8 hourly samples (n=3) for all other parameters. All concentrations in mg/m³.

Sites: TG= Lake Taupo Control Gates, CI= Cherry Island, RF= Reids Farm, HF= Huka Falls.

DATE	SITE	NO3-N	NH4-N	DON	PN	TN	DRP	DOP	PP	TP
19/20 JAN 1988 (12:00-12:00)	TG	2.3	4.7	58.3	23.5	91.2	0.5	1.9	2.5	5.1
	CI	4.0	16.3	43.4	27.0	91.6	3.6	1.4	3.0	7.4
	RF	3.3	9.6	40.8	22.9	77.6	3.1	1.6	2.5	7.4
	HF	3.4	9.0	51.4	24.7	90.0	3.2	1.9	2.7	7.7
Increase in % TG										
		50	90	-10	5	-1	540	0	10	50
to HF										
19/20 JAN 1988 (12:00-12:00)	TG	2.0	3.5	56.7	15.6	78.0	0.4	2.0	1.5	4.1
	CI	4.5	12.7	53.0	12.2	79.8	3.8	2.2	1.4	6.9
	RF	3.3	9.9	51.8	15.8	78.8	3.0	2.2	1.7	6.6
	HF	4.4	9.6	83.8*	23.7*	121.2*	3.2	2.3	2.2*	7.9*
Increase in % TG										
		65	200	-10	1	2	650	10	10	60
to HF										

Note: * = mean values at Huka Falls affected by one outlier (extreme value for DON in sample No. 881637; 19/7 22:00). Hence the difference between TG and RF was used for the calculation of percentage change.

APPENDIX 3

Transect data from the survey of Transect 1-10 March, 1989 (summer resurvey of Transects 2, 4 and 5 August, 1989 (winter).

Records relate to a 1m x 1m quadrat at 2m intervals along a chain transect line. Unless otherwise noted, only visually apparent vegetation types are scored. Herbarium samples were deposited with the Regional Council, PO Box 4010, Hamilton East.

Key

<u>Cover Class</u>	<u>Percentage Cover</u>
1	1-5%
2	6-25%
3	26-50%
4	51-75%
5	76-95%
6	96-100%.

Substrate codes

r = rock
 b = boulders
 g = gravel
 p = pebbles
 m = mud.

Summer Survey of Transects 1-10, March, 1989.

Transect Number 1

<u>Distance along transect (m)</u>	<u>Quadrat Number</u>	<u>Water Depth (m)</u>	<u>Substrate code</u>	<u>Total Vegetation Cover Class</u>	<u>Communities and Species</u>	<u>Mean Height (cm)</u>	<u>Individual Cover Class</u>
-0.6		-	r/s	1	<i>Lilaeopsis ruthiana</i> <i>Nostoc spp.</i> <i>Oedogonium sp.</i>	1 1 1	1 1 1
-0.4		-	r/s	3	<i>Tridontium tasmanicum</i> <i>Nostoc spp.</i> <i>Oedogonium sp.</i>	1 1 1	3 1 1
-0.2		-	r/s	3	<i>Tridontium tasmanicum</i>	1	3
00	01	0	m	2	<i>Tridontium tasmanicum</i> <i>Nostoc spp.</i>	1 1	1 1
02	02	0.6	r/s	6	<i>Tridontium tasmanicum</i> <i>Fissidens rigidulus</i> <i>Nitella hyalina</i> <i>Nostoc spp.</i> <i>Oedogonium sp.</i> Caddis flies	1 1 2 1 4	1 5 1 1 1
04	03	2.0	r/s	6	<i>Potamogeton pectinatus</i> <i>Tridontium tasmanicum</i> <i>Fissidens rigidulus</i> <i>Nitella hyalina</i> <i>Nostoc spp.</i> <i>Oedogonium sp.</i> Caddis flies	1 1 1 2 1 4	1 4 1 1 1 1
06	04	3.6	b/s	5	<i>Tridontium tasmanicum</i> <i>Fissidens rigidulus</i> <i>Nostoc spp.</i> <i>Oedogonium sp.</i> Caddis flies	5 5 1 3	3 2 1 1
08	05	5.0	g	-			
10	06	4.2	r/s	5	<i>Tridontium tasmanicum</i> <i>Fissidens rigidulus</i> <i>Nitella hyalina</i> <i>Nostoc spp.</i> <i>Oedogonium sp.</i>	4 3 8 1 12	4 1 1 1 2
12	07	3.8	r/s	5	<i>Tridontium tasmanicum</i> <i>Fissidens rigidulus</i> <i>Nitella hyalina</i> <i>Nostoc spp.</i> <i>Oedogonium sp.</i>	4 3 8 1 12	4 1 1 1 2
14	08	3.0	r/s	6	<i>Potamogeton pectinatus</i> <i>Tridontium tasmanicum</i> <i>Fissidens rigidulus</i> <i>Eurhynchium austrinum?</i> <i>Nitella hyalina</i> <i>Nostoc spp.</i> <i>Oedogonium sp.</i> <i>Enteromorpha nana</i> Caddis flies	10 4 3 4 6 1 8 6	1 2 2 1 1 2 1 1
16	09	3.1	r/s	6	<i>Potamogeton crispus</i> <i>Tridontium tasmanicum</i> <i>Fissidens rigidulus</i>	5 5 5	1 4 1

					<i>Nitella hyalina</i>	4	1
					<i>Nostoc spp.</i>	1	1
					<i>Oedogonium sp.</i>	15	1
					<i>Tolypothrix distorta</i>	-	1
18	10	3.1	r/s	6	<i>Potamogeton pectinatus</i>	6	1
					<i>Tridontium tasmanicum</i>	5	4
					<i>Fissidens rigidulus</i>	5	1
					<i>Nitella leptostachys</i>	7	1
					<i>Nostoc spp.</i>	1	1
					<i>Oedogonium sp</i>	15	1
					<i>Tolypothrix distorta</i>	-	1
20	11	3.2	r/s	5	<i>Potamogeton pectinatus</i>	10	1
					<i>Potamogeton crispus</i>	5	2
					<i>Tridontium tasmanicum</i>	6	4
					<i>Fissidens rigidulus</i>	3	1
					<i>Nitella leptostachys</i>	5	1
					<i>Nitella hyalina</i>	3	1
					<i>Nostoc spp.</i>	1	2
					<i>Oedogonium sp</i>	10	1
22	12	3.3	r/s	5	<i>Myriophyllum triphyllum</i>	15	2
					<i>Potamogeton pectinatus</i>	8	1
					<i>Potamogeton crispus</i>	6	2
					<i>Tridontium tasmanicum</i>	5	2
					<i>Fissidens rigidulus</i>	5	2
					<i>Nitella leptostachys</i>	4	1
					<i>Nitella hyalina</i>	2	1
					<i>Nostoc spp.</i>	1	2
					<i>Oedogonium sp</i>	8	2
24	13	3.3	r/s	5	<i>Myriophyllum triphyllum</i>	15	2
					<i>Potamogeton pectinatus</i>	8	1
					<i>Potamogeton crispus</i>	6	2
					<i>Tridontium tasmanicum</i>	5	2
					<i>Fissidens rigidulus</i>	5	2
					<i>Nitella leptostachys</i>	4	1
					<i>Nitella hyalina</i>	2	1
					<i>Nostoc spp.</i>	1	2
					<i>Oedogonium sp</i>	8	2
26	14	3.3	r/s	5	<i>Myriophyllum triphyllum</i>	15	2
					<i>Potamogeton pectinatus</i>	8	1
					<i>Potamogeton crispus</i>	6	2
					<i>Eurhynchium austrinum?</i>	3	1
					<i>Tridontium tasmanicum</i>	5	2
					<i>Fissidens rigidulus</i>	5	2
					<i>Nitella leptostachys</i>	4	1
					<i>Nitella hyalina</i>	2	1
					<i>Nostoc spp.</i>	1	2
					<i>Oedogonium sp</i>	8	2
28	15	3.3	r/s	5	<i>Myriophyllum triphyllum</i>	15	2
					<i>Potamogeton pectinatus</i>	8	1
					<i>Potamogeton crispus</i>	6	2
					<i>Tridontium tasmanicum</i>	5	2
					<i>Fissidens rigidulus</i>	5	2
					<i>Nitella leptostachys</i>	4	1
					<i>Nitella hyalina</i>	2	1
					<i>Nostoc spp.</i>	1	2
					<i>Oedogonium sp</i>	8	2
30	16	3.3	r/s	5	<i>Myriophyllum triphyllum</i>	15	2
					<i>Potamogeton pectinatus</i>	8	1
					<i>Potamogeton crispus</i>	6	2
					<i>Tridontium tasmanicum</i>	5	2
					<i>Fissidens rigidulus</i>	5	2
					<i>Nitella leptostachys</i>	4	1
					<i>Nitella hyalina</i>	2	1
					<i>Nostoc spp.</i>	1	2
					<i>Oedogonium sp</i>	8	2

32	17	3.3	s	-	Caddis flies		
34	18	3.0	r/s	6	<i>Tridontium tasmanicum</i>	5	5
					<i>Nitella hyalina</i>	2	1
					<i>Nostoc spp.</i>	1	1
					<i>Oedogonium sp</i>	8	1
36	19	3.0	r	4	<i>Tridontium tasmanicum</i>	5	4
					<i>Fissidens rigidulus</i>	5	2
					<i>Nitella leptostachys</i>	4	1
					<i>Nitella hyalina</i>	2	1
					<i>Nostoc spp.</i>	1	1
					<i>Oedogonium sp</i>	8	1
38	20	3.0	r	6	<i>Ranunculus fluitans</i>	22	1
					<i>Tridontium tasmanicum</i>	4	4
					<i>Fissidens rigidulus</i>	5	3
					<i>Nitella hyalina</i>	6	1
					<i>Nostoc spp.</i>	1	1
					<i>Oedogonium sp</i>	8	1
40	21	1.7	r	4	<i>Tridontium tasmanicum</i>	4	4
					<i>Fissidens rigidulus</i>	5	1
					<i>Nitella hyalina</i>	6	1
					<i>Nostoc spp.</i>	1	1
					<i>Oedogonium sp</i>	8	1
42	22	0.0	r	4	<i>Tridontium tasmanicum</i>	5	4
					<i>Fissidens rigidulus</i>	5	1
					<i>Nitella hyalina</i>	6	1
					<i>Nostoc spp.</i>	1	1
					<i>Oedogonium sp</i>	8	1

Transect Number 2

00	01	0.0	r	3	<i>Fissidens rigidulus</i>	4	3
					<i>Oedogonium sp.</i>	4	1
02	02	2.5	r	3	<i>Fissidens rigidulus</i>	4	3
					<i>Oedogonium sp.</i>	4	1
04	03	4.0	r	6	<i>Fissidens rigidulus</i>	4	6
					<i>Oedogonium sp.</i>	4	2
06	04	5.0	r	6	<i>Fissidens rigidulus</i>	4	6
					<i>Oedogonium sp.</i>	4	2
08	05	6.8	r/p/s	3	<i>Fissidens rigidulus</i>	4	3
					<i>Oedogonium sp.</i>	4	1
10	06	6.5	p/s	1	<i>Fissidens rigidulus</i>	4	1
					<i>Oedogonium sp.</i>	4	1
12	07	6.3	s/p	1	<i>Fissidens rigidulus</i>	4	1
					<i>Oedogonium sp.</i>	4	1
14	08	6.0	s/p	1	<i>Fissidens rigidulus</i>	4	1
					<i>Oedogonium sp.</i>	4	1
16	09	6.0	s/p	1	<i>Fissidens rigidulus</i>	4	1
					<i>Oedogonium sp.</i>	4	1
18	10	6.0	s/p	1	<i>Fissidens rigidulus</i>	4	1
					<i>Oedogonium sp.</i>	4	1
20	11	6.8	s/p	1	<i>Fissidens rigidulus</i>	4	1
					<i>Oedogonium sp.</i>	4	1
22	12	6.8	s/p	1	<i>Fissidens rigidulus</i>	4	1

					<i>Oedogonium sp.</i>	4	1
24	13	6.7	s/p	1	<i>Fissidens rigidulus</i>	4	1
					<i>Oedogonium sp.</i>	4	1
26	14	6.5	s/p	1	<i>Fissidens rigidulus</i>	4	1
					<i>Oedogonium sp.</i>	4	1
28	15	6.0	s/p	1	<i>Fissidens rigidulus</i>	4	1
					<i>Oedogonium sp.</i>	4	1
30	16	6.0	s/p	1	<i>Fissidens rigidulus</i>	4	1
					<i>Oedogonium sp.</i>	4	1
32	17	5.2	s/p	1	<i>Fissidens rigidulus</i>	4	1
					<i>Oedogonium sp.</i>	4	1
34	18	5.3	s/p	1	<i>Fissidens rigidulus</i>	4	1
					<i>Oedogonium sp.</i>	4	1
36	19	5.3	s/p	1	<i>Fissidens rigidulus</i>	4	1
					<i>Oedogonium sp.</i>	4	1
38	20	5.3	p/s	1	<i>Oedogonium sp.</i>	2	1
					<i>Spirogyra sp.</i>	2	1
40	21	4.0	r	6	<i>Fissidens rigidulus</i>	5	5
					<i>Nitella hyalina</i>	8	1
					<i>Chara globularis</i>	8	1
					<i>Nostoc spp.</i>	1	1
					<i>Oedogonium sp.</i>	5	3
42	22	2.5	r	6	<i>Fissidens rigidulus</i>	5	5
					<i>Nitella hyalina</i>	8	1
					<i>Chara globularis</i>	8	1
					<i>Nostoc spp.</i>	1	1
					<i>Oedogonium sp.</i>	5	3
44	23	0.6	r	6	<i>Fissidens rigidulus</i>	5	5
					<i>Tridontium tasmanicum</i>	4	1
					<i>Nitella hyalina</i>	8	1
					<i>Chara globularis</i>	8	1
					<i>Nostoc spp.</i>	1	1
					<i>Oedogonium sp.</i>	5	3
					<i>Tolypothrix distorta</i>	-	-
					<i>Tolypothrix tenuis</i>	-	-

Transect Number 3

-04	-	s/m	6	<i>Myriophyllum triphyllum</i>	20	1	
				<i>Potamogeton crispus</i>	3	1	
				<i>Potamogeton cheesmanii</i>	20	1	
				<i>Glossostigma elatinoides</i>	1	4	
				<i>Lilaeopsis ruthiana</i>	2	1	
				<i>Isoetes kirkii</i>	6	1	
				<i>Pilularia novae-zealandiae</i>	2	1	
				<i>Myriophyllum pedunculatum</i>	5	1	
				<i>Eleocharis pusilla</i>	1	1	
-02	-	s/m	6	<i>Myriophyllum triphyllum</i>	20	1	
				<i>Potamogeton crispus</i>	3	1	
				<i>Potamogeton cheesmanii</i>	20	1	
				<i>Glossostigma elatinoides</i>	1	4	
				<i>Lilaeopsis ruthiana</i>	2	1	
				<i>Isoetes kirkii</i>	6	1	
				<i>Pilularia novae-zealandiae</i>	2	1	
				<i>Myriophyllum pedunculatum</i>	5	1	
				<i>Eleocharis pusilla</i>	1	1	
00	01	0.0	s/m	6	<i>Myriophyllum triphyllum</i>	20	6

02	02	0.8	s/m	6	<i>Lagarosiphon major</i>	20	3
					<i>Myriophyllum triphyllum</i>	20	3
04	03	1.5	s/m	6	<i>Lagarosiphon major</i>	50	6
06	04	2.5	s/m	6	<i>Lagarosiphon major</i>	50	6
08	05	3.0	s/m	6	<i>Lagarosiphon major</i>	50	6
10	06	3.5	s/g	4	<i>Lagarosiphon major</i>	100	3
					<i>Oedogonium sp.</i>	6	1
					<i>Tolypothrix limbata</i>	2	1
12	07	3.0	s/g	2	<i>Nitella hyalina</i>	8	1
					<i>Nitella leptostachys</i>	8	1
14	08	3.5	s/g	2	<i>Nitella hyalina</i>	8	1
					<i>Nitella leptostachys</i>	8	1
16	09	3.5	s/g	2	<i>Nitella hyalina</i>	8	1
					<i>Nitella leptostachys</i>	8	1
18	10	3.2	s/g	2	<i>Nitella hyalina</i>	8	1
					<i>Nitella leptostachys</i>	8	1
20	11	3.0	g/s	-			
22	12	3.0	g/s	-			
24	13	3.0	g/s	-			
26	14	3.0	g/s	-			
28	15	3.0	g/s	-			
30	16	3.3	g/s	-			
32	17	3.3	g/s	-			
34	18	3.3	g/s	-			
36	19	3.5	g/s	-			
38	20	3.5	g/s	-			
40	21	3.5	g/s	-			
42	22	3.5	g/s	-			
44	23	3.5	g/s	-			
46	24	3.5	g/s	-			
48	25	3.5	g/s	-			
50	26	3.5	g/s	-			
52	27	3.3	g/s	-			
54	28	3.2	g/s	-			
56	29	3.0	g/s	1	<i>Tridontium tasmanicum</i>	2	1
					<i>Nostoc spp.</i>	1	1
					<i>Oedogonium sp.</i>	1	1
58	30	3.0	g/s	1	<i>Tridontium tasmanicum</i>	2	1
					<i>Nostoc spp.</i>	1	1
					<i>Oedogonium sp.</i>	1	1
60	31	2.8	g/s	1	<i>Oedogonium sp.</i>	1	1
					<i>Spirogyra sp.</i>	1	1

62	32	2.4	g/s	1	<i>Oedogonium sp.</i>	1	1
					<i>Spirogyra sp.</i>	1	1
64	32	2.0	g/s	1	<i>Oedogonium sp.</i>	1	1
					<i>Spirogyra sp.</i>	1	1
66	33	1.7	g/s	-			
68	34	0.0	g/s	-			

Transect Number 4

-02		-	m	6	<i>Eleocharis pusilla</i>	5	1
					<i>Glossostigma elatinoides</i>	-	2
					<i>Lilaeopsis ruthiana</i>	4	2
					<i>Ranunculus limosella</i>	-	2
					<i>Myriophyllum pedunculatum</i>	-	2
					<i>Isoetes kirkii</i>	4	2
00	01	0.0	r/m	5	<i>Enteromorpha nana</i>	5	1
					<i>Oscillatoria sp</i>	-	2
					Diatoms	-	2
					<i>Cladophora glomerata</i>	4	2
02	02	1.5	r/m	5	<i>Enteromorpha nana</i>	5	2
					<i>Oscillatoria sp</i>	-	2
					Diatoms	-	2
					<i>Cladophora glomerata</i>	4	2
04	03	3.0	r/m	6	<i>Enteromorpha nana</i>	5	5
					<i>Oscillatoria sp</i>	-	2
					Diatoms	-	2
					<i>Cladophora glomerata</i>	4	1
06	04	5.0	b	5	<i>Enteromorpha nana</i>	5	5
					<i>Oscillatoria sp</i>	-	2
					Diatoms	-	2
					<i>Cladophora glomerata</i>	4	3
08	05	5.0	b	5	<i>Enteromorpha nana</i>	1	1
					<i>Oscillatoria sp</i>	-	2
					Diatoms	-	2
					<i>Cladophora glomerata</i>	4	1
10	06	6.2	r/g/m	5	<i>Enteromorpha nana</i>	3	2
					<i>Oscillatoria sp</i>	-	2
					Diatoms	-	2
					<i>Cladophora glomerata</i>	4	4
12	07	6.2	r/g/m	5	<i>Enteromorpha nana</i>	5	1
					<i>Oscillatoria sp</i>	-	2
					Diatoms	-	4
					<i>Cladophora glomerata</i>	4	2
14	08	5.8	r/g/m	5	<i>Enteromorpha nana</i>	5	4
					<i>Oscillatoria sp</i>	-	2
					Diatoms	-	2
					<i>Cladophora glomerata</i>	4	1
16	09	6.0	r/g/m	5	<i>Enteromorpha nana</i>	5	3
					<i>Oscillatoria sp</i>	-	2
					Diatoms	-	2
					<i>Cladophora glomerata</i>	4	1
18	10	6.5	r/g/m	5	<i>Enteromorpha nana</i>	5	2
					<i>Oscillatoria sp</i>	-	2
					Diatoms	-	2
					<i>Cladophora glomerata</i>	4	1

20	11	7.2	g	5	<i>Enteromorpha nana</i>	5	5
					<i>Oscillatoria sp</i>	-	2
					Diatoms	-	2
					<i>Cladophora glomerata</i>	4	3
22	12	7.5	r	6	<i>Enteromorpha nana</i>	5	5
					<i>Oscillatoria sp</i>	-	2
					Diatoms	-	2
					<i>Cladophora glomerata</i>	4	1
24	13	7.3	r	6	<i>Tridontium tasmanicum</i>	3	2
					<i>Fissidens rigidulus</i>	3	1
					<i>Nitella pseudoflabellata</i>	2	1
					<i>Nitella hyalina</i>	2	1
					<i>Nostoc spp.</i>	1	1
					<i>Enteromorpha nana</i>	20	3
					Diatoms	-	3
					<i>Tolypothrix sp.</i>	-	1
26	14	6.5	r	6	<i>Tridontium tasmanicum</i>	3	2
					<i>Fissidens rigidulus</i>	3	1
					<i>Nitella pseudoflabellata</i>	2	1
					<i>Nitella hyalina</i>	2	1
					<i>Nostoc spp.</i>	1	1
					<i>Enteromorpha nana</i>	20	3
					Diatoms	-	3
					<i>Tolypothrix sp.</i>	-	1
28	15	6.0	r	6	<i>Tridontium tasmanicum</i>	3	2
					<i>Fissidens rigidulus</i>	3	2
					<i>Nitella pseudoflabellata</i>	2	1
					<i>Nitella hyalina</i>	2	1
					<i>Nostoc spp.</i>	1	1
					<i>Enteromorpha nana</i>	20	5
30	16	6.0	r	6	<i>Tridontium tasmanicum</i>	3	2
					<i>Fissidens rigidulus</i>	3	2
					<i>Nitella pseudoflabellata</i>	2	1
					<i>Nitella hyalina</i>	2	1
					<i>Nostoc spp.</i>	1	1
					<i>Enteromorpha nana</i>	20	5
32	17	7.3	r	6	<i>Tridontium tasmanicum</i>	3	2
					<i>Fissidens rigidulus</i>	3	2
					<i>Nitella pseudoflabellata</i>	2	1
					<i>Nitella hyalina</i>	2	1
					<i>Nostoc spp.</i>	1	1
					<i>Enteromorpha nana</i>	20	5
34	18	7.3	r	6	<i>Tridontium tasmanicum</i>	3	2
					<i>Fissidens rigidulus</i>	3	2
					<i>Nitella pseudoflabellata</i>	2	1
					<i>Nitella hyalina</i>	2	1
					<i>Nostoc spp.</i>	1	1
					<i>Enteromorpha nana</i>	20	5
36	19	7.5	r	6	<i>Fissidens rigidulus</i>	4	2
					<i>Nitella leptostachys</i>	2	1
					<i>Enteromorpha nana</i>	30	1
					<i>Cladophora glomerata</i>	7	1
					<i>Oedogonium sp.</i>	25	5
38	20	7.2	g	6	<i>Tridontium tasmanicum</i>	2	1
					<i>Fissidens rigidulus</i>	2	2
					<i>Nostoc spp.</i>	1	1
					<i>Cladophora glomerata</i>	5	1
					<i>Enteromorpha nana</i>	10	4
					rock scraping		
					<i>Spirogyra sp.</i>	0.1)	
					Diatoms	0.1)	
					<i>Oscillatoria sp.</i>	0.1)	1
					<i>Tolypothrix sp.</i>	0.1)	

					<i>Oedogonium</i> sp.	0.1)	
40	21	6.7	s/g	4	<i>Cladophora glomerata</i>	10	4
42	22	6.0	s/g	1	<i>Cladophora glomerata</i>	1	1
44	23	5.6	s/g	1	<i>Cladophora glomerata</i>	1	1
46	24	5.5	s/g	1	<i>Cladophora glomerata</i>	1	1
48	25	5.0	s/g	1	<i>Cladophora glomerata</i>	1	1
50	26	4.5	s/g	1	<i>Cladophora glomerata</i>	1	1
52	27	3.8	s/g	1	<i>Cladophora glomerata</i>	1	1
54	28	3.3	s/g	1	<i>Cladophora glomerata</i>	1	1
56	29	3.0	s/g	1	<i>Cladophora glomerata</i>	1	1
58	30	2.4	s/g	-			
60	31	2.1	s/g	-			
62	32	2.0	s/g	-			
64	33	1.7	s/g	-			
66	34	1.5	g/s		<i>Tridontium tasmanicum</i>	3	1
					<i>Cladophora glomerata</i>	20	4
68	35	1.0	g/s		<i>Tridontium tasmanicum</i>	3	1
					<i>Cladophora glomerata</i>	20	4
70	36	0.5	g/s	4	<i>Tridontium tasmanicum</i>	3	1
					<i>Cladophora glomerata</i>	20	4
72	37	0.4	g/s	4	<i>Tridontium tasmanicum</i>	<5	1
					<i>Fissidens rigidulus</i>	<5	1
					<i>Nitella hyalina</i>	<5	1
					<i>Cladophora glomerata</i>	<5	4
					<i>Nostoc spp.</i>	<5	1
74	38	0.0	g/s	3	<i>Tridontium tasmanicum</i>	<5	1
					<i>Fissidens rigidulus</i>	<5	1
					<i>Cladophora glomerata</i>	<5	3

Transect Number 5

00	01	0.0	m	2	<i>Cladophora glomerata</i>	10	2
					<i>Enteromorpha nana</i>	20	1
02	02	1.0	s/g	2	<i>Cladophora glomerata</i>	10	2
04	03	2.2	s/b	4	<i>Lagarosiphon major</i>	15	2
					<i>Cladophora glomerata</i>	15	2
					<i>Enteromorpha nana</i>	20	1
06	04	3.0	s/b	2	<i>Cladophora glomerata</i>	15	2
08	05	3.4	b/s	4	<i>Cladophora glomerata</i>	10	4
10	06	4.0	r/b	5	<i>Tridontium tasmanicum</i>	1	1
					<i>Fissidens rigidulus</i>	1	1
					<i>Cladophora glomerata</i>	10	2
					<i>Enteromorpha nana</i>	20	1
12	07	6.0	g/s	-			
14	08	6.0	g/s	-			

16	09	6.0	g/s	-			
18	10	5.5	b/s	5	<i>Tridontium tasmanicum</i>	1	1
					<i>Fissidens rigidulus</i>	1	1
					<i>Cladophora glomerata</i>	10	1
20	11	5.0	b/s	5	<i>Fissidens rigidulus</i>	1	1
					<i>Cladophora glomerata</i>	10	5
22	12	4.5	b/s	5	<i>Tridontium tasmanicum</i>	1	1
					<i>Cladophora glomerata</i>	10	5
24	13	4.5	b/s	5	<i>Fissidens rigidulus</i>	1	1
					<i>Cladophora glomerata</i>	10	5
26	14	4.8	s/g	4	<i>Cladophora glomerata</i>	15	4
28	15	4.8	s/g	4	<i>Tridontium tasmanicum</i>	2	1
					<i>Fissidens rigidulus</i>	1	2
					<i>Cladophora glomerata</i>	15	4
30	16	4.6	s/g	4	<i>Tridontium tasmanicum</i>	2	1
					<i>Fissidens rigidulus</i>	1	2
					<i>Cladophora glomerata</i>	15	3
					<i>Enteromorpha nana</i>	20	2
32	17	4.6	s/g	4	<i>Tridontium tasmanicum</i>	2	1
					<i>Fissidens rigidulus</i>	1	2
					<i>Cladophora glomerata</i>	15	3
					<i>Enteromorpha nana</i>	20	1
34	18	4.0	s/g	6	<i>Tridontium tasmanicum</i>	2	1
					<i>Fissidens rigidulus</i>	1	2
					<i>Cladophora glomerata</i>	15	3
					<i>Enteromorpha nana</i>	20	4
36	19	4.0	s/g	6	<i>Tridontium tasmanicum</i>	2	2
					<i>Cladophora glomerata</i>	15	5
					<i>Enteromorpha nana</i>	20	1
38	20	3.2	r/g	6	<i>Tridontium tasmanicum</i>	2	2
					<i>Fissidens rigidulus</i>	1	1
					<i>Cladophora glomerata</i>	15	5
					<i>Enteromorpha nana</i>	20	2
40	21	2.5	r/g	6	<i>Cladophora glomerata</i>	10	6
42	22	2.5	r/g	6	<i>Cladophora glomerata</i>	10	6
44	23	2.2	r/g	6	<i>Tridontium tasmanicum</i>	2	1
					<i>Fissidens rigidulus</i>	1	1
					<i>Cladophora glomerata</i>	15	5
					<i>Enteromorpha nana</i>	20	2
46	24	2.2	r/g	6	<i>Tridontium tasmanicum</i>	2	1
					<i>Fissidens rigidulus</i>	1	1
					<i>Cladophora glomerata</i>	15	5
					<i>Enteromorpha nana</i>	20	2
48	25	2.5	r/g	6	<i>Tridontium tasmanicum</i>	2	1
					<i>Fissidens rigidulus</i>	1	1
					<i>Cladophora glomerata</i>	15	5
					<i>Enteromorpha nana</i>	20	2
50	26	2.5	r/g	6	<i>Tridontium tasmanicum</i>	2	1
					<i>Fissidens rigidulus</i>	1	1
					<i>Cladophora glomerata</i>	15	5
					<i>Enteromorpha nana</i>	20	2
52	27	2.5	r/g	6	<i>Tridontium tasmanicum</i>	2	1
					<i>Fissidens rigidulus</i>	1	1

					<i>Cladophora glomerata</i>	15	5
					<i>Enteromorpha nana</i>	20	2
54	28	2.5	r/g	6	<i>Tridontium tasmanicum</i>	2	1
					<i>Fissidens rigidulus</i>	1	1
					<i>Cladophora glomerata</i>	15	5
					<i>Enteromorpha nana</i>	20	2
56	29	2.5	r/g	6	<i>Cladophora glomerata</i>	10	6
58	30	2.5	r/g	6	<i>Cladophora glomerata</i>	10	5
					<i>Enteromorpha nana</i>	20	1
60	31	2.5	r/g	6	<i>Cladophora glomerata</i>	10	5
					<i>Enteromorpha nana</i>	20	1
62	32	2.5	g	5	<i>Cladophora glomerata</i>	10	5
					<i>Enteromorpha nana</i>	20	1
64	33	2.4	m/g	5	<i>Cladophora glomerata</i>	10	5
					<i>Enteromorpha nana</i>	20	1
66	34	2.2	m/g	5	<i>Cladophora glomerata</i>	10	5
					<i>Enteromorpha nana</i>	20	1
68	35	1.5	g	2	<i>Glossostigma elatinoides</i>	1	2
70	36	0.0	m	6	<i>Glossostigma elatinoides</i>	1	4
					<i>Eleocharis pusilla</i>	1	2
					<i>Myriophyllum pedunculatum</i>	3	1
					<i>Enteromorpha nana</i>	10	2

Transect Number 6

00	01		p/b	-			
02	02	2.0	p/b	2	<i>Enteromorpha nana</i>	50	2
04	03	3.0	p/b	4	<i>Cladophora glomerata</i>	5	4
					<i>Enteromorpha nana</i>	50	1
06	04	3.0	p/b	4	<i>Cladophora glomerata</i>	5	4
					<i>Enteromorpha nana</i>	50	1
08	05	3.0	p/b	4	<i>Cladophora glomerata</i>	5	4
					<i>Enteromorpha nana</i>	50	1
10	06	3.0	p/b	4	<i>Cladophora glomerata</i>	5	4
					<i>Enteromorpha nana</i>	50	1
12	07	3.0	p/b	4	<i>Cladophora glomerata</i>	5	4
					<i>Enteromorpha nana</i>	50	1
14	08	3.0	p/b	4	<i>Cladophora glomerata</i>	5	4
					<i>Enteromorpha nana</i>	50	1
16	09	3.0	p/b	4	<i>Cladophora glomerata</i>	5	4
					<i>Enteromorpha nana</i>	50	1
18	10	3.0	p/b	4	<i>Cladophora glomerata</i>	5	4
					<i>Enteromorpha nana</i>	50	1
20	11	3.0	p/b	5	<i>Tridontium tasmanicum</i>	1	1
					<i>Cladophora glomerata</i>	4	5
					<i>Nostoc spp.</i>	1	1
22	12	3.2	p	1	<i>Cladophora glomerata</i>	5	1
24	13	3.2	p	1	<i>Cladophora glomerata</i>	5	1

26	14	3.2	p	5	<i>Cladophora glomerata</i>	20	5
28	15	3.0	p	5	<i>Cladophora glomerata</i> Caddis	20	5
30	16	3.0	b/p	4	<i>Cladophora glomerata</i> Caddis	20	4
32	17	3.2	p	4	<i>Cladophora glomerata</i> Caddis	20	4
34	18	3.5	p	4	<i>Cladophora glomerata</i> Caddis	20	4
36	19	3.5	p	4	<i>Cladophora glomerata</i> Caddis	20	4
38	20	3.5	p	4	<i>Cladophora glomerata</i> Caddis	20	4
40	21	3.5	p	2	<i>Cladophora glomerata</i>	1	2
42	22	3.5	p/b	3	<i>Cladophora glomerata</i>	5	3
44	23	3.0	p/b	5	<i>Cladophora glomerata</i>	4	5
46	24	2.8	p/s	3	<i>Tridontium tasmanicum</i> <i>Cladophora glomerata</i> <i>Enteromorpha nana</i> <i>Nostoc spp.</i>	1 4 3 -	1 2 1 1
48	25	3.2	p/s	3	<i>Cladophora glomerata</i>	5	3
50	26	3.5	p/s	2	<i>Cladophora glomerata</i> <i>Enteromorpha nana</i> <i>Nostoc spp.</i> Diatoms	1 5 1 -	2 1 1 1
52	27	3.5	p/s	2	<i>Cladophora glomerata</i>	6	2
54	28	4.0	p/s	2	<i>Cladophora glomerata</i> <i>Nostoc spp.</i>	6 1	2 1
56	29	3.8	s/p	5	<i>Tridontium tasmanicum</i> <i>Cladophora glomerata</i>	4 1	1 4
58	30	3.5	s/p	4	<i>Cladophora glomerata</i>	6	4
60	31	3.1	s/p	3	<i>Lagarosiphon major</i> <i>Cladophora glomerata</i>	100 10	2 2
62	32	2.5	g/p/s	3	<i>Cladophora glomerata</i>	20	3
64	33	2.3	g/p/s	4	<i>Myriophyllum triphyllum</i> <i>Tridontium tasmanicum</i> <i>Fissidens rigidulus</i> <i>Cladophora glomerata</i> <i>Nostoc spp.</i> <i>Enteromorpha nana</i>	15 1 1 5 - 15	1 1 1 4 1 1
66	34	2.3	g/p/s	5	<i>Cladophora glomerata</i> <i>Nostoc spp.</i> Diatoms	5	4 1 1
68	35	2.2	g/p	5	<i>Cladophora glomerata</i>	5	5
70	36	2.2	p/s	4	<i>Cladophora glomerata</i> <i>Oscillatoria sp.</i> Diatoms	5 - -	4 1 1
72	37	2.0	p/s	1	<i>Cladophora glomerata</i> <i>Nostoc spp.</i>	1 -	1 1

					Diatoms	-	1
74	38	1.5	s	-			
76	39	1.0	s/b	1	<i>Oscillatoria sp.</i>	-	1
					Diatoms	-	1
78	40	0.7	s	-			
80	41	0.0	b/s	1	<i>Oscillatoria sp.</i>	-	1
					Diatoms	-	1

Transect Number 7

00	01	0.0	r	1	<i>Cladophora glomerata</i>	5	1
02	02	1.0	r	4	<i>Cladophora glomerata</i>	4	3
					<i>Nostoc spp.</i>	1	2
04	03	2.2	r	4	<i>Cladophora glomerata</i>	4	3
					<i>Nostoc spp.</i>	1	2
06	04	3.2	r	5	<i>Cladophora glomerata</i>	1	5
08	05	3.5	r	5	<i>Cladophora glomerata</i>	5	5
					<i>Nostoc spp.</i>	1	1
10	06	4.2	g	5	<i>Cladophora glomerata</i>	5	5
12	07	3.0	r	3	<i>Tridontium tasmanicum</i>	2	1
					<i>Fissidens rigidulus</i>	1	1
					<i>Cladophora glomerata</i>	3	2
					<i>Nostoc spp.</i>	1	1
14	08	4.0	r	3	<i>Tridontium tasmanicum</i>	2	1
					<i>Fissidens rigidulus</i>	1	1
					<i>Cladophora glomerata</i>	3	2
					<i>Nostoc spp.</i>	1	1
16	09	5.0	b/r	5	<i>Tridontium tasmanicum</i>	1	1
					<i>Fissidens rigidulus</i>	1	1
					<i>Cladophora glomerata</i>	3	3
					<i>Enteromorpha nana</i>	7	4
18	10	5.2	b/r	5	<i>Tridontium tasmanicum</i>	1	3
					<i>Cladophora glomerata</i>	5	1
					<i>Enteromorpha nana</i>	10	1
					<i>Nostoc spp.</i>	1	2
20	11	5.5	b	5	<i>Tridontium tasmanicum</i>	1	1
					<i>Fissidens rigidulus</i>	1	1
					<i>Cladophora glomerata</i>	4	4
					<i>Enteromorpha nana</i>	6	2
					<i>Nostoc spp.</i>	1	1
22	12	7.0	b	5	<i>Tridontium tasmanicum</i>	1	1
					<i>Fissidens rigidulus</i>	1	1
					<i>Cladophora glomerata</i>	4	4
					<i>Enteromorpha nana</i>	6	2
					<i>Nostoc spp.</i>	1	1
24	13	7.4	g	5	<i>Tridontium tasmanicum</i>	4	1
					<i>Fissidens rigidulus</i>	4	1
					<i>Cladophora glomerata</i>	6	5
					<i>Nostoc spp.</i>	1	1
26	14	7.3	g	5	<i>Tridontium tasmanicum</i>	4	1
					<i>Fissidens rigidulus</i>	4	1
					<i>Cladophora glomerata</i>	6	5

					<i>Nostoc spp.</i>	1	1
28	15	7.2	g	5	<i>Tridontium tasmanicum</i>	4	1
					<i>Fissidens rigidulus</i>	4	1
					<i>Cladophora glomerata</i>	6	5
					<i>Nostoc spp.</i>	1	1
30	16	7.0	g/s	4	<i>Cladophora glomerata</i>	5	4
32	17	6.6	g/s	4	<i>Cladophora glomerata</i>	5	4
34	18	6.3	g/s	4	<i>Cladophora glomerata</i>	5	4
36	19	5.8	g/s	4	<i>Cladophora glomerata</i>	5	4
38	20	5.6	s	-			
40	21	5.3	s	-			
42	22	5.3	s	-			
44	23	5.5	b/s	5	<i>Cladophora glomerata</i>	4	5
46	24	4.6	b/s	5	<i>Cladophora glomerata</i>	5	5
48	25	4.0	b/s	4	<i>Cladophora glomerata</i>	2	4
50	26	3.2	b/s	4	<i>Cladophora glomerata</i>	5	4
52	27	2.2	r/s	1	<i>Cladophora glomerata</i>	12	1
54	28	1.3	r/s	1	<i>Cladophora glomerata</i>	12	1
56	29	0.0	m/r	-			

Transect Number 8

00	01	0.0	m/s	-			
02	02	0.1	s	2	<i>Cladophora glomerata</i>	5	2
04	03	0.9	s	-			
06	04	1.2	g	1	<i>Enteromorpha nana</i>	-	1
					<i>Oscillatoria sp.</i>	-	1
					<i>Tolypothrix limbata</i>	-	1
08	05	1.2	g	1	<i>Enteromorpha nana</i>	-	1
					<i>Oscillatoria sp.</i>	-	1
					<i>Tolypothrix limbata</i>	-	1
10	06	1.5	g	1	<i>Tridontium tasmanicum</i>	5	1
12	07	1.7	g	5	<i>Tridontium tasmanicum</i>	3	4
					<i>Fissidens rigidulus</i>	1	1
					<i>Cladophora glomerata</i>	5	1
					<i>Nitella hookeri</i>	1	1
14	08	1.7	g	5	<i>Tridontium tasmanicum</i>	3	5
					<i>Fissidens rigidulus</i>	1	1
					<i>Nostoc spp.</i>	1	1
16	09	1.8	g	5	<i>Fissidens rigidulus</i>	3	4
					<i>Nitella hookeri</i>	4	1
					<i>Cladophora glomerata</i>	3	1
					<i>Nostoc spp.</i>	1	1
18	10	1.8	g	2	<i>Cladophora glomerata</i>	4	2
20	11	1.8	g	3	<i>Tridontium tasmanicum</i>	3	2

					<i>Fissidens rigidulus</i>	1	1
					<i>Cladophora glomerata</i>	5	1
					<i>Nostoc spp.</i>	1	1
22	12	1.8	g	5	<i>Tridontium tasmanicum</i>	3	4
					<i>Fissidens rigidulus</i>	1	1
					<i>Cladophora glomerata</i>	5	1
					<i>Nostoc spp.</i>	1	1
24	13	1.8	g	5	<i>Tridontium tasmanicum</i>	3	4
					<i>Fissidens rigidulus</i>	1	1
					<i>Cladophora glomerata</i>	5	1
					<i>Nostoc spp.</i>	1	1
26	14	2.0	g	5	<i>Tridontium tasmanicum</i>	3	4
					<i>Fissidens rigidulus</i>	1	1
					<i>Cladophora glomerata</i>	5	1
					<i>Nostoc spp.</i>	1	1
					<i>Enteromorpha nana</i>	3	1
28	15	2.5	g	2	<i>Cladophora glomerata</i>	1	2
30	16	3.0	g	4	<i>Tridontium tasmanicum</i>	3	1
					<i>Fissidens rigidulus</i>	1	1
					<i>Cladophora glomerata</i>	1	1
					<i>Nostoc spp.</i>	1	1
					<i>Enteromorpha nana</i>	3	2
32	17	3.0	g	3	<i>Tridontium tasmanicum</i>	3	2
					<i>Fissidens rigidulus</i>	1	1
					<i>Cladophora glomerata</i>	5	1
34	18	3.2	g	5	<i>Tridontium tasmanicum</i>	3	4
					<i>Cladophora glomerata</i>	5	1
					<i>Nostoc spp.</i>	1	1
					<i>Enteromorpha nana</i>	3	1
36	19	3.4	g	4	<i>Tridontium tasmanicum</i>	3	4
					<i>Fissidens rigidulus</i>	1	1
					<i>Nostoc spp.</i>	1	1
38	20	3.5	g/s	-			
40	21	3.5	g/s	-			
42	22	3.5	g/s	-			
44	23	3.5	g/s	-			
46	24	3.5	g/s	3	<i>Fissidens rigidulus</i>	2	3
					<i>Cladophora glomerata</i>	3	1
					<i>Nostoc spp.</i>	1	1
					Caddis	1	1
48	25	3.5	g/s	-			
50	26	3.0	g	5	<i>Tridontium tasmanicum</i>	3	4
					<i>Fissidens rigidulus</i>	1	1
					<i>Cladophora glomerata</i>	5	1
					<i>Nostoc spp.</i>	1	1
					<i>Enteromorpha nana</i>	4	1
52	27	2.0	g	5	<i>Tridontium tasmanicum</i>	3	4
					<i>Cladophora glomerata</i>	5	2
					<i>Nostoc spp.</i>	1	1
54	28	2.0	g	5	<i>Tridontium tasmanicum</i>	3	4
					<i>Fissidens rigidulus</i>	1	1
					<i>Cladophora glomerata</i>	5	1
56	29	2.0	g	4	<i>Cladophora glomerata</i>	3	3
					<i>Enteromorpha nana</i>	2	2

58	30	2.0	g	6	<i>Tridontium tasmanicum</i>	3	4
					<i>Fissidens rigidulus</i>	1	1
					<i>Cladophora glomerata</i>	5	2
					<i>Nostoc spp.</i>	1	1
					<i>Enteromorpha nana</i>	2	2
60	31	2.0	g	5	<i>Cladophora glomerata</i>	3	5
62	32	1.8	g	5	<i>Fissidens rigidulus</i>	3	4
					<i>Enteromorpha nana</i>	3	2
64	33	1.8	g	4	<i>Oscillatoria sp</i>	-	4
					Diatoms		2
66	34	1.6	g	3	<i>Oscillatoria sp</i>	-	2
					Diatoms		3
68	35	1.6	g	4	<i>Oscillatoria sp</i>	-	4
					Diatoms		2
70	36	0.8	g/s	1	<i>Oscillatoria sp</i>	-	1
					Diatoms		1
72	37	0.0	g/m	-			

Transect Number 9

00	01	0.0	m/s	-			
02	02	1.4	m/s	1	<i>Cladophora glomerata</i>	5	1
04	03	1.7	b/m/s	4	<i>Cladophora glomerata</i>	4	4
06	04	1.6	b/r	5	<i>Tridontium tasmanicum</i>	1	1
					<i>Enteromorpha nana</i>	12	4
					<i>Nostoc spp.</i>	1	1
08	05	1.5	b/r	5	<i>Tridontium tasmanicum</i>	1	1
					<i>Enteromorpha nana</i>	12	4
					<i>Nostoc spp.</i>	1	1
10	06	1.6	b/r	5	<i>Tridontium tasmanicum</i>	1	1
					<i>Cladophora glomerata</i>	10	4
					<i>Enteromorpha nana</i>	8	2
					<i>Nostoc spp.</i>	1	1
12	07	1.8	b/r	5	<i>Tridontium tasmanicum</i>	1	1
					<i>Cladophora glomerata</i>	10	4
					<i>Enteromorpha nana</i>	8	2
					<i>Nostoc spp.</i>	1	1
14	08	2.0	b/r	5	<i>Tridontium tasmanicum</i>	1	1
					<i>Cladophora glomerata</i>	10	4
					<i>Enteromorpha nana</i>	8	2
					<i>Nostoc spp.</i>	1	1
16	09	2.1	b/r	5	<i>Tridontium tasmanicum</i>	1	1
					<i>Cladophora glomerata</i>	10	4
					<i>Enteromorpha nana</i>	8	2
					<i>Nostoc spp.</i>	1	1
18	10	2.0	b/r	5	<i>Tridontium tasmanicum</i>	1	1
					<i>Cladophora glomerata</i>	10	4
					<i>Enteromorpha nana</i>	8	2
					<i>Nostoc spp.</i>	1	1
20	11	2.2	b/r	5	<i>Tridontium tasmanicum</i>	1	1
					<i>Cladophora glomerata</i>	10	4
					<i>Enteromorpha nana</i>	8	2

					<i>Nostoc spp.</i> Caddis	1	1
22	12	2.2	b/r	5	<i>Tridontium tasmanicum</i>	1	1
					<i>Cladophora glomerata</i>	10	4
					<i>Enteromorpha nana</i>	8	2
					<i>Nostoc spp.</i> Caddis	1	1
24	13	3.5	b/g	5	<i>Tridontium tasmanicum</i>	1	4
					<i>Cladophora glomerata</i>	5	1
					<i>Enteromorpha nana</i>	2	1
					<i>Nostoc spp.</i> Caddis	1	1
26	14	3.6	b/g	5	<i>Tridontium tasmanicum</i>	1	4
					<i>Cladophora glomerata</i>	5	1
					<i>Enteromorpha nana</i>	2	1
					<i>Nostoc spp.</i> Caddis	1	1
28	15	4.0	b/g	5	<i>Tridontium tasmanicum</i>	1	4
					<i>Cladophora glomerata</i>	5	1
					<i>Enteromorpha nana</i>	2	2
					<i>Nostoc spp.</i> Caddis	1	1
30	16	4.5	b/g/r	5	<i>Tridontium tasmanicum</i>	1	3
					<i>Fissidens rigidulus</i>	1	1
					<i>Cladophora glomerata</i>	2	3
					<i>Enteromorpha nana</i>	10	1
					<i>Nostoc spp.</i>	1	3
32	17	4.8	b/g/r	5	<i>Tridontium tasmanicum</i>	1	3
					<i>Fissidens rigidulus</i>	1	1
					<i>Cladophora glomerata</i>	2	3
					<i>Enteromorpha nana</i>	10	1
					<i>Nostoc spp.</i>	1	3
34	18	5.0	b/g	5	<i>Tridontium tasmanicum</i>	1	2
					<i>Fissidens rigidulus</i>	1	1
					<i>Cladophora glomerata</i>	2	1
					<i>Enteromorpha nana</i>	10	2
					<i>Nostoc spp.</i>	1	2
36	19	4.5	b/g	2	<i>Cladophora glomerata</i>	1	1
					<i>Enteromorpha nana</i>	3	1
					<i>Nostoc spp.</i>	1	1
38	20	4.5	b/g	2	<i>Cladophora glomerata</i>	1	1
					<i>Enteromorpha nana</i>	3	1
					<i>Nostoc spp.</i>	1	1
40	21	4.5	b/g	2	<i>Cladophora glomerata</i>	1	1
					<i>Enteromorpha nana</i>	3	1
					<i>Nostoc spp.</i>	1	1
42	22	4.5	b/g	2	<i>Cladophora glomerata</i>	1	1
					<i>Enteromorpha nana</i>	3	1
					<i>Nostoc spp.</i>	1	1
44	23	4.3	b/s	1	<i>Cladophora glomerata</i>	1	1
					<i>Enteromorpha nana</i>	3	1
					<i>Nostoc spp.</i>	1	1
46	24	4.0	b/s	1	<i>Cladophora glomerata</i>	1	1
					<i>Enteromorpha nana</i>	1	1
					<i>Nostoc spp.</i>	1	1
48	25	4.0	b/s	1	<i>Cladophora glomerata</i>	1	1
					<i>Enteromorpha nana</i>	1	1
					<i>Nostoc spp.</i>	1	1

50	26	4.0	b/s	1	<i>Cladophora glomerata</i>	1	1
					<i>Enteromorpha nana</i>	1	1
					<i>Nostoc spp.</i>	1	1
52	27	4.0	b/s	1	<i>Cladophora glomerata</i>	1	1
					<i>Enteromorpha nana</i>	1	1
					<i>Nostoc spp.</i>	1	1
54	28	4.0	b/s	1	<i>Cladophora glomerata</i>	1	1
					<i>Enteromorpha nana</i>	1	1
					<i>Nostoc spp.</i>	1	1
56	29	3.5	s/b	6	<i>Elodea canadensis</i>	30	2
					<i>Potamogeton crispus</i>	15	3
					<i>Lagarosiphon major</i>	60	1
					<i>Cladophora glomerata</i>	1	1
					<i>Enteromorpha nana</i>	3	1
58	30	2.2	s	6	<i>Potamogeton crispus</i>	15	4
					<i>Lagarosiphon major</i>	20	1
					<i>Cladophora glomerata</i>	10	2
					<i>Enteromorpha nana</i>	10	1
60	31	1.5	s	2	<i>Potamogeton crispus</i>	10	2
62	32	0.8	s	1	<i>Lagarosiphon major</i>	5	1
64	33	0.0	s	1	<i>Glossostigma submersum</i>	1	1

Transect Number 10

00	01	0.0	m	2	<i>Glossostigma elatinoides</i>		1
					<i>Enteromorpha nana</i>	30	1
02	02	0.5	m	1	<i>Enteromorpha nana</i>	10	1
04	03	2.0	s/b	-			
06	04	2.3	b	2	<i>Tolypothrix limbata</i>	-	2
08	05	3.2	s/b	4	<i>Cladophora glomerata</i>	10	4
10	06	3.6	s/b	5	<i>Cladophora glomerata</i>	1	5
12	07	4.2	s/b	5	<i>Cladophora glomerata</i>	3	5
14	08	4.8	s/b/r	4	<i>Cladophora glomerata</i>	1	4
16	09	5.0	b/g	4	<i>Cladophora glomerata</i>	5	4
18	10	5.6	b/g	4	<i>Cladophora glomerata</i>	1	4
20	11	6.0	b/g	4	<i>Cladophora glomerata</i>	1	4
22	12	7.0	b/g	4	<i>Cladophora glomerata</i>	1	4
24	13	8.0	b/g	2	<i>Tridontium tasmanicum</i>	1	1
					<i>Fissidens rigidulus</i>	1	1
					<i>Cladophora glomerata</i>	1	1
26	14	7.5	b/g	5	<i>Tridontium tasmanicum</i>	4	1
					<i>Cladophora glomerata</i>	4	3
					<i>Enteromorpha nana</i>	4	1
					<i>Nostoc spp.</i>	1	1
28	15	8.0	b/g/s	5	<i>Tridontium tasmanicum</i>	4	1
					<i>Cladophora glomerata</i>	4	3
					<i>Enteromorpha nana</i>	4	1
					<i>Nostoc spp.</i>	1	1

30	16	7.5	b/g/s	5	<i>Tridontium tasmanicum</i>	4	4
					<i>Cladophora glomerata</i>	4	3
					<i>Enteromorpha nana</i>	4	1
					<i>Nostoc spp.</i>	1	1
32	17	7.5	b/g/s	5	<i>Tridontium tasmanicum</i>	4	1
					<i>Cladophora glomerata</i>	4	3
					<i>Enteromorpha nana</i>	4	1
					<i>Nostoc spp.</i>	1	1
34	18	8.0	b/g/s	5	<i>Tridontium tasmanicum</i>	4	1
					<i>Cladophora glomerata</i>	4	3
					<i>Enteromorpha nana</i>	4	1
					<i>Nostoc spp.</i>	1	1
36	19	8.0	b/g/s	5	<i>Tridontium tasmanicum</i>	4	4
					<i>Cladophora glomerata</i>	4	3
					<i>Enteromorpha nana</i>	4	1
					<i>Nostoc spp.</i>	1	1
38	20	7.5	b/g/s	5	<i>Tridontium tasmanicum</i>	4	1
					<i>Cladophora glomerata</i>	4	3
					<i>Enteromorpha nana</i>	4	1
					<i>Nostoc spp.</i>	1	1
40	21	8.5	g	4	<i>Tridontium tasmanicum</i>	4	4
					<i>Cladophora glomerata</i>	4	3
					<i>Enteromorpha nana</i>	4	1
					<i>Nostoc spp.</i>	1	1
42	22	8.5	g	4	<i>Tridontium tasmanicum</i>	1	3
					<i>Cladophora glomerata</i>	3	2
					<i>Nostoc spp.</i>	1	1
44	23	8.0	g	4	<i>Tridontium tasmanicum</i>	1	2
					<i>Cladophora glomerata</i>	4	2
					<i>Enteromorpha nana</i>	3	1
46	24	7.0	s	-			
48	25	6.0	r/s	-			
50	26	6.0	s	-			
52	27	5.2	s	-			
54	28	4.5	s	-			
56	29	3.8	s	-			
58	30	3.4	s	-			
60	31	3.3	s	-			
62	32	3.8	s/b	3	<i>Cladophora glomerata</i>	20	2
					<i>Enteromorpha nana</i>	13	1
64	33	3.6	s/r	5	<i>Cladophora glomerata</i>	1	1
					<i>Tolypothrix tenuis</i>	-	4
					Diatoms	-	4
66	34	3.4	s/r	5	<i>Cladophora glomerata</i>		
					<i>Tolypothrix tenuis</i>		
					Diatoms		
68	35	2.0	s/r	5	<i>Cladophora glomerata</i>	4	1
					<i>Tolypothrix tenuis</i>	-	3
					Diatoms	-	2
70	36	1.3	s/r	5	<i>Tolypothrix tenuis</i>	-	5
					Diatoms		3

72	37	0.0	s/r	6	<i>Tolypothrix tenuis</i>	-	5
					Diatoms	-	4

Winter Survey of Transects 2, 4 and 5, August, 1989.

Transect Number 2 -Winter

00	01	0.0	m	0	-	-	-
02	02	2.5	r/m	6	<i>Fissidens rigidulus</i>	2	3
					<i>Tridontium tasmanicum</i>	2	3
					<i>Oedogonium sp.</i>	5	1
					<i>Nostoc sp</i>	1	1
04	03	4.0	r/m	4	<i>Tridontium tasmanicum</i>	3	3
					<i>Oedogonium sp.</i>	5	2
06	04	4.5	r/m	2	<i>Tridontium tasmanicum</i>	2	1
					<i>Fissidens rigidulus</i>	1	1
					<i>Oedogonium sp.</i>	2	1
08	05	6.5	r	1	<i>Fissidens rigidulus</i>	1	1
					<i>Oedogonium sp.</i>	1	1
10	06	6.5	r	2	<i>Fissidens rigidulus</i>	1	1
					<i>Tridontium tasmanicum</i>	1	1
12	07	6.0	r/s	1	<i>Fissidens rigidulus</i>	1	1
					<i>Oedogonium sp.</i>	1	1
14	08	6.5	r/s	1	<i>Fissidens rigidulus</i>	1	1
					<i>Oedogonium sp.</i>	1	1
16	09	6.5	r/s	1	<i>Fissidens rigidulus</i>	2	1
					<i>Oedogonium sp.</i>	2	1
18	10	6.5	r/s/	1	<i>Fissidens rigidulus</i>	1	1
					<i>Oedogonium sp.</i>	2	1
20	11	7.0	p/s/g	0	-	-	-
22	12	7.0	p/s/g	0	-	-	-
24	13	6.7	p/s/g	0	-	-	-
26	14	6.8	p/s/g	1	<i>Fissidens rigidulus</i>	2	1
					<i>Oedogonium sp.</i>	2	1
28	15	7.0	p/s/g	1	<i>Fissidens rigidulus</i>	1	1
					<i>Oedogonium sp.</i>	2	1
30	16	6.5	p/s/g	1	<i>Fissidens rigidulus</i>	2	2
					<i>Oedogonium sp.</i>	4	1
32	17	6.5	p/s/g	1	<i>Fissidens rigidulus</i>	2	1
					<i>Oedogonium sp.</i>	4	1
34	18	6.0	p/s/g	0	-	-	-
36	19	6.4	p/s/g	1	<i>Fissidens rigidulus</i>	2	1
					<i>Oedogonium sp.</i>	2	1
38	20	6.5	p/s/g	1	<i>Fissidens rigidulus</i>	5	1
					<i>Oedogonium sp.</i>	3	1
40	21	5.0	s/p/b	3	<i>Fissidens rigidulus</i>	4	1
					<i>Nostoc spp.</i>	1	1
					<i>Oedogonium sp.</i>	5	3

42	22	5.5	r	3	<i>Fissidens rigidulus</i>	5	2
					<i>Tridontium tasmanicum</i>	1	2
					<i>Oedogonium sp.</i>	2	1
44	23	4.0	r	6	<i>Fissidens rigidulus</i>	5	3
					<i>Tridontium tasmanicum</i>	4	3
					<i>Nitella hyalina</i>	8	1
					<i>Nostoc spp.</i>	1	1
					<i>Oedogonium sp.</i>	5	3
46	25	2.0	r/m	6	<i>Fissidens rigidulus</i>	4	2
					<i>Tridontium tasmanicum</i>	4	5
					<i>Nitella hyalina</i>	8	1
					<i>Nostoc spp.</i>	1	1
					<i>Oedogonium sp.</i>	5	2
48	26	0.0	r/m	6	<i>Fissidens rigidulus</i>	4	2
					<i>Tridontium tasmanicum</i>	4	3
					<i>Glossostigma submersum</i>	1	2
					<i>Nostoc spp.</i>	1	1
					<i>Oedogonium sp.</i>	5	2

Transect Number 4 - Winter

00	01	-0.0	m/s	6	<i>Enteromorpha nana</i>	50	6
					<i>Glossosigma elatinoides</i>	1	2
02	02	1.5	m/s	6	<i>Enteromorpha nana</i>	50	4
					<i>Oscillatoria sp</i>	-	2
					<i>Cladophora glomerata</i>	20	3
04	03	2.0	m/s	6	<i>Enteromorpha nana</i>	50	3
					<i>Cladophora glomerata</i>	20	3
06	04	3.5	r/m	2	<i>Enteromorpha nana</i>	20	2
					<i>Oscillatoria sp</i>	-	1
08	05	5.5	r/m	6	<i>Cladophora glomerata</i>	20	6
10	06	5.5	s/g	6	<i>Cladophora glomerata</i>	20	6
12	07	6.2	s/g	6	<i>Cladophora glomerata</i>	20	6
					<i>Ghomphonmema sp</i>	5	1
14	08	6.8	r/m	0	-	-	-
16	09	8.0	r/m	6	<i>Cladophora glomerata</i>	20	6
18	10	8.5	r/g/m	6	<i>Cladophora glomerata</i>	10	6
20	11	9.0	s/g	0	-	-	-
22	12	9.0	s/g	0	-	-	-
24	13	9.0	r	6	<i>Cladophora glomerata</i>	10	6
26	14	8.5	r	6	<i>Cladophora glomerata</i>	5	6
28	15	8.5	r	6	<i>Enteromorpha nana</i>	10	3
					<i>Cladophora glomerata</i>	5	2
					<i>Tridontium tasmanicum</i>	1	1
					<i>Oscillatoria sp.</i>	-	1
30	16	8.5	r	6	<i>Enteromorpha nana</i>	10	3
					<i>Cladophora glomerata</i>	5	3
					<i>Tridontium tasmanicum</i>	1	1
					<i>Oscillatoria sp.</i>	-	1

32	17	8.5	r	6	<i>Enteromorpha nana</i>	10	3
					<i>Cladophora glomerata</i>	5	3
					<i>Tridontium tasmanicum</i>	1	1
					<i>Oscillatoria</i> sp.	-	1
34	18	8.5	r	6	<i>Enteromorpha nana</i>	10	3
					<i>Cladophora glomerata</i>	5	3
					<i>Tridontium tasmanicum</i>	1	1
					<i>Oscillatoria</i> sp.	-	1
36	19	8.5	r	6	<i>Cladophora glomerata</i>	10	6
38	20	8.5	r	6	<i>Cladophora glomerata</i>	10	6
40	21	9.0	r	5	<i>Cladophora glomerata</i>	10	5
42	22	8.5	r	5	<i>Cladophora glomerata</i>	10	5
44	23	7.5	s/g	0	-		
46	24	7.5	s/g	0	-		
48	25	7.5	s/g	3	<i>Cladophora glomerata</i>	5	3
50	26	7.5	s/g	3	<i>Cladophora glomerata</i>	5	3
					<i>Vaucheria</i> sp	5	1
52	27	5.5	s/g	3	<i>Cladophora glomerata</i>	5	3
					<i>Vaucheria</i> sp	5	1
54	28	5.5	s/g	5	<i>Cladophora glomerata</i>	10	5
56	29	4.5	s/g	5	<i>Cladophora glomerata</i>	10	3
					<i>Vaucheria</i> sp	5	2
58	30	3.0	s/g/r	5	<i>Enteromorpha nana</i>	100	5
					<i>Tridontium tasmanicum</i>	1	1
60	31	2.8	s/g/r	3	<i>Enteromorpha nana</i>	50	3
					<i>Tridontium tasmanicum</i>	1	1
					<i>Cladophora glomerata</i>	5	1
62	32	2.6	s/g/r	3	<i>Enteromorpha nana</i>	50	3
					<i>Tridontium tasmanicum</i>	1	1
					<i>Cladophora glomerata</i>	5	1
64	33	2.4	s/g	0	-		
66	34	1.8	g/s	1	<i>Tridontium tasmanicum</i>	3	1
					<i>Enteromorpha nana</i>	10	1
68	35	2.5	g/s	0	-		
70	36	2.8	g/s	0	-		
72	37	1.3	b/g/s	4	<i>Tridontium tasmanicum</i>	3	1
					<i>Cladophora glomerata</i>	20	4
74	38	1.0	b/g/s	3	<i>Tridontium tasmanicum</i>	5	1
					<i>Enteromorpha nana</i>	10	1
					<i>Fissidens rigidulus</i>	5	1
					<i>Cladophora glomerata</i>	<5	3
76	39	0.5	b/g/s	4	<i>Tridontium tasmanicum</i>	5	1
					<i>Fissidens rigidulus</i>	5	1
					<i>Nitella hyalina</i>	5	1
					<i>Cladophora glomerata</i>	5	3
					<i>Nostoc</i> spp.	5	1

78 40 0.0 g/s/m 3 *Enteromorpha nana* 10 3

Transect Number 5- winter

00	01	0.0	m/s	6	<i>Enteromorpha nana</i> <i>Glossostigma spp.</i>	50 1	6 1
02	02	1.0	s/m	6	<i>Enteromorpha nana</i> <i>Cladophora glomerata</i>	50 20	4 3
04	03	2.3	s/b	2	<i>Enteromorpha nana</i> <i>Tridontium tasmanicum</i>	20 2	2 1
06	04	3.0	s/b	3	<i>Cladophora glomerata</i>	20	3
08	05	3.4	b/s	6	<i>Cladophora glomerata</i>	10	6
10	06	3.3	b/s	6	<i>Cladophora glomerata</i>	20	6
12	07	5.5	b/s	6	<i>Cladophora glomerata</i>	20	6
14	08	6.0	b/s	6	<i>Cladophora glomerata</i>	10	6
20	11	6.0	b/s	5	<i>Cladophora glomerata</i>	20	5
18	10	6.0	g/s	-			
16	09	6.0	g/s	-			
22	12	6.0	b/s	6	<i>Cladophora glomerata</i>	10	6
24	13	5.5	b/s	6	<i>Oscillatoria sp</i> <i>Cladophora glomerata</i>	1 10	1 5
26	14	6.5	b/s	6	<i>Cladophora glomerata</i>	10	6
28	15	6.0	b/s	6	<i>Cladophora glomerata</i>	10	6
30	16	7.0	b/s	6	<i>Cladophora glomerata</i>	10	6
32	17	7.0	b/s	-			
34	18	6.0	r/g	-			
36	19	5.5	b/g	6	<i>Cladophora glomerata</i>	10	6
38	20	5.5	r/g	6	<i>Tridontium tasmanicum</i> <i>Cladophora glomerata</i> <i>Enteromorpha nana</i>	2 10 10	2 4 3
40	21	4.0	r/g	6	<i>Cladophora glomerata</i>	15	5
42	22	2.5	r/g	6	<i>Cladophora glomerata</i> <i>Enteromorpha nana</i> <i>Tridontium tasmanicum</i>	10 10 2	3 3 2
44	23	2.5	r/g	5	<i>Cladophora glomerata</i>	15	5
46	24	2.5	r/g	5	<i>Cladophora glomerata</i>	10	5
48	25	2.5	r/g/p	6	<i>Cladophora glomerata</i>	15	5
50	26	2.5	r/g/p	6	<i>Cladophora glomerata</i>	10	6
52	27	2.5	r/g/p	6	<i>Cladophora glomerata</i> <i>Vaucheria sp</i>	10 5	4 2

54	28	2.5	r/g	6	<i>Cladophora glomerata</i> <i>Vaucheria sp</i>	10 5	3 3
56	29	2.5	b/g	6	<i>Cladophora glomerata</i> <i>Vaucheria sp</i>	10 5	2 5
58	30	2.5	b/g	6	<i>Cladophora glomerata</i> <i>Vaucheria sp</i>	10 5	3 3
60	31	2.5	r/g	3	<i>Cladophora glomerata</i> <i>Vaucheria sp</i>	5 5	2 1
62	32	2.0	r/g	3	<i>Cladophora glomerata</i> <i>Vaucheria sp</i>	5 5	1 3
64	33	2.0	b/g	5	<i>Cladophora glomerata</i> <i>Vaucheria sp</i>	5 5	1 3
66	34	1.5	m/g	5	<i>Ghomphonema sp.</i> <i>Enteromorpha nana</i>	10 10	3 2
68	35	1.5	m/s	6	<i>Enteromorpha nana</i>	100	6
70	36	0.0	m/s	6	<i>Glossostigma elatinoides</i> <i>Myriophyllum pedunculatum</i> <i>Enteromorpha nana</i>	1 3 100	4 1 4

APPENDIX 4 Transect Survey (summer) Summary Table

324

Key:



not recorded

*Dominant form is epiphytic and/or epilithic/epipellic algae.

N/A = not applicable

N/M = not measured

neg. = negligible

River Section	1			2A		2B		2C		
Transect Number	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩
Frequency of Occurrence	18/25	23/23	6/36	1/39						
% Frequency	72	100	16	3						
Oedogonium Maximum Cover Class	2	3	1	5						
Median Cover Class	1	1	1	N/A						
Epiphytic										
Epilithic /Epipellic										
Maximum Local Standing Crop (g. dry wt. m ⁻²)	35	28	neg	320						
Frequency of Occurrence	19/25	3/23	2/36	8/39						
% Frequency	76	13	5	21						
Nostoc Maximum Cover Class	2	1	1	1						
Median Cover Class	1	1	1	1						
Epiphytic										
Epilithic /Epipellic										
Maximum Local Standing Crop (g. dry wt. m ⁻²)	84	21	neg	neg						
Frequency of Occurrence	1/25			20/39	20/36	12/41	4/29	9/37	27/33	12/37
% Frequency	4			51	56	22	14	22	82	32
Enteromorpha Maximum Cover Class	1			5	4	2	4	2	4	1
Median Cover Class	N/A			3-4	2	1	2	1-2	1	1
Epiphytic										
Epilithic /Epipellic										
Maximum Local Standing Crop (g. dry wt. m ⁻²)	neg			435	166	135	N/M	286	800	1008
Frequency of Occurrence				28/39	31/36	35/41	25/29	19/37	27/33	23/27
% Frequency				71	86	86	86	51	82	85
Cladophora Maximum Cover Class				4	6	5	5	5	4	5
Median Cover Class				1	5	4	4	1	1	3
Epiphytic										
Epilithic /Epipellic										
Maximum Local Standing Crop (g. dry wt. m ⁻²)				1226	>430	820	820	800	>190	560

Note: Maximum local standing crop given may either be sampled directly from the transect or in the immediate vicinity of the transect -refer to transect descriptions.

APPENDIX 5 Transect Survey (winter) Summary Table

325

Key:



not recorded

*Dominant form is epiphytic and/or epilithic/epipelic algae.

N/A = not applicable

N/M = not measured

neg. = negligible

River Section		1			2A		2B		2C		
Transect Number		①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩
Frequency of Occurrence			19/26								
% Frequency			73								
Oedogonium	Maximum Cover Class		3								
	Median Cover Class		1								
Epiphytic											
Epilithic /Epipelic											
Maximum Local Standing Crop (g. dry wt. m ⁻²)			20								
Frequency of Occurrence			5/26		1/40						
% Frequency			19		3						
Nostoc	Maximum Cover Class		1		1						
	Median Cover Class		1		1						
Epiphytic											
Epilithic /Epipelic											
Maximum Local Standing Crop (g. dry wt. m ⁻²)			9		neg						
Frequency of Occurrence					14/40	8/36					
% Frequency					35	22					
Enteromorpha	Maximum Cover Class				6	6					
	Median Cover Class				3	3-4					
Epiphytic											
Epilithic /Epipelic											
Maximum Local Standing Crop (g. dry wt. m ⁻²)					414	205					
Frequency of Occurrence					27/40	27/36					
% Frequency					66	75					
Cladophora	Maximum Cover Class				6	6					
	Median Cover Class				3	5					
Epiphytic											
Epilithic /Epipelic											
Maximum Local Standing Crop (g. dry wt. m ⁻²)					143	553					

APPENDIX 6 :Gorham's medium

Gorham's medium as used contained :

Compound	Amount (mg l ⁻¹)
NaNO ₃	4 96
K ₂ HPO ₄	39
MgSO ₄ .7H ₂ O	75
CaCl ₂ .2H ₂ O	36
Na ₂ SiO ₃ .9H ₂ O	58
Na ₂ CO ₃	20
ferric citrate	6
citric acid	6
EDTA	1

from Fitzgerald and Nelson (1966).

The ph of the medium was 8.5 and was made up in 20 litre batches.

The malachite green-molybdate assay was modified from Motomiyu et al (1983) by Dr. P.R. Poole MAF, Ruakura (pers comm.).

This assay was employed in the analysis of PO₄ concentration in the Extractive Phosphorous and Phosphate Uptake Rate nutrient availability tests.

METHOD

Reagents:

1. Malachite green 0.91g l⁻¹
3. PVA 1g(100ml)⁻¹
(hot water soluble SIGMA Cat. # P1763)
4. conc. H₂SO₄

Reagent Mixtures:

Solution A; Mix 200 ml of (1)
 125 ml of (4)
 300 ml of (2),

in that order. Store in a amber glass bottle..

Solution B ;Dissolve PVA by heating to boiling.

ASSAY METHODQD

1. Take a 2 ml sample of solution to be tested.
2. Make up four blank standards;

Blank	μgPml^{-1}	dist. H_2O
1	0.0	2.0
2	0.2	1.8
3	0.4	1.6
4	0.6	1.4

Add to all tubes including blanks:

- 0.333 ml of Solution A
- 0.333 ml of Solution B

Allow 30 minutes for colour to stabilise at 18-25 °C. Samples were read using a Cecil Instruments CE 29Z Digital UV Spectrophotometer at 630nm.

The results from standard tubes were graphed and a regression line fitted to the data for conversion of absorbancies to PO_4 concentration.

APPENDIX 8.**NITROPRUSSIDE/PHENOL HYPOCHLORITE METHOD FOR NH₄ ASSAY**

This assay follows that described in Brown (1973) and was used in the analysis of NH₄ concentration in the Ammonium Absorption Rate test.

Reagents:- (A). Dissolve 10g of phenol in 800ml of distilled water.

Add 0.08g sodium nitroprusside.

Dissolve and dilute to 1 litre volume, mix well.

(B) Dissolve 5.5g of sodium hydroxide in 800ml of distilled water.

Add 32ml of Janola

Dilute to 1 litre volume, mix well.

STANDARDS: 5 and 10 ppm N as NH₄⁺.

METHOD

Take a 0.45 ml aliquot of each sample to be assayed. Add 2.5 ml of phenol reagent (A).and 2.5 ml of hypochlorite reagent (B). Mix well and leave for at least 15 minutes at room temperature. read the absorbance of samples at 625 nm. Samples were read on a Cecil Instruments CE 29Z Digital UV Spectrophotometer.

APPENDIX 9

Tables i to vii contain results from the Nutrient Availability Tests (TTN, TTP, AUR, PUR, APA, EP, water and site data) Monitoring Data for *Oedogonium*, *Enteromorpha* and *Cladophora* form the Upper Waikato River, May 1989-January 1990. For location of sampling sites see Figure 36.

Table i Total Tissue Nitrogen (%N) Monitoring Data for *Oedogonium*, *Enteromorpha* (Transect 4 &5) and *Cladophora* (Transect 4 & 5) from May, 1989 - January, 1990.

Species	Oedogonium-T2		Enteromorpha-T4		Cladophora-T4		Enteromorpha-T5		Cladophora-T5	
	mean	90% CI	mean	90% CI	mean	90% CI	mean	90% CI	mean	90% CI
Time										
29/5/89	0.24	0.14	0.97	0.55	3.60	0.36	3.47	0.45	2.56	0.74
06/6/89	0.47	0.02	1.85	0.98	2.80	1.32	2.40	2.96	1.21	2.33
12/6/89	0.48	0.52	3.06	0.56	3.48	0.66	3.83	0.16	2.85	2.43
27/6/89	0.33	0.02	2.00	0.92	2.51	0.54	3.84	0.90	2.69	0.46
04/7/89	0.56	0.11	1.16	0.62	2.44	0.29	3.83	0.31	3.38	0.86
11/7/89	0.57	0.16	1.17	0.09	1.42	0.45	3.68	0.22	2.79	0.54
18/7/89	0.87	1.23	1.20	0.19	1.99	0.53	3.72	0.22	3.50	1.31
25/7/89	--	-	1.63	0.34	2.80	1.26	4.01	0.06	3.34	0.94
01/8/89	-	-	-	-	-	-	-	-	-	-
08/9/89	-	-	-	-	-	-	2.43	0.70	2.19	0.64
15/9/89	-	-	-	-	-	-	4.03	0.29	3.23	3.14
8/10/89	-	-	-	-	-	-	-	-	-	-

Note: -90% CI = +/-90% confidence interval.

-Units=% N

-For location of sampling sites see Figure 36.

Table ii Total Tissue Phosphorus (%P) Monitoring Data for *Oedogonium*, *Enteromorpha* (Transect 4 &5) and *Cladophora* (Transect 4 & 5) from May, 1989 - January, 1990.

Species	Oedogonium-T2		Enteromorpha-T4		Cladophora-T4		Enteromorpha-T5		Cladophora-T5	
	mean	90% CI	mean	90% CI	mean	90% CI	mean	90% CI	mean	90% CI
Time										
29/5/89	0.14	0.12	0.08	0.02	0.24	0.07	0.18	0.05	0.14	0.07
06/6/89	0.05	0.01	0.19	0.19	0.17	0.17	0.14	0.15	0.08	0.11
12/6/89	0.06	0.06	0.14	0.05	0.14	0.09	0.22	0.10	0.22	0.29
27/6/89	0.33	0.11	0.13	0.13	0.16	0.27	0.20	0.09	0.26	0.15
04/7/89	0.09	0.05	0.11	0.04	0.19	0.09	0.24	0.04	0.21	0.06
11/7/89	0.07	0.03	0.09	0.04	0.09	0.04	0.20	0.03	0.16	0.06
18/7/89	0.16	0.17	0.08	0.03	0.12	0.05	0.28	0.04	0.19	0.06
25/7/89	--	-	0.13	0.01	0.21	0.09	0.25	0.04	0.19	0.05
01/8/89	-	-	-	-	-	-	-	-	-	-
08/9/89	-	-	-	-	-	-	0.24	0.09	0.23	0.01
15/9/89	-	-	-	-	-	-	0.31	0.06	0.25	0.24
8/10/89	-	-	-	-	-	-	-	-	-	-

Note: -90% CI = +/-90% confidence interval.

-Units = %P.

-For location of sampling sites see Figure 36.

Table iii Ammonium Uptake Rate (AUR) Monitoring Data for *Oedogonium*, *Enteromorpha* (Transect 4 & 5) and *Cladophora* (Transect 4 & 5) from May, 1989 - January, 1990.

Species	Oedogonium-T2			Enteromorpha-T4			Cladophora-T4			Enteromorpha-T5			Cladophora-T5			Vaucheria-T5			Cladophora-T2		
	mean	90% CI		mean	90% CI		mean	90% CI		mean	90% CI		mean	90% CI		mean	90% CI		mean	90% CI	
Time																					
29/5/89	113.63	10.14		32.45	8.56		46.61	8.17		38.69	5.15		61.73	3.82		-	-		-	-	
06/6/89	143.70	4.39		50.36	17.19		35.13	4.30		41.53	1.74		66.16	8.83		-	-		-	-	
12/6/89	124.63	3.62		54.99	0.50		68.55	4.92		40.22	8.04		58.93	10.49		-	-		-	-	
27/6/89	144.16	20.34		25.74	5.76		42.52	17.08		91.26	15.24		99.16	11.61		-	-		-	-	
04/7/89	-	-		--	-		-	-		-	-		-	-		-	-		-	-	
11/7/89	151.53	23.85		37.52	8.08		57.87	6.72		30.00	5.04		69.85	15.87		-	-		-	-	
18/7/89	118.10	1.82		16.17	1.82		55.05	8.82		20.64	4.08		70.69	13.05		-	-		-	-	
25/7/89	156.99	13.74		29.16	8.20		38.66	10.31		24.00	5.35		38.41	2.15		-	-		-	-	
01/8/89	118.07	13.70		35.10	5.82		39.75	10.03		39.31	4.05		51.94	4.36		-	-		-	-	
08/9/89	-	-		-	-		-	-		28.10	7.53		14.53	3.65		-	-		-	-	
15/9/89	-	-		-	-		-	-		72.65	11.12		26.29	4.87		-	-		-	-	
8/10/89	-	-		9.33	0.70		12.40	2.16		33.70	4.73		11.57	2.75		20.96	12.54		13.54	0.33	
12/1/90	27.87	0.76		11.89	1.63		14.31	2.91		8.00	1.99		8.76	0.48		-	-		-	-	
19/1/90	19.17	3.91		15.84	1.86		17.17	2.69		14.31	0.65		13.47	2.69		-	-		-	-	
26/1/90	16.14	3.85		15.47	1.70		21.21	3.50		15.26	1.91		15.64	1.93		-	-		-	-	

Note; - 90% CI= +/-90% confidence interval.

-Units= ug N 10mg⁻¹hr.⁻¹

-For location of monitoring sites see Figure36.

Table iv Phosphate Uptake Rate (PUR) Monitoring Data for *Oedogonium*, *Enteromorpha* (Transect 4 &5) and *Cladophora* (Transect 4 & 5) from May, 1989 - January, 1990.

Species Time	Oedogonium-T2			Enteromorpha-T4			Cladophora-T4			Enteromorpha-T5			Cladophora-T5			Vaucheria-T5			Cladophora-T2		
	mean	90% CI		mean	90% CI		mean	90% CI		mean	90% CI		mean	90% CI		mean	90% CI		mean	90% CI	
29/5/89	14.81	4.67		6.88	4.31		11.01	1.49		4.05	1.96		9.00	2.05		-	-		-	-	
06/6/89	27.73	5.62		12.56	7.71		12.87	7.45		6.86	1.60		15.54	5.45		-	-		-	-	
12/6/89	17.72	3.09		-0.06	0.08		-0.49	0.29		-0.08	0.28		1.22	1.06		-	-		-	-	
27/6/89	16.85	4.23		10.77	3.02		6.21	2.78		9.18	4.29		17.00	9.73		-	-		-	-	
04/7/89	18.18	4.88		8.13	7.70		8.58	0.59		4.14	0.45		9.42	1.34		-	-		-	-	
11/7/89	-2.10	1.19		0.39	1.08		2.78	2.86		0.98	1.98		-2.17	3.30		-	-		-	-	
18/7/89	18.20	5.53		3.36	0.92		6.92	3.40		4.03	1.28		9.10	3.84		-	-		-	-	
25/7/89	19.13	1.41		4.80	1.34		5.31	1.09		4.30	1.36		5.56	1.40		-	-		-	-	
01/8/89	19.65	1.93		6.80	0.73		6.98	3.13		8.06	1.04		6.92	3.61		-	-		-	-	
08/9/89	-	-		-	-		-	-		1.52	2.57		1.26	1.07		-	-		-	-	
15/9/89	-	-		-	-		-	-		1.06	0.37		1.32	0.29		-	-		-	-	
8/10/89	-	-		3.08	0.70		1.37	0.53		4.46	2.02		1.94	0.17		0.08	0.61		2.86	0.40	

Note; - 90% CI= +/-90% confidence interval.

-Units= ug P (10mg)⁻¹hr⁻¹.

-For location of monitoring sites see Figure36.

Table v Alkaline Phosphatase Activity (APA) Monitoring Data for *Oedogonium*, *Enteromorpha* (Transect 4 &5) and *Cladophora* (Transect 4 & 5) from May, 1989 - January, 1990.

Species	Oedogonium-T2			Enteromorpha-T4			Cladophora-T4			Enteromorpha-T5			Cladophora-T5			Vaucheria-T5			Cladophora-T2		
	mean	90% CI		mean	90% CI		mean	90% CI		mean	90% CI		mean	90% CI		mean	90% CI		mean	90% CI	
Time																					
29/5/89	276.18	204.71		58.04	39.83		94.12	87.75		32.98	11.44		63.53	12.02		-	-		-	-	
06/6/89	81.60	26.17		19.10	14.07		39.98	60.82		11.94	6.12		23.41	0.37		-	-		-	-	
12/6/89	30.38	36.60		24.74	0.78		66.06	7.79		24.08	5.37		49.95	6.14		-	-		-	-	
27/6/89	233.97	99.92		34.09	12.77		45.47	2.42		37.16	20.17		54.03	10.11		-	-		-	-	
04/7/89	104.20	29.83		3.96	2.16		34.24	18.43		6.64	5.35		30.44	13.37		-	-		-	-	
11/7/89	93.39	28.29		9.69	1.47		60.48	65.32		8.03	3.91		27.64	2.60		-	-		-	-	
18/7/89	15.17	7.85		8.54	5.24		66.57	33.74		58.74	37.55		166.08	94.12		-	-		-	-	
25/7/89	92.34	100.39		9.75	0.52		19.08	2.18		21.61	12.26		13.89	3.09		-	-		-	-	
01/8/89	58.37	23.56		6.31	1.19		41.53	24.54		16.63	5.76		57.57	19.81		-	-		-	-	
08/9/89	-	-		-	-		-	-		6.42	3.33		15.08	6.60		-	-		-	-	
15/9/89	-	-		-	-		-	-		2.14	0.36		13.06	2.12		-	-		-	-	
8/10/89	-	-		2.66	0.48		6.28	1.62		3.70	1.63		3.33	1.68		5.13	3.49		12.76	5.79	
12/1/90	16.59	6.12		7.82	0.33		11.24	1.49		5.20	1.55		7.00	3.14		-	-		-	-	
19/1/90	10.05	0.62		4.55	0.50		12.93	1.88		4.10	0.51		14.25	0.75		-	-		-	-	
26/1/90	17.68	11.61		1.64	0.70		8.41	6.10		3.58	1.83		12.00	8.70		-	-		-	-	

Note: -90% CI = +/-90% Confidence Interval.

-APA units = enz. units (mg dw algae)⁻¹.

-For location of monitoring sites see Figure 36.

Table vi Extractive Phosphorus (%) Monitoring Data for *Oedogonium*, *Enteromorpha* (Transect 4 &5) and *Cladophora* (Transect 4 & 5) from May, 1989 - January, 1990.

Species	Oedogonium-T2			Enteromorpha-T4			Cladophora-T4			Enteromorpha-T5			Cladophora-T5			Vaucheria-T5			Cladophora-T2		
	mean	90%CI		mean	90%CI		mean	90%CI		mean	90%CI		mean	90%CI		mean	90%CI		mean	90%CI	
Time																					
29/5/89	0.277	0.271		0.019	0.013		0.030	0.025		0.029	0.007		0.083	0.028		-	-		-	-	
06/6/89	0.113	0.010		0.117	0.085		0.141	0.032		0.143	0.023		0.102	0.051		-	-		-	-	
12/6/89	0.033	0.013		0.024	0.012		0.041	0.010		0.057	0.009		0.083	0.017		-	-		-	-	
27/6/89	0.227	0.033		0.082	0.028		0.133	0.030		0.130	0.065		0.145	0.025		-	-		-	-	
04/7/89	0.109	0.062		0.066	0.029		0.098	0.054		0.089	0.049		0.075	0.008		-	-		-	-	
11/7/89	0.141	0.022		0.091	0.023		0.173	0.097		0.096	0.019		0.165	0.119		-	-		-	-	
18/7/89	0.034	0.002		0.060	0.029		0.054	0.033		0.068	0.003		0.093	0.023		-	-		-	-	
25/7/89	0.061	0.018		0.052	0.015		0.105	0.073		0.046	0.022		0.106	0.134		-	-		-	-	
01/8/89	0.028	0.023		0.030	0.005		0.057	0.033		0.049	0.024		0.064	0.036		-	-		-	-	
08/9/89	-	-		-	-		-	-		0.059	0.015		0.038	0.013		-	-		-	-	
15/9/89	-	-		-	-		-	-		0.044	0.008		0.034	0.012		-	-		-	-	
8/10/89	-	-		0.284	0.055		0.176	0.151		0.371	0.134		0.318	0.063		0.318	0.093		0.196	0.091	

Note: -90% CI= +/-90% confidence interval

-Units= %P

-For location of monitoring sites see Figure 36.

Table vii. Upper Waikato River Water Analyses Monitoring data from algal collection sites (Transects 2, 4 and 5) from May 1989 - January 1990.

Date	T2 DRP	T4 DRP	T5 DRP	T2 NH4-N	T4 NH4-N	T5 NH4-N	T2 NO3-N	T4 NO3-N	T5 NO3-N
29/05/89	0.51	0.42	2.17	4.10	3.59	8.21	0.44	0.83	2.32
06/06/89	0.35	0.23	1.64	6.15	2.05	6.15	0.86	0.17	1.04
12/06/89	0.59	0.93	2.86	11.80	7.18	8.21	1.18	1.34	2.27
27/06/89	0.48	0.39	3.52	5.13	5.13	11.8	0.28	0.86	2.67
04/07/89	0.48	1.02	2.03	6.15	8.21	5.64	1.19	0.47	1.43
11/07/89	0.29	0.26	1.77	4.87	3.85	5.38	0.18	0.47	1.43
18/07/89	0.26	0.24	2.59	3.08	3.08	10.26	0.52	0.75	1.40
25/07/89	0.71	0.17	2.74	5.13	2.05	11.28	0.80	0.51	1.33
01/08/89	0.41	0.56	2.28	7.18	9.23	9.74	0.79	1.44	1.55

Note: all values are reported as mg m⁻³. For location of sites see Figure 36.

APPENDIX 10

Mean Coefficients of Variation for Nutrient Availability Tests for the Monitoring Period (May, 1989 - Jan, 1990), Upper Waikato River. Values obtained are compared to those of Freeman (1986)

Date	TTN	TTP	AAR	PUR	EP	APA
29-05-89	11.26	15.32	8.91	12.74	22.25	20.61
06-06-89	28.76	32.17	8.26	14.08	12.17	23.39
12-06-89	16.09	16.09	6.01	49.76	10.70	12.10
27-06-89	7.88	25.68	7.20	14.37	9.81	11.28
04-07-89	8.16	13.14	-	10.92	15.78	18.61
11-07-89	6.34	12.25	10.90	56.48	15.48	16.58
18-07-89	16.53	15.62	8.26	12.62	13.99	20.24
25-07-89	8.50	8.54	11.27	8.02	21.85	14.56
01-08-89	-	-	8.97	9.22	18.60	7.41
08-09-89	13.38	13.31	16.01	10.16	10.90	17.01
15-09-89	17.89	19.40	10.45	25.59	8.92	5.89
18-10-89	-	-	12.84	56.03	14.07	14.86
12-01-89	11.61	8.35	8.27	-	-	9.19
19-01-89	7.04	12.86	9.06	-	-	3.12
26-01-90	11.52	9.09	9.39	-	-	21.29
Mean	12.70	15.52	9.05	23.33	14.54	14.41
Freeman	20	20	25	30	15	20

Alage Transplant Experiment Results Summary Table, Upper Waikato River, September 1989.

Sample Code	TTP		TTN		PUR		AUR		EP		APA	
	mean	90%CI	mean	90%CI	mean	90%CI	mean	90%CI	mean	90%CI	mean	90%CI
8/9/89												
above TB-PCPdischarge												
Cladophora	0.09	0.09	1.19	0.22	0.95	0.43	32.27	1.07	0.083	0.010	16.72	0.40
Enteromorpha	0.08	0.04	2.14	2.78	0.83	0.19	30.77	4.90	0.023	0.008	5.90	1.17
below TB-PCP discharge												
Cladophora	0.15	0.23	2.11	1.81	1.27	0.69	41.14	14.11	0.053	0.020	9.15	5.51
Enteromorpha	0.58	0.11	4.99	1.97	1.10	0.17	26.85	6.05	0.041	0.016	7.73	2.94
in-situ populations												
Cladophora	0.23	0.01	2.79	0.64	1.32	0.29	28.10	7.53	0.059	0.013	15.08	6.60
Enteromorpha	0.24	0.09	4.03	0.29	1.06	0.37	31.90	2.56	0.038	0.015	6.42	3.33
15/9/89												
below TB-PCPdischarge												
Cladophora	0.07	0.02	1.19	0.22	5.73	1.56	74.10	4.74	0.090	0.072	10.07	3.85
Enteromorpha	0.08	0.01	1.24	0.21	5.85	3.07	27.18	3.46	0.030	0.006	2.32	0.48
below TB-PCP discharge												
Cladophora	0.07	0.01	2.38	0.35	3.26	2.06	42.26	10.48	0.049	0.010	8.76	1.73
Enteromorpha	0.42	0.36	4.02	1.18	3.79	0.34	19.91	0.80	0.044	0.022	4.27	1.22
in-situ populations												
Cladophora	0.25	0.24	3.23	3.14	1.26	1.07	33.66	6.13	0.044	0.012	13.06	2.12
Enteromorpha	0.31	0.06	2.43	0.70	4.34	2.57	14.53	3.65	0.034	0.008	2.14	0.36

Note: -90% CI= +/-90% confidence interval

-For location of sampling locations see Figure37.