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INTERACTIONS OF EFFLUENTS WITH
A RIVER SYSTEM

A thesis presented in partial fulfilment of the
requirement for the degree

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ABSTRACT

The lower Oroua River, Manawatu, was studied during the 1977-1978 summer and 1978 autumn to determine what effect two waste discharges had on the quality of the river.

The two discharges were both organic in nature, one being effluent from Thomas Borthwick & Sons (Feilding) meatworks and the other was the effluent from the Feilding Borough Council sewage treatment plant. Both wastes had been biologically treated, Borthwick's wastes by ponding and the Feilding domestic sewage by trickling filtration.

Chemical, microbiological and biological parameters were considered with respect to the effect that the effluents had on the river. The chemical parameters studied were dissolved oxygen, pH, BOD, COD, suspended solids, total kjeldahl nitrogen, nitrate, total phosphorus and orthophosphate. Broad microbiological groups of proteolytic, lipolytic and saccharolytic bacteria were used to quantify the microbiological effects while a brief study was also made on the presumptive and faecal coliforms. The macro-invertebrates and benthic algae were the biological factors studied.

The results showed the Borthwick's effluent to be of very high quality and having minimal effect on the Oroua River. In comparison, the Feilding domestic sewage was of poor quality and it appeared that the trickling filter was seriously overloaded. Consequently this discharge had a pronounced effect on the Oroua River. Most of the chemical parameters were affected by this discharge as were the microbiological densities. The growth of algae did not appear to be influenced by any nutrient input by the discharges.

During daylight hours the high amount of algal photosynthesis more than compensated for the oxygen demand from degradation of organic matter below the Feilding domestic sewage and supersaturated dissolved oxygen levels were recorded. However, at night the combination of this oxygen demand and that of algal respiration resulted in severe oxygen deficits.

The structure of the macroinvertebrate communities in the Oroua River upstream of the 2 discharges had changed imperceptibly since 1956 (Pol. Adv. Council, 1957). The macroinvertebrate community structure below the Borthwick's meatworks discharge indicated that the river quality had improved substantially since 1956 while the community below the sewage discharge showed that the river recovered in a shorter flow distance. The chemical results were found to corroborate the macroinvertebrate results.

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LIST OF ABBREVIATIONS

B.O.D.	Biochemical oxygen demand (g/m^3)
BI	Biotic index (Trent)
b (subscripted)	Benthic conditions
C	Dissolved oxygen concentration (g/m^3)
C_c	Critical dissolved oxygen concentration (g/m^3)
C_0	Saturation dissolved oxygen concentration (g/m^3)
C.O.D.	Chemical oxygen demand (g/m^3)
D.O.	Dissolved oxygen (g/m^3)
H	Stream depth (m)
IDI	Diversity index based on information theory
K	Reaeration constant ($\text{g}/\text{m}^3/\text{unit time}$)
K'	Average reaeration constant ($\text{g}/\text{m}^2/\text{unit time}$)
K_1	Deoxygenation coefficient (time^{-1})
K_a	Deoxygenation coefficient in benthic sediments (time^{-1})
K_b	Bacterial death rate coefficient (time^{-1})
K_{COD}	Decline rate constant for C.O.D. (time^{-1})
K_{KN}	Decline rate constant for kjeldahl nitrogen (time^{-1})
L	B.O.D. concentration (g/m^3)
LDI	Diversity index based on logarithmic series
L_0	Initial B.O.D. concentration (g/m^3)
N	Bacterial density (no/100 ml)
N	Number of macroinvertebrates
N_i	Number of macroinvertebrates in ith specie
N_0	Initial bacterial density (no/100 ml)
P	Productivity (or photosynthesis) ($\text{g}/\text{m}^3/\text{unit time}$)
P'	Average productivity (or photosynthesis) ($\text{g}/\text{m}^3/\text{unit time}$)
P	Period of day
P_m	Peak productivity rate ($\text{g}/\text{m}^2/\text{unit time}$)
Q_e	Rate of change in D.O. at dusk ($\text{g}/\text{m}^3/\text{unit time}$)
Q_m	Rate of change in D.O. at dawn ($\text{g}/\text{m}^3/\text{unit time}$)
R	Respiration ($\text{g}/\text{m}^3/\text{unit time}$)
R'	Average respiration ($\text{g}/\text{m}^2/\text{unit time}$)
R	Redundancy (biotic results)
S	Number of macroinvertebrate species
SCI	Sequential comparison index
S_e	Percent D.O. saturation at dusk
S_m	Percent D.O. saturation at dawn

t	time (hours or days)
T	Temperature °C
\bar{T}	Average annual temperature °C
t_1	Time for start of photosynthesis
t_c	Critical time in D.O. sag curve
V	Velocity m/s
w/v	Weight/volume
Y	Daily oxygen demand at a point in a river (g/m ³ /day)
Y'	Average daily oxygen demand at a point in a river (g/m ² /day)

1. INTRODUCTION

1.1 Rationale

The intrinsic uses of rivers are those of a transport medium in the hydrological cycle and an environment to support aquatic communities. With the colonization of New Zealand, its rivers have received many new uses, some of which conflict with each other or with the intrinsic uses. The main river uses of concern nowadays are those relating to aquatic ecology, water supplies, recreation and, regrettably, waste disposal. Rivers receive wastes from many inland towns and industries, much of which has undergone only minimal treatment.

The 1967 Water and Soil Conservation Act was established so as to manage, via Catchment Authorities, the many conflicting uses and thus to compromise between the various ecological, economic, sociological and engineering aspects. To date there has been little New Zealand data on which to base management decisions concerning waste discharges and Catchment Authorities have had to rely mainly on overseas experiences, assuming these to be applicable to the New Zealand situation.

The Oroua River is typical of many rivers in New Zealand in both its nature and its uses. It is a swift, shallow stream and has a shingle bed on which benthic algae develop in the summer months. The waters of the Oroua River are used for water supplies, for recreation and for receiving waste effluents from a meat works and a domestic sewage treatment plant. This river thus offers an ideal opportunity to show how the waste effluents affect the microbiology, biology and chemistry of the waters hence providing another New Zealand example to use when making management decisions.

1.2

Objectives of the Study

The Oroua River, a major tributary of the Lower Manawatu River was studied during the 1977-1978 summer and 1978 autumn to determine what effect two effluents had on the river in terms of chemical, microbiological and biological parameters.

The chemical parameters studied were the dissolved oxygen, pH, biochemical oxygen demand (BOD), chemical oxygen demand (COD), orthophosphate, total phosphorus, nitrate and kjeldahl nitrogen. Parameters such as hardness, alkalinity and conductivity were not considered because these depend more upon the geological nature of the stream substrata rather than effluent discharges.

The microbiological parameters considered were the generalized biochemical groups of proteolytic, lipolytic and saccharolytic bacteria. In addition a brief study was made on the presumptive and faecal coliform numbers.

The biological parameters considered were the types of benthic macroinvertebrates and the structure of their community as well as the development of benthic algae.

In a general river study such as this, many varied objectives are possible and the ones considered in this study are listed below.

- (1) The quality of the water above any know discharge was studied and compared to the quality found at that site some 21 years previously, in 1956 (Pol. Adv. Council, 1957) to establish if there had been any

change over the years. Because of the limited nature of the 1956 study this comparison was restricted to macroinvertebrates and faecal coliform only.

- (2) The quality of the two discharges, the Feilding domestic sewage and the Borthwicks meatworks effluent, was determined. The concentrations of components of sites above and below each discharge were determined and compared to see whether or not that particular discharge significantly affected the water quality. Any noticeable change in water quality was then related to the effluent parameters.
- (3) The rates of organic and microbiological decline in the river were estimated so as to determine the self purification capacity of the river.
- (4) The growth of algae in the river was visually estimated and the growth of algae was considered with respect to the concentrations of nitrates and orthophosphates, the stream temperature and the stream flow to determine what factors influenced its development and decline.
- (5) Productivity analyses of the algae were made at 3 sites. This was to determine the net effect the algae had on the stream dissolved oxygen levels thus establishing whether benthic algae was a benefit or a liability to the stream.
- (6) The macroinvertebrate type, density and diversity were all considered with respect to the pollution levels at each site. Several different diversity indices were used and the most appropriate one for use in the Oroua River was determined.

This study thus provides information which will be useful in both water management and research fields. The information obtained on the quality of the river sites and effluents, the assimilative capacity of the river and the effect the present discharges are having on the river can be used by water engineers in both water use planning and pollution abatement decisions. As well this data provides a basis on which to compare the 1977-1978 river quality with either past or future river quality to determine long term changes in the quality of the Oroua River.

2.

REVIEW OF THE RELEVANT LITERATURE

In order to meet the above objectives, consideration must be given not only to the previous state of the Oroua River but also to findings of other investigators on other river systems so that the interpretation of the newly acquired data can be made in the light of recognised phenomena.

2.1

Background Water Quality

There is a growing body of literature on the physicochemical status of unpolluted waters in New Zealand. Table 1 summarizes the physicochemical and chemical composition of unpolluted reaches of the Tokomairiro (Scott, 1973), Wainui-O-Mata (Gibbs and Penny, 1973), Hutt (Davies and Shirley, 1976), Manawatu (Currie, 1977), Waimakariri (Winterbourne *et al.*, 1971) and Waikato (Elam, 1971) rivers and the Horokiwi Stream (Allen, 1951).

The natural pH of water may be between 6.7 and 8.6 although more acid conditions occur when rainfall flushes out peat bogs while photosynthesis may increase the pH (Anon, 1969a; Klein, 1959). The pH values for the rivers listed in Table 1 are well within these limits. Fish can exist in the range of 5 to 9 with maximum productivity occurring between 6.5 and 8.5 (Anon, 1969a). Bell (1971) studied the effect of pH on selected macroinvertebrates and found that while most of the macroinvertebrates tested were tolerant to a wide pH, the emergence of these organisms was more sensitive. Of the macroinvertebrates tested he found that the trichopterans were the most resistant, then the plecopterans and odonatans and the most sensitive were the Ephemeroptera.

TABLE 1 PHYSICOCHEMICAL STATUS OF SOME N.Z. RIVERS

	TOKO	WAINUI	HUTT	MANAWATU	WAIMAK	WAIKATO	HORO
BOD (TOTAL)	-	3.2	-	.9	.1-1.6	3	-
SS	1.0	-	-	2.6	-	-	-
DO	9.0	-	-	9.8	7.0-9.4	-	8.8
TEMPERATURE	-	-	-	20.2	13.8-16.6	-	-
SPEC. COND	-	-	-	208	83-122	-	-
pH	-	-	7.28	8.2	6.6-7.0	7.3	6.9
NITRATE-N	-	.15-.26	0.06	0.06	-	-	0.003
NITRITE-N	-	-	0.001	-	-	0.11	-
AMMONIA-N	0.015	-	0.07	0.03	-	0.046	0.18
PHOSPHATE-P	-	.003-.012	0.012	0.01	-	-	-

Units: Temperature °C, Spec. Cond. $\mu\text{mho/cm}$, otherwise g/m^3

Abbreviations:

- Toko : Tokomairiro
- Waimak : Waimakariri
- SS : Suspended Solids
- Spec. Cond : Specific Conductivity
- Wainui : Wainui-O-Mata
- Horo : Horokiwi
- DO : Dissolved oxygen

From various sources - see text.

Dissolved oxygen is an essential factor for a healthy aquatic environment. In New Zealand a minimum dissolved oxygen level of 6 g/m^3 is specified for receiving waters classified as A, B or C. All other receiving waters except SD and SE (which have no minima) have a limit of 5 g/m^3 . (Schedule to the 1967 Water and Soil Conservation Act.) The rivers listed in Table 1 have dissolved oxygen levels well above these minima.

The specific conductivity, alkalinity and hardness of a river depend mainly upon the geology of the stream bed. Streams in which feldspar rocks predominate show high levels of conductivity, alkalinity and hardness while streams that contain the more basic rocks show low levels of these species. Table 1 shows that the Manawatu River has a high specific conductivity whilst the Waimakariri River has a low specific conductivity which thus reflects the geology of the respective catchments.

The Schedule to the New Zealand Water and Soil Conservation Act (1967) specifies that all waters except those classified SD and SE (which are unspecified) must not have their natural water temperature altered by more than 3°C . The European Inland Fisheries Advisory Commission (E.I.F.A.C.) are more specific and state that to avoid high mortality of trout, winter and autumn water temperatures should not rise above 6°C , spring temperatures should not rise above 10°C and summer temperatures should be below 21°C (Anon, 1969b).

Large variations occur in the river temperatures because of the many factors influencing temperature. Hopkins (1971) followed the temperature change in the Hinau Stream, a tributary of the Mangatere Stream, Southern Wairarapa. Four periods of temperature change were found corresponding to the four seasons. The summer and winter seasons showed no prolonged trends and stayed either consistently high or low respectively. Spring and autumn were periods of continuous increase and decrease of water temperatures respectively. This data contradicts the temperature profile found by Walker and Lawson (1977) in the Latrobe River catchment, Victoria, Australia which was one of a complete sinewave. The Hinau Stream had a small annual temperature range when compared to the Kaituna Stream, Masterton. This is because the Kaituna Stream has a wider valley which hence provides more area

for insolation. The highest daily temperature in the Hinau Stream occurred between 1 and 3 p.m. while the lowest temperature varied with season. In summer the lowest temperature was later in the night than in winter. During daytime the stream temperature increased with the distance downstream. This was because the downstream water has had a longer period of insolation. Similarly, the maximum stream water temperature occurs downstream. At night, the stream temperature is almost constant throughout the stream length (Hopkins, 1971).

Suspended solids are intermediate between solids that readily settle to the river bottom and solids that are readily dissolved. They are held in suspension by the stream turbulence and can be organic or inorganic (Klein, 1962). High concentrations of suspended solids cause opacity and thus reduce photosynthesis and hinders fauna, such as fish, that hunt by sight. In addition, deposition of the suspended solids in stiller reaches can smother the benthic biota and usually causes the diverse clean water species to be replaced by burrowing and tube building animals (Hynes, 1963; Klein, 1962). The suspended solids from sewage or meat wastes are organic in nature (Klein, 1962).

Nitrate and phosphate concentrations vary widely between rivers. This variability relates to the land use, geology, slope and drainage properties of the catchment as well as the amount of fertilizer added (Hart, 1974). These nutrients will be discussed in a later section (2.4.1).

The Biochemical Oxygen Demand (BOD) of the rivers listed in Table 1 were mainly below 3 g/m^3 . The Royal Commission of Sewage Disposal, 1915, classified rivers of BOD up to 3 g/m^3 as ranging between very clean to fairly clean rivers. A BOD of 5 g/m^3 indicates doubtful purity while 10 g/m^3 implies

polluted rivers (Holden, 1970). The BOD is determined by calculating the amount of oxygen required for the microbiological degradation of a sample incubated for a specific time and temperature and this indicates the strength of the organic matter (A.P.H.A., 1971). The Chemical Oxygen Demand (COD) in contrast estimates the organic content by chemically oxidizing the sample. With many wastes, once the initial tests have been made, a relationship between BOD and COD can be found and then one needs only to test regularly for one of them. The COD can often be 5 or 6 times greater than the BOD and generally the more purified an effluent the higher is the COD : BOD ratio (A.P.H.A., 1971).

2.2 Effluent Characterization

2.2.1 Sewage composition

Fresh sewage is yellow brown to grey in colour and has little odour. Strong smelling, dark coloured sewage may be due to trade wastes or putrefaction. Sewage has large hourly fluctuations in both flow and concentration. Such fluctuations are less marked in large communities. The flow patterns depend on both the length of the sewer and the nature of the community served. Peak flows usually occur around midday while low flows occur in the early morning. There is little daily or seasonal variation in sewage characteristics except that the bacterial content is expectedly higher in the warmer months (Painter, 1971).

The concentration of sewage depends upon the per capita use of water. This is high in the United States (450-900 l/head/day) which has a weak sewage. However, in the United Kingdom the water usage is low (120 l/head/day) and hence strong sewage results (Painter, 1971). Table 2 gives the typical component concentration for sewages of varying strengths and also includes values obtained for United States and United Kingdom sewage for comparison. Cooke (1977) gives the concentration of Palmerston North's primary treated sewage and this is summarized in Table 3. This sewage corresponds to a weak sewage (Painter, 1971).

The temperature of sewage is usually 1 to 2 degrees above that of the town water supply. This may be increased by thermal discharges or decreased by addition of storm waters. The pH of sewage is typically above 7 but this depends upon the hardness of the water. Hard water has a higher pH (7.5-8) than does soft water (6.8-7.5).

TABLE 2 TYPICAL ANALYSIS OF SEWAGE

COMPONENT	STRONG	MEDIUM	WEAK	UK	USA
TOTAL SOLIDS	1000	500	200	1309	290-680
VOLATILE SOLIDS	700	350	120		
FIXED SOLIDS	300	150	80		
SUSPENDED SOLIDS (TOTAL)	500	300	100		
VOLATILE SUSPENDED SOLIDS	400	250	70		54-208
FIXED SUSPENDED SOLIDS	100	50	30		
DISSOLVED SOLIDS	500	200	100		
VOLATILE DISSOLVED SOLIDS	300	100	50		
FIXED DISSOLVED SOLIDS	200	100	50		
SETTLEABLE SOLIDS	450	50	20		
BOD (TOTAL)	300	200	100	340-390	50-280
PERMANGANATE VALUE	150	75	30		
DISSOLVED OXYGEN	0	0	0		
TOTAL NITROGEN	86	50	25		
ORGANIC NITROGEN	35	20	10	16-23	10
AMMONIA-N	50	30	15	41-53	4-35
NITRITE-N	.1	.05	.00		
NITRATE-N	.4	.2	.10		
CHLORIDE	175	100	15		
ALKALINITY	200	100	50		
PROTEINS				42	27
FATS	40	20	0	140	26
CARBOHYDRATES				34	34

All values are given in g/m^3

Source: Painter (1971) and Babbitt (1947)

TABLE 3 ANALYSES OF LOCAL WASTES

	PALMERSTON NORTH SEWAGE	Longburn Meatworks
TOTAL SOLIDS	313	-
SUSPENDED SOLIDS	-	207
BOD (TOTAL)	155	687
COD	180	905
pH	7.0	7.8
TOTAL PHOSPHORUS	4.5	6.2
ORTHOPHOSPHATE	2.6	3.0
TOTAL KJELDAHL NITROGEN	31.3	58.4
NITRATE-N	0.6	0.3
TOTAL COLIFORMS	2.10^7	2.10^8
FAECAL COLIFORMS	5.10^6	4.10^6
FAECAL STREPTOCOCCI	6.10^5	6.10^5

Units: Chemical species in g/m^3
microbiological density in numbers/100 ml

Source: Cooke (1977)

Sewage is a very weak slurry with only around 0.5 percent solids. Organic matter is contained in both the soluble and insoluble fractions while most of the inorganic matter is contained in the insoluble phase (Hunter and Heukelekian, 1965).

The soluble fraction of sewage has a high dissolved solids content and contains approximately 64 percent of the total solids (Hunter and Heukelekian, 1965). Thirty percent of these solids are volatile, that is, are organic in nature. This is further illustrated by the organic carbon, organic nitrogen and COD content as is shown in Table 4. Sugars, free and bound amino acids, volatile and non volatile acids, anionic detergents and

some unknown ether-soluble compounds constitute the major portion of the soluble organic load while organic bases, amphoteric substances, phenols, sterols and various nitrogen containing compounds are of minor importance (Painter 1971).

TABLE 4 DISTRIBUTION OF THE ORGANIC LOAD IN SEWAGE

	SOLUTION	SETTLEABLE	SEMICOLLOIDAL	COLLOIDAL
PARTICLE SIZE	1 nm	100 nm	1-100 nm	1 nm - 1 μ m
% ORGANIC C	31-41	30	19-24	10-14
TOTAL SOLIDS (g/m ³)	264	75	47	29
% TOTAL SOLIDS	64	18	11	7
VOLATILE SOLIDS (g/m ³)	81	58	38	21
ORGANIC N (g/m ³)	3.6	3.1	3.1	1.1
COD (g/m ³)	54	83	56	33

Source: Hunter and Heukelekian (1965) and Painter (1971)

The inorganic components found in sewage vary according to the water supply. The soluble phase contains 85 percent of the inorganic substances of which chloride, silicon, calcium, magnesium, potassium, sodium, sulphur, and phosphorus compounds are the most common (Painter 1971).

There are three insoluble fractions; the settleable, semicolloidal and colloidal solids. They are best differentiated by their sizes and their composition is shown in Table 4. The settleable phase contains most of the total solids and the colloidal phase has the least. A similar distribution of COD, volatile solids and organic carbon occurs while organic nitrogen is distributed evenly between the settleable and semicolloidal phase and little organic nitrogen is contained within the colloidal phase.

Fats, proteins and carbohydrates account for 60-80 percent of the total solids in the insoluble phases although, different sewages can show wide variations in the concentrations. This is especially so for the fat content. The fat content of United Kingdom sewage is 5 times that of United States sewage and this has been attributed to the greater use of soap with respect to water consumption in the United Kingdom (Painter, 1971). Hunter and Heukelekian (1965) give the following relative concentrations for the three main constituents: fats 17%, carbohydrates 24% and amino acids 19%. The carbohydrates in sewage are generally high molecular weight polymers of cellulose and starch while esterified fatty matter and unsaponifiable matter are the important fats. Proteins and amino acids contain 60 percent of the nitrogen in sewage and Sridhar and Pillai (1973) have identified 36 percent of the proteins as albumin 7.9%, globulin 7.8%, glutelin 18.6% and protamin 2.6%.

The microorganisms in sewage originate from faeces, soil and water and include viruses (such as the Coxsackie virus and Poliovirus), bacteria (for example the genera Salmonella, Shigella, Escherichia, Streptococcus and Proteus), fungi, ciliated and flagellated protozoa and parasitic worms such as tape worms and nematode worms (Painter, 1971; Porteous, 1975; Klein, 1959). The density of bacteria in fresh sewage is 10^5 bacteria per milliliter and this can rise to 10^8 bacteria per milliliter in stale sewage (McKinney, 1962). Thus it appears that primary treatment of Palmerston North sewage does little to reduce the bacterial numbers (see Table 3; Cooke, 1977).

2.2.2

Meatworks effluent

Chemically, meat wastes are similar to domestic sewage. They are organic and consist of dissolved, colloidal and suspended matter, of which a high

percentage is protein, cellulose or grease. These wastes are much more concentrated than sewage and the concentration of components varies widely between factories (Loehr, 1977). Meat wastes typically show large hourly fluctuations which correspond to different runs, "smoko" or lunch-times. There is, however, little variation in overall daily flow and concentration. Meat production is seasonal in New Zealand and this is reflected in the waste flows. In New Zealand the total daily effluent flow over the killing season amounts to some 2.4 million ℓ /day (Denmead, 1973).

The main effluent sources are the stockyards, viscera department, boning room and the rendering department if wet rendering is practiced. These wastes are accumulated during wash down of floors and equipment. Fellmongery operations also result in a high waste load but these wastes are usually treated separately to the main effluent flow (Hicks, 1959).

The range of waste characteristics occurring in the meat industry is shown in Table 5 which well illustrates the large variations occurring between works. Comparison of this table with Table 3 (Cooke, 1977) shows the Longburn Meat Works wastes to be at the lower end of the range.

The microorganisms in the effluent originate from the paunch contents and the stockyard run-off and hence intestinal organisms predominate. There are also microorganisms of soil and human origin. Bacterial levels may be as high as 10^7 aerobes/ml and 10^8 facultative and obligate anaerobes/ml. Coliform counts alone can be between 10^5 and 10^6 /ml with faecal coliforms counts of 10^4 /ml. Meat wastes generally have a higher level of faecal streptococci than has domestic sewage and densities of 10^5 /ml have been recorded (Nottingham, 1969) and these levels were recorded in the Longburn Meat Works' wastes (Cooke, 1977). The common pathogens occurring in meat wastes include Salmonella, Leptospira and enteric viruses (Nottingham, 1969).

TABLE 5 MEAT WASTE CHARACTERISTICS

FLOW	2440 ℓ /animal
SUSPENDED SOLIDS	300-4200 g/m^3
VOLATILE SUSPENDED SOLIDS	80-97%
ORGANIC NITROGEN	20-300 g/m^3
GREASE	200-300 g/m^3
BOD (TOTAL)	600-4000 g/m^3
COD	960-8300 g/m^3
pH	6.0-11.5
SETTLABLE SOLIDS	5-40 g/m^3
SULPHIDE-S	0-50 g/m^3
ALKALINITY	400-1200 g/m^3
CHLORIDES (Cl_2)	200-500 g/m^3

Source: Loehr (1977), Nemerow (1953) and Hicks (1959).

2.2.3 Effect of biological treatment on organic effluents

Biological, or secondary treatment may produce effluents with a BOD between 15 and 20 g/m^3 and 15-30 g/m^3 suspended solids. The inorganic load is similar to the influent. Table 6 shows the component concentrations of biologically treated effluent. Secondary treatment does reduce bacterial numbers but none is completely eliminated (Painter, 1971).

TABLE 6 CHARACTERISTICS OF BIOLOGICALLY TREATED WASTES

PARAMETER	CONCENTRATION (g/m ³ EXCEPT pH)
Total Solids	640-930
Suspended Solids	8-51
Permanganate Value	9-16
BOD	2-29
COD	31-90
Organic Carbon	13-41
Detergent	0.6-2.1
Protein	2-4
Carbohydrate	1-3
Fat	0.08-0.2
Ammoniacal-Nitrogen	2-7
Nitrite-Nitrogen	0.2-2
Nitrate-Nitrogen	21-38
Total Phosphorus	6-10
Chlorides	60-98
Sulphates	61-212
Sodium	124-144
Potassium	21-26
pH	7.2-7.6

Source: Painter (1971)

2.3

Interactions of Organic Wastes in a River

Components, when added to a river, may act conservatively or non-conservatively (Thomann, 1972). A conservative component is one which does not decay with time and thus its reduction is by dilution alone. Total dissolved solids, chlorides, total nitrogen and total phosphorus are all conservative when both the stream flow and sediments are considered (Thomann, 1972).

A non-conservative component decays with time and hence its concentration is a function of the river flow time after discharge as well as dilution and upstream concentration. Bacterial densities and BOD are both non-conservative components.

Interactions of waste effluent compounds in a river may be by a single system or a coupled system (Thomann, 1972). In a single system the output of a component is merely a function of the input of that component as is the decrease of BOD with downstream flow. The output of a coupled system depends upon two or more inputs. For example, the dissolved oxygen content of a stream depends upon both deoxygenation and reoxygenation inputs and is thus described as a coupled system.

When modelling component interactions in rivers a number of simplifying assumptions are made (Thomann, 1972).

- (1) River flow may be represented by plugflow, that is the entire river cross section flows at the same rate. In practice, the centre of the river flows faster than any other point while the water at the banks may be almost stationary.

- (2) A uniform concentration exists for the entire cross-section and no axial diffusion occurs. Thus the river may be considered as one dimensional.
- (3) The stream cross sectional area is constant throughout the study area.
- (4) A steady state exists at any one point. This implies no variation in the discharging effluents concentration and flow and that diurnal fluctuations of temperature and dissolved oxygen do not occur.

2.3.1

Organic self purification

Organic self purification is the return of the river to its natural condition after enrichment by organic matter. Self purification is achieved through natural means and is the result of physicochemical, chemical and biological interactions which occur simultaneously (Benoit, 1971).

Dilution and mixing of organic discharges are two important physico-chemical factors since they determine the initial concentration of components in the receiving waters (Klein, 1962). Mixing occurs predominantly by eddy diffusion, which is the result of thermal or concentration gradients, and from the slope and irregularity of the stream bed. Rapids and riffles greatly increase the stream's mixing capacity.

Adsorption of ions; molecules and microorganisms (Faust et al., 1975) onto the suspended particles of the stream and the subsequent sedimentation of these particles may remove a large proportion of organic matter from the stream flow. These sediments accumulate on the stream bottom, eliminating some benthic invertebrates by smothering, yet encouraging the growth of others by supplying an increased food source. In freshly deposited sediments the decay of organic matter is aerobic and hence constitutes an oxygen sink.

The older, compacted sediments, however, degrade anaerobically producing gases such as methane, ammonia and hydrogen sulphide. These gases when lost to the atmosphere transfer their oxygen debt to the atmosphere. In fresh flows, the stream sediments are resuspended and these suspended solids and their anaerobic decay intermediates may exert a high BOD (Benoit, 1971). The rate of sedimentation of suspended solids depends upon the stream velocity and it can be assumed that sedimentation in streams of velocities greater than 0.2 m/s is negligible (Velz, 1970).

The dissolution of atmospheric oxygen into the stream is the major oxygen source for self purification. Oxygen solubility in water is a function of temperature, pressure and salt concentration. The rate of oxygen transfer at a particular point is proportional to the dissolved oxygen deficit, that is the difference between the dissolved oxygen concentration at that point and its saturation value (Velz, 1970). Equation 1 describes this relationship.

$$\frac{dc}{dt} = K_2 (C_s - C) \quad (1)$$

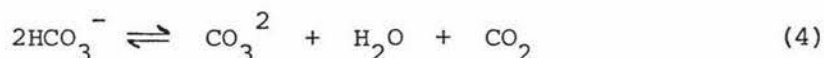
The dissolved oxygen at any time, t days, is defined as C while C_s is the saturation value (in g/m^3) for the specified temperature, pressure and salinity and K_2 ($days^{-1}$), the proportionality constant, is known as the reaeration coefficient. The magnitude of the reaeration coefficient depends upon the stream velocity and stream depth. A swift, shallow stream has a much higher reaeration coefficient than a deep slow moving river. Various formulae have been presented to define the reaeration coefficient (O'Conner and Dobbins, 1958; Owens et al., 1964; Odum, 1956; and Nemerow 1974). Equation 2 shows one that was developed by Owens et al., (1964) for shallow, swift flowing streams with velocities between 0.03 and 1.5 m/s and depths between 0.12 and 3.5 m.

$$K_2 = 5.316(v^{.67}/H^{1.85}) \quad (2)$$

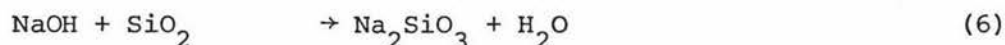
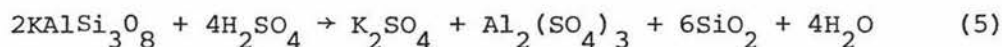
The equation gives K_2 in days⁻¹ when the velocity (v) and depth (H) are in SI units. Temperature also affects the reaeration coefficient and Owens et al., (1964) found that equation 3 adequately fitted their data when T is the temperature of the water.

$$K_2 (T) = K_2 (20^\circ\text{C}) (1.024)^{T-20} \quad (3)$$

Chemical processes important in stream self purification are the equilibria reactions, redox reactions and acid/base reactions. The carbonate/bicarbonate interchange (equation 4) is the most important equilibrium reaction as this is the major buffering system of a stream (Klein, 1959).



In acid/base chemical reactions the stream minerals neutralize any acids or bases discharges to a stream (Benoit, 1971). Many stream minerals may be involved in such reactions and two typical reactions are given in equations 5 and 6.



The rate at which these reactions occurs depends upon the solubility of the interacting species in the water.

Important biological self purification interactions involve the aerobic degradation of organic matter by microorganisms. The organic matter in the

receiving waters acts as a food source for the heterotrophic organisms of the stream. Most of these heterotrophs are bacteria which originate with the organics from the discharge while others such as Sphaerotilus natans are endemic and after organic stimuli form immense colonies known as sewage fungus. The aerobic degradation of the organic matter reduces the BOD of the receiving waters while simultaneously exerting a demand on the stream's dissolved oxygen. If the rate of deoxygenation through organic degradation exceeds the rate of reoxygenation the stream's dissolved oxygen levels decrease. This decrease in dissolved oxygen continues until the deoxygenation rate equals the reoxygenation rate, at a geographical point known as the critical point. After this reoxygenation exceeds deoxygenation and the dissolved oxygen increases. This decrease and subsequent increase of dissolved oxygen is known as the dissolved oxygen sag curve (Nemerow, 1974). The position and magnitude of the critical point depends upon the initial concentration of the organics and the streams reaeration capacity. At night the critical point is further downstream because as photosynthesis is not occurring the rate of reoxygenation is less.

The decay of organics in a stream (as measured by the BOD) follows first order kinetics (Eckenfelder, 1970). That is, the rate of decline of BOD is directly proportional to the concentration of BOD. This is expressed in equation 7 where L is the BOD at any time, t days, and K_1 is the deoxygenation constant in days⁻¹.

$$\frac{dL}{dt} = -K_1 L \quad (7)$$

Manipulation of this equation reveals a log normal relationship between the BOD and time, as is shown in equation 8 where L_0 is the initial BOD.

$$\log L/L_0 = -K_1 t \quad (8)$$

This relationship provides a convenient way to determine the deoxygenation coefficient. The deoxygenation coefficient, K_1 , applies solely to oxidation of the soluble organics. Immediately below an effluent discharge point much of the BOD may be lost through volatilization of volatile compounds or sedimentation of suspended solids (Eckenfelder, 1970). Here, the proportionality constant K_x is used to describe the first order decline. The coefficient may be several times the value of the deoxygenation coefficient when the receiving water contains high suspended or volatile matter (Eckenfelder, 1970).

Benthal sediments may also exert an oxygen demand. This is assumed to follow first order kinetics and equations 9 and 10 may be used to define the demand. The subscript b is used to define benthal conditions, K_a is the proportionality constant, and other terms are defined previously.

$$\left(\frac{dL}{dt}\right)_b = -K_a L_b \quad (9)$$

$$\left(\log \frac{L}{L_0}\right)_b = K_a t \quad (10)$$

Streams with large amounts of algae have photosynthesis as an additional oxygen source during daylight hours. The rate of reoxygenation through photosynthesis depends on the intensity of illumination. On a clear sunny day the rate of reoxygenation against time curve resembles a half sine wave. Equations 11 and 12 were used by Rutherford (1977) to model the oxygen production of algae in the Waikato River. P' is the photosynthetic rate at time, t , P_m is the peak rate, p is the fraction of the day in which photosynthesis occurs and t_1 is the time at which photosynthesis commences.

$$P'(t) = P_m \sin \frac{\pi}{p} (t - t_1) \quad t_1 \leq t \leq t_1 + p \quad (11)$$

$$P'(t) = 0 \quad t_1 + p \leq t \leq t_1 + l \quad (12)$$

Simonsen and Harremoes (1978) found that the total oxygen production per day (gross productivity) was dependant upon the solar radiation but was independent of the algal standing crop and the temperature. The effect that algae have on a stream is discussed in a later section (2.4).

Respiration is the final oxygen sink to be considered. This term does not include bacterial respiration as this is already considered in the BOD oxygen sink. Algae and bottom fauna are the important species that contribute to respiration. Generally, respiration is considered to be a constant throughout the 24 hours (Odum, 1956) and is thus readily incorporated into calculations as will be seen in a later section (2.4).

2.3.2 Modelling of dissolved oxygen levels

Modelling of dissolved oxygen levels involves the addition of oxygen sources and the subtraction of oxygen sinks at each point under consideration. Equation 13 summarizes this process (Eckenfelder, 1970).

$$\frac{dc}{dt} = K_2 (C_S - C) - K_1 L - K_a L_b - R + P \quad (13)$$

The rate of oxygen removal through respiration is represented by R' while P' is the rate of addition through photosynthesis. In simplified models only the BOD exertion and reaeration are considered, giving equation 14, the Streeter-Phelps model (Eckenfelder, 1970).

$$\frac{dc}{dt} = K_2 (C_S - C) - K_1 L \quad (14)$$

In this simplified situation the critical time, t_c , can be calculated from equation 15, while equation 16 may be used to determine the critical dissolved oxygen deficit ($C_S - C_C$). The initial dissolved oxygen deficit is ($C_S - C_0$).

$$t_c = \frac{1}{K_2 - K_1} \log \left\{ \frac{K_2}{K_1} \left[1 - \frac{(C_S - C_0) (K_2 - K_1)}{L_0 K_1} \right] \right\} \quad (15)$$

$$(C_S - C_C) = \frac{K_1}{K_2} L_0 10^{-K_1 t_c} \quad (16)$$

Another model, applying Monod type relationships to stream purification, has been developed (Gates and Marljar, 1968; Gates et al., 1969). At high substrate concentrations the kinetics are zero order while at low concentrations first order kinetics apply. First order kinetics thus fits stream data because the stream represents a dilute system. Usually a BOD of 500 g/m³ or more is required for zero order kinetics to predominate.

Rutherford (1977) modelled the Waikato River with first order kinetics. He considered reaeration, deoxygenation through BOD decay and the effect of algal plants. A deoxygenation coefficient of 1.8/day was found to fit the data best. From his observations he concluded that periphyton was of minor importance in the river when compared to phytoplankton and macrophytes. A study on the Tarawera River by Rutherford and O'Sullivan (1974) revealed a first order deoxygenation coefficient of 3.5/day which is much higher than for most streams. As well, first order kinetics did not adequately describe the rate of decay observed. Application of the Monod model fitted the data well. The Tarawera River contains a high pumice content and this pumice was found to be responsible for the high rates of decay. It was

postulated that the pumice harboured high concentrations of microorganisms which hence promoted rapid degradation. Table 7 gives values of reaeration and deoxygenation coefficients that have been found in the literature.

TABLE 7 VALUES THAT HAVE BEEN OBTAINED FOR THE REAERATION
AND DEOXYGENATION COEFFICIENTS

Deoxygenation Coefficient

Type of Water	Value (day ⁻¹)	Source
Swift shallow streams	1-3	Velz (1970)
Swift shallow streams	20	Eckenfelder (1970)
Highly polluted shallow streams	0.2-0.3	Klein (1962)
Waikato River	1.8	Rutherford (1977)
Tarawera River	3.5	Rutherford (1974)

Reaeration Coefficient

Rivers in Michigan (USA)	2.5-6.1	O'Connor and Di Toro (1970)
Truckee River (USA)	6.8-8.0	O'Connor and Di Toro (1970)
Ivel River (UK)	2.4	O'Connor and Di Toro (1970)
Shallow streams (0.15 m deep)	9.5	Benoit (1971)
Deep rivers (14 m deep)	0.1	Benoit (1971)

2.3.3 Microbiological self purification

Microbiological self purification is the decrease in the density of all types of microorganisms with respect to flow time from discharge (Wuhrmann, 1972). Usually this concept is confined to only those organisms alien to the stream ecology such as the bacteria of faecal origin.

Where as the decay of organic matter in streams is of importance only from ecological aspects, microbiological self purification is important in terms of public health as well. Sewage contains many human pathogens along

with vast numbers of enteric coliforms and enterococci and it is by this route that many diseases are transmitted (Geldreich, 1972). Thus it is important to know the rate of die off of these organisms in the stream environment. Because the large variety of pathogens require many tests to define them and because these pathogens are usually low in concentration, easily detected non-pathogenic organisms whose presence indicate faecal contamination, and hence the likelihood of pathogens, are usually tested for. The non-pathogenic organisms most commonly used are the faecal coliforms and faecal streptococci both of which occur in high densities in the human and animal gut (McKinney, 1962).

The decline of enteric microorganisms in the aquatic environment is the result of many different biological and physical factors.

Biological factors influencing the decline are predation, competition and the initial density of the introduced bacteria. The bacterial predators that are present in the non-polluted stream or sea are in very low concentrations and feed off indigenous bacteria types. When the waters are polluted the number of predators swell and can cause a large reduction in the number of introduced microorganisms. An initial concentration of 100 protozoa/ml can reduce the density of an Escherichia coli population from 10^9 to 10^4 /ml in four days (Mitchell, 1972). Protozoa are the most important predators in the freshwater environment and include both Sarcadinae and ciliates. Parasitism by the bacterium Bdellovibrio on gram negative bacteria can also influence the decline of foreign microorganisms (Mitchell, 1972).

The survival of enteric bacteria in the aquatic environment is greatest when the total bacterial numbers are low. Hence bacteria survive longer in well water (which is usually free from large populations of microorganisms)

than in river water (Geldreich, 1972; Joyce and Weiser, 1967). Enteric microorganisms can not compete successfully with the native flora and they are thus very susceptible to predation and parasitism. Velz (1970) states that competitive life is an important factor influencing the decline of these microorganisms. However, in vitro experiments by Verstraete and Voets (1976) showed no correlation between the native flora and the decline rates.

The initial density of the introduced microorganisms also affects the rate by which the bacteria numbers decline (Kittrell and Furfari, 1963). Populations with a high initial density decrease at a greater rate than those with lower densities.

The physical and chemical factors that affect the rate of decay of the microorganisms are dilution, adsorption, sedimentation, temperature, light intensity and the physical and chemical nature of the stream (Velz, 1970; Geldreich, 1972; Faust et al., 1975; Kittrell and Furfari, 1963; Wuhrmann, 1972; Canale et al., 1973).

Dilution of the microorganisms may occur through run off from land or the confluence of another tributary. Velz (1970) states that the adsorption of microorganisms on to suspended stream particles and the subsequent sedimentation of these particles can remove considerable numbers of bacteria from the stream flow. Large numbers of coliforms and pathogens are thus deposited below sewage outfalls (Mitchell, 1968) and these can then grow and multiply in the sediments (Van Donsel and Geldreich, 1971). Some of these bacteria may then reinfect the waters via an aquatic food chain but most will be buried by further sedimentation.

Temperature has been shown to be an important factor affecting the rate of bacterial die off under laboratory conditions (Verstraete and Voets, 1976). In streams, however, only two broad temperature ranges can be distinguished, one relating to warm seasons and one to cold seasons (Velz, 1970). The survival time of bacteria is shortest in summer and longest in winter (Faust et al., 1975 and Geldreich, 1972). Faust et al., (1975) have found a linear relationship between the half life of a bacteria population and the water temperature.

The coliform numbers in sea water have been found to decrease logarithmically with the increase of cumulative radiation (Gameson and Saxon, 1967) while sunlight was found to help kill the coliforms that remained on the grass after trickle irrigation with sewage (Bell and Bole, 1976). Bellair et al., (1977) have found a correlation between death rate and the light intensity. In aquatic systems the correlation between the death rate and light intensity may be direct or it may be an indirect result of the increased water temperatures or increased photosynthetic activity that usually occur with increased light intensities (Gameson and Saxon, 1967).

The bacteria in a swift shallow stream which has many riffles and rapids die off at a greater rate than those in slow moving rivers (Kittrell and Furfari, 1963). This is because benthic algae, macrophytes and floating debris accumulate at the riffles and offer shelter for large numbers of bacterial predators. As well the shallow waters means that the bacteria will be exposed to high levels of solar radiation which has been discussed previously. The riffle area thus acts similarly to a trickling filter (Kittrell and Furfari, 1963). The rate of decrease in bacteria numbers in shallow streams may be 20 times that in deep rivers and the bacteria numbers may be reduced to 10 percent in just 2 hours (Wuhrmann, 1972).

The bacteria in streams with high concentrations of organic material decline at a greater rate than those in cleaner water and Wuhrmann (1972) has suggested that the high organic content favours the growth of secondary consumers and hence bacterial predators. Velz (1970) states that acidity and alkalinity both affect the rate of die off whilst pH is only important at extreme values. Salts such as those in estuaries or return irrigation water increase the survival of microorganisms as for example, with Shigella (Geldreich, 1972). Similarly there is increased Shigella survival in raw sewage supplemented with sodium chloride and potassium chloride. Calcium chloride, however, exerts an inhibitory effect (Geldreich, 1972). Brasfield (1972) found correlations between the logarithm of bacteria numbers and concentrations of phosphates, sulphates, bicarbonates and chlorides.

The rate of die off of bacteria in an unfavourable environment was first defined as a logarithmic relationship by Chick (quoted by Velz, 1970). A logarithmic relationship is consistent with first order kinetics and equation 17 expresses the rate of bacteria decline in this form (Velz, 1970).

$$\frac{dN}{dt} = -K_b N \quad (17)$$

The density of bacteria at any time, t days, is defined as N while K_b is the bacteria death rate constant (days^{-1}). Integration of equation 17 gives the logarithmic relationship that is given in equation 18.

$$\log \frac{N}{N_0} = -K_b t \quad (18)$$

The initial bacteria density is defined as N_0 . A plot of $\log \frac{N}{N_0}$ against time will thus have the bacterial death rate constant as its slope. This coefficient is a measure of an organisms ability to survive a given environment

(Lombardo and Oh, 1974).

There are two main deviations from first order behaviour. The first is that in many cases an initial lag phase occurs before the logarithmic decline (Velz, 1970; Kittrell and Furfari, 1963; Wuhrmann, 1972). This lag phase may be the result of bacteria multiplying in the stream or it could be due to the limitations of the testing procedure in that clumps of bacteria initially analysed as a single cell have broken up to give many cells (Kittrell and Furfari, 1963). Canale et al., (1973) found that faecal streptococci do not exhibit this initial lag phase and thus are probably better organisms to study than are faecal coliforms.

The second deviation from first order kinetics is a decrease in the death rate after a certain period of time. This usually occurs after a 99 percent reduction in numbers has occurred, a situation some five days after the initial discharge (Velz, 1970). This change in the death rate is probably due to an increased resistance in the remaining bacteria. This situation is incorporated into death rate equation by introduction of a second rate expression as is shown in equation 19. The subscripted variables indicate the resistant phase.

$$N = N_0 (10^{-K_b t}) + N_0' (10^{-K_b' t}) \quad (19)$$

Velz (1970) summarizes the magnitudes of the bacterial decline rate constants defined in the literature. For warm weather the constant is 0.46-0.96/day while in cold weather the range is 0.3-0.5/day. The constants are further defined as 0.5 ± 0.15 /day for large rivers and 0.8 ± 0.2 /day for moderate sized rivers. This implies that in two days flow time a large river will only have 10 percent of the initial bacteria still viable and a small

river will have only 3 percent of the original numbers. Kittrell and Furfari (1963) found only 1.7 percent of the initial bacteria content present in small shallow streams remaining after one day's flow time.

2.4 Algae in Rivers

2.4.1 Nutrients and algae

Nitrogen, phosphorus, silicon, iron, magnesium, potassium, calcium, sodium, copper, manganese, cobalt, molybdenum and vanadium are some of the elements essential for algal growth (Porteous, 1975). Of these nitrogen and phosphorus are usually the ones that limit algal growth and algae blooms may develop once their limiting concentrations are exceeded. Schindler (1977) found that phosphorus was the limiting nutrient in the lakes that he studied. He suggested that this was because phosphorus has a closed geochemical cycle and hence there is no alternative source.

Generally flowing water is relatively free from the problem of eutrophication. Where as levels above 25 mg/m^3 total phosphorus in lakes can cause eutrophication, rivers can carry up to 100 mg/m^3 total phosphorus with little adverse effects (Hart, 1974). This is because the short retention times and lack of nutrient recycle from sediments in river waters does not favour algal growth (Owens and Woods, 1968). Hornberger *et al.*, (1977), however, found that the productivity of a river responded to small changes in nutrient concentrations. They postulated that this was because flowing water avoided depletion of nutrients around the vegetation.

It is generally only the slow moving rivers and estuaries that develop large planktonic algae populations (Owens and Wood, 1968). New Zealand, however, has many swift shallow streams which favour the development of attached benthic algae and these are a greater liability than planktonic algae (Stout, 1970; O'Connell and Thomas, 1965). Planktonic algae when carried longitudinally downstream with the river flow diffuse both laterally and axially. Thus the response of a large river to enrichment is carried

downstream and is distributed over a larger area (O'Connell and Thomas, 1965). In comparison, benthic algae are attached to the stream bed and thus no longitudinal, axial or lateral movement of algae occurs. The net effect of this is to concentrate any enrichment effects into a smaller stream area which is closer to the discharge point. A major problem with attached algae in flowing waters is that the mass of water in which dissolved oxygen levels are depleted at night through algal respiration is not the same mass of water that has had its dissolved oxygen levels boosted through the algae's photosynthesis in daylight. A large drop in night time dissolved oxygen levels is thus a typical response to benthic algae (O'Connell and Thomas, 1965).

The major source of stream nitrates is run-off from agricultural land and only a small percentage originates from sewage discharges. Smith (1977) found high correlation between the yearly increase in the use of nitrogen fertilizers and the nitrate concentration of Lough Neagh. Similarly Owens and Wood (1968) found that only 10 percent of nitrate in the Great Ouse is accountable for by sewage effluents.

Another important source of nitrates in polluted rivers is from the bacterial nitrification of ammonia formed from the deamination of proteins (Klein, 1962; Eckenfelder, 1970). The bacterium, Nitrosomonas, oxidizes ammonia to nitrite whilst Nitrobacter completes the oxidation to nitrate. These bacteria require phosphate as a nutrient, dissolved oxygen and bases to neutralize the nitrous and nitric acids produced (Klein, 1962). These bacteria also have high optimum stream temperatures (Eckenfelder, 1970).

The major source of phosphate is from effluent discharges. In the Lough Neagh study only 25 percent of the phosphate had originated from land drainage whilst there was significant correlation between the soluble

orthophosphate concentration of the water and the catchment population over the past years. Synthetic detergents contain high levels of phosphorus and studies have shown that the phosphorus content in rivers had increased with the use of these detergents (Owens and Wood, 1968).

Once phosphorus has entered a water way it is rapidly absorbed by the bottom sediments and the aquatic biota. Aiba and Ohtake (1977) give a material balance for phosphorus in a shallow river. Fifteen percent of the daily input is fixed by the benthic algae while thirty percent is either absorbed by the bottom sediments or passed into the ground water system. The remainder passes downstream with the river flow. The deposition of phosphorus to the bottom sediments and the accumulation of these sediments is a storage phase for phosphorus in the biogeochemical cycle (Keup, 1968).

Jaworski (1969) followed phosphorus distribution in the Potomac River. Under steady state conditions a first order model identical to the BOD model was observed and the decay rate constant was found to vary between 0.2 and 0.7 /day.

2.4.2 Determining the effect of algae on rivers

The algal population in a stream may be determined either directly or indirectly. Direct determinations can be obtained through cell counts, volume measurements and mass measurements (dry weight, wet weight or ash free dry weight). Chlorophyll concentration and the rate of change in the dissolved oxygen concentration or carbondioxide concentration in the water are the most important indirect methods. These methods are discussed by Wetzel and Westlake (1969) while Paerl (1977) compares four of them as used in Lake Taupo. Periphyton, or the attached algae, occur in clumps rather than a random distribution throughout the stream (O'Connell and Thomas, 1965).

Thus periphytic sampling by the direct methods or chlorophyll concentration method can give erroneous results when related to the stream as a whole. The rate of change in gas concentration, in comparison, reflects the average algal activity and can hence be used with periphytic algae (Odum, 1956).

The rate of oxygen change in water may be measured by several methods. The light and dark bottle method (A.P.H.A., 1971) is more relevant to phytoplankton than periplankton. Algal chambers (A.P.H.A., 1971) have been developed for use with benthic algae. Light and dark chambers are placed on the stream bottom and the change in oxygen concentration over a certain period of time is determined. The light chamber represents both the photosynthesis and the respiration of the algae while the dark chamber represents respiration only. From the results, information can be obtained on the net oxygen input from photosynthesis and net oxygen removal by respiration. The main disadvantage with this method is that a non-flowing system is used to simulate a flowing system when flow is obviously an important environmental factor in a stream ecosystem.

A third method to determine rate of oxygen change is the diurnal curve method of Odum (1956) and this method was used in the Oroua River. This method is analogous to the algal chamber method in that the daytime rate of oxygen change represents the light chamber and the night time rate represents the dark chamber. This technique assumes that the water entering a stream section has had the same history as the water immediately before it. Reaeration can be accounted for in this method by using a reaeration equation such as Owens et al., (1964) equation (equation 2) to determine the rate of change of oxygen occurring through reaeration. This is subtracted from the actual rate of change occurring. Alternatively, the reaeration rate can be determined from the diurnal curve by taking two points, one pre-dawn and one post sunset, where rate of oxygen change from photosynthesis is zero.

Thus the rate of change depends only upon reaeration and respiration (which is assumed constant) and hence the reaeration rate is determined by simultaneous equations. Respiration is assumed constant throughout the 24 hours and is calculated from the average of the night time rate of change corrected for reaeration. The net daily oxygen input through photosynthesis can be determined by integrating the area between the rate of change curve corrected for reaeration (known as the P-R curve) and the respiration line.

O'Connell and Thomas (1965) implemented the above technique but calculated the results by finite difference rather than graphical integration.

The relationship between photosynthesis (P) and respiration (R) gives an indication of the stream's trophic status. Oligotrophic waters have a P:R ratio close to unity (Cole, 1975). This indicates a balance between the solar energy used in photosynthesis and the chemical energy released by heterotrophes. In eutrophic waters P:R is much greater than unity because high algal activity results in more energy being trapped by photosynthesis than is released by respiration. P:R ratios less than unity indicate high heterotrophic activity such as that which results after organic enrichment (Cole, 1975).

Diurnal curve analyses have been used in several fresh water situations. Odum (1960) found that both P and R can range from 1 to 60 g/m²/day in fresh water. The reaeration coefficient for streams at normal stream temperatures varies between 0.6 and 4.3 g/m²/day (Odum, 1956). Table 8 shows the results obtained for many different situations.

TABLE 8 DATA FROM DIURNAL CURVES

RIVER	P (g/m ² /d)	R (g/m ² /d)	SOURCE
TRUCKEE (USA)	8.1 - 41.1	7 - 12.9	1,2
IVEL (UK)	3.2 - 19.7	6.7 - 15.4	2,3
GRAND (USA)	7.6 - 22.5	16 - 22	2
CLINTON (USA)	8.6 - 15.0	18 - 20	2
FLINT (USA)	1.6 - 22.3	5 - 20	2
HAVELSE (DENMARK)			
Winter	0.2 - 3.5	7.4 - 8.9	4
Summer	7.7 - 17.8	4.8 - 13.1	4

Sources: 1. O'Connell and Thomas (1965)
 2. O'Connor and Di Toro (1970)
 3. Edwards and Owens (1962)
 4. Simonsen and Harremoës (1978)

Legend

P - Gross productivity
 R - Community Respiration

O'Connell and Thomas (1965) determined the productivity of the Truckee River, Nevada. This is a shallow, swift river. Upstream of the city of Reno, total nitrogen and soluble orthophosphate levels were relatively low (0.3 g/m³ and 0.08 g/m³ respectively), mild dissolved oxygen fluctuations occurred and the river supported a healthy biotic community. Downstream of Reno, effluent from the cities trickling filter plant is discharged. This effluent increased total nitrogen concentrations to 1.2 g/m³ and orthophosphate concentrations to 1.8 g/m³ and large daily fluctuations in dissolved oxygen occurred. Below the discharge the stream bed was covered by benthic Cyanobacteria of the genus Oscillatoria. A gross productivity (P) of 8.1 g/m²/day and respiration (R) of 7.3 g/m²/day was estimated by the diurnal curve method for the 5 mile stretch below the discharge.

Simonsen and Harremoës (1978) have used the diurnal curve method of Odum (1956) to study the River Havelse, Denmark. This is a small stream and the study was conducted immediately below a discharge of a predominantly biologically treated waste from a community of 20,000 people. Data accumulated by these workers showed that the reaeration coefficient remained relatively constant at $7.0 \text{ g/m}^2/\text{day}$ while gross productivity varied between 0.2 and $26 \text{ g/m}^2/\text{day}$ and respiration varied between 7 and $23 \text{ g/m}^2/\text{day}$. The higher values were recorded when peak algal growths occurred while mechanical removal of algae reduced these values by two thirds. The lowest productivity values were recorded in the winter months while respiration values remained relatively constant throughout the year provided mechanical removal of algae was practised.

2.5 Benthic Macroinvertebrates in Rivers

2.5.1 New Zealand benthic macroinvertebrates

The bottom fauna of a river consists of macroinvertebrates. The density of these organisms in New Zealand streams is as high as that occurring overseas (100-1000/ft²) (Allen, 1961) but the diversity of New Zealand bottom fauna is far less than in Europe (Stout, 1975). There are fewer genera than in European streams and within each genera there are fewer species.

New Zealand bottom fauna includes molluscs, annelids, crustaceans, insects and water mites (Stout, 1973). The distribution of macroinvertebrates depends on both the current speed of the stream and the nature of the substrata (Hynes, 1973). Insects of the orders Ephemeroptera, Trichoptera and Plecoptera are the major inhabitants of swift, stony New Zealand streams whilst the dipterans and some genera of trichopterans and ephemeropterans inhabit the less swift area of the stony stream (Allen, 1951; Stout, 1970, 1973 and 1975). On a depositing, silty river bed molluscs, annelids, tubificids, crustaceans and Hydrocarina (a water mite) exist, utilizing any weed growth for food and shelter (Stout, 1970, 1973 and 1975).

Other environmental factors that influence the presence of one or more types are calcium content, hardness, temperature, dissolved oxygen, amount of organic matter and concentration of nutrients (Hynes, 1973; Stout, 1970). The calcium content of water affects what type of mollusc can live there because calcium is necessary for formation of snail's shells and different species of snails require different concentrations (Stout, 1970). In soft water, fewer worms, amphipods, molluscs and chironomids occur while numbers of ephemeropterans and plecopterans are increased (Stout, 1970). Low

dissolved oxygen and high temperatures are especially inhibitory to ephemeropterans and plecopterans and to some extent, trichopterans as well (Hynes, 1973).

The ephemeropteran, Deleatidium and trichopterans Sericostomatidae and sometimes Helicopsychidae have been reported to be the dominant species of stony sections of many New Zealand streams (Allen, 1951; McLay, 1968; Cadwaller, 1975; Winterbourne, 1974 and Hopkins, 1965). In more isolated occasions, members of the order Plecoptera can dominate. For example, in a small forest stream in north Canterbury, species of the family Gripopterygidae accounted for 38 percent of macroinvertebrates on the detritus and 13½ percent of those on stones (Winterbourne, 1978). In the less swift reaches of the Horokiwi stream, chironomids, Austrosimuliidae and Hydropsyche developed along with Deleatidium while in slow waters the mollusc Potamophyrgus, coleopteran Elmidae and oligochaetes dominated (Allen, 1951).

2.5.2 Species diversity

Species diversity is a parameter of communities. It measures the richness of species within a community and their relative abundance. A typically diverse community consists of many species, most of which are relatively rare and only a few are abundant (Krebs, 1972).

Two important trends are discernable in species diversity. The first is that a stable (or predictable) environment can support a diverse community. Estuarine waters are very unpredictable and exhibit low diversity while in contrast deep sea water is very predictable and has a high diversity (Pielou, 1975). The second trend is that an irregular environment supports

a more diverse community than a regular environment. This is because an irregular environment provides more potential niches and hence more species (Colinvaux, 1973).

Many attempts have been made to statistically describe the distribution of species within a community. A distribution based on the logarithmic series was established by Williams (1953 and 1964). This assumes that the greatest number of species have minimum abundance. In many cases this assumption is not true (Preston, 1948). Generally, both the number of species that are very rare or very abundant are few while greater numbers of species contain individual numbers between these two extremes. Preston (1948 and 1962) found that this form of distribution was log normal. A log normal distribution follows a bell shaped curve when plotted on graph paper. Experimentally this curve is never complete because an experimental sample is generally small and thus there is a high probability that rare specimens will not be collected. Thus the bell shaped curve is truncated at the rare species end, at a point known as the veil point.

A negative binomial distribution is used for communities in which clumping occurs. Such an example is the benthic invertebrates of the stream bottoms (Elliott, 1977). The equation of this distribution involves a constant which ranges from 0, for maximum clumping, to 1, for the random distribution that fits the logarithmic series (Hairston, 1959).

Fresh water communities have a low diversity when compared to other communities. This is because although the geographic discontinuity of fresh waters favours speciation, lack of isolation in time does not. Geologically streams and lakes are transient bodies and thus the latter predominates (Odum, 1963). Polluted waters have even less diverse communities.

This situation is analogous to an estuary, that is the waters are unpredictable and hence cannot support a diverse community (Pielou, 1975). Even domestic sewage which is generally of uniform quality is unpredictable because of periodic fluctuations in quantity and because of the diurnal variations in the receiving water interactions. Thus the diversity of the stream biota can be used to illustrate the level of pollution in the receiving waters. Texts by Hynes (1963) and Hart and Fuller (1974) discuss the ecology of polluted waters while Van Belle and Fisher (1977) discuss some of the approaches one can use with this aspect.

To illustrate diversity it is necessary to express it either graphically or mathematically. Numerous mathematical formulae have been developed to express the diversity of a sample by means of a diversity index (Wilhm, 1975). To be of use the diversity index must be independent of sample size and should reflect the distribution and relative abundance of the species (Wilhm and Dorris, 1968). Many of the early diversity indices developed were not independent of sample size (Wilhm and Dorris, 1968).

Wilhm and Dorris (1968) developed a diversity equation, described by Brillouin (1962), for use with macroinvertebrates. This equation is derived from information theory and is independent of sample size. With the use of a second equation (redundancy expression) the dominance of one or more species may be illustrated. This method has been used more recently by Kaesler and Herricks, (1970). Its main disadvantage is that it requires differentiation of organisms at the species level. This, in the fresh water situation, can often prove impossible. The sequential comparison index (SCI) was developed to eliminate tedious identification (Cairns and Dickson, 1971; Cairns et al., 1968). This method determines the number of runs of similar individuals in a randomly selected sequence of individuals. The more runs there are in a sample, the more diverse is the sample. This

method is dependant upon sample size only when the samples are small. More recently, Keefe and Bergerson (1977) have further developed this concept and have adapted it so only the total sample size and number of different species need to be known. Williams (1964) developed a diversity index to fit the logarithmic series distribution of a community. This method is independant of sample size and the diversity is determined by use of a nomograph.

Usually only certain communities of the river are sampled to determine the diversity. The communities that are commonly used are the phytoplankton (Patrick, 1972), protozoa (Cairns, 1974), benthic macroinvertebrates (Gaufin, 1973) and fish (Wilhm, 1975). Of these the macroinvertebrates are the most suitable. This is because their low motility means that they cannot escape pollution whilst their long life cycle means that they indicate past as well as present river conditions (Wilhm and Dorris, 1968).

Wilhm and Dorris (1966) applied their diversity index to communities of benthic macroinvertebrates exposed to sewage and oil refinery wastes. They found that the diversity index and the redundancy increased with the distance from the discharge point. This indicated a more diverse fauna downstream. With this method they were able to show the downstream movement of pollution zones in colder seasons. Mason (1977) also used an information theory based diversity index. He found that similar results were obtained whether the number of individuals, the biomass or the respiration values were used in the diversity expression and all gave lower diversity indices for the culturally europic site. He also found that in certain months a higher density of chironomids lowered the diversity index although there was no change in the structure of the rest of the community.

Cairns et al., (1968) determined the diversity of the stream macro-invertebrates below a sewage outfall in Lyttle Creek, Ohio by the Sequential Comparison Index. The diversity decreased markedly at the discharge point and had decreased even more at a point 400 metres downstream. At the fourth site, 5 km below the discharge, the diversity had returned to the upstream level.

A simpler approach to biologically measure the pollutional status of a river is the indicator organism concept. Certain species cannot tolerate any degree of pollution while others abound in polluted waters. Thus the relative abundance of selected species serves to indicate the level of pollution. Hirsch (1958) found tubificid worms dominating in grossly polluted New Zealand waters while chironomids and naid worms were also present. With some purification molluscs reappear and caddisflies were present after the majority of self purification had occurred. Mayflies were only present in clean waters.

A comparison of three different British biotic indices has been given by Sládecěk (1973) while Hare and Carter (1976) studied the effect of pollution on chironomids. They found that as well as affecting what species were present the pollution also causes deformities in the remaining species as if they were near the limits of the ecological range. Ghetti and Bonazzi (1977) also compared three biotic indices and they found close correlations at the diverse end while with the low biotic indices associated with pollution there was greater variation. The biotic index used by the Trent River Board has been published by Woodiwiss and is reproduced in Figure 1. This system is applicable to New Zealand with the exception of Assellus, leeches and Gammarus which do not occur here. As New Zealand streams have a much lower diversity than English streams the Trent Biotic

FIGURE 1 THE TRENT BIOTIC INDEX

		Total number of groups present				
		0-1	2-5	6-10	11-15	16 +
		Biotic index				
<u>Plecoptera</u> nymph present	More than one species	-	7	8	9	10
	One species only	-	6	7	8	9
<u>Ephemeroptera</u> nymph present	More than one species	-	6	7	8	9
	One species only	-	5	6	7	8
<u>Trichoptera</u> larvae present	More than one species	-	5	6	7	8
	One species only	4	4	5	6	7
Tubificid worms and/or Red Chironomid larve present	All above species absent	1	2	3	4	-
All above types absent	Some organisms not requiring oxygen may be present	0	1	2	-	-

The groups are as follows:

Each species of: Annelida, Mollusca, Crustacea, Plecoptera, Neuroptera, Coleoptera, Hydracarina and Diptera (other than specified below).

Each genus of: Nais and Ephemeroptera.

Each family of: Trichoptera, Chironomidae and Simulidae.

Source: Woodiwiss (1964)

Index (TBI) maximum of 10 would probably not be applicable here.

There are certain inherent limitations when using biological methods to determine pollution levels. These are associated with environmental factors and life cycles of the organisms concerned, both of which affect a species abundance (Gaufin and Tarzwell, 1952). The influence of stream velocity, substrata type and other environmental factors on macroinvertebrates has been discussed previously. Hirsch (1958) found that silt and sand bottom streams had a less diversity than stony streams, thus biological methods used in the former are not as effective as in the latter. The lower diversity on silty bottoms reflects the regularity of that environment when compared to a stony stream. Insects will not be collected during the periods in which they are eggs, small instars or at non aquatic stages and thus a knowledge of their ecology must be applied when interpreting the various indices (Gaufin and Tarzwell, 1952). Allen (1960) considered the effect that land development has on composition of benthic macroinvertebrate samples.

3. THE STUDY AREA

3.1 General Geography

The Oroua River is a permanent stream which originates from the central Ruahine Ranges, Manawatu. From the ranges it flows south-west to pass by Feilding, to its confluence with the Manawatu River just west of Rangiotu (NZMS 1 N148 942253). There are two major tributaries to the lower reaches of the Oroua River. These are the Kiwitea Stream, the confluence of which is near Feilding (NZMS 1 N149 008520), and the Makino Stream which joins the river just upstream of Awahuri (NZMS 1 N149 019452). Figure 2 maps the Oroua Rivers, its tributaries and the discharge points and sites used in this study.

The geology and topography of the Oroua River and surrounding district has been characterized by Heerdegen (1972), Hall (1964) and Whatman (1964) while the soils have been described by Cowie (1964) and Cowie and Rijske (1977). The following description is limited to the Lower Oroua River only, that is, the Oroua River below its confluence with the Kiwitea Stream.

Nevins (1964) classifies the rivers that flow from the greywacke complex of the Ruahine Ranges as hard bed rock rivers. These rivers typically have long mountainous and shingle phases. The mountainous phase consists of a series of waterfalls and rapids and the bed material is large cubical greywacke stones. The shingle phase has many rapids and riffles and the bed material has been smoothed into shingle deposits. Below the shingle phase the silt phase forms and the bed material consists of silt and sand. The Lower Oroua River is at the shingle phase until Awahuri after which the silt phase predominates.

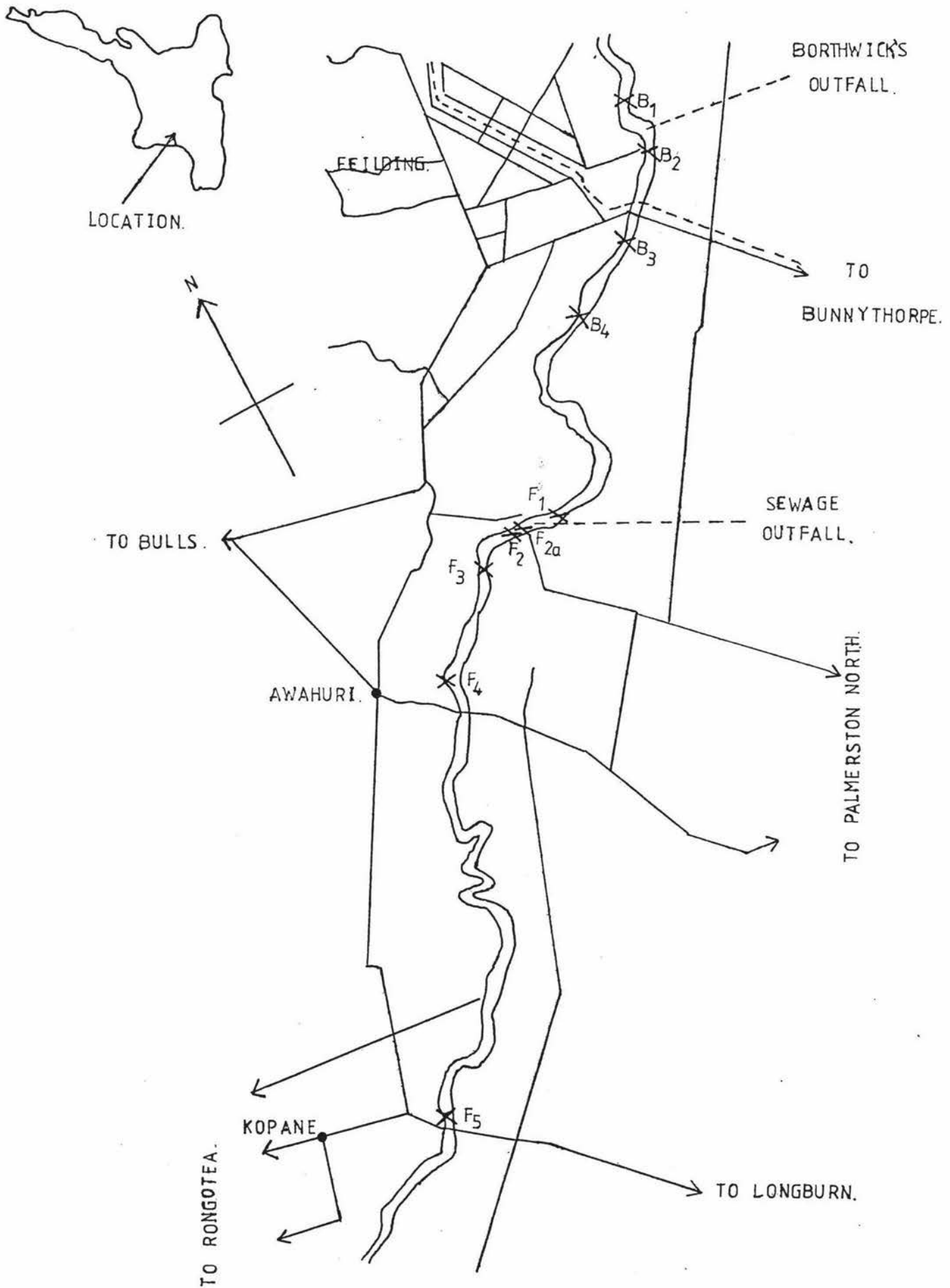


FIGURE 2 THE STUDY AREA

During wet weather the Oroua River carries a high sediment load. This is because the valley sides of the Upper Oroua River are soft sedimentary rocks that are easily eroded (Heerdegen, 1972).

Soils in the Lower Oroua River catchment were formed through river deposition and are hence very fertile and this has resulted in intensive agriculture in the area. Dairying, fat lamb production, market gardening and grain cropping are the major land uses.

The climate of the Manawatu has been described by Saunders (1964). It is generally moderate with few extremes, rain falls regularly and severe droughts are rare. The daily temperature change is comparatively large and this is more marked in the summer months. Rainfall in the study area varies between 90 and 100 cm a year while the headwaters receive an annual rainfall of 125-150 cm. This area is characteristically windy and a high proportion of the winds are strong. Table 9 gives the monthly average for the Manawatu as determined by the DSIR, Palmerston North.

TABLE 9 WEATHER CONDITIONS FOR MANAWATU

MONTH	NOV	DEC	JAN	FEB	MAR	APR
<u>RAINFALL</u> (1941-1970) (mm)	79	104	84	69	74	74
<u>TEMPERATURE</u> (1928-1970)						
MEAN MAXIMUM ($^{\circ}$ C)	18.5	20.6	21.8	22.2	20.9	18.1
MEAN MINIMUM ($^{\circ}$ C)	9.7	11.5	12.6	12.6	11.5	9.4
<u>HOURS SUNSHINE</u>	175	194	210	185	171	138

The uppermost site of the Oroua River is 75 m above sea-level while the bottom site is at 30 m (NZMS 1). This gives an average river gradient of .0032:1.

The uses of the Oroua River have been defined as fishing, water supply, swimming, picnicing and stock watering (Pol. Adv. Council, 1957). Feilding water supply is taken from the Oroua River above the village of Kiwitea while Borthwick's Meat Works takes from the river just upstream from the meat works. Fishing, swimming and picnicing is generally confined to the river above Feilding although Awahuri and Kopane are used occasionally. Stockwatering has been reported at Kopane.

3.2

Waste Sources

3.2.1

Borthwick's meatworks effluent

The first major waste discharged to the Oroua River is from T. Borthwick and Son's meatworks. This waste has been extensively treated. After screening and primary sedimentation the wastes flow through a sequence of anaerobic and aerated ponds from which it flows through a secondary sedimentation tank to the river. The aerated pond had been completed in the year previous to this study and the author has observed a major improvement in river appearance since then.

The main mutton killing season at Borthwick's is from November through to March whilst the beef season is from March until June (B. Birch, pers. com.).

The discharge to the Oroua River is 1.5 km above the Aorangi Bridge (NZMS 1 N149 076497) at which point the river is swift and turbulent with a shingle substrata. The discharge did not noticeably affect the river's clarity. Samples of the Borthwick's effluent were taken immediately after secondary sedimentation.

3.2.2

Domestic sewage

Domestic sewage is discharged into the Oroua River opposite the end of Milsons Line (NZMS 1 N149 041463) at which point the river is swift, turbulent and stony bottomed.

The domestic sewage originates from the populace of Feilding (population 10,000) and intermittent discharges from a local abattoir and woolscour plant.

Treatment of the wastes consists of primary sedimentation, trickling filtration and secondary sedimentation. This system was extremely overloaded and recently (after this study) a second trickling filter was completed. Both the abattoir and wool scour discharges are seasonal. Peak abattoir loads occur from November until May when the abattoir is operating 5 days a week. During this period the wastes enter the sewage treatment plant between 7.00 a.m. and 4.00 p.m. Peak woolscour loads occur between December and May when wastes are discharged to the sewage treatment plant 24 hours a day (W. Blakelock, pers. com.). Thus the trickling filters receive a very variable influent which is an undesirable factor and reduces the efficiency of the trickling filter. The treated sewage is piped overland to the Oroua River bed where it was discharged and channelled across the dry river bed to the main river channel. Samples of the sewage were taken at its discharge from the pipe.

3.3

Site Descriptions

Nine sites were selected for this study. The basis of selection was on accessibility rather than any other factor. The 9 sites were considered in two groups. The upper 4 sites were studied with respect to the Borthwick's discharge and were designated B₁-B₄ respectively while the lower 5 sites (F₁-F₅) were studied with respect to the domestic sewage discharge. Table 10 summarizes the position of each site while Table 11 shows site characteristics and Figures 3-6 illustrate some of these sites.

TABLE 10 SITE LOCATION

<u>SITE</u>	<u>MAP REFERENCE (NZMS 1)</u>	<u>POSITION</u>
B ₁	N149 078500	above Borthwick's discharge
B ₂	N149 074494	below Borthwick's discharge
B ₃	N149 069492	Aorangi Bridge
B ₄	N149 061487	Kawa Woolscour
F ₁	N149 043463	above sewage outfall
F ₂	N149 039463	below sewage outfall
F ₃	N149 030460	off Milsons Line
F ₄	N149 019449	Awahuri Bridge
F ₅	N148 993403	Kopane Bridge



Figure 3 Site B₁ - above Borthwick's discharge

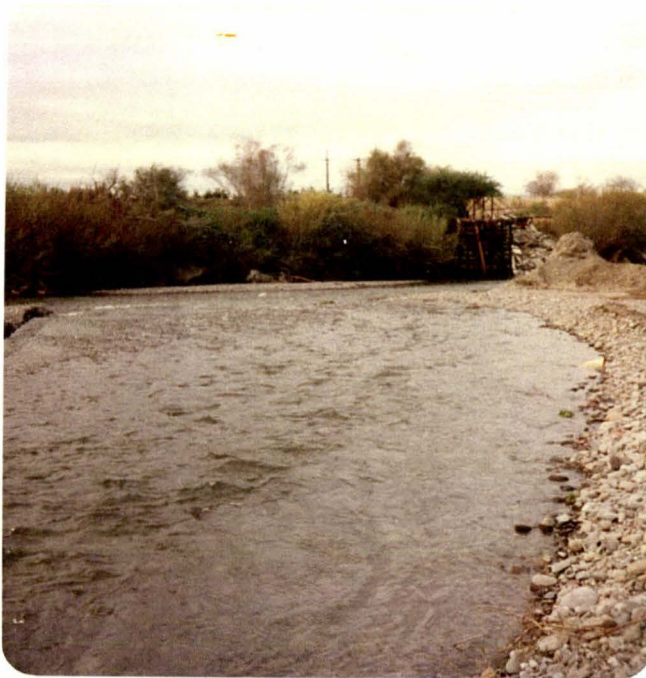


Figure 4 Site F₂ - immediately below sewage discharge

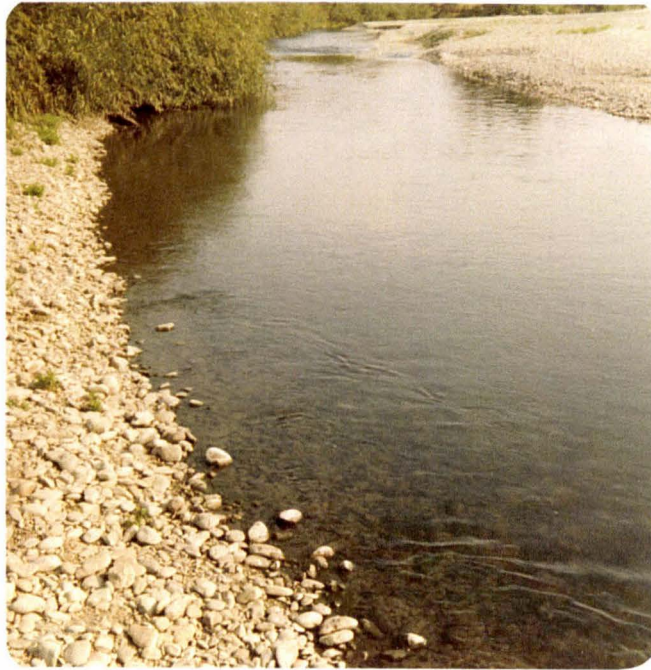


Figure 5 Site F₄ - Oroua River at Awahuri

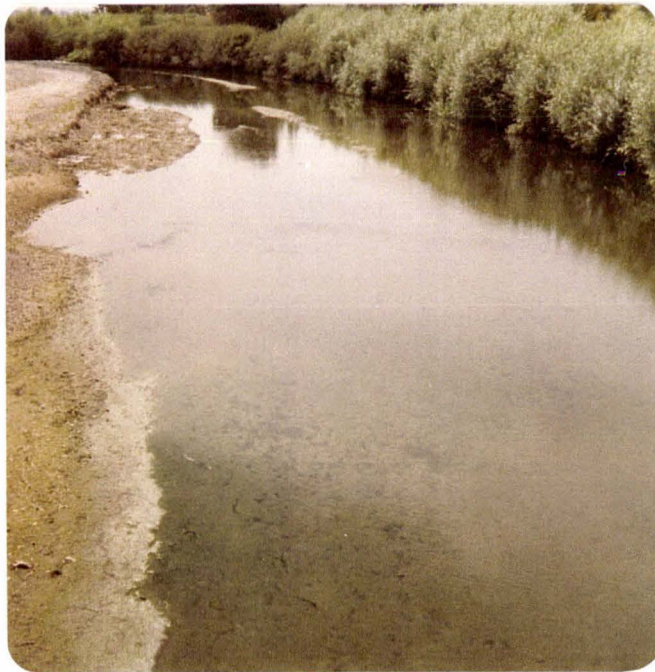


Figure 6 Site F₅ - Oroua River at Kopane

TABLE 11 SITE DESCRIPTION

<u>SITE</u>	<u>FLOW</u>	<u>SUBSTRATA</u>	<u>APPEARANCE</u>	<u>BANK COVER</u>
B ₁	swift/riffles	shingle	clear	fairly clear
B ₂	swift/riffles	shingle	clear	trees
B ₃	swift/riffles	shingle	clear	fairly clear
B ₄	moderate/pools	shingle/silt	clear	fairly clear
F ₁	swift/riffles	shingle	clear	clear
F ₂	swift/riffles	shingle	turbid	clear
F ₃	moderate	shingle/silt	turbid	fairly clear
F ₄	swift/riffles	shingle	turbid*	clear
F ₅	moderate	silt	clear	clear

* clear in high flows

3.4

Previous Work on the Oroua Rivér

A study was made under the direction of the Pollution Advisory Council (1957) to determine the level of pollution. At that time the river received wastes from several sources that no longer exist. For example, in 1957 there were four dairy company discharges while today there are none. Feilding domestic sewage was treated by septic tanks only and passed in an open drain to the river. This drain also carried wastes from the local abattoirs, a boiling down works and the woolscour works and discharged to the river at the Kawa Woolscour plant.

Analysis of the abattoir wastes revealed a BOD of 2870 g/m^3 and a suspended solids content of 2490 g/m^3 . This waste had only the gross solids removed from it. The Kawa Woolscour plant had two different effluents. A steady stream of clear wash water of approximately 50 g/m^3 BOD was discharged for 7 hours a day while each evening scour liquor of about 5000 g/m^3 BOD and $22,850 \text{ g/m}^3$ suspended solids was discharged. Borthwick's effluent consisted of all the wastes except for most of the blood which was saved. Only the gross solids were removed from the effluent which had a BOD of $590\text{--}890 \text{ g/m}^3$ and 860 g/m^3 suspended solids. This effluent was discharged to the river near where the present day discharge point is and caused substantial blankets of sludge on the river bottom.

This study considered dissolved oxygen, microbiological and biological parameters in the river. Six sites used in the 1957 study corresponded to sites used in the present study and Table 12 shows the dissolved oxygen concentrations, presumptive coliform densities and faecal coliform densities at these sites.

TABLE 12 DISSOLVED OXYGEN CONCENTRATIONS,
PRESUMPTIVE COLIFORM DENSITIES AND FAECAL COLIFORM
DENSITIES IN THE OROUA RIVER, 1957

SITE	D.O. CONCENTRATION (g/m ³)		PRESUMPTIVE COLIFORM/ 100 ml	FAECAL COLIFORM/ 100 ml
	NOVEMBER	MARCH	(NON FLOOD FLOWS)	(NON FLOOD FLOWS)
B ₁ (O ₅)	-	9.1	240-800	20-800
B ₃ (O ₆)	8.6	3.8	-	-
B ₄ (O ₇)	-	1.8	> 20000	> 20000
F ₁ (O ₉)	8.6	4.4	-	-
F ₄ (O ₁₀)	9.2	11.6	> 200000	> 200000
F ₅ (O ₁₁)	8.8	9.4	> 200000	> 50000

N.B. The equivalent 1957 sites are given in parentheses.

Source: Pol. Adv. Council (1957).

Studies on the periphytic growths made in November 1956 showed little present while in March 1957 green algae was common at the sites above all discharges and dense populations of sewage fungus, diatoms and green algae occurred at most sites below the discharges.

Macroinvertebrates were also studied in the river and in March quantitative samples were taken by a surber sampler. Table 13 shows the March 1957 densities of macroinvertebrates at the sites used in the present study. Deleatidium dominated in sites above the discharges while in the polluted areas naid worms and chironomids were abundant. Qualitative samples taken in clean areas in both November and March showed Sericostomatidae (Pycnocentrids) and Plecoptera to be more common in November while numbers of Hydropsychidae, Chironomidae and Rhyacophilidae were higher in March. Deleatidium and Elmidae (Hydora) numbers were slightly more abundant in March.

TABLE 13 DENSITIES OF MACROINVERTEBRATES IN THE
OROUA RIVER, MARCH 1957

MACROINVERTEBRATE GROUP	SITE DENSITY (No/m ²)			
	B ₁ (O ₅)	B ₃ (O ₆)	F ₁ (O ₉)	F ₂ (O ₁₀)
Coloburiscus	11	0	0	0
Deleatidium	899	33	0	0
Hydropsyche	135	0	5	0
Rhyacophilidae	11	0	0	0
Pycocentrids	22	0	0	0
Elmidae	199	38	0	0
Chironomidae	118	44	16	6
Other Diptera	11	0	5	16
Mollusca	38	0	0	16
Tubificidae	0	44	33	55
Naididae	5	6	84	6
Total	1449	165	143	99

N.B. The equivalent 1957 sites are given in parentheses.

Source: Pol. Adv. Council (1957) and Hirsch (1958).

The general conclusion of the P.A.C. (1957) study was that recovery of the river was apparent only at Kaimatarau Road, which is downstream from Kopane (F₅) but even at this site small bits of suspended sewage fungus were evident. The biological results have been further discussed by Hirsch (1958).

Recent work on the Oroua River has been conducted by the Manawatu Catchment Board and Regional Water Board (Currie, 1977). The river was sampled at Rangiotu just before its confluence with the Manawatu River and Table 14 summarizes the results obtained. The results showed the river to be of

TABLE 14 THE OROUA RIVER AT RANGIOTU, 1977

<u>COMPONENT</u>	<u>MIN</u>	<u>MAX</u>	<u>AVE</u>	<u>UNITS</u>
Dissolved Oxygen	6.0	7.3	-	g/m ³
Dissolved Oxygen	64	85	-	% saturation
Temperature	19.3	24.8	-	°C
BOD	4.0	5.5	4.2	g/m ³
pH	7.25	7.6	7.4	
Suspended Solids	2.5	9.4	5.3	g/m ³
Specific Conductivity	195	255	230	µmho/cm
Ammonia-N	0.01	1.6	0.7	g/m ³
Nitrate-N	-	-	0.5	g/m ³
Phosphate-P	-	-	0.15	g/m ³
Presumptive Coliform	-	-	7900	/100 ml
Faecal Coliform	-	-	2400	/100 ml

relatively poor quality. The specific conductivity was relatively high and the pH was typical of that conductivity level. The dissolved oxygen was low, never reaching saturation values and the BOD was indicative of waters of doubtful quality (Royal Commission on Sewage Disposal criteria; quoted by Holden, 1970). The nutrients, ammonia, nitrate and orthophosphate were all relatively high while faecal coliform numbers indicated that these waters are unsuitable for swimming.

The present study examines the Oroua River at sites upstream of Rangiotu and determines what causes the poor quality of the river. As well it determines the maximum concentrations the above parameters reach in the Oroua River. This study includes some of the sites used by the Pollution Advisory Council in 1956-1957 (Pol. Adv. Council, 1957) and thus can be used to illustrate the changes in water quality since 1956.

4.

METHODS AND MATERIALS

4.1

General Procedures

The Borthwick's sequence (B_1 - B_4 and Borthwick's effluent) and the Feilding sequence (F_1 - F_5 and the sewage) were sampled on alternative weeks from November 1977 until March 1978. By March it was obvious that the Feilding domestic sewage affected the river far more than the Borthwick's effluent and to gain more information of the effect of the Feilding domestic sewage the Feilding sequence was sampled twice every three weeks while the Borthwick's sequence was sampled only once.

Dissolved oxygen and temperature were determined on site and four samples were taken for analysis for other species. A two litre sample of the river water or effluent was collected in a plastic bottle and used for most of the physicochemical tests while microbiological samples were obtained in 100 ml sterile glass bottles and held at 4°C. Total kjeldahl nitrogen and total phosphorus samples were collected in other 100 ml glass bottles as were the samples for sulphides estimation and these were held at 4°C. Other physicochemical and chemical species tested for were pH, suspended solids, BOD, COD, phosphates and nitrates. The two discharges were also tested for protein and carbohydrate content. All the reagents used in the testing procedures were BDH, (Dorset, England), analytical grade unless otherwise specified. The microbiological tests were for saccharolytic, proteolytic and lipolytic bacteria and as well a twelve week study was made on the presumptive and faecal coliforms. The bacteria analyses were made within 4 hours of sampling while the chemical tests were completed on the day of sampling.

Biotic sampling was conducted monthly at five sites. These sites

represented the river above and below the Borthwick's outfall (B_1 and B_3) and above, immediately below and downstream of the sewage discharge (F_1 , F_2 and F_4). Although information from sites further downstream would have been desirable, the change in river regime from the shingle phase to the silt stage meant that comparisons with upstream samples would have been meaningless. This was also noted by Hirsch (1958) in his biotic survey of the Oroua River. Sampling commenced on 25 November and continued until 31 March after which flooding in the Oroua River had removed most of the invertebrates.

The effect of algae on the Oroua River was determined by the diurnal curve method of Odum (1956). Three hourly monitoring of dissolved oxygen levels and temperature at three sites (B_3 , F_2 and F_4) was conducted for 24 hours on the 21 and 22 March. The sites selected were those that involved the minimum amount of travel with easy accessibility.

4.2 Chemical and Physicochemical Methods

4.2.1 Temperature and dissolved oxygen

The dissolved oxygen content and the temperature were measured in situ by a Yellow Springs Instrument, Yellow Springs, Ohio, U.S.A., (YSI) 54 dissolved oxygen meter and probe. The use of dissolved oxygen meters has been discussed by A.P.H.A. (1971, 218 F) and Reynolds (1969) favourably compares the dissolved oxygen meter method with the standard Winkler method (A.P.H.A., 1971, 218 F). The advantages of dissolved oxygen meters are that they are fast and simple and allow on site measurements to be made.

4.2.2 Biochemical Oxygen Demand (BOD)

The total BOD₅ of the samples was determined by the standard A.P.H.A. (1971, 219) method except that the dissolved oxygen readings were made using a YSI 57 dissolved oxygen meter and YSI 5270A Self Stirring BOD bottle probe rather than by Winkler.

4.2.3 Chemical Oxygen Demand (COD)

The total COD of the discharges was determined by the micro-technique of Jirka and Carter (1975). This method uses the same reagents and concentrations specified by A.P.H.A. (1971, 220) but at 1/10 the specified volume. The sample and reagents were placed in small 10 ml Hach (Hach Chemical Company, Iowa, USA) screw topped test tubes, capped, mixed and digested in a small Hach heating mantle. Refluxing was at 160°C for 2 hours. This method determined the conversion of Cr IV ions to Cr III ions spectrophotometrically and undiluted samples of up to 900 g/m³ can be determined. Jirka and Carter (1975) found that the micro method has a similar precision to the standard method (A.P.H.A., 1971, 220) at low COD

values while with high COD values the micro-method has the higher precision. This is because the standard method refluxes to the atmosphere and volatiles may be lost in reflux or mixing. The main advantages with the micro method are that only small amounts of reagents are required which thus reduces cost and disposal problems and the reflux equipment is simpler, cheaper and less easily broken. The compactness of the equipment means that far more samples can be refluxed at once, for example the Hach mantel can accommodate 16 tubes.

A standard curve for COD determinations was prepared with 8 acid phthalate standards (A.P.H.A., 1971, 220). Equation 20 gives the resultant regression line and this fitted the data points with a 0.999 regression coefficient.

$$\text{COD (g/m}^3\text{)} = \text{absorbance at 600 nm} \times 3369 \quad (20)$$

The COD of the river water was determined by the standard method (A.P.H.A., 1971, 220) except that since the river represented a dilute system the reagents were used at 1/5 the specified concentrations. In both the river water and effluent samples the chloride modification (Dobbs and Williams, 1963) was not used. The sulphuric acid used in these tests was commercial grade.

The two COD methods were both used on the sample collected at site F₂, so as to compare the methods. No significant difference was found between the methods when a t test was applied to the results. The reproducibility of the micro method was determined by triplicate analyses on the discharge and results were found to agree within 10 percent. Most of this discrepancy was probably due to difficulty in obtaining a representative 1 millilitre sample.

4.2.4

Suspended Solids

The suspended solids of both the river water and discharges were determined by filtration through 7 cm Whatman (Whatman Limited, Maidstone, U.K.) glass fibre filter paper (grade GF/C) which was then dried at 103°C for 2 hours (A.P.H.A., 1971, 224 C).

4.2.5

pH

The pH of the samples was determined as soon after collection as possible using an Electronic Instruments Limited (EIL) Model 7030 extended scale pH meter with a glass electrode.

4.2.6

Phosphates

The total dissolved and suspended orthophosphate concentration of the samples was determined by the Ascorbic Acid method (A.P.H.A., 1971, 223 F). This method was used because its simplicity meant that preparation time was minimal. This method is suitable for measuring orthophosphate concentrations of 0.01-6 g/m³ (A.P.H.A., 1975). Twelve standards of potassium dihydrogen phosphate in the range of 0 to 1.2 g/m³ was used to construct the phosphate standard curve. The regression line for the data is given in equation 21 and the regression coefficient was 1.000.

$$\text{phosphate-P (g/m}^3\text{)} = \text{absorbance 880 nm} \times 1.485 \quad (21)$$

4.2.7

Total phosphorus

Total phosphorus determinations were made by the Soil Science Department, Massey University. Samples were digested in a perchloric acid solution (O'Connor and Syers, 1975) and phosphorus was then determined by a molybdenum blue reaction (Murphy and Riley, 1962).

4.2.8

Nitrates

Nitrates were determined by the Brucine method (A.P.H.A., 1971, 213 C) again because of the simplicity of the method. Equation 22 shows the regression line fitting a series of 11 anhydrous potassium nitrate ($0-1.0 \text{ g/m}^3$) standards. The regression coefficient was 0.998.

$$\text{Nitrate-N (g/m}^3\text{)} = \text{absorbance 410 nm} \times 3.53 \quad (22)$$

This method is suitable for nitrate-nitrogen concentrations between 0.1 and 2 g/m^3 (A.P.H.A., 1975).

4.2.9

Kjeldahl Nitrogen

The kjeldahl nitrogen content of the samples was also determined by the Soil Science Department, Massey University. Total kjeldahl nitrogen was determined on an auto-analyser using a kjeldahl type digestion (Terry, 1966).

4.2.10

Protein

Protein determinations were made by the Folin-Ciocalteu technique, developed by Lowry et al. (1951) as modified by Millar (1959).

The advantages of this test are that it is rapid (the reaction is complete within 10 minutes), requires no digestion and yet it is 100 times more sensitive than the biuret test. The disadvantages are that colour intensity varies with protein composition and that the absorbance and protein concentration do not always vary linearly. As effluent proteins are a mixture, the first limitation can be ignored and a comprehensive standard curve showing the areas of linearity overcomes the second.

The standard protein curve was based on bovine serum albumen (Sigma Chemical Co., U.S.A.). The curve was found to be linear in the working range (0-2000 g/m³) and fitted the regression equation (equation 23) with a correlation of 0.96 when 6 protein standards were used.

$$\text{Protein (g/m}^3\text{)} = \text{absorbance (750 nm)} \times 5540 \quad (23)$$

This correlation was somewhat lower than desirable but it was considered sufficient to characterize these effluents because of their large hourly changes in concentration.

4.2.11

Carbohydrates

The carbohydrate content of the discharges was determined by the anthrone method of Golterman (1969) except that a 0.2% (w/v) anthrone solution was substituted for the 0.1% (w/v) solution specified. This is a rapid method

requiring only a 15 minute incubation time.

The carbohydrate standard curve was constructed from 6 glucose standards from 0-200 g/m³ concentration and equation 24 gives the equation for the standard curve which had a regression coefficient of .998.

$$\text{Carbohydrates (g/m}^3\text{)} = \text{absorbance (630 nm)} \times 315 \quad (24)$$

4.2.12

Sulphides

Sulphides were qualitatively tested for in this study by the use of lead acetate paper (A.P.H.A., 1971, 228). The samples were fixed at the site by addition of 2N zinc acetate. At the laboratory the samples were made slightly acidic with 6N hydrochloric acid and sulphide evolution was detected by blackening of the lead acetate paper. This test has a high specificity for hydrogen sulphide, is very sensitive and gives rapid results.

4.3 Microbiological Methods

4.3.1 Sample Preparation

The samples that had been stored at 4°C were diluted in peptone water (A.P.H.A., 1975) that was also stored at 4°C and duplicate samples of the appropriate dilutions were plated out by the pour plate method (A.P.H.A., 1975) with the different sterile media as noted below. The plates were incubated at 28°C for 36 hours, a time temperature combination found to give the maximum growth with distinct margins between colonies. Readings were expressed as number of cells per 100 millilitres.

4.3.2 Proteolytic bacterial counts

A mixture of 5% (w/v) Davis high grade gelatin (Davis Gelatine N.Z. Limited, Christchurch) and 1% (w/v) Davis agar in Oxoid Thioglycollate Liquid Medium (Oxoid Limited, London) was used to select for proteolytic saprophytes. The method of Frazier as modified by Skerman (1959) was used to determine gelatin hydrolysis and hence proteolytic action. A mixture of 15 g HgCl_2 and 20 ml concentrated hydrochloric acid was mixed with 100 ml distilled water and flooded onto the plates. Unhydrolysed gelatin formed a white precipitate with the mercury salt and hence the proteolytic colonies were those with cleared zones around them.

4.3.3 Saccharolytic bacterial counts

Saccharolytic bacteria were selected for on a starch agar made from 0.2% soluble starch in Oxoid nutrient agar (Harrigan and McCance, 1966). Saccharolytic colonies were defined as those with a clear zone around them after flooding with an iodine solution. The non-hydrolysed starch formed the typical purple colour with the iodine.

4.3.4 Lipolytic bacteria counts

Lipolytic bacteria were enumerated by growth of these bacteria on Oxoid Tributyrin agar. Positive colonies were defined as those which caused visually observable clearing of the normally opaque agar around the colony in question.

4.3.5 Presumptive and faecal coliforms

Presumptive coliform content of each sample was determined by the Most Probable Number (MPN) Index method as described by A.P.H.A. (1971, 407 C) except that MacConkey's Broth (Oxoid) was used instead of the EC Medium. A positive coliform test was defined as one that produced both acid and gas after 48 ± 2 hours incubation at $37 \pm 0.5^{\circ}\text{C}$.

Each positive presumptive culture tube was then inoculated into a second MacConkey tube and incubated at $44.5 \pm 0.2^{\circ}\text{C}$. A positive result for faecal coliforms was acid and gas production after 24 ± 2 hours at $44.5 \pm 0.2^{\circ}\text{C}$. Counts of both presumptive and faecal coliforms were read from McCrady Tables and expressed as the most probable number of bacteria per 100 ml of sample.

4.4

Biological Methods

4.4.1

Biotic Sampling

Biotic samples of the macroinvertebrates were taken by means of a 625 cm² Surber Sample (Surber, 1969). This type of sampler is widely used in shallow, flowing waters (A.P.H.A., 1971; 604 A; Cairns et al., 1968). Only the riffle areas were sampled since these have the highest diversity of macroinvertebrates and similar riffles were sampled at each site. The procedure used aimed at obtaining uniformity of sampling techniques between sites rather than quantitative determinations for the whole river bed.

Sampling involved the scraping of the stones contained within the sampling area using a plastic brush. The Surber Sampler was arranged so that these scrapings were carried into the net by the stream flow. To achieve further uniformity between the sites each 625 cm² area was sampled for 3 minutes. Three samples were taken at each site as this was the minimum number required to obtain statistically significant results (Cairns and Dickson, 1971). The net contents were transported to the laboratory in wide necked containers held at ambient temperatures.

The samples were sorted manually and sucrose was added during the final stages of sorting to float the remaining organisms. The specimens collected were preserved in alcohol until identification could be performed.

Identification of organisms was aided by a low powered microscope at 1, 3 or 6 times magnification. Identification keys of Penniket (1961 and 1964), Winterbourne (1964 and 1965) and Ponder (1964) were used. In addition, works by Pendergrast and Crowley (1966), Marples (1962) and McLellan (1975) proved invaluable. The specimens were identified as completely as possible and unidentified individuals were compared with each other to determine whether or not they belonged to the same species.

4.5

Data Analysis

4.5.1

Analysis of the Weekly Physicochemical,
Chemical and Microbiological Results

- (1) The range, mean and standard deviation of components at each site and effluent were determined.
- (2) The concentrations of selected parameters in the Borthwick's effluent and the Feilding domestic sewage were plotted with respect to the sampling date. The data was then smoothed using a 5 point moving average (Gregg et al., 1967). and inspected for trends. A trend was defined as a definite change in concentration with respect to time and was illustrated by a positive or negative slope when the smoothed data was plotted against time.
- (3) All possible combination of paired parameters at any one site were analysed to determine if one of the parameters influenced the other, or if both were influenced by a third factor, or if the two parameters were independant of each other. This was done by pairing the concentration data obtained for each sampling day and then testing this for a significant correlation coefficient using Minitab (a standard computer package) on the Massey University Burroughs B6700 computer. The significant correlation coefficients obtained at each site and discharge were then compared to see if a particular correlation between two parameters was unique to a certain site or applied to the river as a whole.
- (4) The effect the two discharges had on the river quality was estimated by comparing the site immediately upstream of the discharge with that

immediately downstream. This was done by applying a t test to the means and standard deviations calculated previously in the section 2.5.1 (1) (Chadwick, 1970). The effluent was said to affect a certain river component if the t test showed the upstream concentration to be significantly different from the downstream concentration. The 95 percent level of significance was used.

- (5) The reduction of COD, BOD and orthophosphate concentrations and the number of bacteria/100 ml for each bacterial group in the sites below the Feilding domestic sewage discharge was inspected for conformance to first order kinetics. This was done through the Minitab statistical package. The concentrations of the parameter under consideration at each site and the time of flow from the point of discharge to each sites were the inputs to the Minitab package. The concentration data was then converted to a logarithmic form and the line of best fit for the log concentration versus time of flow was found by linear regression. These regressions were then tested for significance by a t test (Chadwick, 1970). A 90% significance level was used on the chemical data while an 80% significance level was used on the BOD and microbiological data because of the greater coefficient of variation in these testing procedures (A.P.H.A., 1975).

The slope of the significant regression lines gave the proportionality constant for the first order decay of the component under consideration. The proportionality constants for each parameter obtained for each sampling run were investigated to see if they varied with environmental factors such as stream flow, stream velocity and temperature. This was done by determining the statistical correlations between the proportionality constants and the environmental parameters again using the Minitab statistical package.

- (6) The temperature model of Walker and Lawson (1977) as given in equation 25 was tested with the temperature data obtained at sites B₄ and F₁. These sites are the adjacent ones in the two sampling series and by using both, weekly temperature data could be used.

$$T = a (\text{Sin } (bx + c)) = \bar{T} \quad (25)$$

This equation gives the average temperature (T) for a river with an average annual temperature of \bar{T} when a is the amplitude of the sinewave ($^{\circ}\text{C}$), (representing half the annual temperature variation), b is $360^{\circ}/365$ days, c is the phase coefficient ($^{\circ}$), and x is the number of days since January 1. As this study lasted only 6 months the mean annual temperature was determined when the relationship in equation 26 was satisfied.

$$a \text{ Sin } (bx + c) = 0 \quad (26)$$

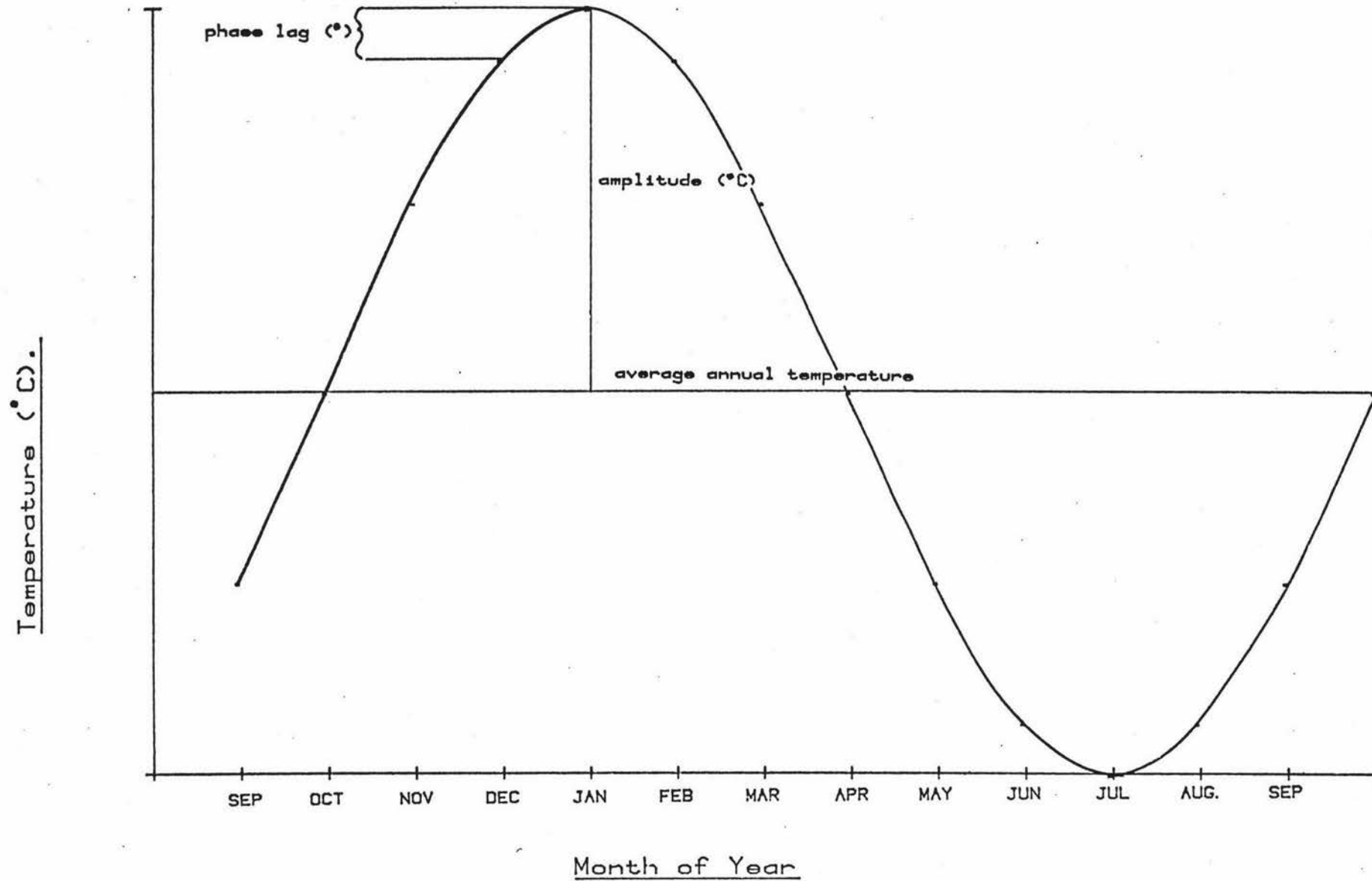
Figure 7 shows a theoretical temperature profile and illustrates how to determine the different parameters.

4.5.2 Analysis of the diurnal oxygen curve

The analysis of the diurnal oxygen curve was performed by the methods described by Odum (1956), Odum and Hoskin (1958) and Odum (1960) and is briefly listed below.

- (1) The field temperatures and dissolved oxygen data were plotted against time of day.
- (2) The dissolved oxygen values were converted to percent saturation and plotted against time of day.

FIGURE 7. Typical Stream Temperature Profile.



- (3) The average two hourly dissolved oxygen change ($\text{g/m}^3/\text{hour}$) over the 24 hours was determined from the above graph and plotted below these graphs using the same horizontal axis (time of day) giving the "rate of change graph".
- (4) The reaeration coefficient, K , was determined from the rate of change graph using equation 27.

$$K \text{ (g/m}^3\text{/hr at 0\% sat)} = \frac{q_m - q_e}{s_m - s_e} \quad (27)$$

In this equation q_m and q_e are the rates of change of dissolved oxygen at a predawn and post sunset point in $\text{g/m}^3/\text{hr}$ respectively and s_m and s_e are the percentage saturation deficits at these times.

- (5) From K and the percentage saturation curve the rate of oxygen transfer by reaeration is determined for each two hour interval. This is then subtracted from the values on the "rate of change" graph and plotted to give the rate of change graph corrected for reaeration, or the "P-R" graph.
- (6) The community respiration, R , ($\text{g/m}^3/\text{day}$) is determined by averaging the night time rate of change in the "P-R" graph and then multiplying by 24.
- (7) The gross productivity, P , ($\text{g/m}^3/\text{day}$) is then determined by graphically integrating the area between the "P-R" curve and the average hourly respiration line.

The above procedures were also fitted into a finite difference table as used by O'Connell and Thomas (1965) and the results were obtained by

that method as well.

The reaeration coefficient equation of Owens et al., (equation 2) was assumed to fit this river. By equating the two reaeration equations the average depths of the river stretches were determined. This average depth was then applied to the gross productivity and respiration results as calculated above to give the average productivity, \bar{P} , and respiration, \bar{R} , in $\text{g/m}^2/\text{day}$.

The daily oxygen demand (Y) at any point in the river was calculated by manipulation of equation 7 and the resulting expression is given in equation 28. L_0 is the ultimate BOD of the river water at any point and K_1 is the river deoxygenation coefficient (days^{-1}) based on natural logarithms.

$$Y \text{ (g/m}^3/\text{day)} = L_0 \text{ (g/m}^3) K_1 \text{ (day}^{-1}\text{)} \quad (28)$$

The ultimate BOD, L_0 , was calculated by assuming bottle deoxygenation coefficients of 0.12/day for the polluted waters and 0.10/day (natural base) for the clean waters (Eckenfelder, 1970) giving equations 29 and 30 as the relationships between the 5 day BOD and the ultimate BOD for clean and polluted water respectively.

$$L_0 = \frac{\text{BOD}_5}{0.369} \quad (29)$$

$$L_0 = \frac{\text{BOD}_5}{0.6019} \quad (30)$$

A value of 0.18 was used for the deoxygenation coefficient (natural base) in equation 28 for the clean water sites (calculated from Eckenfelder, 1970). The deoxygenation coefficient used at the polluted site was the one

determined for the river on the next sampling run (23 March 1978).

4.5.3 Analysis of the biological data

The biological data was used in 4 different ways to illustrate the water quality.

- (1) The biotic index was determined using the Trent River Board method (Woodiwiss, 1964) as given in Figure 1. The discrepancies between New Zealand fauna and English fauna were ignored.
- (2) A sequential comparison index (SCI) was obtained through computer simulation of the technique of Cairns and Dickson (1971). The biological data was randomized using a Burroughs B6700 computer and the procedure of selecting individuals to determine the number of runs in the sample then followed. The SCI was defined as the total number of runs divided by the number of individuals selected. The whole sample was used when there were less than 250 individuals collected. The sample was then rerandomized and the number of runs was determined again. A second SCI was found from the pooled results of the two runs. This process was continued, pooling the results of all previous run determinations until two consecutive results were the same to one decimal place. For samples with more than 250 individuals runs of 50 individuals were made. After the first run was made and an approximate SCI determined, the total number of runs to be made was determined from equation 31 (Cairns and Dickson, 1971).

$$\text{No Runs} = 3.3 \text{ SCI} + 5.5 \quad (31)$$

The extra runs were then done, the results were pooled and the SCI determined.

- (3) A diversity index (IDI) of the sample was determined from the method of Wilhm and Dorris (1968). The relevant equations are given below (32-35) and were solved by the use of a Burroughs B6700 computer.

$$IDI = \frac{1}{N} (\log_2 N! - \sum_{i=1}^S \log_2 N_i) \quad (32)$$

$$DMAX = \frac{1}{N} (\log_2 N! - S \log_2 (\frac{N}{S})!) \quad (33)$$

$$DMIN = \frac{1}{N} (\log_2 N! - \log_2 (N - (S-1))!) \quad (34)$$

$$R = \frac{DMAX - IDI}{DMAX - DMIN} \quad (35)$$

The total number of individuals in the sample was N , and N_i represented the number of individuals in the i th specie and S was the number of species. $DMAX$ is the theoretical maximum IDI that could be obtained for a sample with the specified number of individuals and species while $DMIN$ is the minimum IDI. The redundancy R illustrates the position of the actual IDI between these two extremes.

- (4) The final diversity index (LDI) determined from the sample was based on Williams (1964) logarithmic series (equation 36).

$$P(x) = \frac{LDI}{x} + \frac{LDI^2}{x/2} + \frac{LDI^3}{x/3} + \frac{LDI^4}{x/4} + \dots \quad (36)$$

For any particular population LDI is constant and can be used as a diversity index, x is also a constant and is less than unity. In this study the nomograph of Williams (1964) was used to determine LDI. This nomograph is given in Appendix 1 and one needs only to know the total number of individuals and number of species to use it.

5.

RESULTS

5.1

General Description

Sampling was conducted from the beginning of November until the end of April. During this period river flows varied from fresh flows in November, December and late April to extremely low flows in February and March. These low flows coincided with one of the most severe droughts recorded. Table 15 gives the average monthly weather conditions that occurred during the sampling period. This, when compared to Table 9, the average monthly weather conditions recorded over the last thirty years well illustrates the extreme nature of the drought.

TABLE 15 AVERAGE MONTHLY WEATHER DURING THE SAMPLING PERIOD

MONTH	NOV	DEC	JAN	FEB	MAR	APR
RAINFALL (mm)	76.7	94.0	7.9	9.0	16.3	122.6
TEMPERATURE:						
MEAN MAXIMUM ($^{\circ}$ C)	17.3	19.1	22.7	25.0	23.0	19.5
MEAN MINIMUM ($^{\circ}$ C)	9.2	10.5	12.2	14.1	11.9	12.3
HOURS SUNSHINE	186.9	161	237.3	248.3	181.8	131.0

Source: N.Z. Meteorological Service, DSIR, Palmerston North

The river flow, weather conditions and general river appearance recorded for each sampling day are given in Appendix 2. The river flow was recorded near the Kawa woolscour site (B_4) by the Manawatu Catchment Board and Regional Water Board and can be related to velocity by a simple logarithmic relationship which is also given in Appendix 2. The Manawatu Catchment Board and Regional Water Board also supplied flow time and flow distance data on the Oroua River at low flow and this is summarized in Appendix 2. From this data the average velocity at each site and its ratio

to the average velocity of the Kawa Woolscour site (B_4) was determined. These ratios were assumed constant for all the flows that occurred during the study period.

The daily flow of Borthwick's effluent to the river for each sampling day was obtained from Mr B. Birch of Borthwick's while Mr W. Blakelock of the Feilding Borough Council forwarded the same for the Feilding domestic sewage. These flows are all given in Appendix 2. The Borthwick's flow, because of its large ponding capacity, could be assumed constant throughout the day. This was not the case for the Feilding domestic sewage which had little storage capacity and thus large hourly fluctuations in flow would occur.

Mr Birch and Mr Blakelock also supplied data on the concentrations of total $B.O.D._5$ and suspended solids entering the respective treatment systems during the study period. The range, mean and standard deviation of total $B.O.D._5$ of 22 weekly samples of the Borthwick's influent were 484-1733 g/m^3 , 1245 g/m^3 and 307 g/m^3 respectively. The suspended solids content of these same samples ranged from 869 to 2454 g/m^3 with a mean of 1618 g/m^3 and standard deviation of 476 g/m^3 . The influent total $B.O.D._5$ to the Feilding Sewage Treatment Plant ranged between 346 and 1005 g/m^3 (average, 602 g/m^3) when trade wastes were present while suspended solids concentrations ranged from 240-870 g/m^3 with an average of 460 g/m^3 . When the local abattoir and the woolscour were shut down the average raw sewage values of the total $B.O.D._5$ was 245 g/m^3 and the suspended solids was 180 g/m^3 .

Dense algal growth developed in the Oroua River in February 1978 and remained until early April 1978. Sites B_2 , F_1 and F_4 had the densest growths and algal strands covered the stream bottom at these sites. These were the sites

that contained coarse, shingle areas as the substrata which hence provided many attachments for the algae. Sites B₁, B₃ and F₃ supported less dense algal populations. Continual movement of shingle at site B₁, through the operation of shingle companies, probably limited algal growth at this site while at B₃ and F₃ the growth of algae was less because of the finer substrata. Sites B₄ and F₅ had little algal development and this would be because the silty nature of the river bed provided few attachments for the algae.

5.2

Site Quality Descriptions

The physicochemical, chemical and microbiological data accumulated for each site is tabulated in Appendix 3. This data is summarized in terms of range, mean and standard deviation in Tables 16 to 18.

The quality of water at these sites shall be considered in three ways. Firstly the data from site B₁ will be used to illustrate the background quality of the Oroua River in terms of the physicochemical, chemical and microbiological parameters studied. Secondly the Borthwick's series of sites (B₁-B₄) and the uppermost site of the Feilding domestic sewage series (F₁) will be used to illustrate what effect the Borthwick's effluent has on the concentrations of the physicochemical, chemical and microbiological parameters in the Oroua River. Lastly the Feilding domestic sewage series of sites (F₁-F₅) will be used to illustrate what effect the domestic sewage discharge has on these parameters in the river.

5.2.1

Background water quality

The uppermost site (B₁) was assumed to represent the background water quality. The organic composition at this site, as measured by BOD, COD, suspended solids and kjeldahl nitrogen, was found to be low (see Table 16). The orthophosphate concentration was also low and was usually less than 0.01 g/m³. Nitrate concentrations were usually higher than the orthophosphate concentration and the maximum concentration recorded was 0.3 g/m³. The concentration of nitrates increased as the flow rate increased and this is discussed in a later section (5.5.3).

TABLE 16 A SUMMARY OF THE PHYSICOCHEMICAL AND CHEMICAL CONTENT OF SAMPLES
COLLECTED FROM SITES UPSTREAM OF THE FEILDING DOMESTIC SEWAGE DISCHARGE IN
THE OROUA RIVER (NOVEMBER 1977 - APRIL 1978).

COMPONENT	SITES SAMPLED				
	B ₁	B ₂	B ₃	B ₄	F ₁
TEMPERATURE (°C)					
- Range	14.5-21.5	13.5-21.5	13.5-21.7	14.7-22.7	16.2-21.6
- Mean	17	18	18	18	19
- Std Deviation	2	2	3	3	2
DISSOLVED OXYGEN (g/m ³)					
- Range	9.1-11.5	9.1-10.8	8.9-11.4	8.8-10.4	9.2-16.0
- Mean	10.0	9.8	9	9.9	12
- Std Deviation	0.8	0.7	2	0.5	2
pH					
- Range	7.0-8.0	7.0-8.1	7.1-8.3	7.0-8.2	7.5-9.2
- Mean	7.7	7.8	7.8	7.8	8.1
- Std Deviation	0.2	0.2	0.3	0.2	0.5
SUSPENDED SOLIDS (g/m ³)					
- Range	0.2-11	0.8-13	2-28	2-18	1-11
- Mean	4	7	8	7	5
- Std Deviation	4	7	8	5	3
TOTAL BOD ₅ (g/m ³)					
- Range	< 0.1-1	< 0.1-1	0.3-3	0.3-3	0.5-3
- Mean	0.5	0.7	1.1	1.2	1.5
- Std Deviation	0.4	0.4	0.9	0.9	0.7
TOTAL COD (g/m ³)					
- Range	2-10	5-23	5-27	4-26	5-23
- Mean	5	11	13	13	16
- Std Deviation	2	6	7	7	6
KJELDAHL NITROGEN (g/m ³)					
- Range	0.08-0.4	0.1-4	0.2-2	0.3-1	0.3-2
- Mean	0.2	1	0.7	0.6	0.8
- Std Deviation	0.1	2	0.5	0.3	0.6
NITRATE-NITROGEN (g/m ³)					
- Range	< 0.01-0.3	0.02-0.3	0.06-0.3	0.1-0.4	0.08-1
- Mean	0.2	0.1	0.2	0.1	0.6
- Std Deviation	0.1	0.1	0.1	0.1	0.5
TOTAL PHOSPHORUS (g/m ³)					
- Range	0.09-0.17	0.17-0.5	0.06-0.4	0.1-0.4	0.2-0.9
- Mean	0.12	0.2	0.2	0.2	0.3
- Std Deviation	0.03	0.1	0.1	0.1	0.2
ORTHOPHOSPHATE-P (g/m ³)					
- Range	< 0.01-0.03	< 0.01-0.2	< 0.01-0.4	< 0.01-0.4	0.02-0.2
- Mean	< 0.01	0.07	0.1	0.1	0.12
- Std Deviation	-	0.07	0.1	0.1	0.08

TABLE 17 THE MEAN MICROBIOLOGICAL CONTENT OF THE OROUA RIVER

NOVEMBER 1977 - APRIL 1978

SITE	BACTERIAL DENSITY (NO./100ml)			
	Proteolytic Bacteria	Lipolytic Bacteria	Saccharolytic Bacteria	Faecal Coliforms
B ₁ : Mean	4.10 ³	7.10 ³	3.10 ⁴	.10 ²
: Std Dev	3.10 ³	1.10 ⁴	2.10 ⁴	.10 ²
B ₂ : Mean	5.10 ³	1.10 ⁴	3.10 ⁴	1.10 ³
: Std Dev	4.10 ³	1.10 ⁴	1.10 ⁴	8.10 ²
B ₃ : Mean	2.10 ⁴	1.10 ⁴	4.10 ⁴	3.10 ³
: Std Dev	2.10 ⁴	1.10 ⁴	1.10 ⁴	6.10 ³
B ₄ : Mean	1.10 ⁴	8.10 ³	3.10 ⁴	2.10 ³
: Std Dev	1.10 ⁴	7.10 ³	3.10 ⁴	2.10 ³
F ₁ : Mean	1.10 ⁴	8.10 ³	8.10 ⁴	8.10 ²
: Std Dev	2.10 ⁴	1.10 ⁴	9.10 ⁴	5.10 ²
F ₂ : Mean	1.10 ⁶	2.10 ⁶	2.10 ⁷	> 2.10 ⁵
: Std Dev	1.10 ⁶	2.10 ⁶	3.10 ⁷	
F ₃ : Mean	5.10 ⁵	1.10 ⁶	5.10 ⁶	> 2.10 ⁵
: Std Dev	6.10 ⁵	2.10 ⁶	3.10 ⁶	
F ₄ : Mean	2.10 ⁵	5.10 ⁵	3.10 ⁶	> 2.10 ⁵
: Std Dev	3.10 ⁵	6.10 ⁵	3.10 ⁶	
F ₅ : Mean	1.10 ⁵	1.10 ⁵	1.10 ⁶	> 2.10 ⁵
: Std Dev	1.10 ⁵	1.10 ⁵	3.10 ⁶	

The average pH of the Oroua River was relatively high (8.1). This is because of the relatively high specific conductivity of this river (Table 14) and because samples were only taken in the summer months when photosynthetic activity elevated the pH.

The dissolved oxygen content of the Oroua River at B₁ was consistently high and there was only slight variations between sampling days. As these samples were all taken at the same time of day no diurnal variation in dissolved oxygen through algal activity was illustrated. A diurnal curve of the dissolved oxygen concentrations in the Oroua River at site B₃ was obtained on the 21-22 March. This showed that dissolved oxygen concentrations of 10-11 g/m³ were recorded between 9.00 and 11.00 a.m. while at night time the dissolved oxygen concentration dropped to 6.9 g/m³ (Appendix 3). This type of daily variation was probably also applicable to site B₁ and should not stress the stream biota.

Tables 16 and 17 show that the standard deviations of the chemical and microbiological results were of similar magnitude to the mean at site B₁, as well as other sites. This indicates a very variable stream quality. The background quality of the river water is possibly varying because of the quality of run-off water entering the river. Quality of run-off will depend on factors, such as live stock density on the river valley, the quantity of agricultural fertilizers reaching the river and the volume of this run-off, as well as the river flow available to dilute this run-off. In cases of parameters with low values, a high experimental error may be involved.

5.2.2

The effect of Borthwick's effluent

The immediate effect that Borthwick's effluent had on the Oroua River was determined by comparing site B₁ with B₂ using a t test (see Appendix 3). These were the sites immediately upstream and downstream of the discharge. The t test showed that only two parameters, the orthophosphate concentration and the COD, were significantly increased by the discharge. The mean kjeldahl nitrogen results in Table 16 and the faecal coliform results in Table 17 both appear to be increased by the discharge but the large standard deviations of these results meant that such increases were not significant.

Inspection of Tables 16 and 17 shows that the concentration of organic parameters, nutrient and bacteria usually increased as the river flowed downstream from site B₂ to F₁. This suggests that non point discharges, such as run-off from the town of Feilding and the surrounding countryside, provides a more important source of pollution than does the Borthwick's effluent. Figure 8 illustrates some of the changes that occur as the river flows past Borthwicks and further downstream.

Thus the quality at sites B₂, B₃, B₄ and F₁ differ only slightly from that measured at B₁ and is indicative of waters with little pollution. These waters should hence support a healthy diverse aquatic community.

5.2.3

The effect of Feilding domestic sewage discharge

A t test comparing site F₁ with site F₂ showed that the Feilding domestic sewage discharge significantly increased all the parameters studied except temperature, dissolved oxygen, pH, total phosphorus and nitrates (see Appendix 3). The pH and the dissolved oxygen concentrations were shown to be significantly

FIGURE 8. Changes in Stream Quality at Borthwick's Sites.

a. B.O.D. and Suspended Solids.

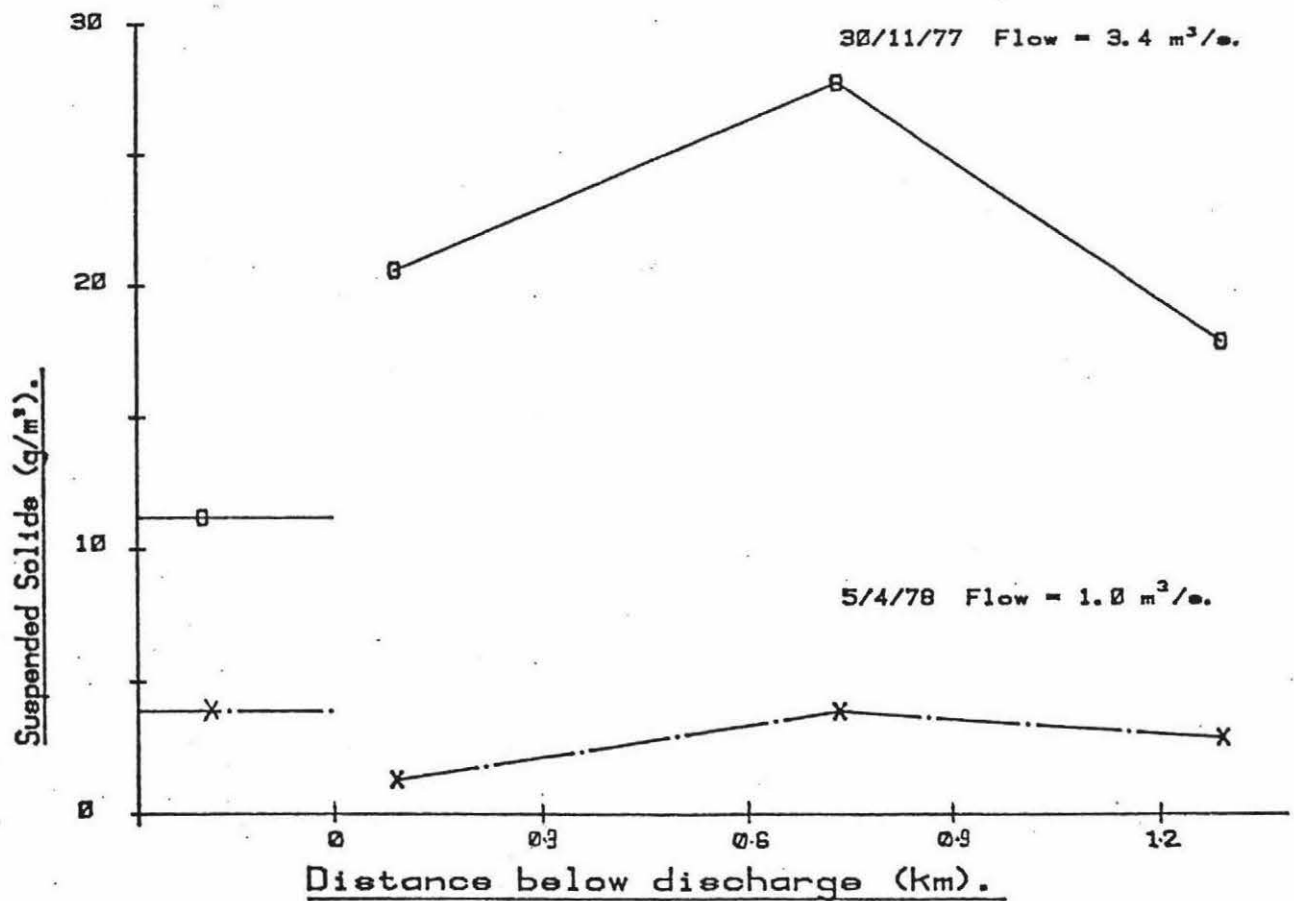
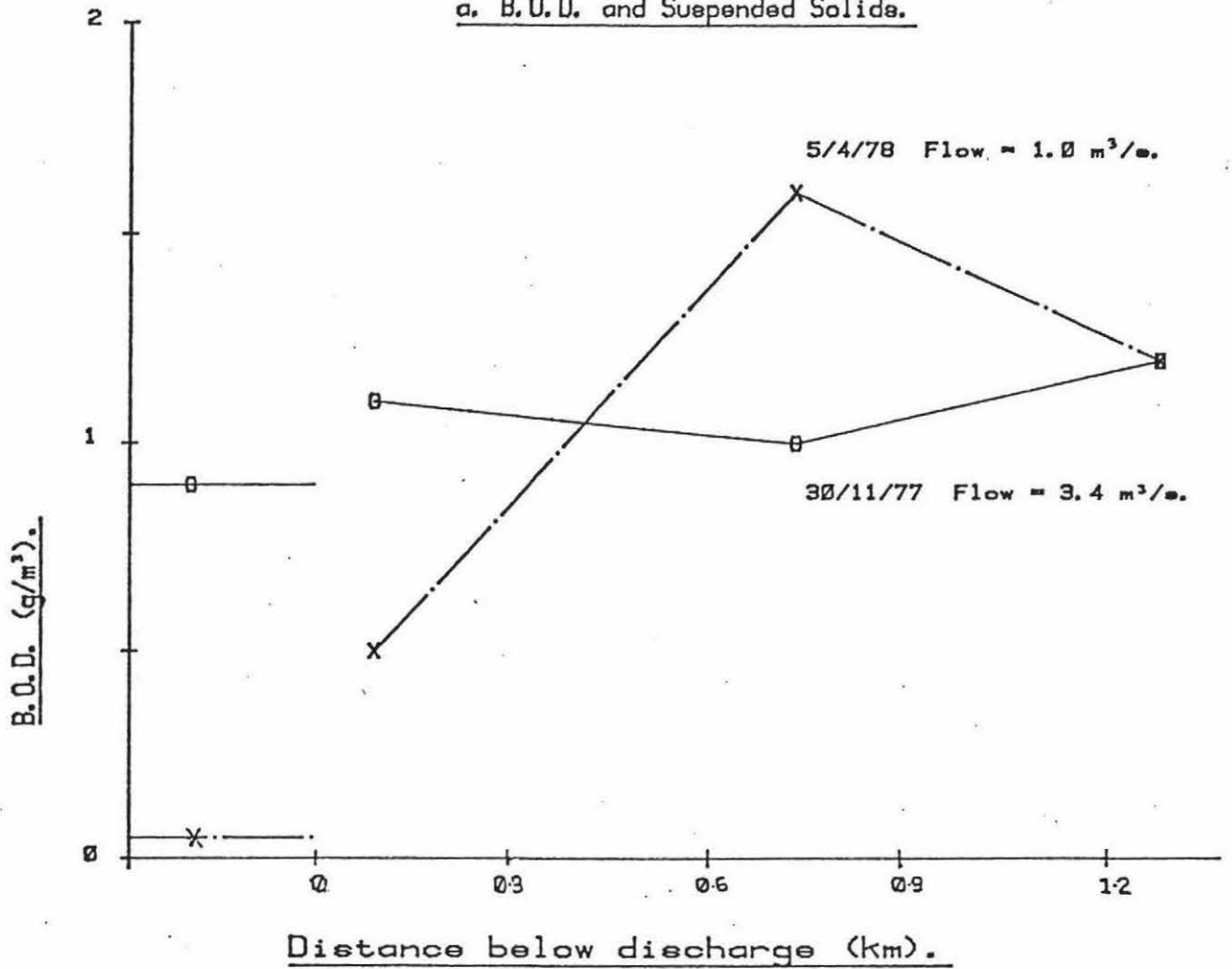
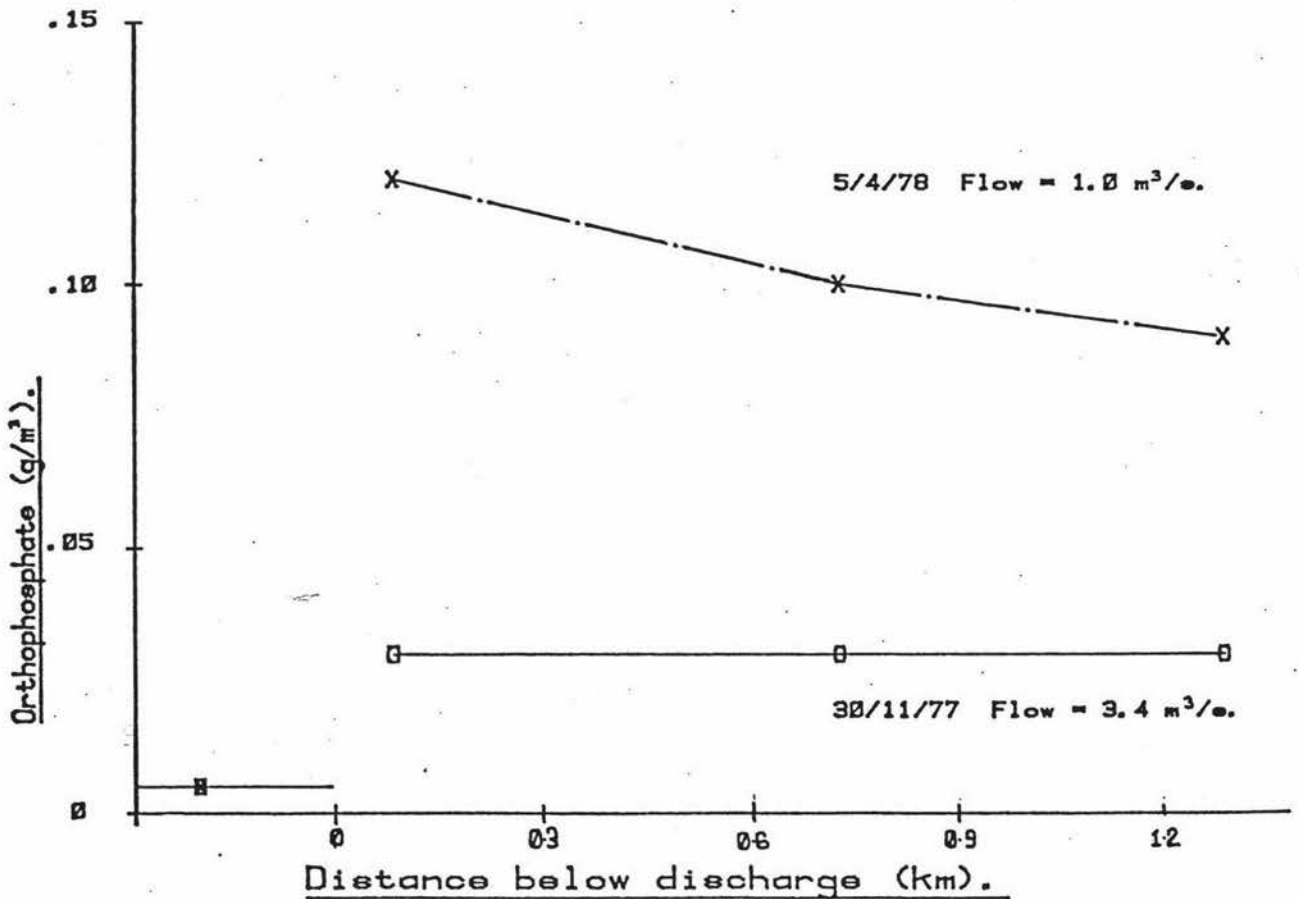
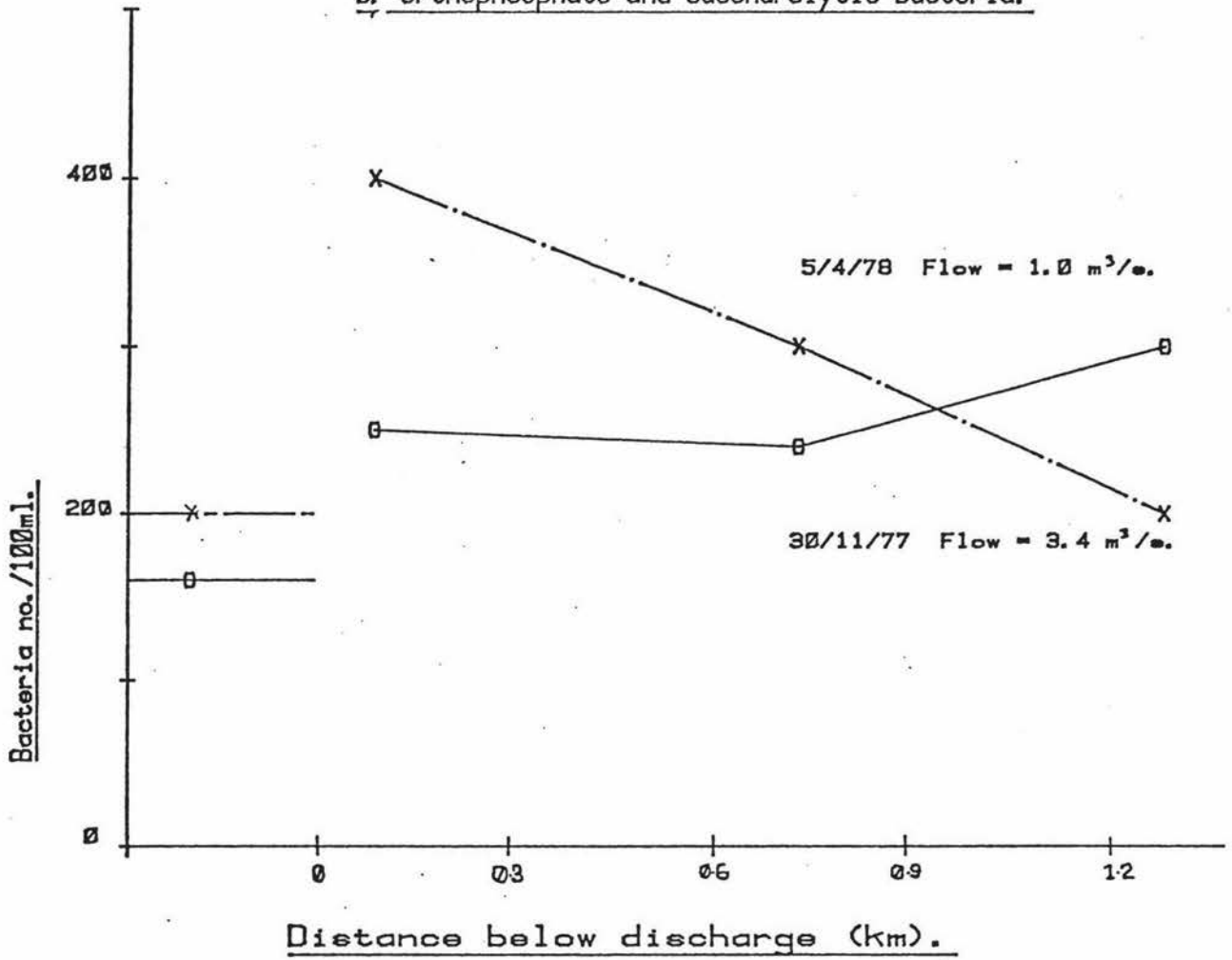


FIGURE 8. Changes in Stream Quality at Borthwick's Sites.

b. Orthophosphate and Saccharolytic Bacteria.



decreased by the discharge while the temperature, total phosphorus and nitrate concentrations were not affected by the discharge. As the river flowed downstream from site F_2 the concentration of the various parameters tended towards the concentrations recorded upstream of the domestic sewage discharge. This is illustrated in the mean results given in Tables 17 and 18. The change in concentrations of suspended solids, BOD, COD, bacteria and orthophosphate with the time of flow after discharge is discussed in later sections (5.5.1, 5.5.2 and 5.5.3). At site F_5 the mean pH, temperature, dissolved oxygen, nitrate total phosphorus orthophosphate and total kjeldahl nitrogen concentrations were comparable to those at F_1 . The suspended solids, total BOD_5 , total COD and bacterial concentrations were, however, still appreciably higher. Figure 9 illustrates some of the changes that occur when treated domestic sewage is discharged into the Oroua River.

Generally the increase in concentration of parameters between sites F_1 and F_2 was greater than could be accounted for by the dilution of sewage components in the stream flow (see Appendix 3 for mass balances). There are two possible reasons that could account for this. The first is that the sewage discharge may not have been completely mixed in the stream flow. The sample taken at F_2 was from below a large shallow riffle which should have mixed the sewage completely with the stream water. At times the concentrations of parameters at site F_4 (some 3 kilometers downstream of the discharge) was also greater than that expected at site F_2 by mass balance considerations. It is thus thought that these discrepancies are not due to incomplete mixing. The more likely reason is that the flow data used in mass balance considerations was the mean daily flow while the sewage flow at the sampling time was approaching peak values. Thus the quantity of the parameters entering the river via the domestic sewage discharge was underestimated.

FIGURE 9. Changes in Stream Quality at Feilding Sites.

a. C.O.D. and Suspended Solids.

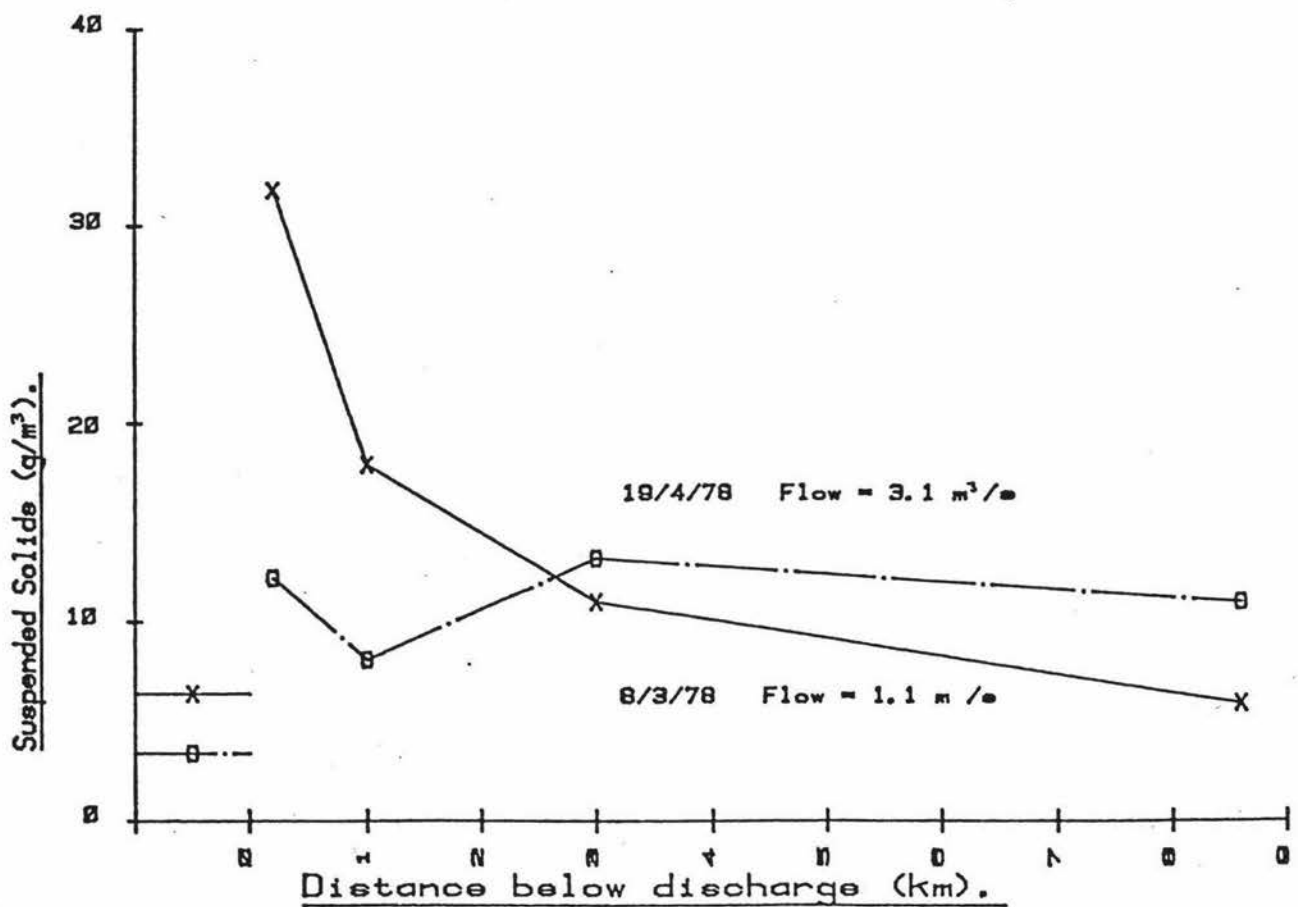
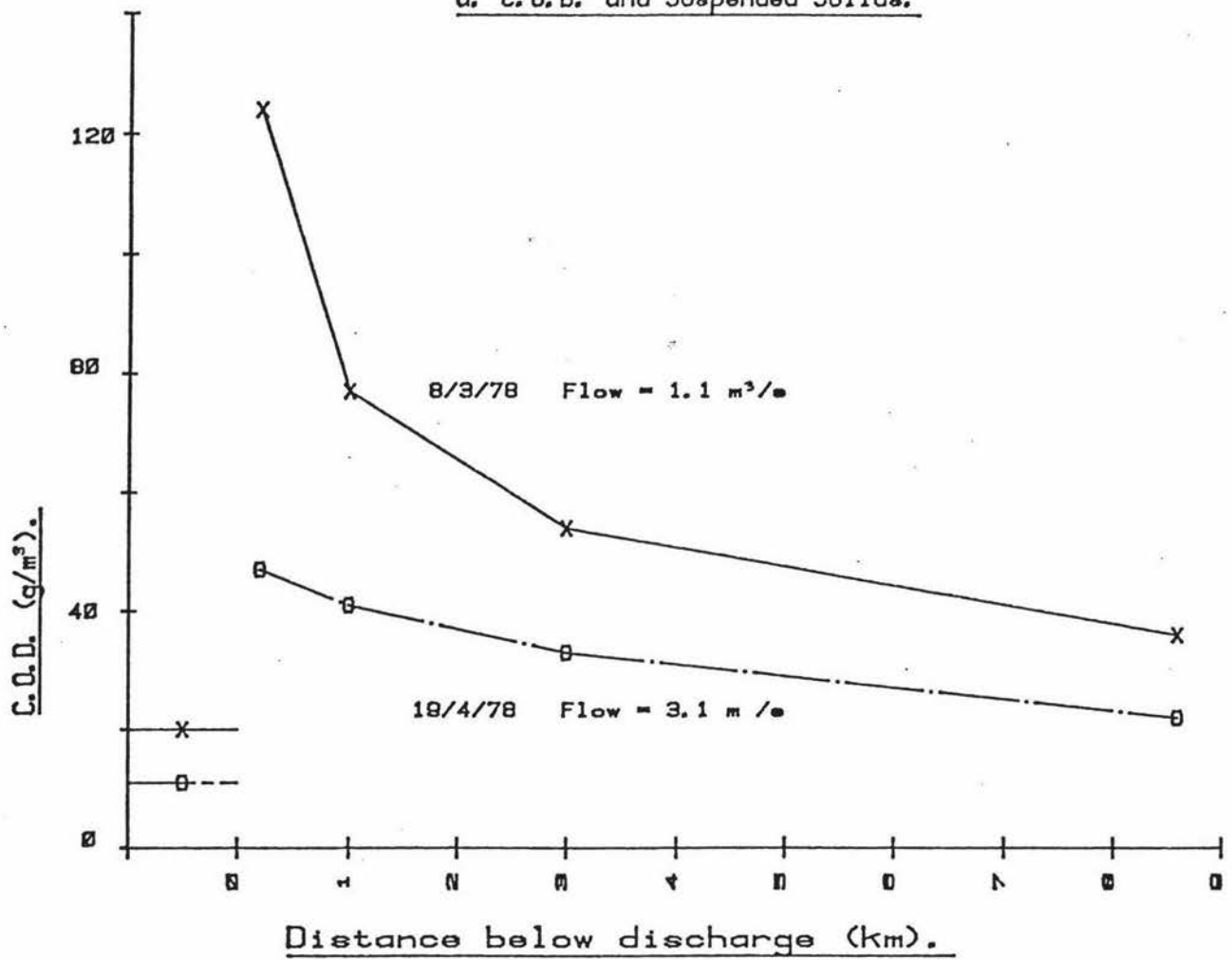


FIGURE 9. Changes in Stream Quality at Feilding Sites.

b. Orthophosphate and Saccharolytic Bacteria.

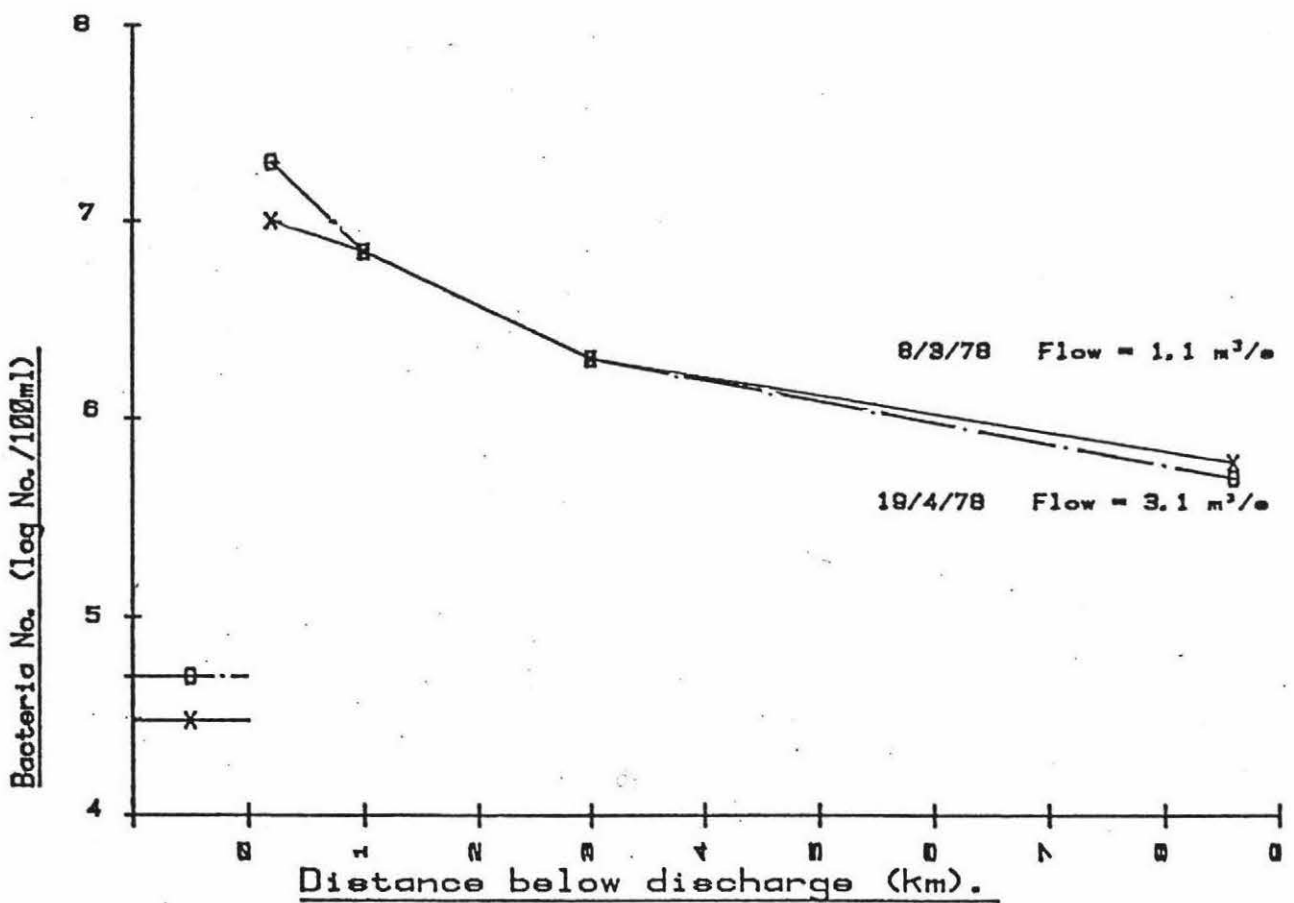
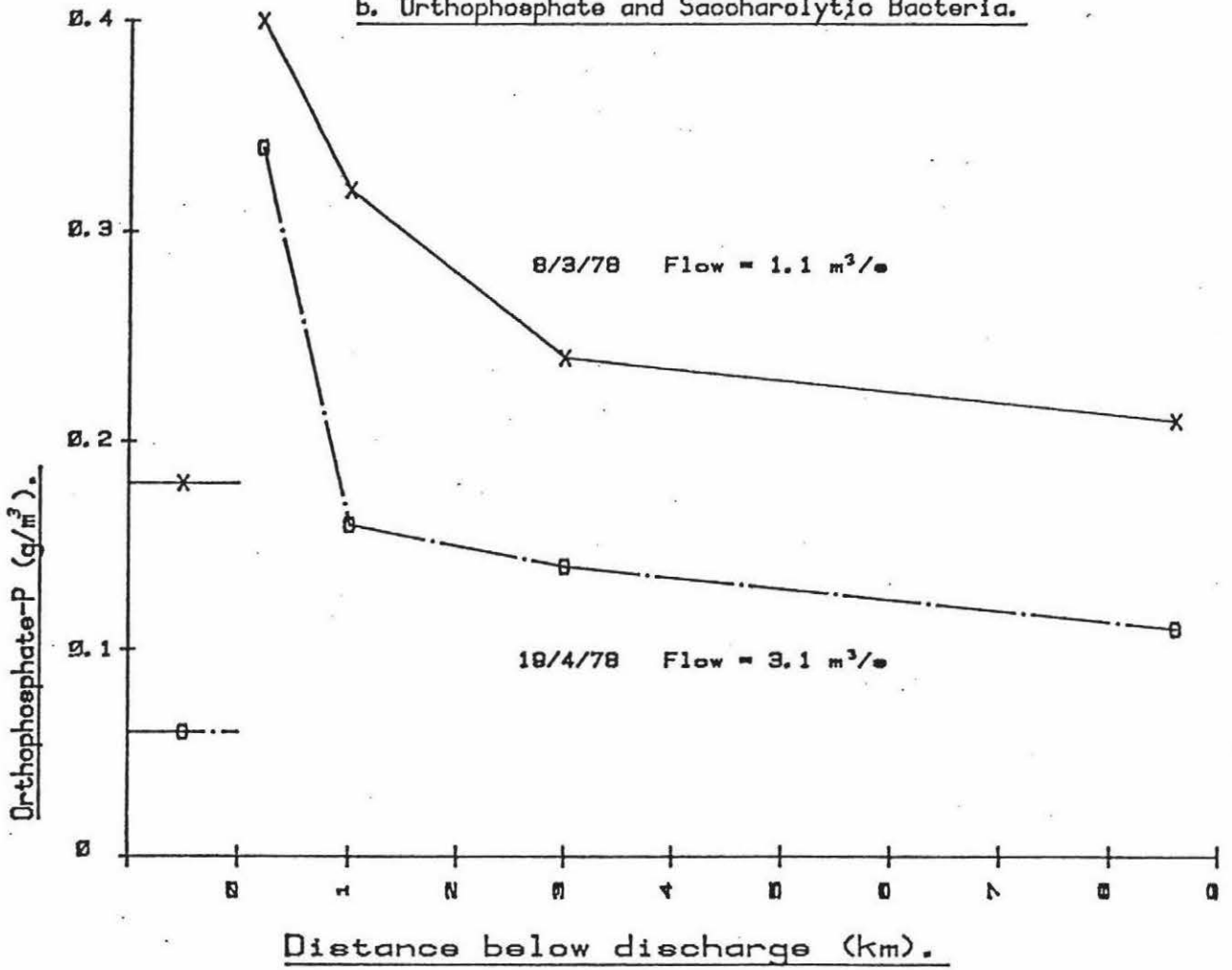


TABLE 18 A SUMMARY OF THE PHYSICO-CHEMICAL AND CHEMICAL CONTENT OF SAMPLES
COLLECTED FROM SITES IN THE FEILDING DOMESTIC SEWAGE SEQUENCE IN THE OROUA RIVER
(NOVEMBER 1977 - APRIL 1978)

COMPONENT	SITES SAMPLED				
	F ₁	F ₂	F ₃	F ₄	F ₅
TEMPERATURE (°C)					
- Range	16.2-21.6	15.8-22.0	14.7-20.8	15.4-21.0	16.2-22.2
- Mean	19	18	18	18	19
- Std Deviation	2	2	2	2	2
DISSOLVED OXYGEN (g/m ³)					
- Range	9.2-16.0	8.0-12.1	6.9-11.1	8.2-12.2	7.6-15.0
- Mean	12	9	9	10	11
- Std Deviation	2	1	1	1	2
pH					
- Range	7.5-9.2	7.4-8.4	7.4-8.4	7.2-8.4	7.5-9.1
- Mean	8.1	7.7	7.7	7.8	8.1
- Std Deviation	0.5	0.3	0.3	0.4	0.6
SUSPENDED SOLIDS (g/m ³)					
- Range	1-11	11-46	4-28	5-24	0.4-20
- Mean	5	20	11	7	9
- Std Deviation	3	10	6	3	6
TOTAL BOD ₅ (g/m ³)					
- Range	0.5-3	2-108	2->40	2->20	2-12
- Mean	1.5	40	11	7	5
- Std Deviation	0.7	30	6	4	3
COD (g/m ³)					
- Range	5-23	25-302	20-140	25-102	14-100
- Mean	16	110	60	50	40
- Std Deviation	6	80	30	20	20
KJELDAHL NITROGEN (g/m ³)					
- Range	0.3-2	1-7	1-3	0.7-2	0.6-1
- Mean	0.8	4	2.0	1.4	1.0
- Std Deviation	0.6	2	0.5	0.5	0.4
NITRATE NITROGEN (g/m ³)					
- Range	0.08-1	0.1-1	0.1-1	0.2-1	0.2-1
- Mean	0.6	0.5	0.6	0.6	0.5
- Std Deviation	0.5	0.4	0.4	0.4	0.3
TOTAL PHOSPHORUS (g/m ³)					
- Range	0.2-0.9	0.1-0.6	0.1-0.6	0.2-0.5	0.2-0.5
- Mean	0.3	0.3	0.3	0.3	0.3
- Std Deviation	0.2	0.2	0.2	0.1	0.1
ORTHOPHOSPHATE-P (g/m ³)					
- Range	0.02-0.2	0.1-0.5	0.06-0.3	0.06-0.2	0.04-0.3
- Mean	0.12	0.3	0.18	0.15	0.14
- Std Deviation	0.08	0.1	0.09	0.07	0.08

TABLE 19 THE AVERAGE LOAD OF PARAMETERS CARRIED BY THE FLOW
 AT THE FEILDING SITES EXPRESSED IN g/s

PARAMETER	SITE				
	F ₁	F ₂	F ₃	F ₄	F ₅
<u>Biochemical Oxygen Demand</u>					
Mean	3	60	25	17	10
Std. Dev.	1	30	17	11	6
<u>Chemical Oxygen Demand</u>					
Mean	51	240	130	120	90
Std. Dev.	43	130	60	80	60
<u>Suspended Solids</u>					
Mean	16	60	26	24	27
Std. Dev.	19	50	15	16	23
<u>Nitrate-N</u>					
Mean	1.1	1.1	1.2	1.2	1.1
Std. Dev.	0.7	0.5	0.7	0.7	0.7
<u>Kjeldahl-Nitrogen</u>					
Mean	1.6	7	4	3	2
Std. Dev.	1.3	4	2	2	2
<u>Orthophosphate-P</u>					
Mean	0.2	0.6	0.4	0.3	0.3
Std. Dev.	0.1	0.3	0.1	0.1	0.1
<u>Total Phosphorus</u>					
Mean	0.6	0.6	0.5	0.7	1.2
Std. Dev.	0.3	0.4	0.4	0.5	0.8

The concentration of a parameter in the river often depends upon the river flow. In low flow, there is less dilution of any discharge to the river and thus higher concentrations of parameters results. It may thus be more meaningful to quantify site quality below a discharge in terms of the weight of a component carried per second (g/s) rather than its concentration. Table 19 gives the river quality at the Feilding sites in terms of the mean component load. Inspection of this table shows that the standard deviations are relatively high which is because of a very variable input from the sewage discharge.

In summary, the physicochemical, chemical and microbiological results showed that the Feilding domestic sewage discharge had a major detrimental effect on the Oroua River quality. While the water at site F_1 was of high quality, site F_2 was grossly polluted. Sites F_3 and F_4 were also badly polluted, particularly in times of low flow while site F_5 was the only site that had a physicochemical and chemical water quality comparable to that upstream of the domestic sewage discharge. The microbiological densities at this site were, however, still indicative of polluted waters.

5.2.4 Correlation of parameters in the Oroua River

A statistical correlation may occur between parameters either when the concentration or level of one parameter affects that of another parameter or, as is the case in the Oroua River, when both parameters are influenced by a common factor. Table 20 lists the significant statistical correlations found for parameters in the Oroua River. This table shows many significant correlations, some which occur only at specific sites while others apply to the river as a whole. Figure 10 shows correlation between dissolved oxygen and pH while figure 11 shows correlations between organic parameters in the Oroua River.

There is a significant correlation between pH and dissolved oxygen at most sites in the Oroua River. This correlation occurs because of the photosynthetic activity in the rivers. Periods of high dissolved oxygen occur when algal activity is high and hence when carbon dioxide assimilation is also high. Removal of carbon dioxide from the river water by photosynthetic organisms alters the bicarbonate/carbonate equilibria (equation 4) so that the ratio of carbonate:bicarbonate is increased and this results in a corresponding rise in pH. Figure 10 illustrates this correlation.

Other important statistical correlations occurring in the Oroua River are those between the organic parameters measured at site F₂. The BOD, COD, suspended solids and total kjeldahl nitrogen concentrations all had significant positive statistical correlations at this site. Very few of these correlations were illustrated at other sites. These correlations occur because of a common factor, the dilution of a domestic sewage discharge, and thus such correlations can be used to illustrate that a waterbody has been adversely affected by a discharge. As these parameters decline at different rates in the receiving water these correlations do not occur at sites further downstream. Figure 11 illustrates these correlations.

There was also significant correlation between nitrates and orthophosphates at several sites. Factors that influence both the nitrate and orthophosphate concentrations are river flow, run-off, effluent discharges and algal activity.

Table 20 shows that there were statistical correlations between the microbiological parameters at many sites. The bacterial densities are all influenced by the same factors and these are stream flow, effluent discharges, run-off and the streams capacity to assimilate these bacteria. Thus it is not surprising that correlations between bacterial densities do occur.

FIGURE 10. Correlations Between Stream pH and Dissolved
Oxygen Concentrations.

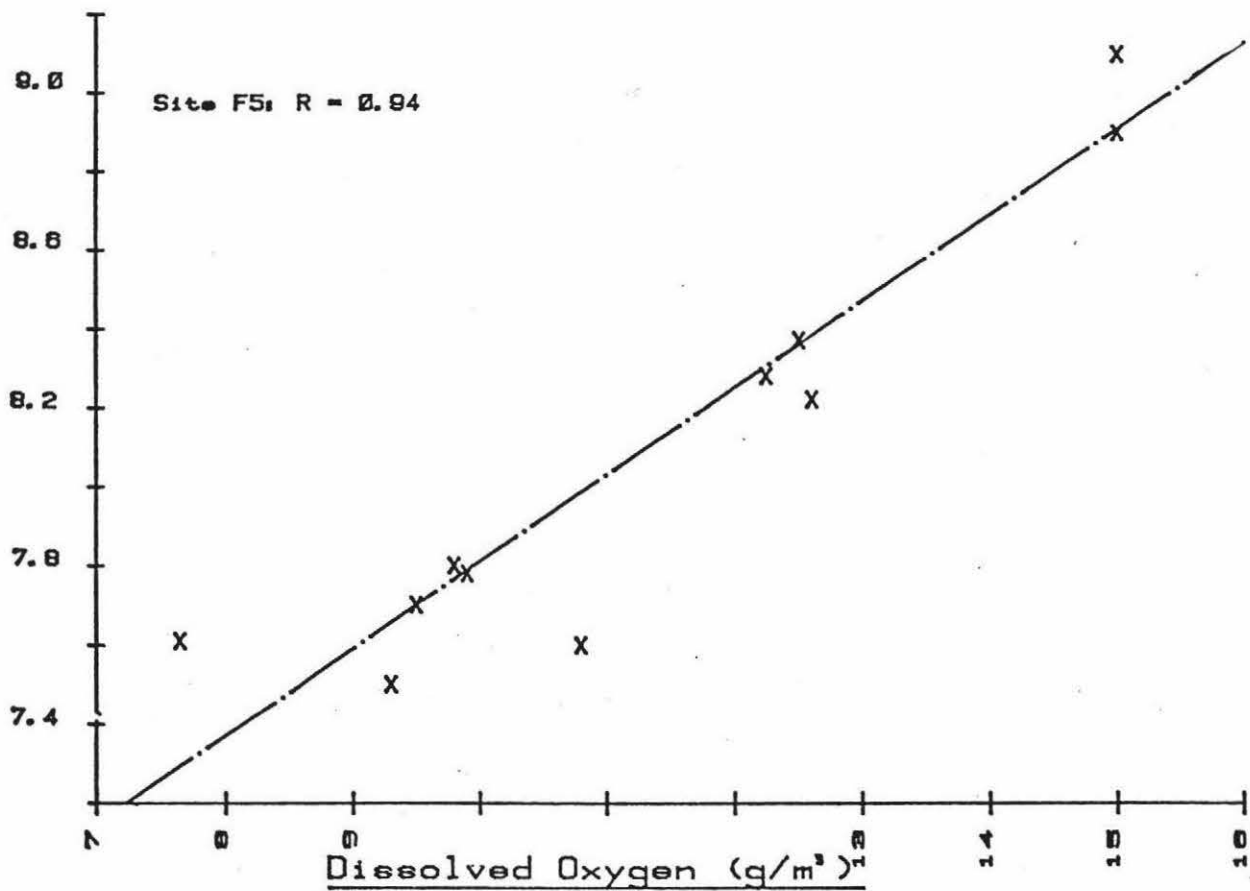
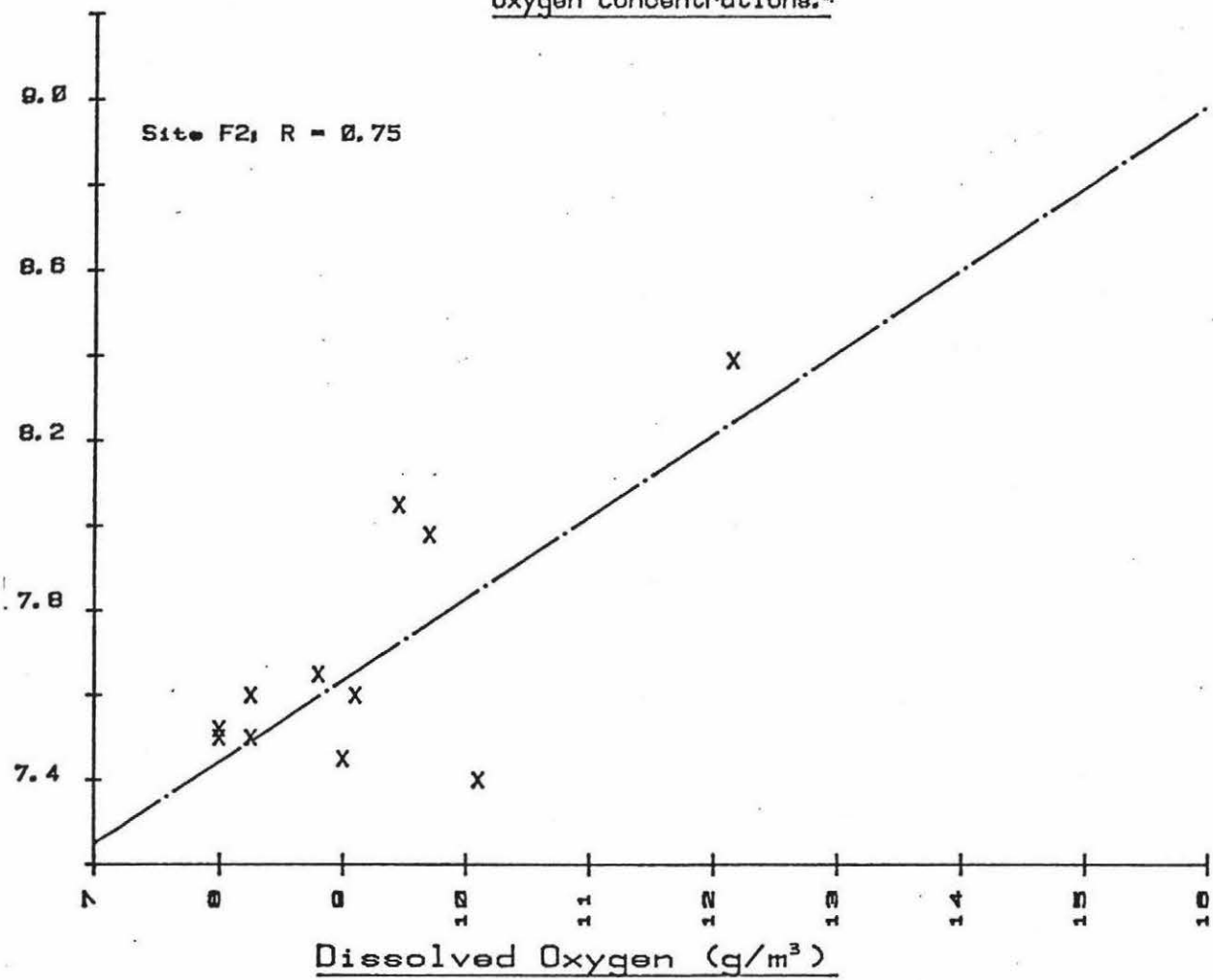


FIGURE 11. Correlations Between C.O.D. and other Organic

Parameters at Site F2.

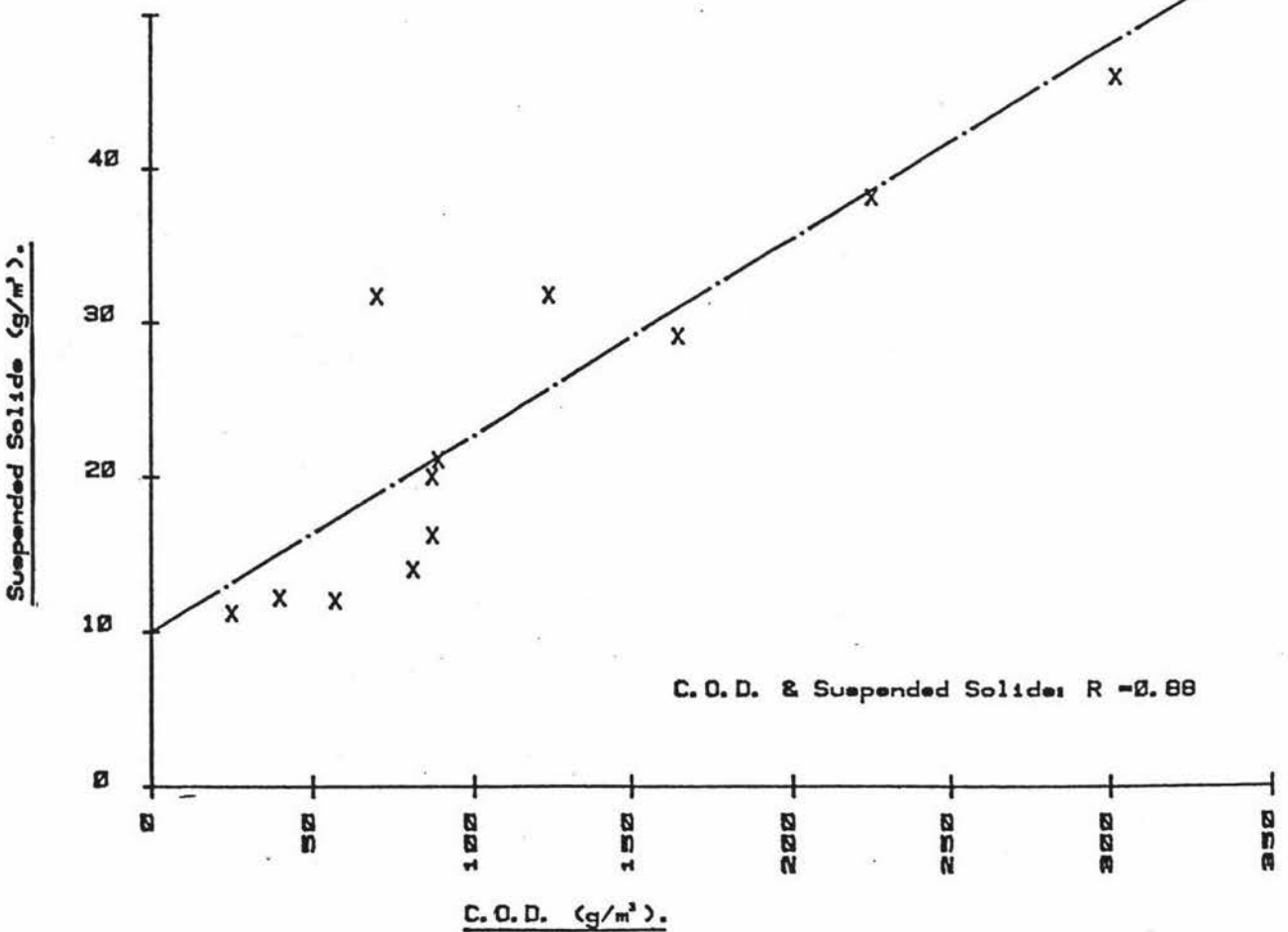
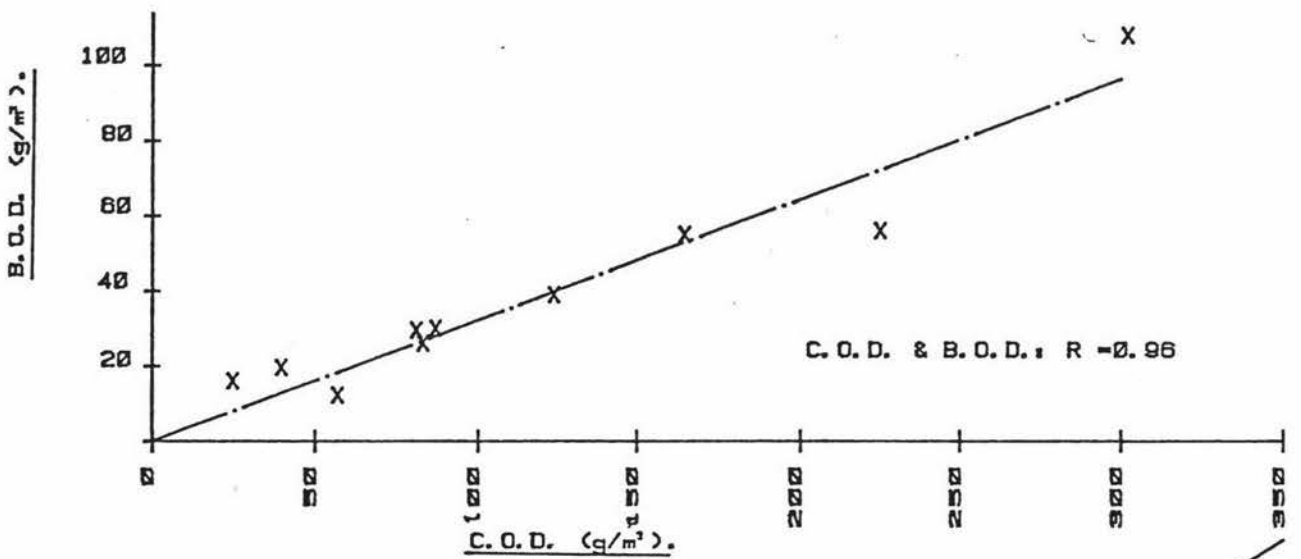
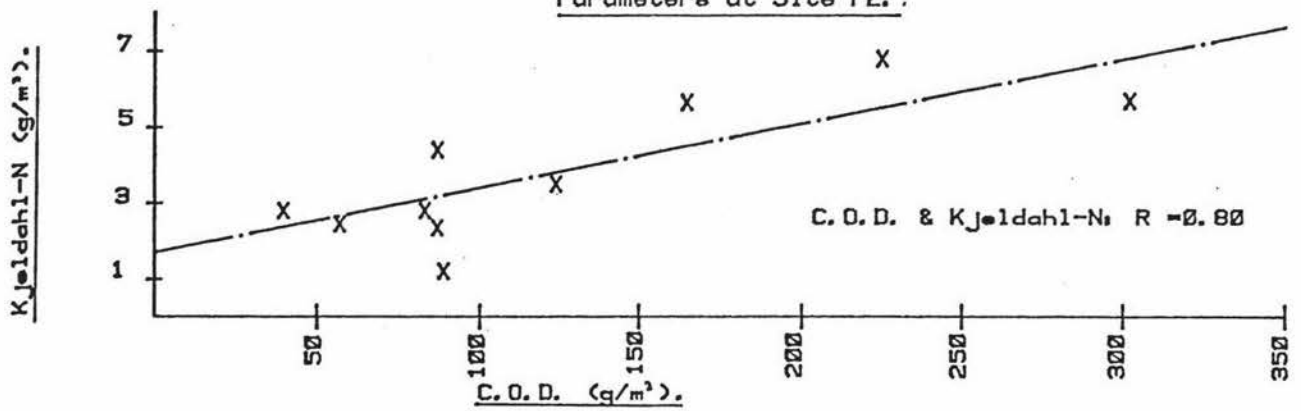


TABLE 20 SIGNIFICANT CORRELATIONS BETWEEN PARAMETER
CONCENTRATIONS IN THE OROUA RIVER
NOVEMBER 1977 - APRIL 1978

FIRST PARAMETER	SECOND PARAMETER	SITES WITH SIGNIFICANT CORRELATIONS
pH	Dissolved oxygen	B ₂ , F ₁ , F ₂ , F ₃ , F ₄ , F ₅
BOD	COD	B ₁ [*] , F ₂
COD	Suspended solids	F ₂ , F ₃
BOD	Suspended solids	F ₂
COD	Kjeldahl nitrogen	F ₂
BOD	Kjeldahl nitrogen	F ₂
Nitrate-N	Orthophosphate-P	F ₁ , F ₂ , F ₃ , F ₄ , F ₅
COD	Orthophosphate-P	B ₂ , B ₃ , B ₅
BOD	Orthophosphate-P	B ₃ , B ₄
COD	Nitrate-N	F ₁
Nitrate-N	Kjeldahl nitrogen	F ₂
Nitrate-N	Temperature	B ₂ [*] , F ₅ [*]
Dissolved oxygen	Orthophosphate-P	B ₂ , F ₁
COD	Dissolved oxygen	B ₂
BOD	Temperature	B ₂
Lipolytic bacteria	Saccharolytic bacteria	F ₂ , F ₅
Lipolytic bacteria	Proteolytic bacteria	B ₁
Proteolytic bacteria	Saccharolytic bacteria	F ₁ , F ₄ , F ₅

* designates a negative correlation.

A significant negative correlation between BOD and COD was found at site B₁ and this illustrates the inadequacy of these parameters when quantifying clean waters.

5.3

Temperature Levels in the Oroua River

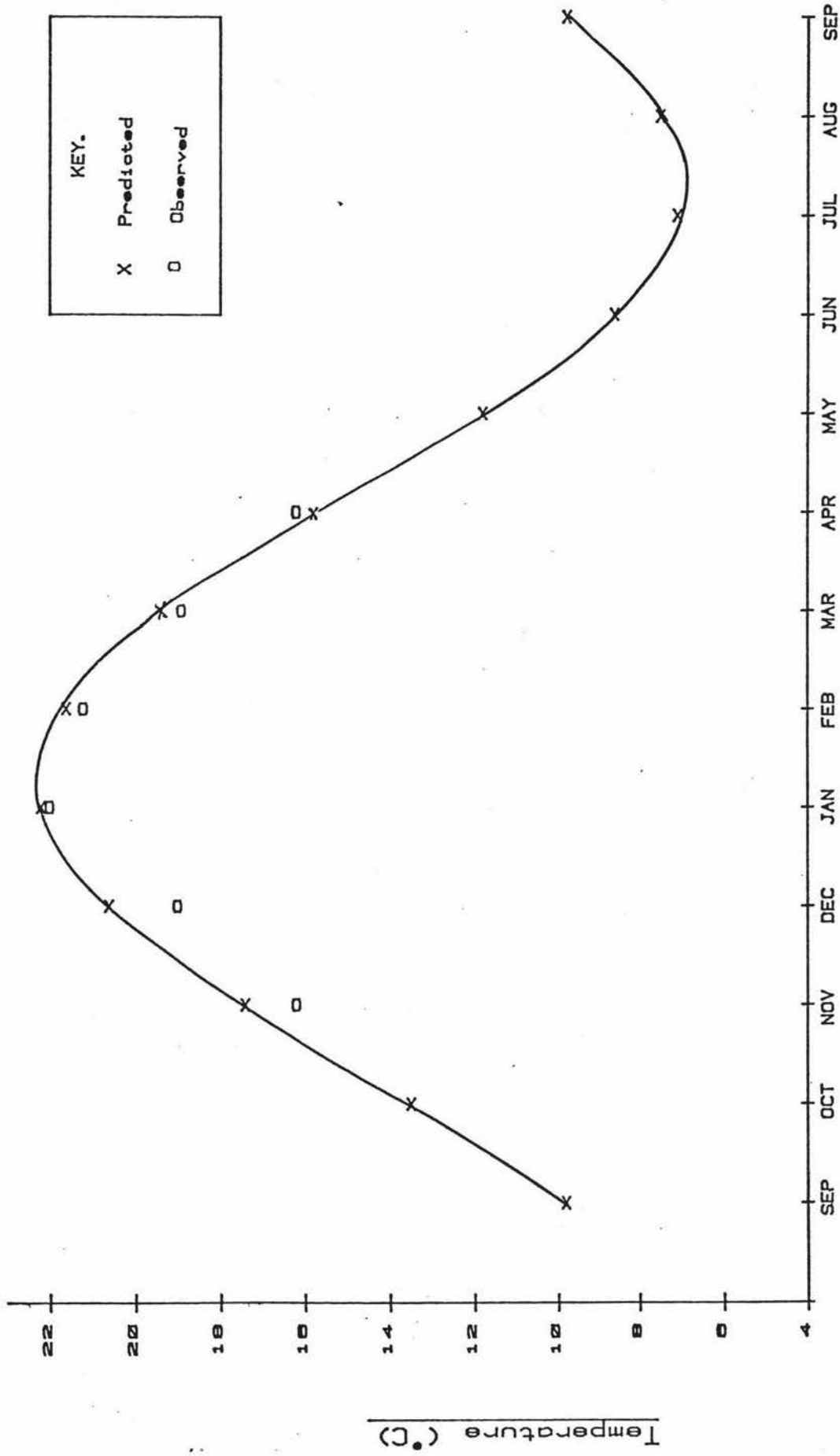
The average monthly temperatures recorded in the Oroua River between 10.00 and 11.00 a.m. are tabulated in Table 21 and plotted in Figure 12. These results closely resembled a half sine wave with an amplitude of 7.6°C and phase coefficient of 67.8° . A theoretical mean monthly temperature curve was also plotted in Figure 12 by assuming a sine wave function and using the amplitude and phase coefficient given above. An average yearly temperature of 14.6°C was determined by extrapolation of the mean temperature results. The resultant sine wave fits the expression given in equation 37 when T is the mean monthly temperature at 10.00-11.00 a.m. for any month, X days from January 1.

$$T(^{\circ}\text{C}) = 7.6 (\text{Sin} (\frac{360}{365} X + 67.8)) + 14.6$$

The theoretical and experimental summer temperatures correspond well as is illustrate in Figure 12. A temperature model such as this could be useful for management purposes when the maximum, minimum or average daily temperatures are used.

TABLE 21 AVERAGE MONTHLY TEMPERATURES BASED
ON SITES B₄ AND F₁

MONTH	AVERAGE TEMPERATURE ($^{\circ}\text{C}$)
November	16.2
December	19.0
January	22.2
February	21.3
March	18.9
April	16.1



Month (1977-1978)

During the 24 hour study on dissolved oxygen concentrations in the Oroua River conducted on the 21-22 March 1978 the temperature of the river was also recorded. These results are given in Appendix 3 and show a daily temperature range of 4.7°C at site B_3 ($13.8-18.5^{\circ}\text{C}$), 5.6°C at site F_2 ($13.8-19.4^{\circ}\text{C}$) and 6.3°C at site F_4 ($13.8-20.1^{\circ}\text{C}$). These results thus show that the minimum temperature in the Oroua River is similar at all sites while the maximum temperature and hence maximum temperature range are greatest at sites furthest downstream. Minimum river temperature occurred between 4.00 and 5.00 a.m. while maximum temperatures were recorded at 2.00-3.00 p.m. (New Zealand Standard time).

5.4

Effluent Characterization

The composition of samples taken from the Borthwick's Meat Works discharge and the Feilding domestic sewage treatment plant between November 1977 and April 1978 is tabulated in Appendix 3 and summarized in Table 22. Several significant statistical correlations were found between the concentrations of different parameters in these discharges and these are given in Table 23.

Mr B. Birch of T. Borthwick and Sons Meat Works supplied data on the influent loading of total BOD_5 to the Borthwick's treatment plant (Appendix 2). This data showed that the influent loading increased steadily from November and peak values were recorded between February and April. In late April the load of total BOD_5 in the influent started to decrease. The concentration of some parameters in the Borthwick's effluent mirrored the trend of the influent total BOD_5 loading and some of these are illustrated in Figure 13. The pH and concentrations of kjeldahl nitrogen, nitrate, dissolved oxygen and protein, however, appeared to show no distinct trend.

In comparison, the treated Feilding domestic sewage showed no apparent trend in the concentration of parameters but large variations between sampling days occurred (Figure 14). The concentrations of many of the Feilding domestic sewage components varied between two distinct ranges, one range being about twice the other. The higher range of concentrations indicated an effluent strength that was greater than raw sewage and this was attributed to the presence of concentrated trade wastes in the effluent. The lower concentration range was assumed to represent a discharge that contained no concentrated trade wastes and was hence mainly the domestic sewage. The concentrated trade wastes were those originating from the Kawa Woolscour and the Feilding Abattoirs and these would thus bias the averaged results. The

FIGURE 13. Changes in Borthwick's Effluent Quality
During the Study Period.

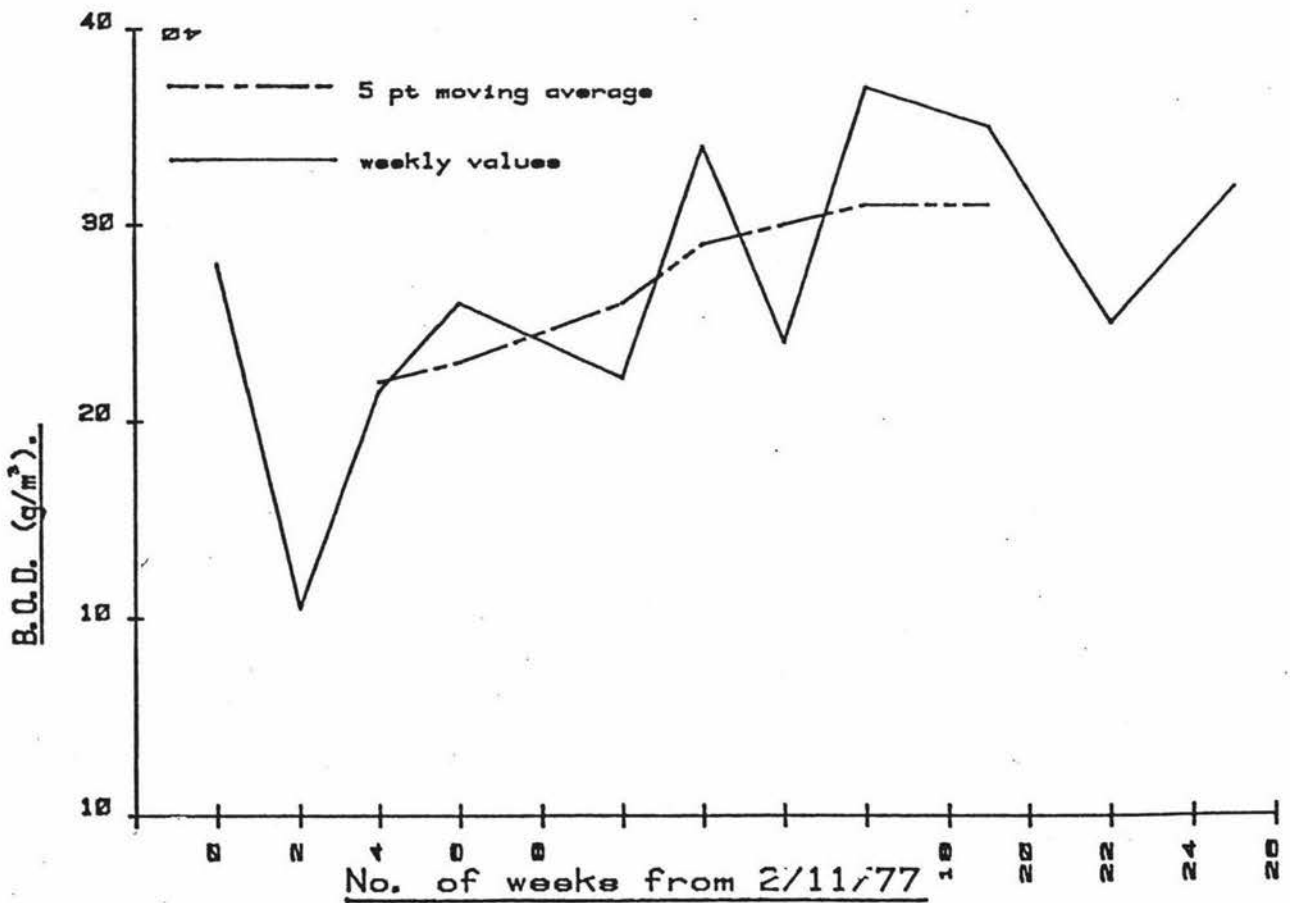
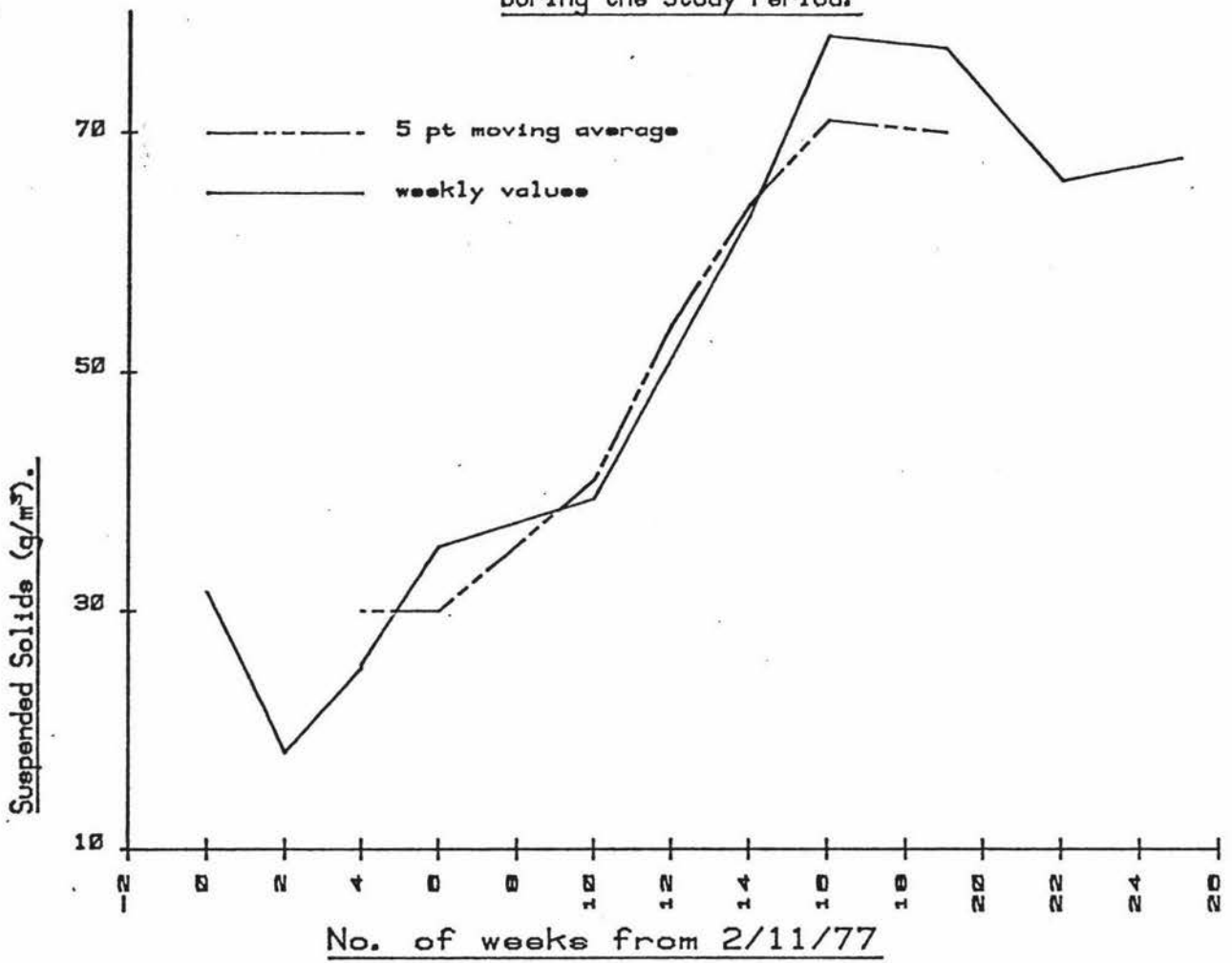
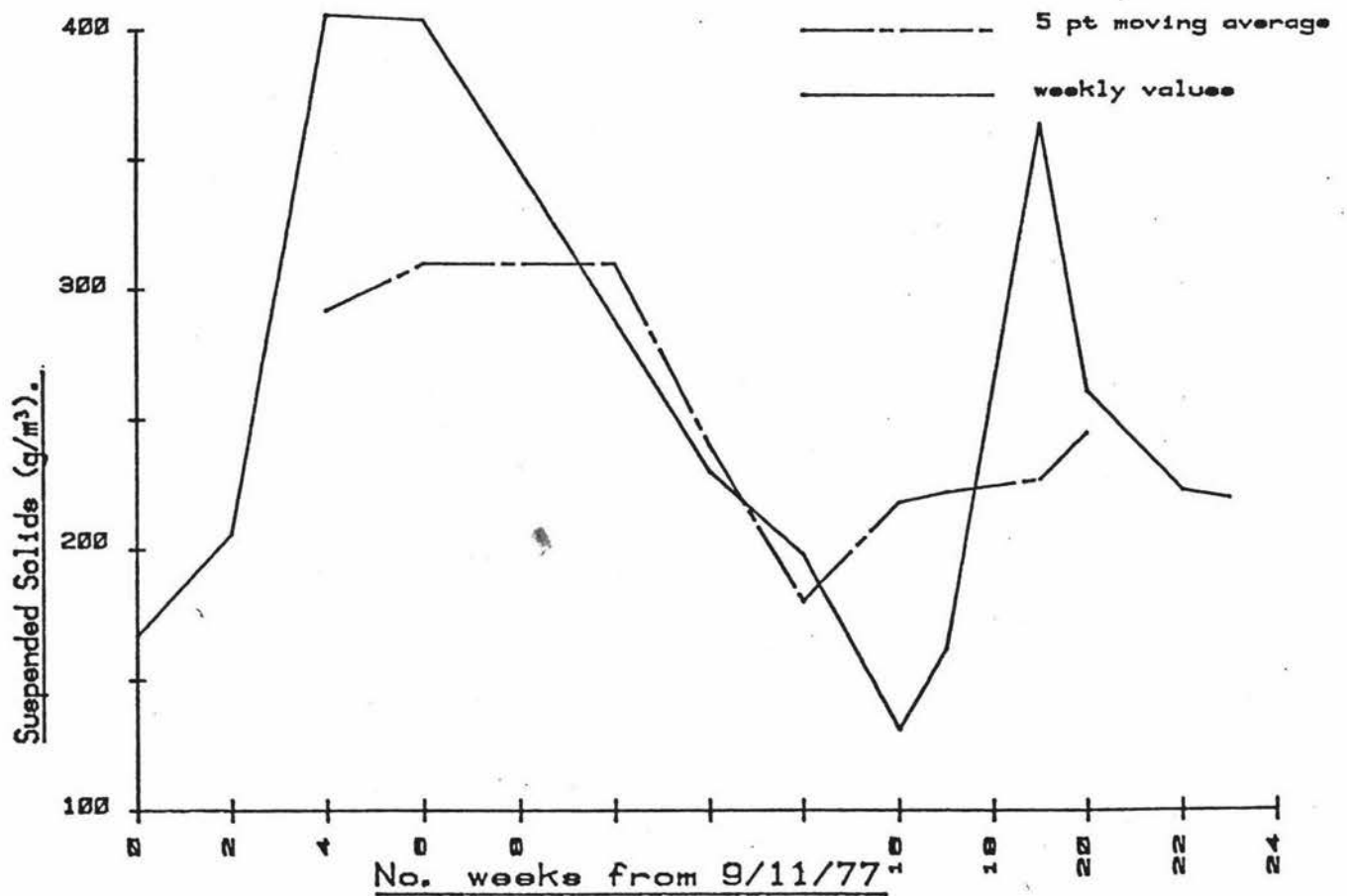
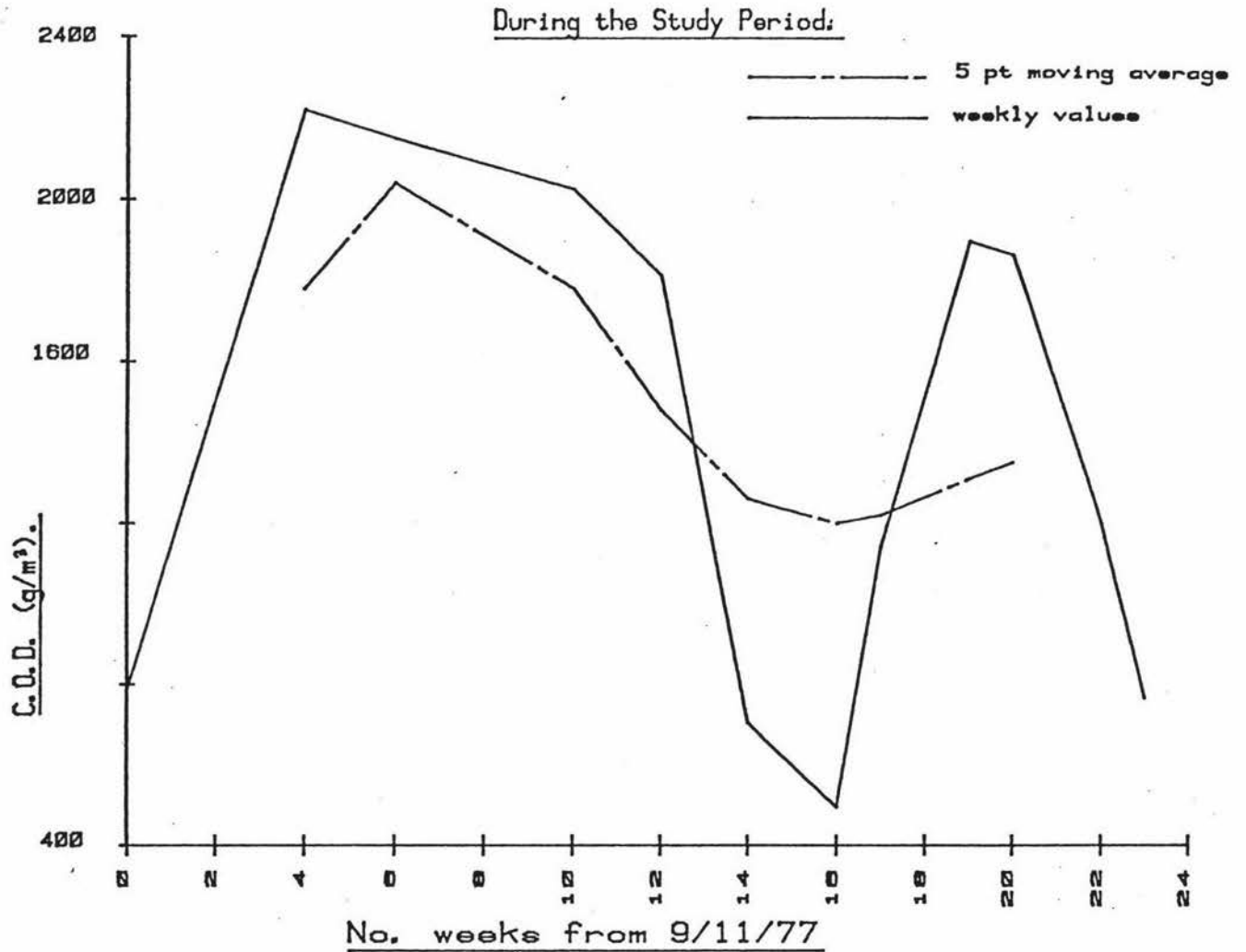


FIGURE 14. Changes in the Feilding Domestic Sewage Quality



last column in Table 22 gives the average for the low concentration range only, in an attempt to characterize the domestic sewage components.

TABLE 22 SUMMARY OF EFFLUENT RESULTS

I. BORTHWICKS MEAT WORKS DISCHARGE

PARAMETER	MEAN	σ	RANGE
Temperature ($^{\circ}\text{C}$)	19	3	15.5-24
Dissolved oxygen (g/m^3)	6	1	4.7-8.3
pH	7.9	0.2	7.3-8.0
Suspended solids (g/m^3)	52	23	18.1-78.0
BOD (g/m^3)	26	8	10.5-37
COD (g/m^3)	280	40	222-349
Protein (g/m^3)	320	50	245-364
Carbohydrate (g/m^3)	19	5	13-31
Kjeldahl nitrogen (g/m^3)	70	7	54-76
Nitrate-N (g/m^3)	0.08	0.05	0.04-0.45
Ammoniacal-N (g/m^3)	23	7	14-33
Total phosphorus (g/m^3)	8	4	3.1-14.3
Phosphate-P (g/m^3)	7	2	3.9-8.9
Lipolytic bacteria (/100 ml)	3.10^5	4.10^5	$(3-10).10^5$
Saccharolytic bacteria (/100 ml)	1.10^6	2.10^6	$(4-500).10^4$
Proteolytic bacteria (/100 ml)	4.10^5	7.10^5	$(1-100).10^4$
Faecal Coliforms (MPN)	5.10^4	1.10^5	$(3-200).10^3$

II. FEILDING DOMESTIC SEWAGE

PARAMETER	MEAN	σ	RANGE	LOW MEAN
Temperature ($^{\circ}\text{C}$)	20	2	15.5-23	
Dissolved oxygen (g/m^3)	2	1	0.9-5.0	
pH	7.3	0.3	6.9-7.8	
Suspended solids (g/m^3)	250	90	131-406	
BOD (g/m^3)	410	180	251-782	280
COD (g/m^3)	1400	600	495-2200	760
Protein (g/m^3)	1370	500	577-2122	740
Carbohydrate (g/m^3)	39	11	24-57	27
Fat (g/m^3)	229	87	127-342	
Kjeldahl Nitrogen (g/m^3)	61	16	30-81	30
Nitrate-N (g/m^3)	0.3	0.3	< .01-0.83	
Total phosphorus (g/m^3)	5	2	3.3-10.3	
Phosphate-P (g/m^3)	3	1	1.7-4.4	2.4
Lipolytic bacteria (/100 ml)	5.10^7	3.10^7	$(4-1000).10^5$	
Saccharolytic bacteria (/100 ml)	3.10^8	2.10^8	$(7-600).10^6$	
Proteolytic bacteria (/100 ml)	7.10^7	1.10^8	$(2-30000).10^4$	

TABLE 23 SIGNIFICANT CORRELATIONS BETWEEN THE PARAMETERS
MONITORED IN THE TWO EFFLUENTS

COMPONENT	TYPE	EFFLUENT(S) *
Temperature/dissolved oxygen	-ve	F&B
Temperature/pH	-ve	F
Temperature/nitrate	+ve	F&B
Dissolved oxygen/phosphate	+ve	B
Kjeldahl nitrogen/protein	+ve	F
COD/suspended solids	+ve	F
BOD/suspended solids	+ve	F&B
Carbohydrates/suspended solids	+ve	F&B
Carbohydrates/COD	+ve	F
Carbohydrates/BOD	+ve	F
Protein/COD	+ve	F
COD/BOD	+ve	B
Carbohydrates/phosphates	+ve	B
Suspended solids/phosphates	+ve	B
COD/Proteolytic bacteria	-ve	B
COD/Saccharolytic bacteria	-ve	B
Saccharolytic bacteria/Proteolytic bacteria	+ve	B
MPN/Saccharolytic bacteria	+ve	B
MPN/Proteolytic bacteria	+ve	B
Proteolytic bacteria/Lipolytic bacteria	+ve	F
Saccharolytic bacteria/Lipolytic bacteria	+ve	F

* F = Feilding Domestic Sewage Treatment Wastes Effluent

B = Borthwick's Meat Works Effluent

5.4.1

Temperature

The temperature of both effluents reflected that of the surrounding atmosphere. Minimum temperatures of 15-16°C were recorded in November 1977 and late April 1978 while maximum temperatures of 23-24°C were recorded in late January and February 1978.

5.4.2

Dissolved oxygen

The dissolved oxygen concentrations of the Borthwick's effluent were rarely below 4.5 g/m³ whereas the domestic sewage had very low dissolved oxygen concentrations. The highest value recorded for the domestic sewage was 5 g/m³ but usually the levels were below 2 g/m³. Both discharges showed significant correlations between the temperature and the dissolved oxygen concentration (Figure 15). This was due to the decreased solubility of oxygen at higher temperatures and/or the increase in heterotrophic activity with increased temperatures.

5.4.3

pH

The pH of Borthwicks effluent usually varied within a narrow range (7.7-8.0). Two low values, 7.3 and 7.45, were recorded in November 1977 and were probably associated with the long retention times that had occurred before the beginning of the killing season. In comparison, the pH of the domestic sewage varied widely and probably depended upon the concentration of trade wastes present. A minimum of 6.9 was recorded in February 1978 while a maximum of 7.8 was recorded in November 1977. There was a significant negative correlation between temperature and pH in the Feilding domestic sewage (Figure 16). This correlation is due to the activity of microorganisms in the sewage. At higher temperatures there is a greater microbiological

FIGURE 15. Correlations Between the Temperature and the Dissolved Oxygen Concentrations in the Borthwick's Effluent and the Feilding Domestic Sewage.

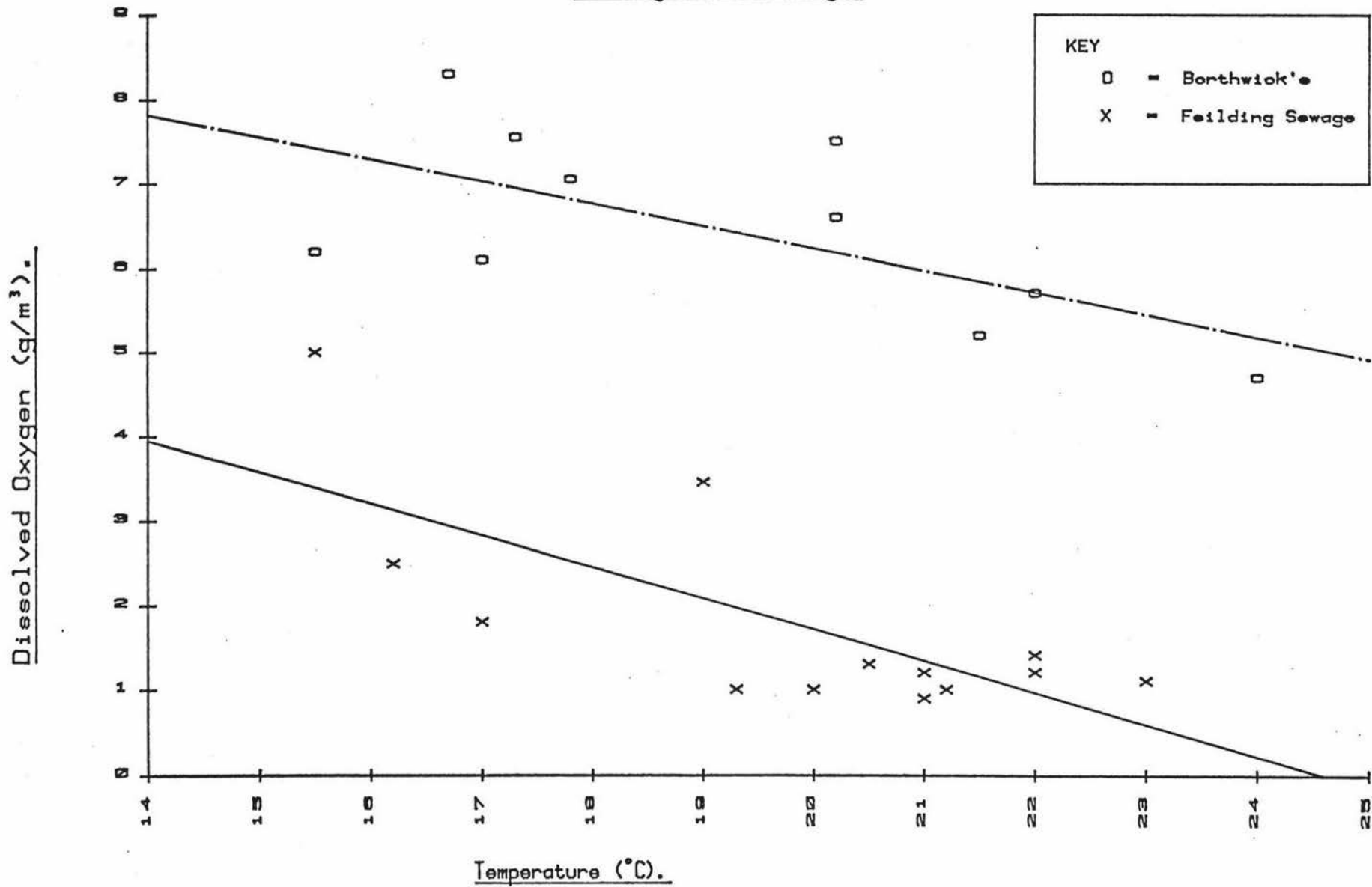
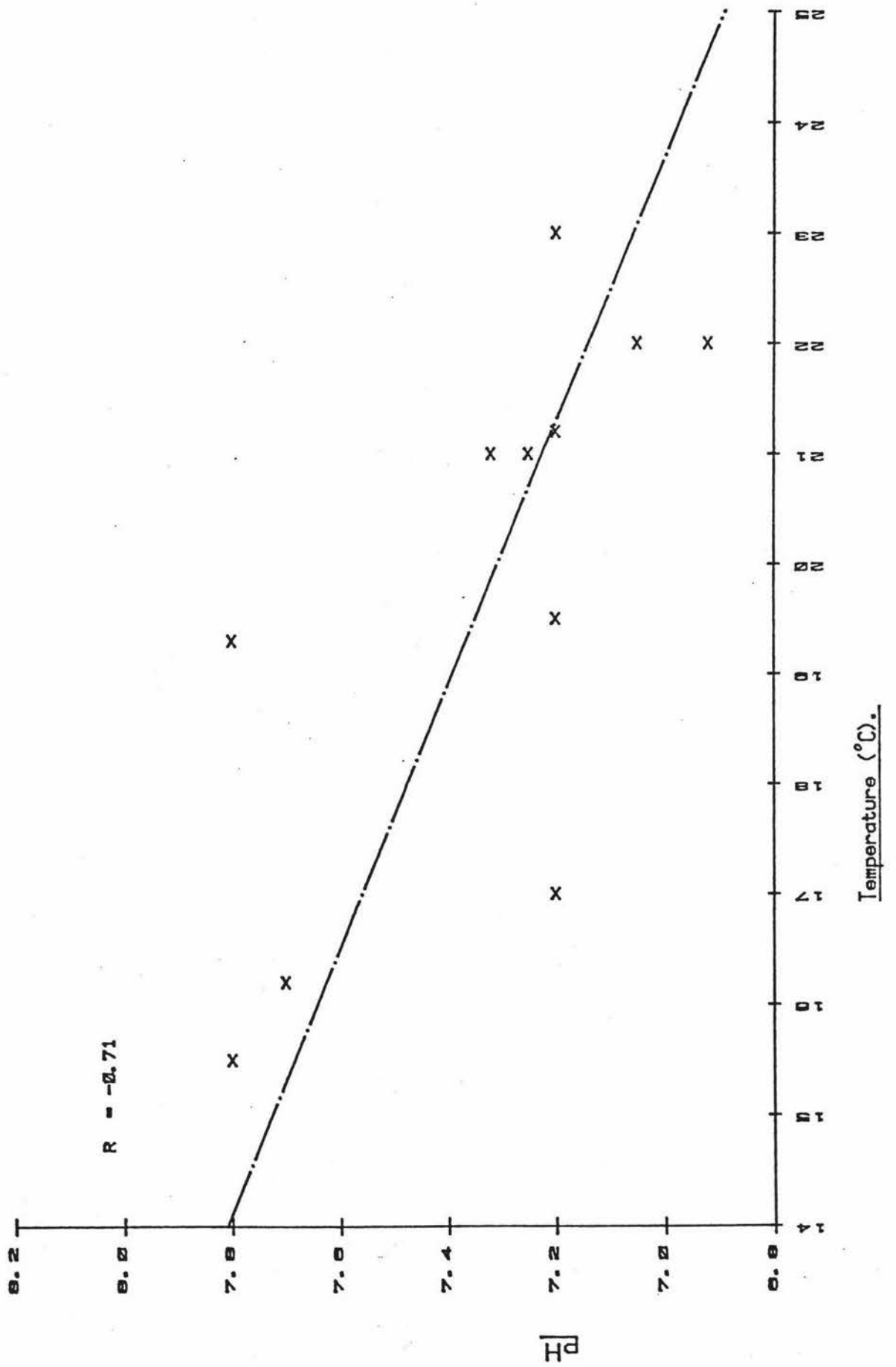


FIGURE 16. Negative Correlation Between Temperature and pH in the Feilding Domestic Sewage.



activity and hence more carbon dioxide is produced which thus reduces the pH. The strongly buffering capacity of sewage helps to depress greater pH fluctuations.

5.4.4 Suspended solids

The suspended solids concentration of the Borthwick's effluent samples was low. Early in the season the suspended solids varied between 30 and 40 g/m³ while a maximum of nearly 80 g/m³ was reached near the peak of the killing season. The suspended solids in the Feilding domestic sewage samples were considerably more concentrated. Low values that were assumed to correspond to a "pure" sewage discharge were 150-250 g/m³ while values of 350-450 g/m³ indicated the presence of strong trade wastes. The suspended solids content of both effluents correlated with their organic composition, as measured by BOD, COD and carbohydrates (Figure 17). This implies that the organic components are an important constituent of the suspended solids.

5.4.5 Oxygen demand

The total BOD₅ of the Borthwick's samples varied from 10-30 g/m³ in early season samples, to 30-40 g/m³ during the main killing season while total COD varied between 220-270 g/m³ and 270-350 g/m³ respectively. The total BOD and total COD concentrations of the Borthwick's effluent correlated (Figure 18) and the ratios of COD to BOD were usually around 10. This is a high ratio and indicates a high inorganic to organic concentration which is typical of a well treated effluent.

Total BOD concentrations of 250-300 g/m³ and COD concentrations of 500-800 g/m³ were recorded for the "pure" domestic sewage. Trade wastes increased these values to more than 650 g/m³ BOD and 1800-2200 g/m³ COD.

FIGURE 17. Correlations Between the Suspended Solids Content and the
and other Organic Parameters in the Borthwick's Effluent
and the Feilding Domestic Sewage.

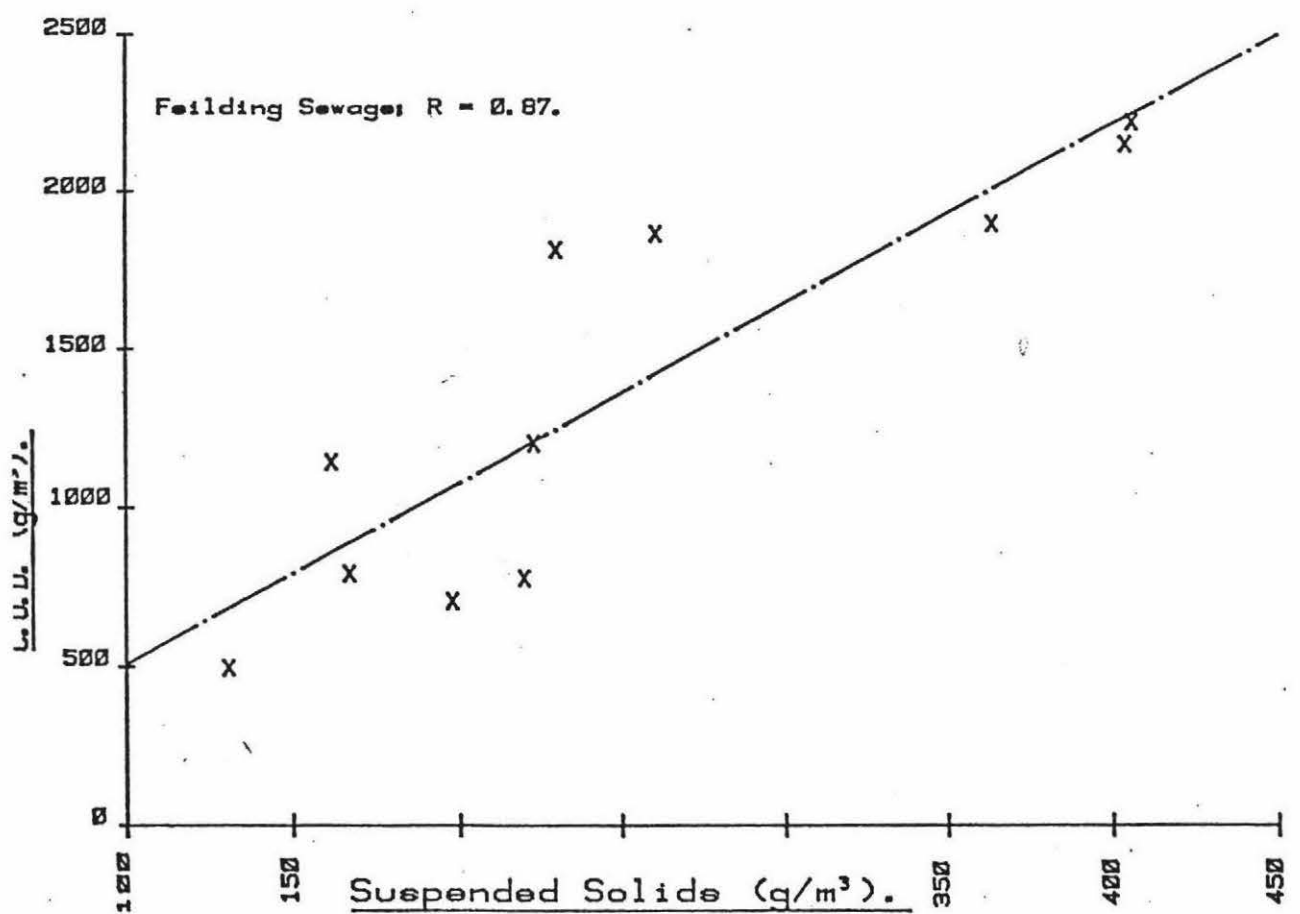
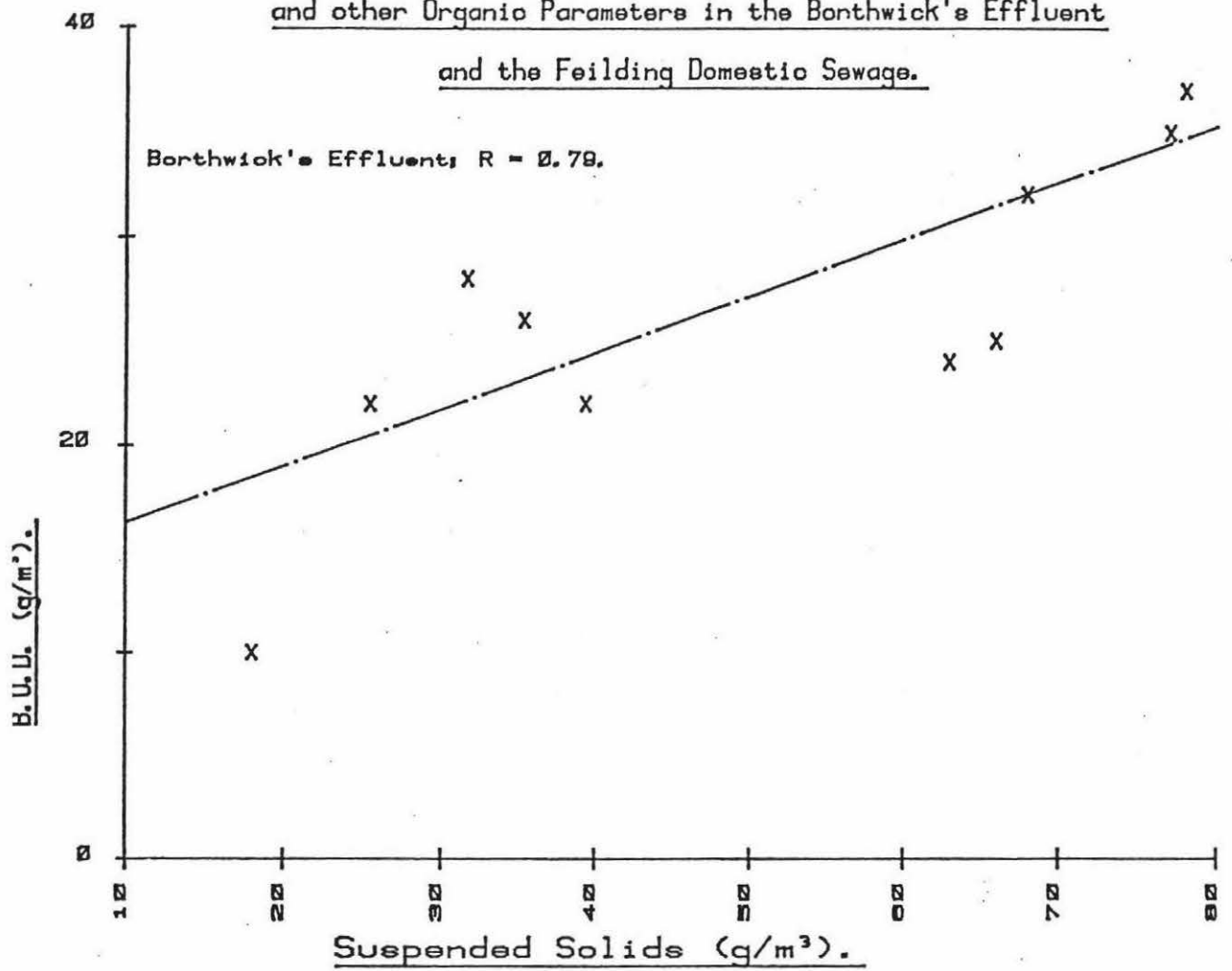
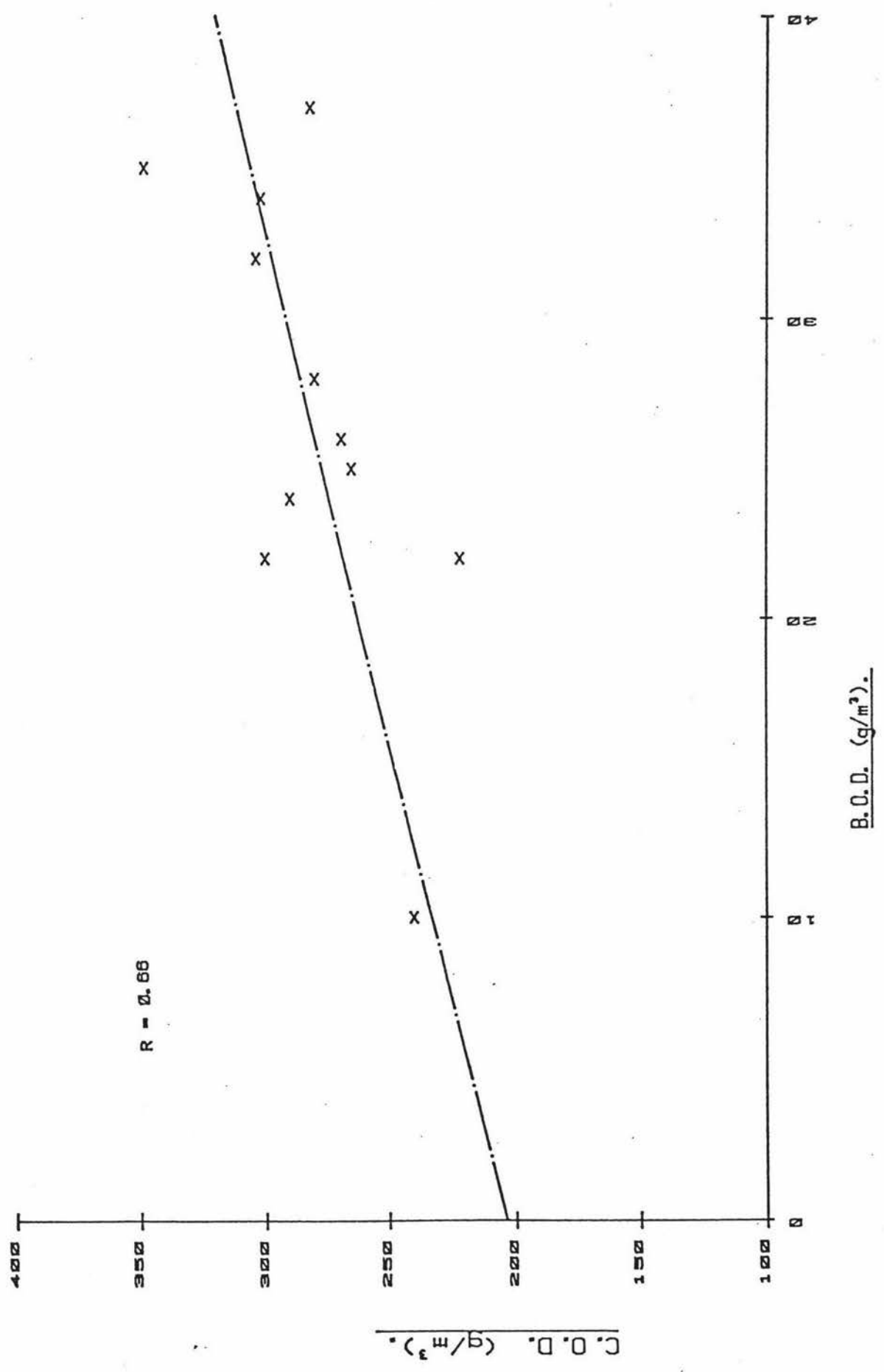


FIGURE 18. Correlation Between B.O.D. and C.O.D.
in the Borthwick's Effluent.



No correlation existed between the BOD and COD of the sewage discharge and this was probably because of the variable nature of the discharge. The ratio of COD:BOD was, however, in the order of 3 which indicates a poorly treated effluent.

5:4.6

Carbohydrates

The carbohydrate content of Borthwick's effluent samples was 10-20 g/m³ in November and December and 20-30 g/m³ after December. Concentrations of 25-30 g/m³ carbohydrates were recorded in the "pure" domestic sewage samples which were increased up to 55 g/m³ by the trade wastes. Significant correlations between carbohydrates and COD and BOD were found in the Feilding domestic sewage (Figure 19). Thus it appears that carbohydrate is an important oxygen demanding component in the sewage.

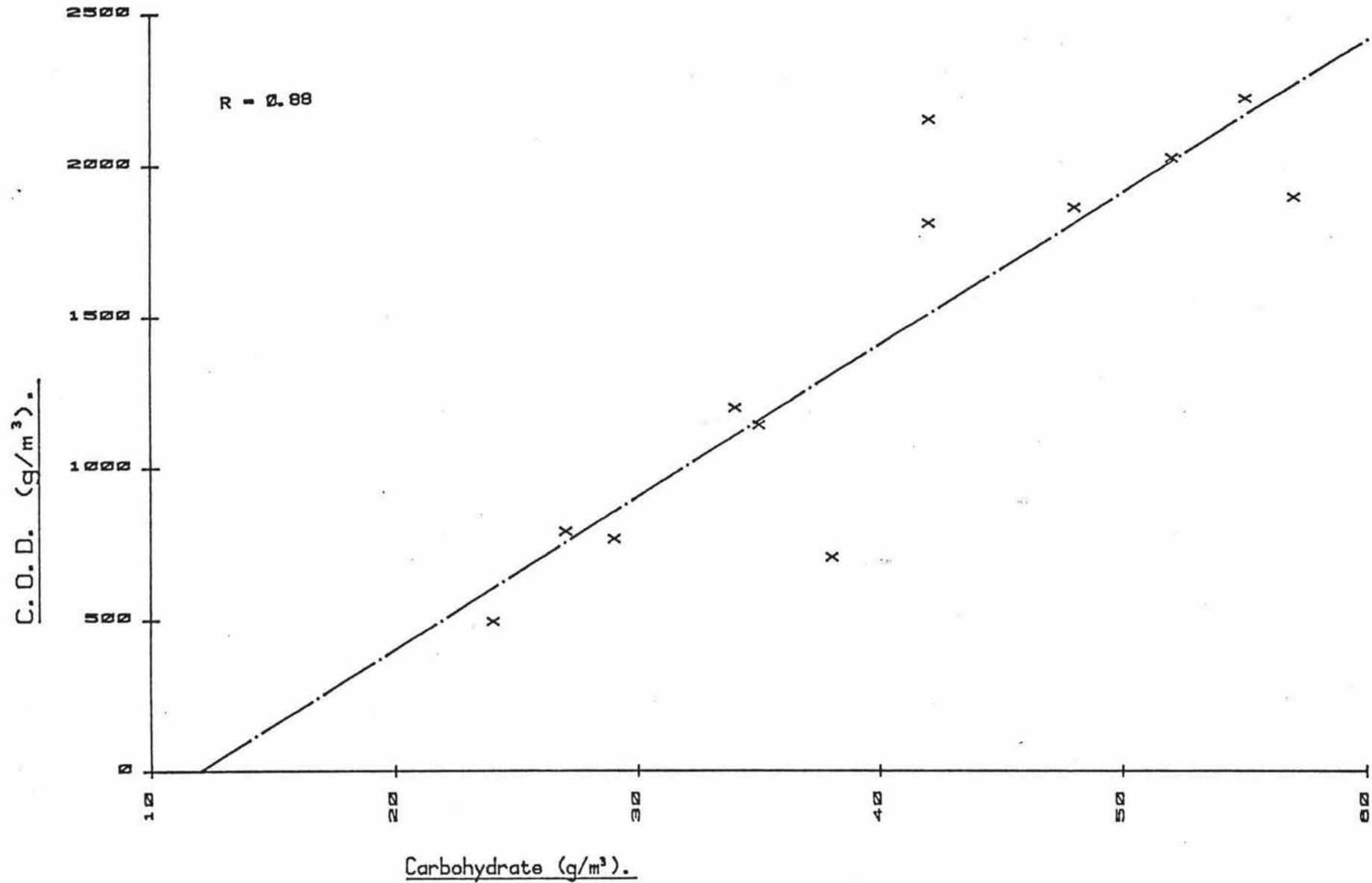
5.4.7

Protein and kjeldahl nitrogen

No significant correlation was found between the protein concentration and the kjeldahl nitrogen content in the Borthwick's effluent. As the kjeldahl nitrogen measurement includes ammonia as well as organic nitrogen the lack of correlation may indicate a high ammonia content. A significant correlation between kjeldahl nitrogen and protein concentration was illustrated for the Feilding domestic sewage (Figure 20). This implies that the ammonia content was negligible and thus little degradation of protein had occurred during waste treatment.

Protein levels in the Borthwick's effluent varied from 245 to 364 g/m³ while 70-76 g/m³ kjeldahl nitrogen were recorded, indicating that the kjeldahl nitrogen measurement consisted of 54-80% protein. The domestic

FIGURE 19. Correlation Between Carbohydrate Concentration and the C.O.D. in the Feilding Domestic Sewage.



sewage had kjeldahl nitrogen values of similar magnitude to the Borthwick's effluent ($30-75 \text{ g/m}^3$) while the protein concentration was much higher ($600-2000 \text{ g/m}^3$). Using the assumption that protein contains 16% nitrogen, manipulation of these results shows that the kjeldahl nitrogen levels were much lower than the nitrogen available from protein alone. This discrepancy is thought to be due to the automated kjeldahl nitrogen technique used. This method had only a 15 minute digestion time which was probably insufficient to completely digest the high sediment content of the domestic sewage. The sediment remaining after digestion was not accounted for in the kjeldahl nitrogen determination. The significant correlation between the kjeldahl nitrogen and protein results, however, indicates that the error in determining the kjeldahl nitrogen was consistent for all sewage samples.

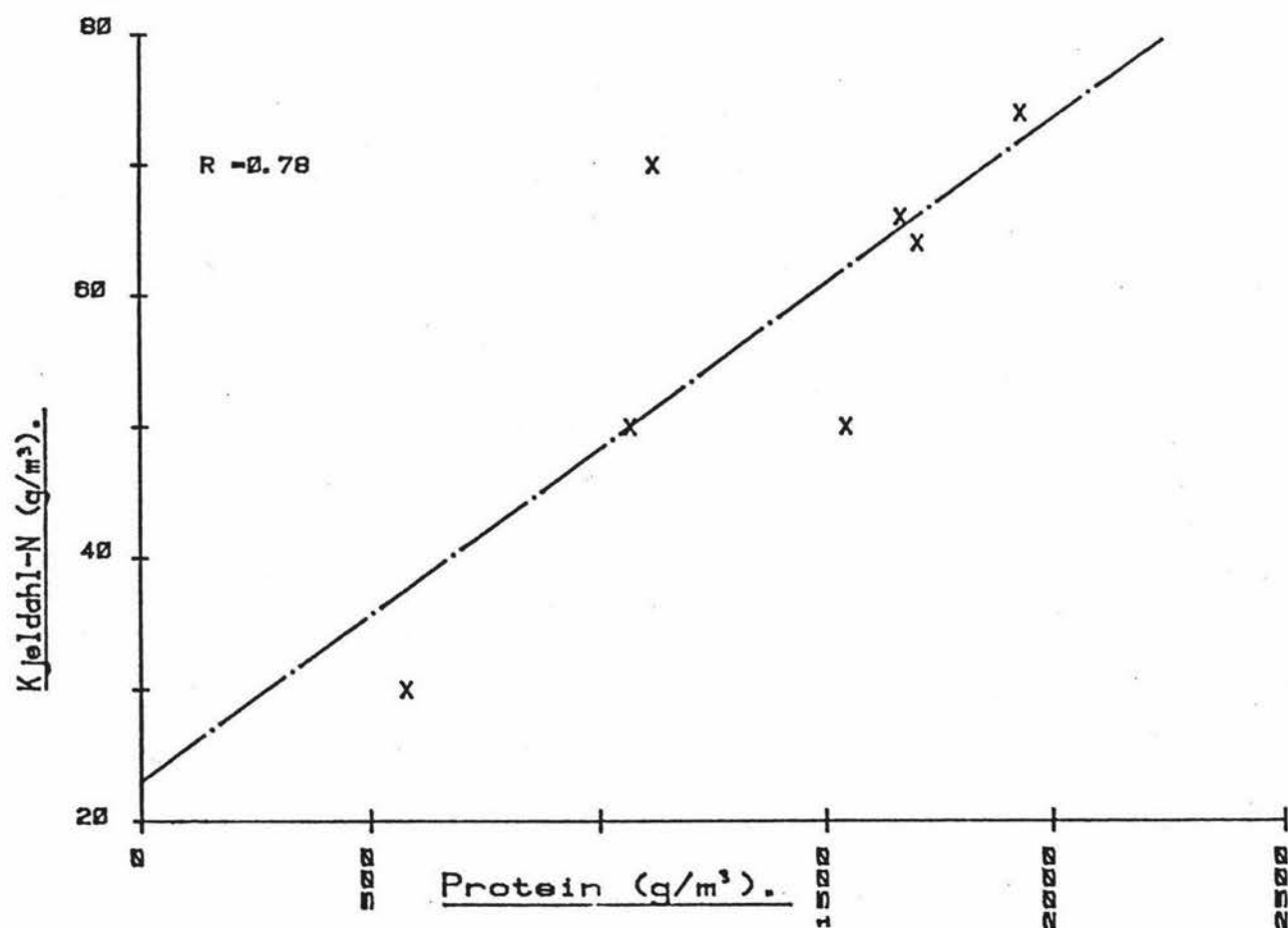
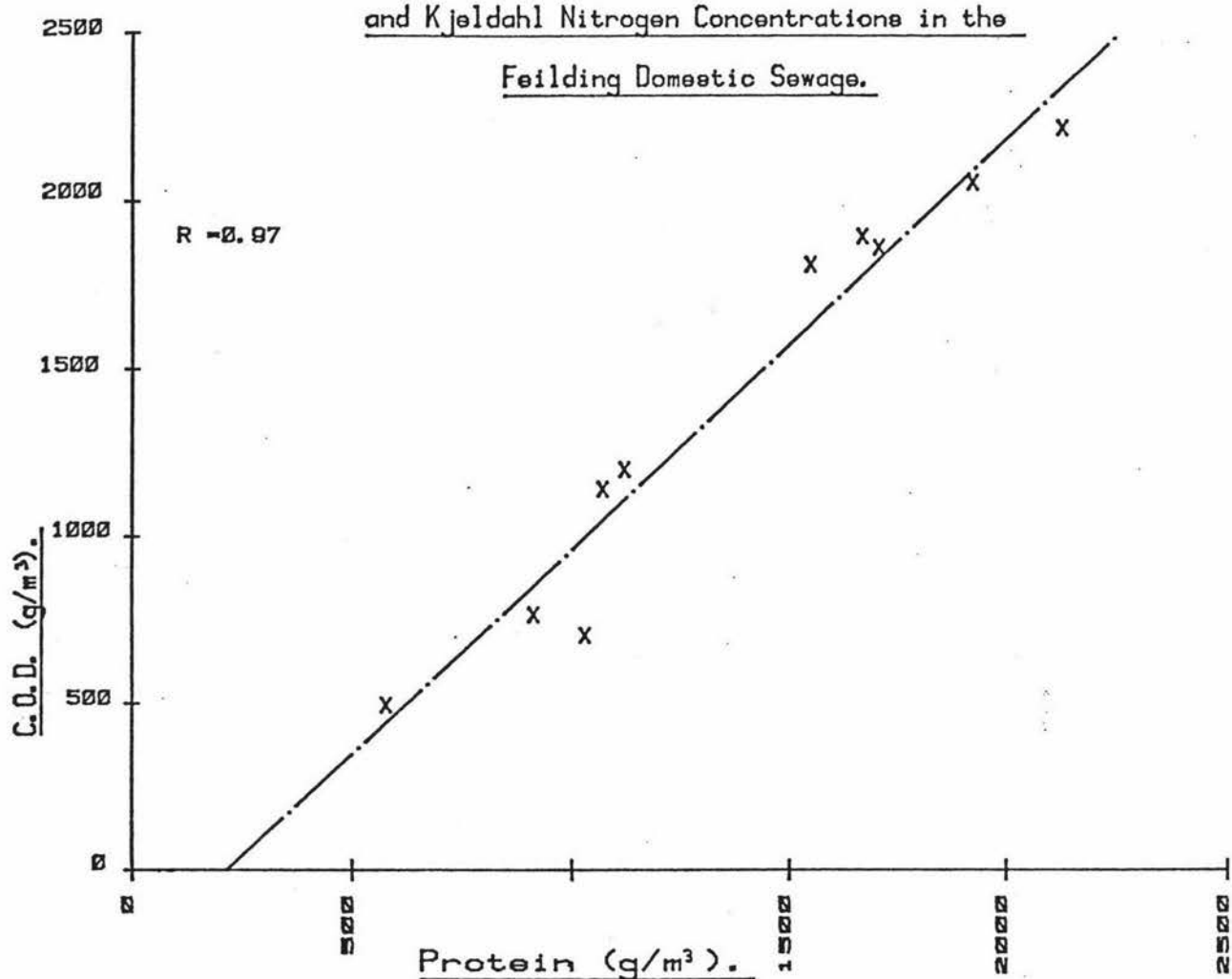
Thus the protein results were taken as the most appropriate for describing the sewage effluent. The "pure" domestic sewage had protein concentrations of $600-1000 \text{ g/m}^3$ while the "mixed" sewage had higher concentrations ($1650-2100 \text{ g/m}^3$). Correlations between the protein and COD in the domestic sewage (Figure 20) were significant which indicates that protein too is an important source of oxygen demand.

5.4.8

Fats

Fats were not analysed in the effluent, however, the difference between the measured COD and the COD theoretically derived from the protein and carbohydrate components was used to estimate the fat concentration. Glucose exerts a COD of 1.038 g/g glucose while cellulose exerts 1.15 g COD/g cellulose (Moore et al., 1949). Thus a value of 1.1 g COD/g carbohydrate was assumed. Fats have a similar molecular formula and thus also were assumed to exert 1.1 g COD/g fat. The protein ratios given by Moore et al. (1949) were more variable, for example 0.63 g/g for glycine and

FIGURE 20. Correlations Between Protein Concentration and the C. O. D. and Kjeldahl Nitrogen Concentrations in the Feilding Domestic Sewage.



1.642 g/g for tyrosine. A value of 0.9 COD/g protein was assumed. Fat estimates by this method are 0-30 g/m³ for Borthwick's and 0-350 g/m³ for the domestic sewage (Appendix 3).

The high COD:BOD ratio for Borthwick's effluent implies that the COD is derived from a high inorganic load. This is further illustrated by the lack of correlation of the measured COD with the organic fractions. The estimated fat content for the Borthwick's effluent will thus be significantly higher than the actual value. In comparison, good correlation occurred between the COD and protein and carbohydrate content of the domestic sewage which also had a small COD:BOD ratio. Thus the fat concentration estimated for the Feilding domestic sewage should be close to the actual value.

5.4.9

Nitrates

Nitrate levels of 0.04-0.17 g/m³ and < 0.01-0.83 g/m³ were recorded in samples from the Borthwick's effluent and the Feilding domestic sewage respectively. A positive correlation between temperature and nitrate was found for Borthwick's effluent (Figure 21).

5.4.10

Orthophosphate and total phosphorus

The phosphorus concentrations increased with the Borthwick's killing season. Early season results were 4-7 g/m³ of orthophosphate and 3-8 g/m³ total phosphorus. These values increased to 7-9 g/m³ orthophosphate and 10-14 g/m³ total phosphorus at the peak of the killing season. Correlations between orthophosphate and suspended solids and carbohydrates were found to be significant (Figure 22). This suggests that the majority of the orthophosphates in the effluent are associated with the carbohydrates and are in an insoluble form.

FIGURE 21. Correlation Between Temperature and Nitrate Concentration
in the Borthwick's Effluent.

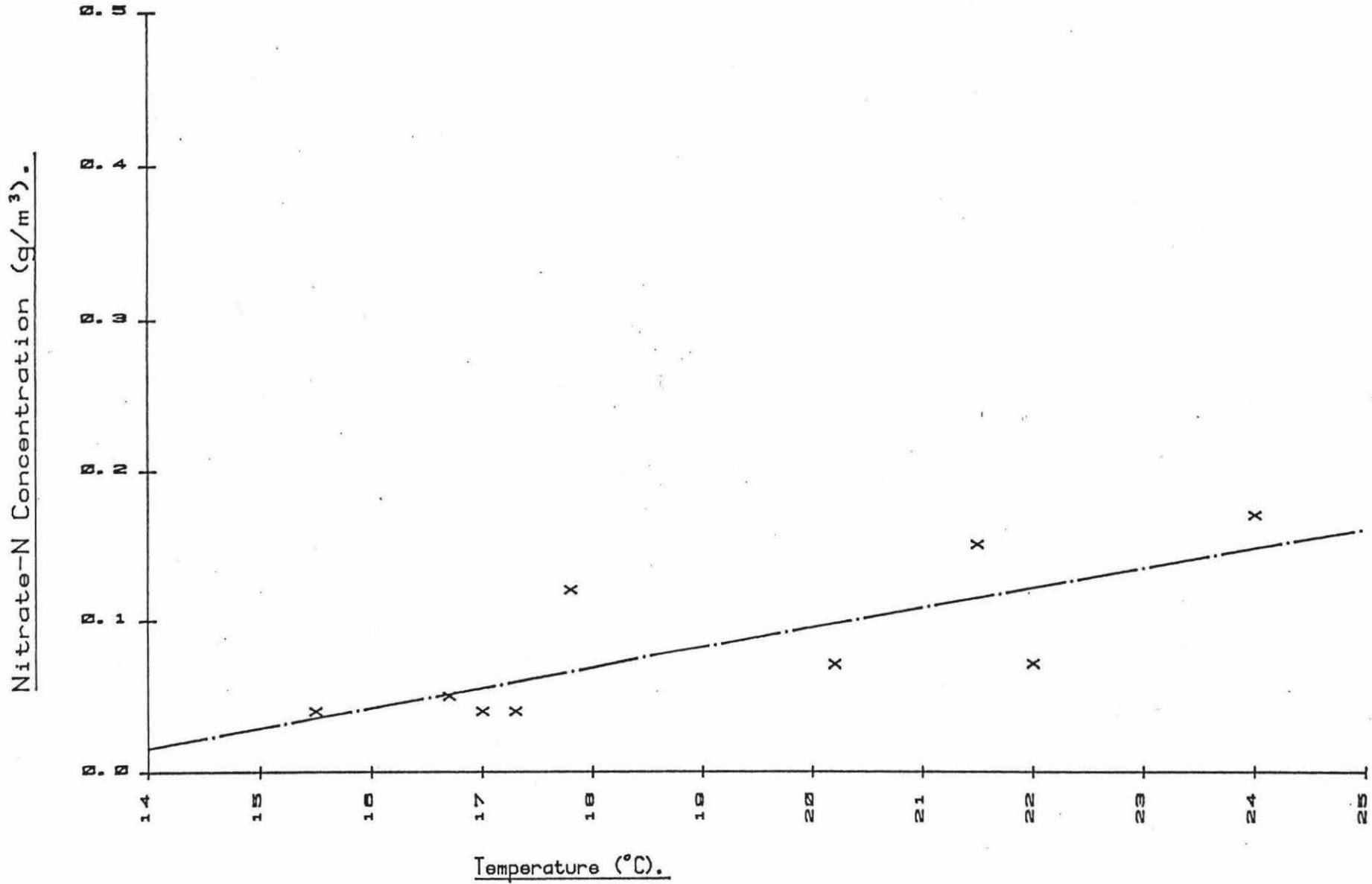
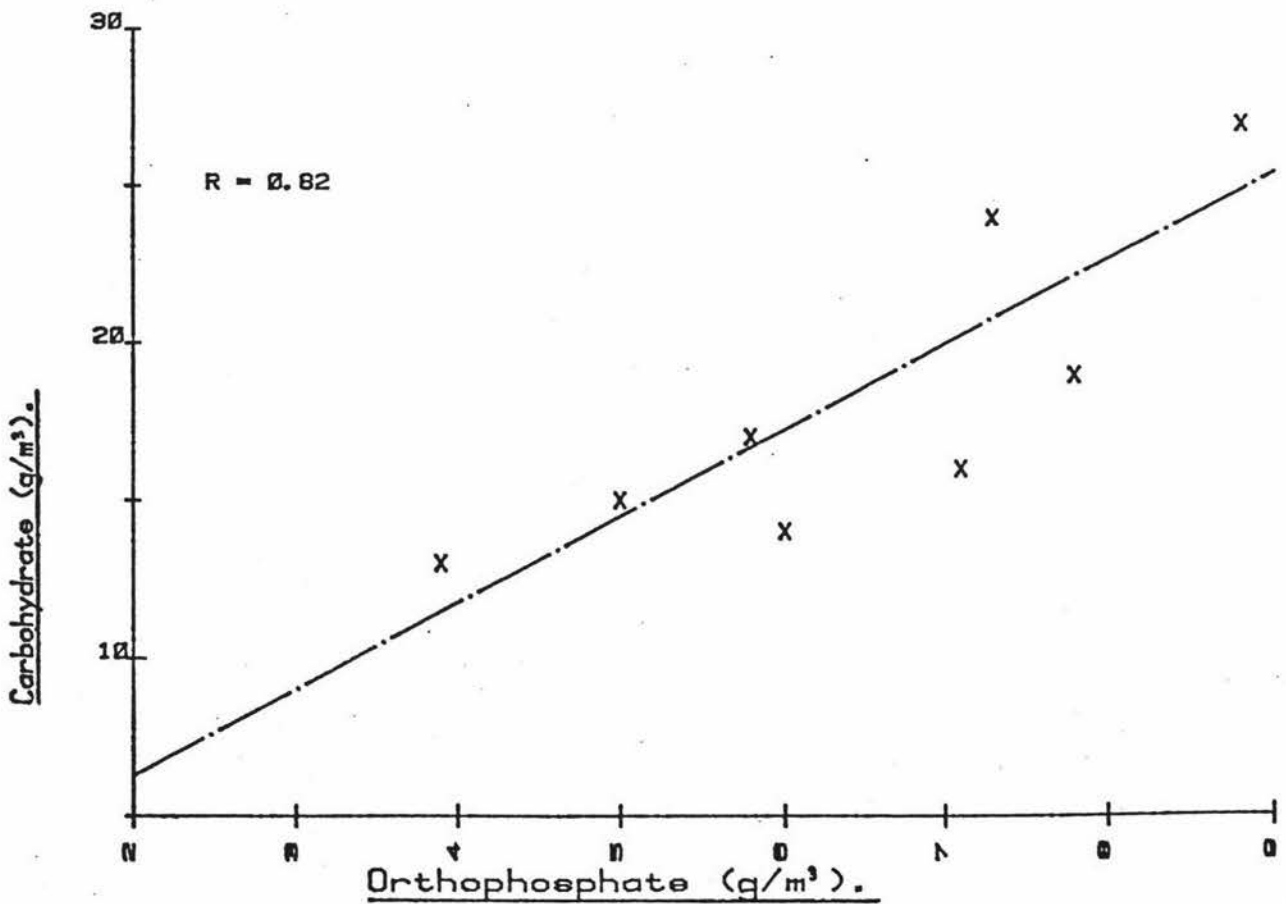
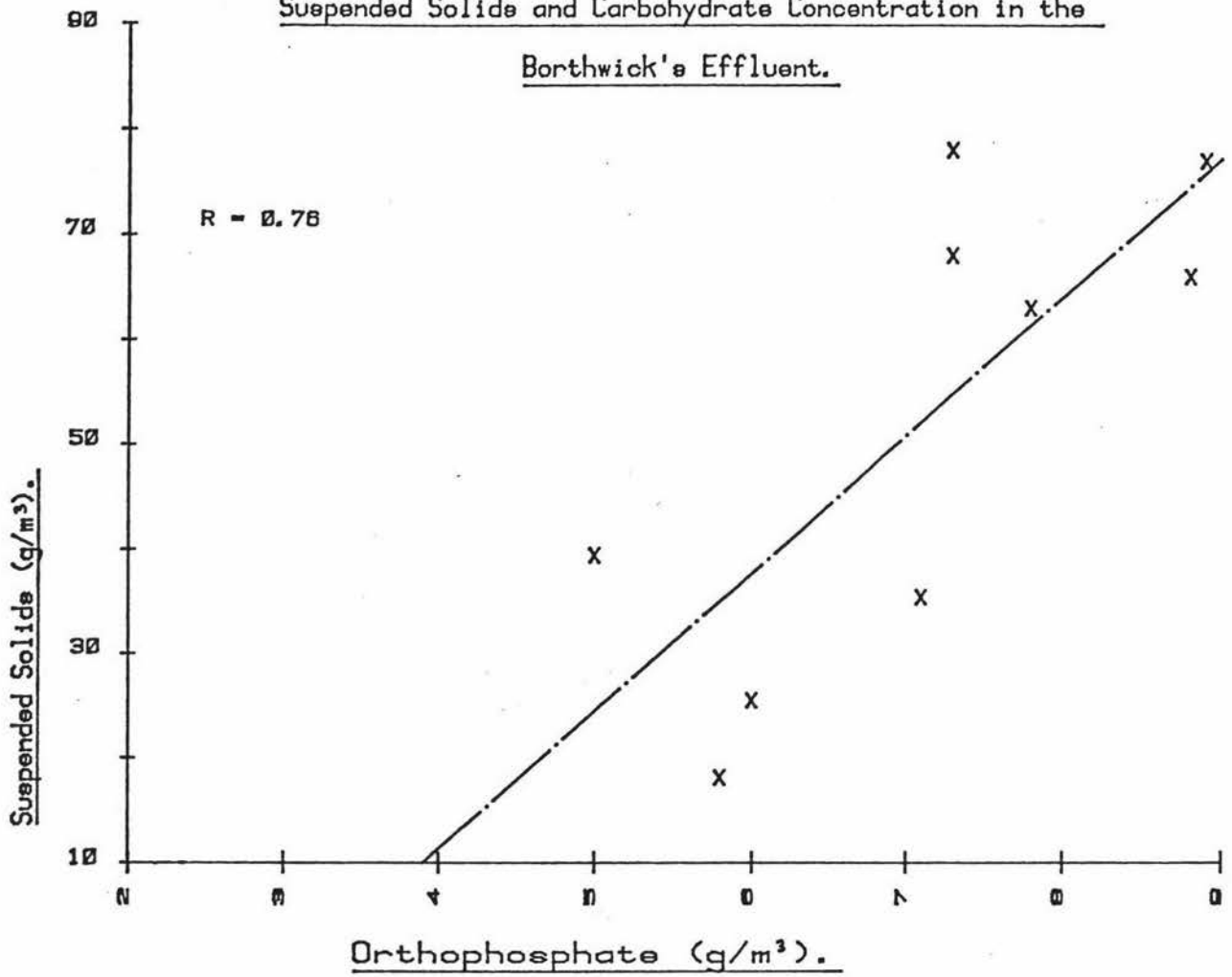


FIGURE 22. Correlations Between Orthophosphate Concentration and the
Suspended Solids and Carbohydrate Concentration in the
Borthwick's Effluent.



Orthophosphate levels in the domestic sewage varied between 1.7 to 4.4 g/m³. The lower concentrations occurred in the "mixed" sewage. Total phosphorus levels were 3.3-10 g/m³ and the presence of trade wastes caused the lower concentrations.

5.4.11 Sulphides

Sulphides were never detected in the Borthwick's effluent and were only occasionally detected in the domestic sewage. The times of sulphide presence corresponded with low dissolved oxygen content and high organic content.

5.4.12 Ammonia

Proteins usually consist of 16% nitrogen and are a major component measured in the total kjeldahl nitrogen. Ammonia is the other important specie which contributes to total kjeldahl nitrogen. Thus ammonia may be estimated from the difference between total kjeldahl nitrogen and protein nitrogen. This procedure was used to estimate the ammoniacal nitrogen content of the Borthwick's effluent (Appendix 3), it could not be used in the domestic sewage because of the failure of the total kjeldahl nitrogen method in estimating sediment nitrogen. The results indicate ammonia concentrations of 14-33 g/m³ with a mean of 23 g/m³. This at low stream flows and high effluent flows could result in concentrations of 1.5 g/m³ ammoniacal-N in the stream. At high stream flows the concentration of ammonia in the stream would be about 0.1 g/m³.

5.4.13 Microbiological results

The microbiological content of Borthwick's effluent was extremely variable. Highest densities were recorded on January 11, 1978, and were

probably associated with the long retention times during the Christmas close down. The lowest bacterial densities were recorded at the beginning and end of the sampling period when temperatures were lower. Significant correlations were found between all the bacteria groups tested except the lipolytic types. This is because the bacteria mainly originate from the meat wastes and they interact similarly in the ponding system.

Bacterial numbers in the Feilding domestic sewage were extremely high (10^7 - 10^8 cells/100 ml) and in most cases the MPN value was missed through too few dilutions being taken (Table 22). Significant correlations between saccharolytics and proteolytics and saccharolytics and lipolytics indicated a common source and similar interactions. No correlation was found between the lipolytic and proteolytic bacteria and this was probably because of too few comparisons.

5.4.14 Summary of the effluent results

5.4.14.1 Borthwick's effluent

The Borthwicks effluent was found to be a well treated, high quality effluent and thus it is not surprising that it had little effect on the receiving waters.

The organic load, as measured by the BOD, was low and most of the organic material was contained within the suspended solids.

The ratio of COD:BOD was high which indicated that the COD comprised of a high percentage of inorganic material. This was further illustrated by a lack of correlation of COD with the organic species.

Of the inorganic nutrients studied orthophosphates were at high

concentrations and nitrates at low concentrations. Sulphides were never present and it appeared that ammonia may occur in high concentrations. Orthophosphates were found to occur with carbohydrates while the presence of nitrates was found to depend upon the temperature.

The microbiological content of the Borthwick's effluent was between 10^5 and 10^6 /100 ml. The results showed that the initial numbers of bacteria were interdependent and that the bacterial groups interacted in a similar way in the treatment system.

5.4.14.2 Feilding domestic sewage

The quality of the Feilding domestic sewage was found to be very poor and the concentration of effluent components varied greatly. Large fluctuations in sewage quality was attributed to the intermittent discharges of concentrated trade wastes which were found to increase the organic sewage components by about two times the usual concentration.

The domestic sewage had a high organic content (even without trade wastes) and, as with the Borthwick's effluent, the suspended solids contained most of the organic components. The ratio of COD:BOD was low which indicates a poor conversion of organic matter to inorganic nutrients thus both BOD and COD were primarily derived from organic components.

The domestic sewage was found to be a poor nitrate source. Orthophosphate concentrations were slightly lower than in the Borthwick's effluent and sulphides were only detected when high organic concentrations, indicative of concentrated trade wastes, were present.

The microbiological content of the sewage was high (10^6 - 10^8 /100 ml) and the different groups of bacteria originated from a common source and were affected similarly in the treatment system.

5.5 Interactions of Components in the Oroua River

The Oroua River has certain features that affected the interactions of components in it. The river is at the shingle stage and consists of a series of riffles and pools. In the riffle immediately below the Feilding domestic sewage outfall a large area of sewage fungus has developed while on riffles further downstream large benthic algae populations occur. The area of sewage fungus exerts an intensive heterotrophic action on the river components flowing over the riffle and the sewage fungus also tends to some extent physically filter the water. Similar actions occur in the algae riffles further downstream and the algal population can also shelter populations of bacterial predators and other secondary consumers. These areas thus act analogously to trickling filters hence causing a rapid decay of organic components and destruction of foreign microorganisms. The rate of decay depends upon the area of riffles and the density of heterotrophic organisms in the riffles.

5.5.1 Suspended solids in the Oroua River

The rate of decrease of suspended solids in the Oroua River depended upon the stream velocity. At velocities greater than 0.2 m/s (6 fps) settling of suspended solids is negligible (Velz, 1970) and as the velocity of the Oroua River was always more than 0.2 m/s little sedimentation would occur. With low river flows the decline of the suspended solids resembled first order kinetics while at high flows there was initially a large drop in suspended solids (between sites F_2 and F_3) after which there is little decrease or even an increase in suspended solid levels. As sedimentation of suspended solids is of minor importance in the Oroua River the major mechanisms of removal must be by oxidation of particles or by filtration of

particles through the periphytic microbial growth in the riffle areas. In high flows the first order decline of suspended solids is distorted by the scouring action of the stronger velocities resuspending sediments. The increased suspended solids content further downstream may be because of large planktonic algae populations.

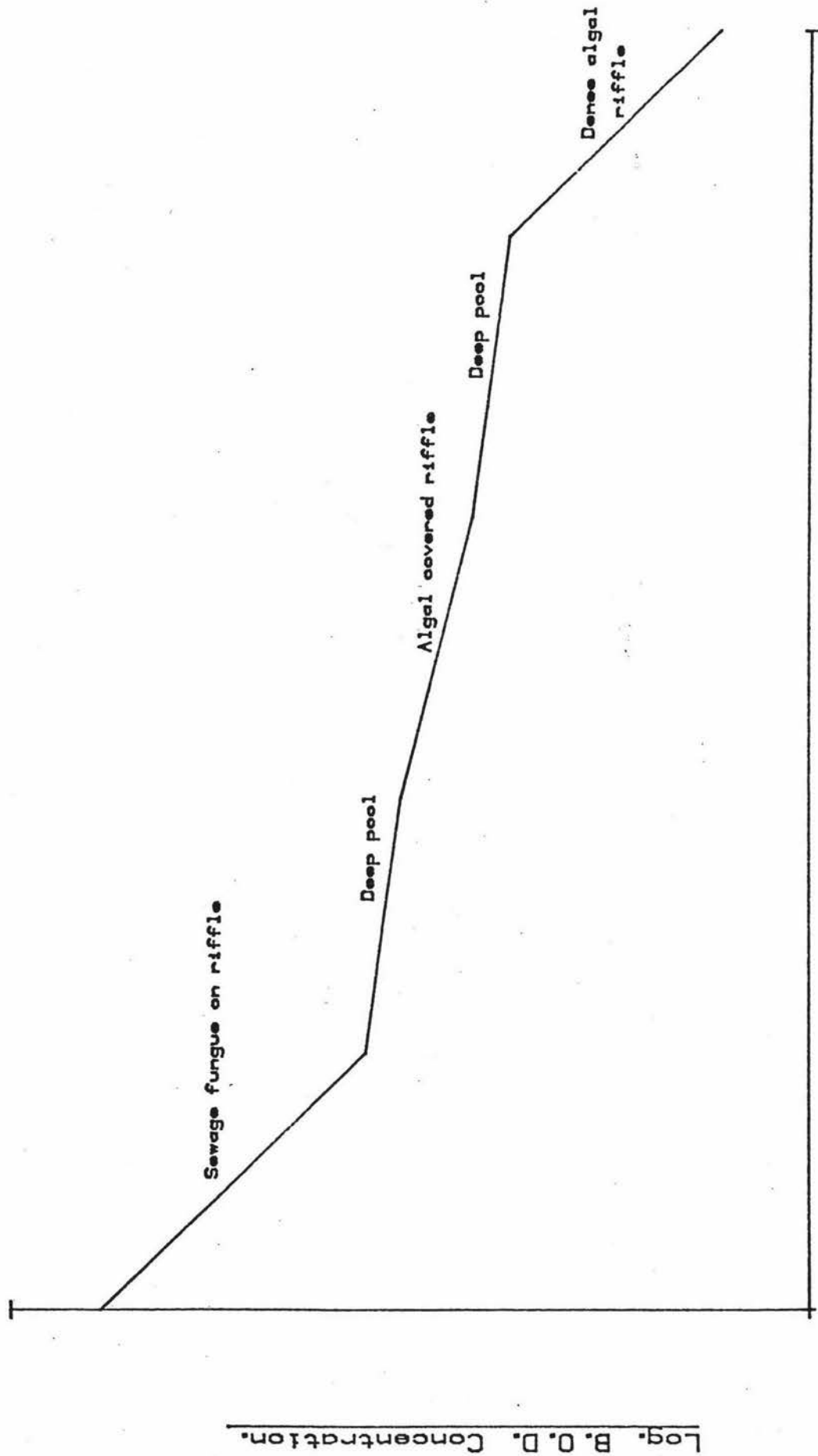
5.5.2 Organic Self purification

First order kinetics did not always adequately describe the BOD and COD decay rates and rarely described the decay of the total kjeldahl nitrogen.

There are several possible reasons why the data did not fit first order kinetics. Firstly, the BOD that was measured consisted of both dissolved and suspended organics. Thus much of the apparent decrease in BOD could be due to removal of suspended solids by means other than biological oxidation. Sedimentation and filtration are the most likely mechanisms. As the stream velocities were always greater than the minimum velocities for sedimentation this is unlikely to be an important phenomena. Filtration of large amounts of suspended solids could have occurred as the water flowed through the periphytic growths on the riffles. These riffle zones may also exert the "trickling filter effect" mentioned previously which would cause localised areas of high rates of organic decay. One could postulate that this would lead to a series of slopes on a log normal plot (Figure 23). The steepest slopes occur at the riffles with dense periphytic growths while the shallowest slopes would occur in deep pools. River regimes between these two extremes would have intermediate slopes.

The log normal plots of non-conforming data generally showed greatest slope near the discharge point and shallowest slope at points furthest downstream. These curves as well as some typically first order curves are shown

FIGURE 23. Trickling Filter Effect on Log-Normal Plots.



in Figure 24. This type of non-conformity agrees with the proposed reasons given above. Firstly the removal of suspended solids is greatest near the sewage outfall because there is a greater concentration gradient. Secondly the riffle areas were more frequent above Awahuri (F_4) and this area would thus promote a more rapid degradation of organic matter than that downstream. The high initial decay rates between sites F_2 and F_3 occurred because of the dense sewage fungus growth in a large riffle immediately below the discharge.

For the purpose of further study removal of organic matter by sedimentation and filtration was considered negligible and the slopes of the log normal plots as determined by regression analysis were assumed to represent the average rate of oxidation of organics. The deoxygenation coefficients obtained by these regressions are given in Table 24. No significant correlations were found between the deoxygenation coefficients and the stream flow, stream velocity, water temperature, and the initial concentration of the parameter under consideration. As well, there was no significant correlation between the total COD deoxygenation coefficient and the total BOD deoxygenation coefficient. It thus appears that the rate of decline of BOD and COD depends more upon factors that were not measured. Important factors could be the area of riffles and the density of benthic growth on these riffles.

Few significant log normal regressions were obtained for the kjeldahl nitrogen data and this may have been because of algae recycling the nitrogen nutrients back to organic nitrogen.

The average of the total BOD deoxygenation coefficient was greater than the average of the total COD deoxygenation coefficients. This is because a certain amount of the total COD consists of inorganic components which is not available to participate in first order kinetics.

FIGURE 24. B.O.D. Log-Normal Plots for the Oroua River Below The Feilding Domestic Sewage Discharge.

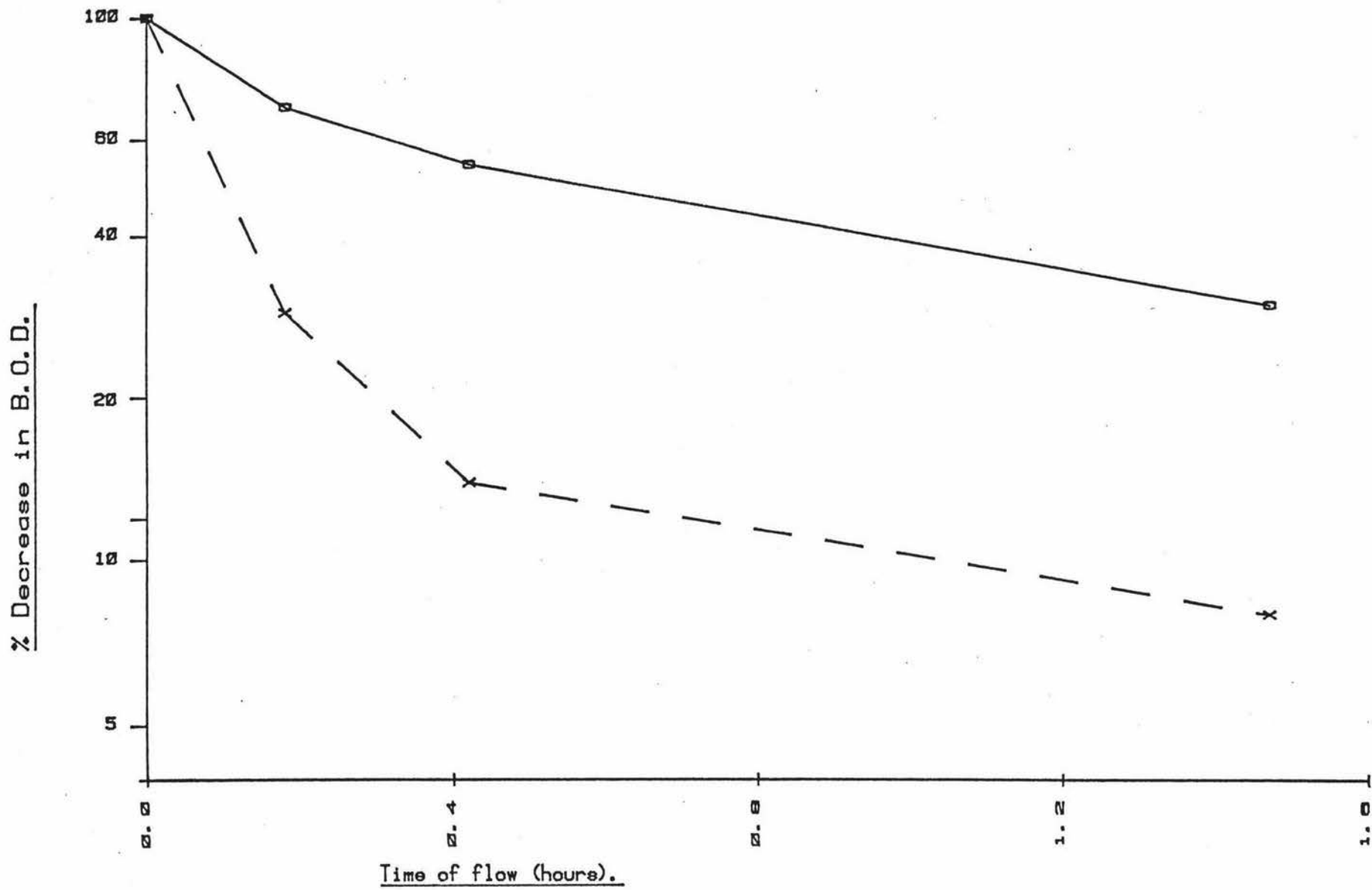


TABLE 24 FIRST ORDER DEOXYGENATION COEFFICIENTS
FOR BOD, COD AND TOTAL KJELDAHL NITROGEN IN THE OROUA RIVER
BELOW THE FEILDING DOMESTIC SEWAGE DISCHARGE

BOD

Date	K_1 (days ⁻¹)	Correlation Coefficient	F Statistic
18/1/78	5.8	-0.964	26.1
15/2/78	9.8	-0.825	4.3
1/3/78	4.3	-0.870	6.2
22/3/78	10.1	-0.823	4.2
12/4/78	9.8	-0.828	4.3
19/4/78	5.8	-0.903	8.9

COD

Date	$K_{(COD)}$ (days ⁻¹)	Correlation Coefficient	F Statistic
7/12/77	8.4	-0.923	11.6
18/1/78	7.2	-0.969	30.6
1/3/78	4.1	-0.985	65
8/3/78	5.5	-0.905	9.1
29/3/78	7.7	-0.904	9.0
19/4/78	3.8	-0.985	67

TOTAL KJELDAHL NITROGEN

Date	$K_{(TKN)}$ (days ⁻¹)	Correlation Coefficient	F Statistic
18/1/78	7.0	-0.923	11.5
1/3/78	9.1	-0.961	24.1
22/3/78	9.6	-0.907	9.3

5.5.3

Nutrients in the Oroua River

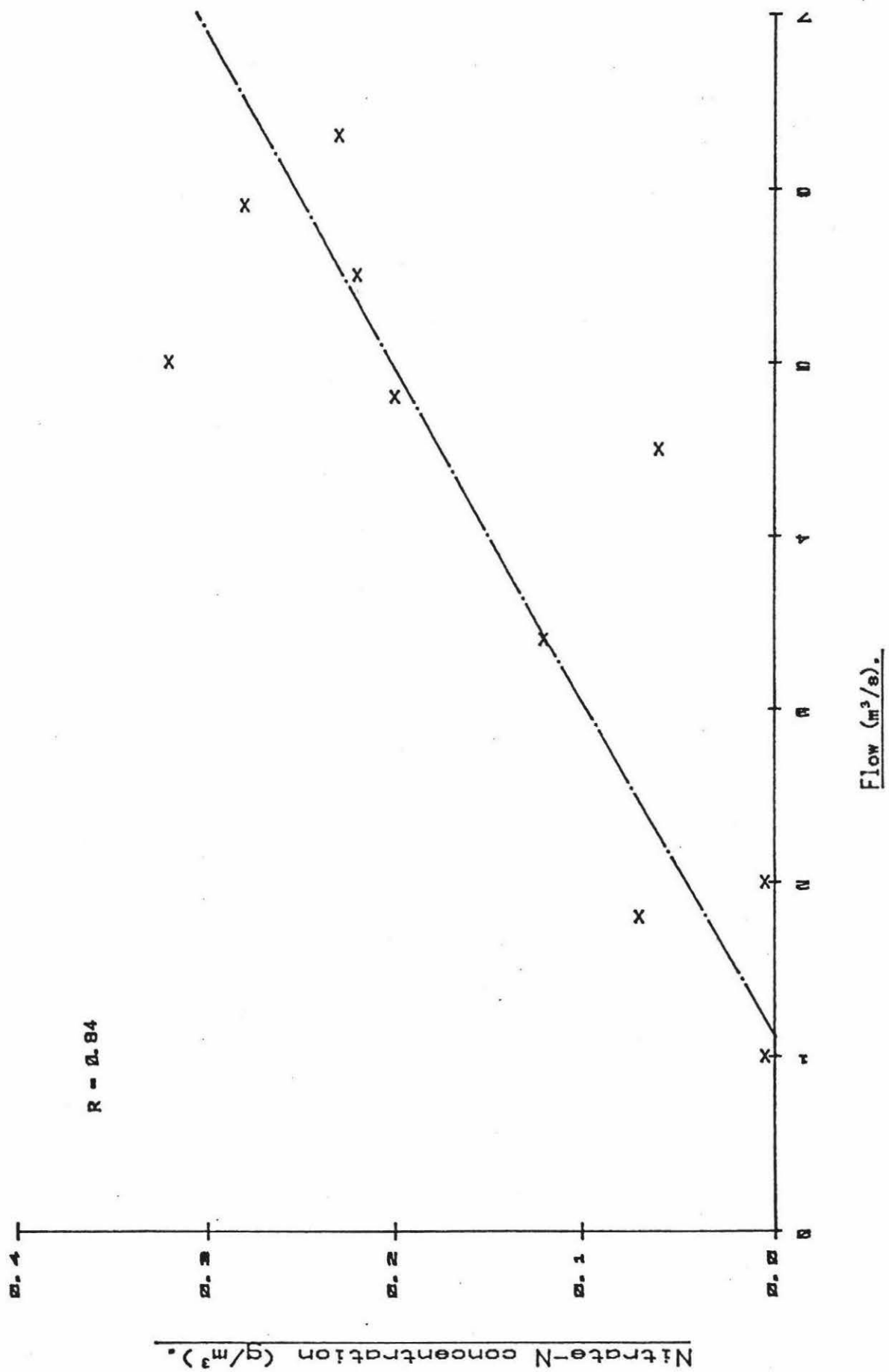
In high flow the nitrate concentrations in the Oroua River were relatively constant throughout the study area. With flows less than 3 m/s the nitrate levels gradually increased from the first site (B_1) until the discharge of sewage after which the nitrates remained relatively constant. Neither the Borthwick's effluent nor the Feilding domestic sewage directly affected the nitrate concentration in the river. The nitrate concentration above Borthwick's (site B_1) correlated at the 95% significant level ($r = .85$) with the river flow (Figure 25). Further downstream the river flow correlated less with the nitrate concentration ($r = .66$ at site B_3 and $-.47$ at F_5).

The correlation between nitrate concentration and flow at site B_1 indicates that factors occurring with high flows increases the nitrate concentration in the river. Two such factors that could affect the nitrate concentration are the amount of run off and the sediment load carried by the stream. High run off occurs at high river flows and water running off agricultural land can contain high nitrate concentrations. The upper Oroua valley is very prone to slipping which usually occurs in wet weather and hence high river flows. Thus during high flows the river also carries more soil sediments and hence soil nitrates.

At sites below B_1 the nitrate concentration becomes relatively independent of river flow. This indicates that other factors must also contribute to the nitrate concentration at these sites.

Total phosphorus increased slightly during the river's flow downstream. Total phosphorus concentrations were increased by both the Borthwick's effluent and the Feilding domestic sewage. This latter increase is not

FIGURE 25. Correlation Between Nitrate Concentration and Flow at Site B1.



illustrated in the averaged results because there was a large variation in the total phosphorus results.

The orthophosphate concentrations in the Oroua River did not appear to decrease according to first order kinetics as there were few log normal regressions significant at the 90% level. This could be because of the high algal activity in the river or because of "trickling filter actions" discussed previously (5.5.2).

5.5.4 Microbiological self purification

The estimates of the bacterial death rate constant (K_b) which were determined by regressions of the logarithm of bacteria numbers against the time of flow after discharge are given in Table 25. This table also includes the F statistic which illustrates the degree of fit between the regression line and the data points. All but one of the results were significant at the 80% level and many were significant at the 90% level. These levels of confidence were considered to be sufficient because of the large errors inherent in the microbiological testing methods.

No correlations were found to exist between the bacterial death rate constants and environmental factors such as temperature, flow, velocity and the initial microbiological concentration and variations in the constants were thus assumed to represent a normal distribution. Means and standard deviations were calculated and are given in Table 26. These results were then compared by a t test to determine whether the bacterial death rate constants for the three bacterial groups were significantly different. The lipolytic bacterial death rate constant and the saccharolytic bacterial death rate constant were significantly different to each other while the proteolytic

TABLE 25 BACTERIAL DEATH RATE CONSTANTS MEASURED IN THE OROUA RIVER
DOWNSTREAM OF THE FEILDING DOMESTIC SEWAGE DISCHARGE

BACTERIAL GROUP	DATE	K_b	F
Proteolytic Bacteria	21/12/77	7.2	14.3
	18/1/78	20.0	156.4
	15/2/78	9.8	2.77
	1/3/78	14.1	6.75
	8/3/78	10.4	2.43
Lipolytic Bacteria	21/12/77	10.9	16.1
	15/2/78	11.9	4.37
	1/3/78	13.5	37.4
	29/3/78	9.6	2.45
	12/4/78	11.9	2.91
19/4/78	10.1	3.29	
Saccharolytic Bacteria	21/12/77	11.8	0.72
	18/1/78	14.0	175.7
	15/2/78	14.3	4.3
	1/3/78	17.6	12.4
	8/3/78	14.4	23.3
	29/3/78	16.4	12.4
	12/4/78	17.9	3.3
19/4/78	17.6	14.8	

where: K_b is the bacterial death rate constant in days⁻¹ and F is the F statistic which illustrates the goodness of fit of the regression lines.

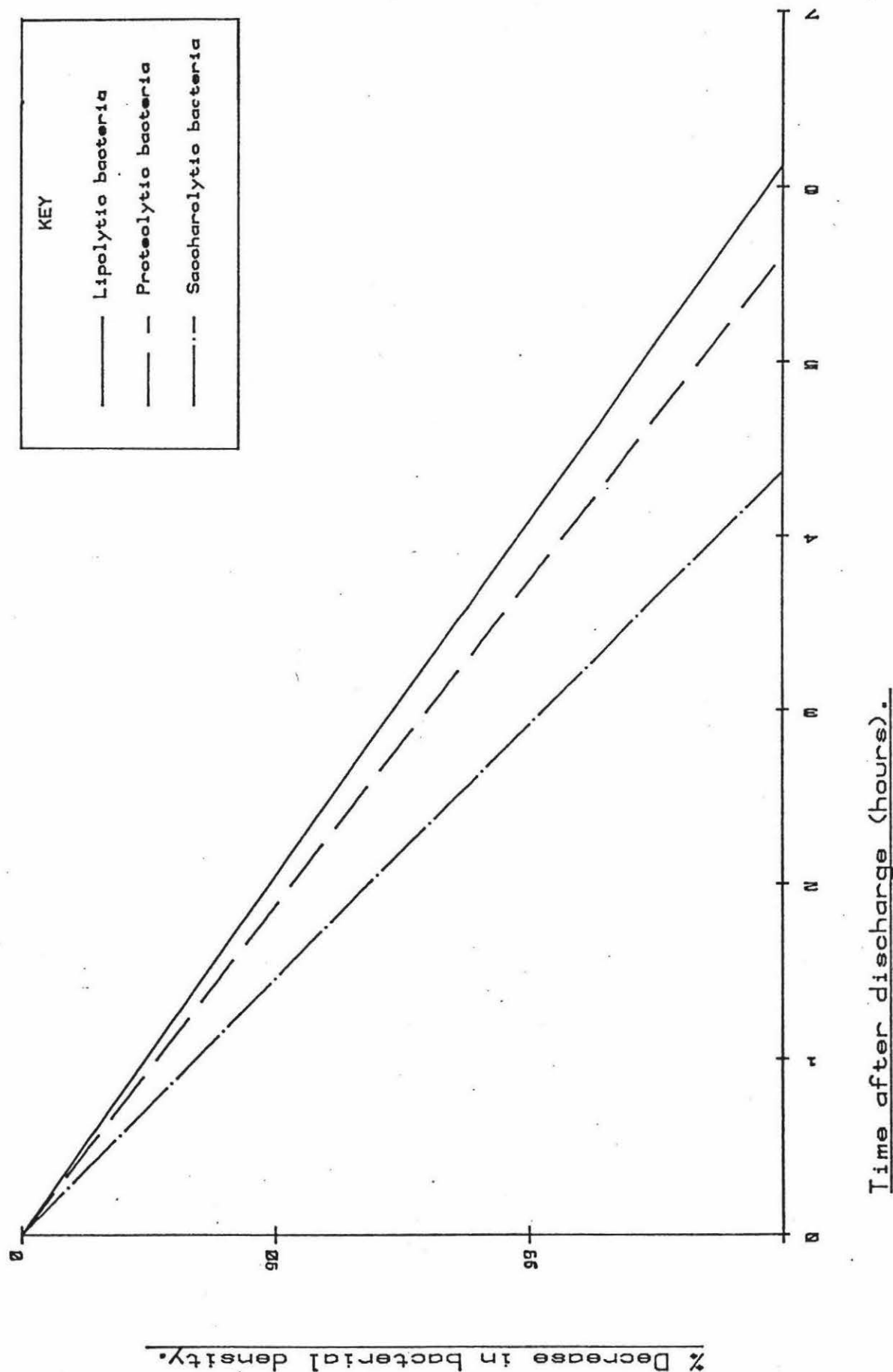
bacterial death rate constant (probably because of its large standard deviation) was not significantly different to either the saccharolytic or lipolytic bacterial death rate constants.

TABLE 26 MEAN BACTERIAL DEATH RATE COEFFICIENTS IN THE
OROUA RIVER BELOW THE FEILDING DOMESTIC SEWAGE DISCHARGE

BACTERIAL GROUP	MEAN K_b (DAYS ⁻¹)	STD DEV.
Proteolytic	12.3	4.96
Lipolytic	11.3	1.42
Saccharolytic	15.5	2.20

The death rate constants show that the rate of decline of bacterial numbers is exceptionally high in the Oroua River and that the rate of decline may vary slightly for different bacterial groups. The high rate of decline may again be attributed to the "trickling filter" features of the riffle areas which could support large populations of bacterial predators. Figure 26 summarizes the microbiological self purification results obtained for the Oroua River.

FIGURE 26. A Summary of the Microbiological Results.



5.6 Algae In The Oroua River

5.6.1 Factors influencing algal growth

The development of algae in the Oroua River was studied visually at three sites, B₁, F₁ and F₄. These sites all developed dense benthic algal populations and represent river conditions from clean to that heavily stressed by domestic sewage discharge.

The development of benthic algae was considered with respect to nitrate concentration, orthophosphate concentration, stream flow and stream temperature (Figures 27 and 28). Only the nutrient concentrations, stream flow and stream temperatures recorded on a sampling day were considered although it was realised that past, as well as present river conditions influenced algal growth.

Figures 27 and 28 show that the temperature did not affect the benthic algal development. Maximum stream temperatures were recorded in January and February while dense algal growths occurred from late February to mid April. The temperature levels during the period of maximum benthic algae growth corresponded to the temperatures of November and December, months when no algae were noted in the river.

At sites F₁ and F₄ there appears to be a parallel between algae density and nitrate concentration, orthophosphate concentration and stream flow. However, at site B₁, the orthophosphate concentration remained low (less than 0.03 g/m³) throughout the study period but this site still supported a dense algal population in February and March 1978. This indicates that the orthophosphate range occurring in the Oroua River does not limit the annual algal development. A positive correlation between stream flow and nitrate

FIGURE 27. Comparison of Algal Density and the Flow, Nutrient Concentration

and temperature at Site B1.

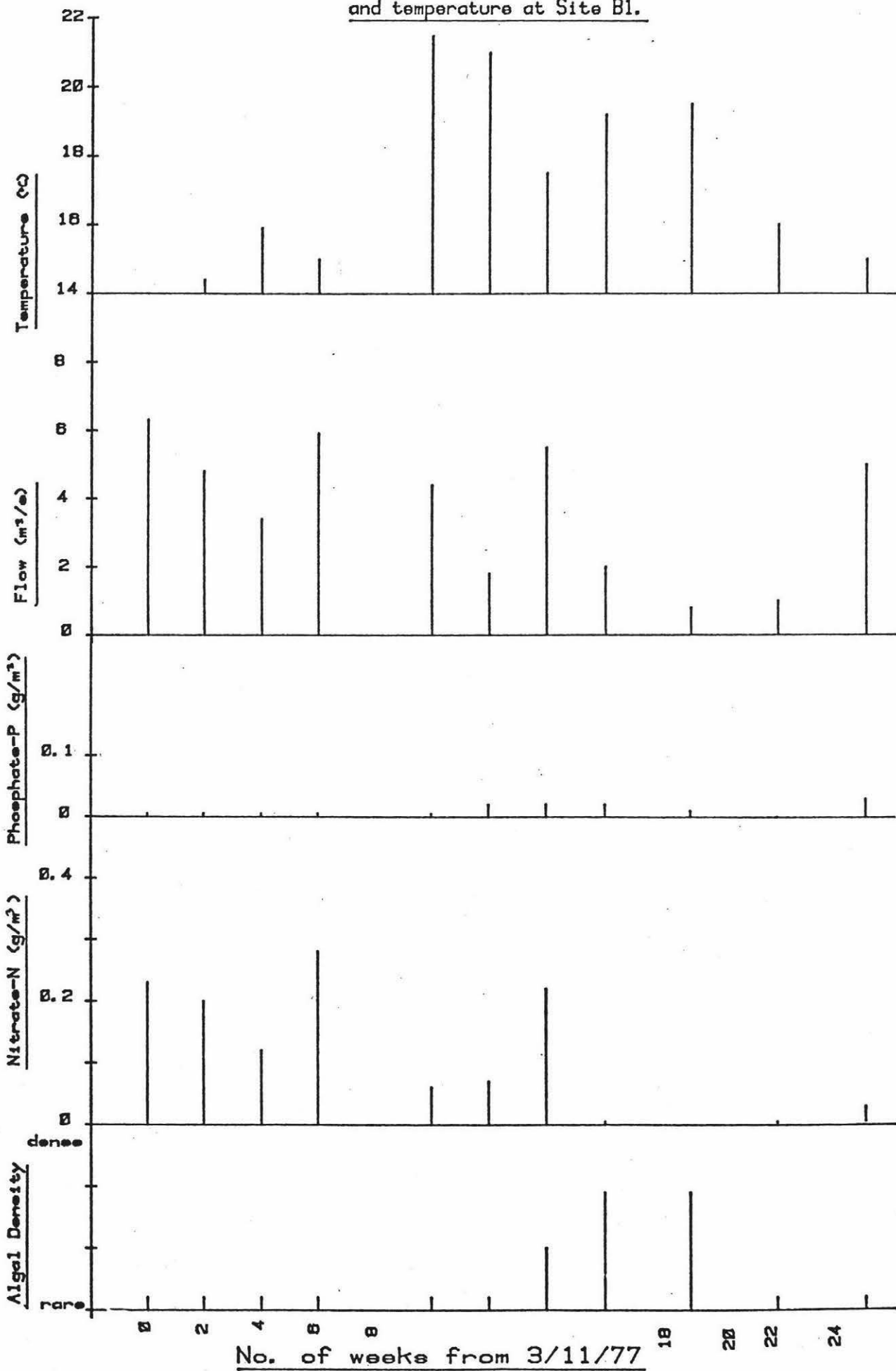
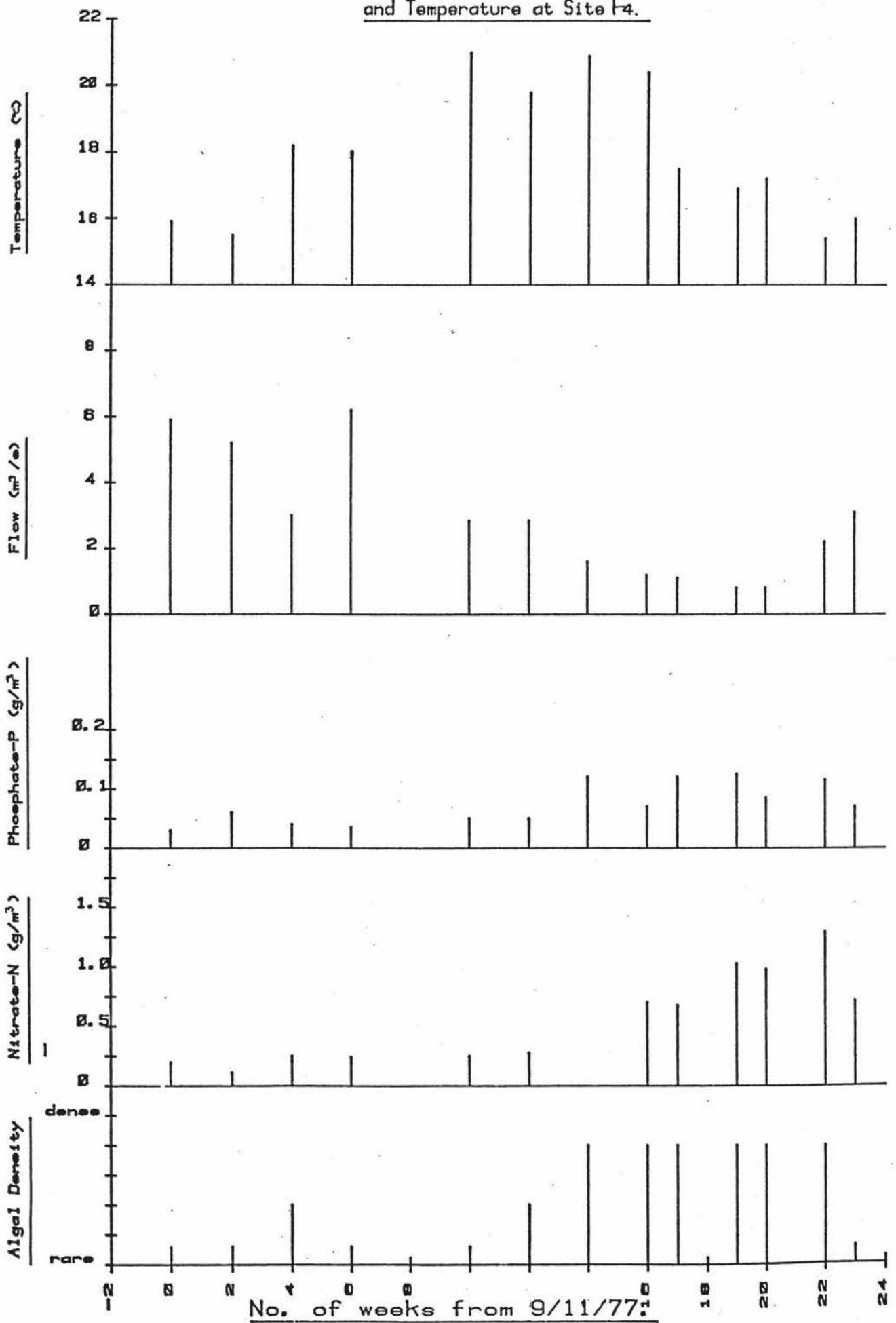


FIGURE 28. Comparison of Algal Density and the Flow, Nutrient Concentration and Temperature at Site F4.



concentration at site B₁ means that the algal development was at its maximum when stream nitrates were most dilute and thus the nitrate concentrations occurring in the Oroua River do not limit algal growth.

Thus it appears that stream flow is the most important factor influencing algal growth in the Oroua River. This is because high flows result in high velocities which would tend to rip the benthic algae from its attachments. Figure 28 shows that large algae populations developed at site F₄ when flow were less than 2 m³/s. This corresponds to average stream velocities of 0.6 m/s or less (calculated from data in Appendix 2).

The nitrate and orthophosphate concentrations at F₄ appear to limit algal growth because these concentrations are also dependant upon the stream flow.

5.6.2 Algal productivity

The three hourly dissolved oxygen concentrations and temperature readings recorded at sites B₃, F_{2a} and F₄ on the 21-22 March 1978 are tabulated in Appendix 3 along with a summary of the weather conditions. The two days were clear and sunny, conditions ideal for the implementation of the dissolved oxygen diurnal curve to determine gross productivity and respiration. Of the three sites, site B₃ only meets the criterion of steady state because the domestic sewage discharge upsets the equilibrium at the lower two sites. Site F_{2a} was immediately downstream of the Feilding domestic sewage discharge and upstream of the main sewage fungus area. Thus the rate of deoxygenation at this site would be much less than that indicated by the BOD₅ of the water because the heterotrophic bacteria have not had time to become acclimated to the discharge. Figures 29 to 31 show the graphical productivity calculations while Tables 27 to 29 give the finite difference method and Table 30 summarizes

the results that were obtained. This table also includes the in situ hourly oxygen demand as calculated from the total BOD₅ of the waters.

A rate constant of 10.1/day (base 10) was used to determine the in situ oxygen demand at site F₄. This was the deoxygenation constant found on 23 March 1978, the next sampling day. This value converts to 23.25/day when using a natural base.

At site F_{2a} the BOD₅ value used was the average value recorded at site F₁ (Table 17) because as mentioned previously the deoxygenation at this site is more typical of site F₁. The average BOD₅ values for sites B₃ and F₄ (Tables 16 and 17) were used to determine the consumption of oxygen at these sites.

The calculation of the reaeration constants by the dissolved oxygen diurnal curve method is shown in Appendix 3. The reaeration values obtained were equated with the theoretical reaeration equations (equations 2 and 3) using known stream velocities and temperatures to calculate the average stream depth. The depths calculated by this method corresponded with those estimated visually. These depths were then used to determine average productivity, respiration and BOD exertion for each site (Table 31).

Table 31 shows that the two sites assumed to be unaffected by the sewage discharge (B₃ and F_{2a}) had similar average productivity, respiration and BOD exertion. The site 3 km below the discharge (F₄) had a similar average productivity but a much larger average respiration. Inspection of the final column in Table 31 shows that most, if not all the increase in respiration is due solely to the oxidation of organic material introduced by the sewage.

TABLE 27 PRODUCTIVITY DETERMINATION AT SITE B₃ BY THE
FINITE DIFFERENCE METHOD (21-22 MARCH 1978)

where C is the dissolved oxygen

$\frac{DC}{DT}$ is the hourly rate of change in dissolved oxygen

C_S is the saturation dissolved oxygen

P is the gross productivity

R is the gross respiration

K₂ is the reaeration coefficient

TIME	$\frac{DC}{DT}$ g/m ³ g/m ³ /hr	TEMP °C	C _S g/m ³	C g/m ³	C % Sat	K ₂ D kg/m ³ /hr	P-R g/m ³ /hr	P g/m ³ /hr
0000	7.3							
	.15	14.3	10.3	7.4	71.8	0.88	-.73	.04
0002	7.6							
	.20	14.0	10.4	7.7	74.0	0.81	-.61	.16
0004	8.0							
	.40	13.8	10.4	8.4	80.8	0.60	-.20	.57
0006	8.8							
	.55	13.8	10.4	9.3	89.4	0.33	.22	.99
0008	9.9							
	.50	14.0	10.4	10.5	101.0	-0.03	.53	1.30
0010	10.9							
	.25	15.0	10.2	11.3	110.8	-0.34	.59	1.36
0012	11.4							
	-.25	16.9	9.7	11.3	116.5	-0.51	.26	1.03
0014	10.9							
	-.50	18.2	9.5	10.4	109.5	-0.30	-.20	0.57
0016	9.9							
	-.70	18.2	9.5	9.2	96.8	0.10	-.80	0
0018	8.5							
	-.55	17.2	9.7	7.8	80.4	0.61	-1.16	0
0020	7.4							
	-.20	15.9	9.9	7.1	71.7	0.88	-1.08	0
0022	7.0							
	.15	15.0	10.2	7.0	68.6	0.98	-.83	0
0000	7.3							
								6.02

K₂ = 3.11 (g/m³/hr at 0% saturation)
R = (-.73 -.61 -.20 -1.16 - 1.08 -.83) ÷ 6 = 0.77 g/m³/hr
GROSS RESPIRATION = 0.77 × 24 = 18.5 g/m³/day
GROSS PRODUCTIVITY = 6.02 × 2 = 12.04 g/m³/day

FIGURE 29. Determination of Productivity at Site B3

by Graphical Integration.

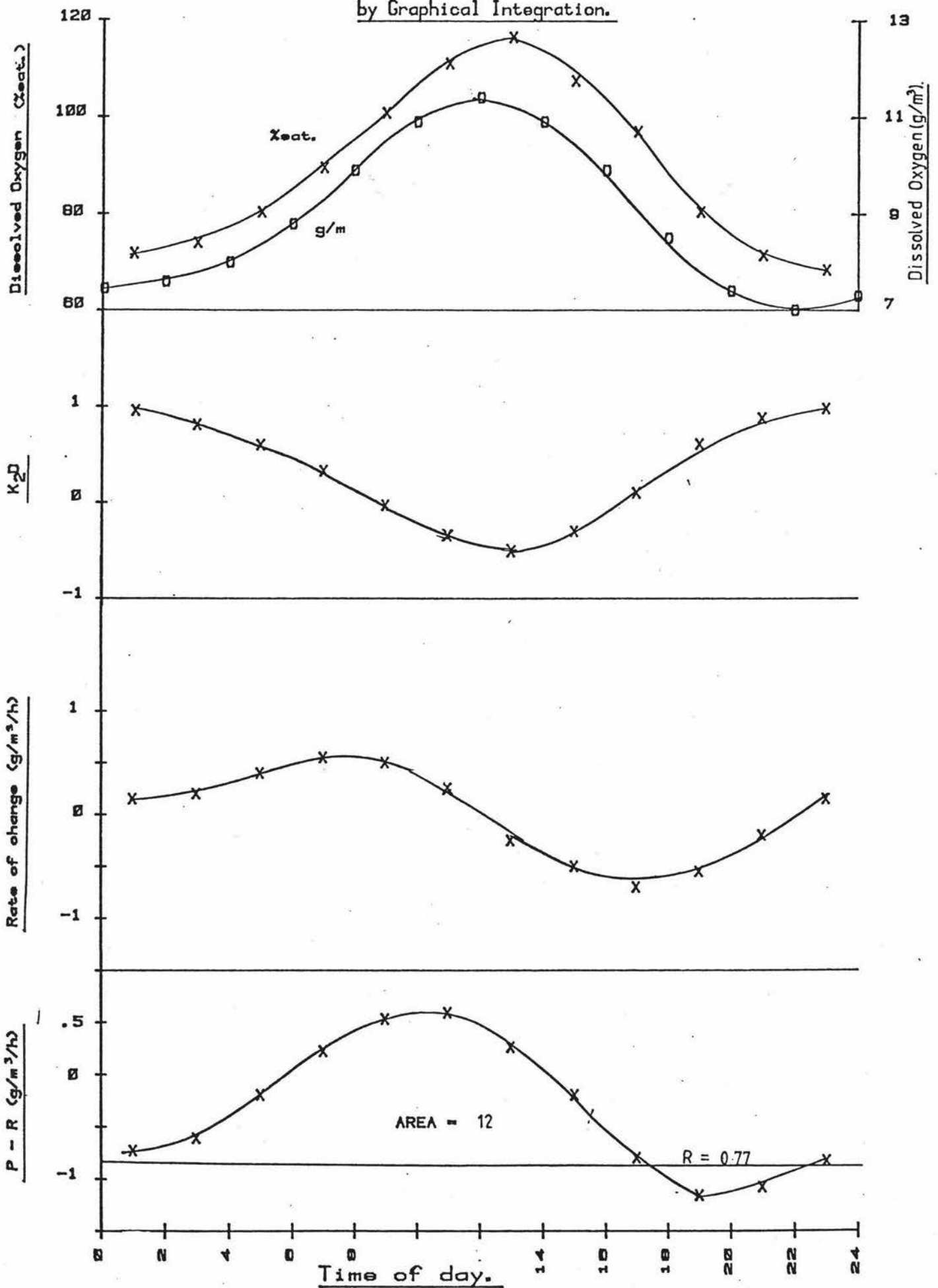


TABLE 28 PRODUCTIVITY DETERMINATION AT SITE F_{2a} BY THE
FINITE DIFFERENCE METHOD (21-22 MARCH 1978)

where C is the dissolved oxygen

$\frac{DC}{DT}$ is the hourly rate of change in dissolved oxygen

C_S is the saturation dissolved oxygen

K₂D is the rate of reaeration

P is the gross productivity

R is the gross respiration

K₂ is the reaeration coefficient

TIME	C	$\frac{DC}{DT}$	TEMP	C _S	C	C	K ₂ D	P-R	P
	g/m ³	g/m ³ /hr	°C	g/m ³	g/m ³	% Sat	g/m ³ /hr	g/m ³ /hr	g/m ³ /hr
0000	6.7								
		.45	14.6	10.3	7.0	68.0	1.22	-.77	.17
0002	7.6								
		.42	14.0	10.4	8.0	76.9	.88	-.46	.48
0004	8.45								
		.43	13.4	10.5	8.9	84.8	.58	-.15	.79
0006	9.3								
		.45	13.2	10.6	9.7	91.5	.32	.13	1.07
0008	10.2								
		.38	14.2	10.4	10.6	101.9	-.07	.45	1.39
0010	10.95								
		.27	16.2	9.9	11.1	121.1	-.81	1.08	2.02
0012	11.5								
		-.05	18.4	9.4	11.6	123.4	-.89	.84	1.78
0014	11.4								
		-.48	19.4	9.3	11.1	119.4	-.74	.26	1.20
0016	10.45								
		-.55	18.9	9.3	9.5	102.2	-.08	-.47	.47
0018	8.35								
		-.77	17.9	9.5	7.5	78.9	.81	-1.58	0
0020	6.80								
		-.20	16.7	9.8	6.5	66.3	1.29	-1.49	0
0022	6.40								
		.15	15.3	10.1	6.5	64.4	1.36	-1.21	0
0000	6.70								
									9.37

K₂ = 3.82 (g/m³/hr at 0% saturation)

R = -(-.77 -.46 -.15 -1.58 -1.49 -1.21) ÷ 6 = .94 g/m³/hr

GROSS RESPIRATION = .94 × 24 = 22.6 g/m³/day

GROSS PRODUCTIVITY = 9.37 × 2 = 19.74 g/m³/day

FIGURE 30. Determination of Productivity at Site F2a

by Graphical Integration.

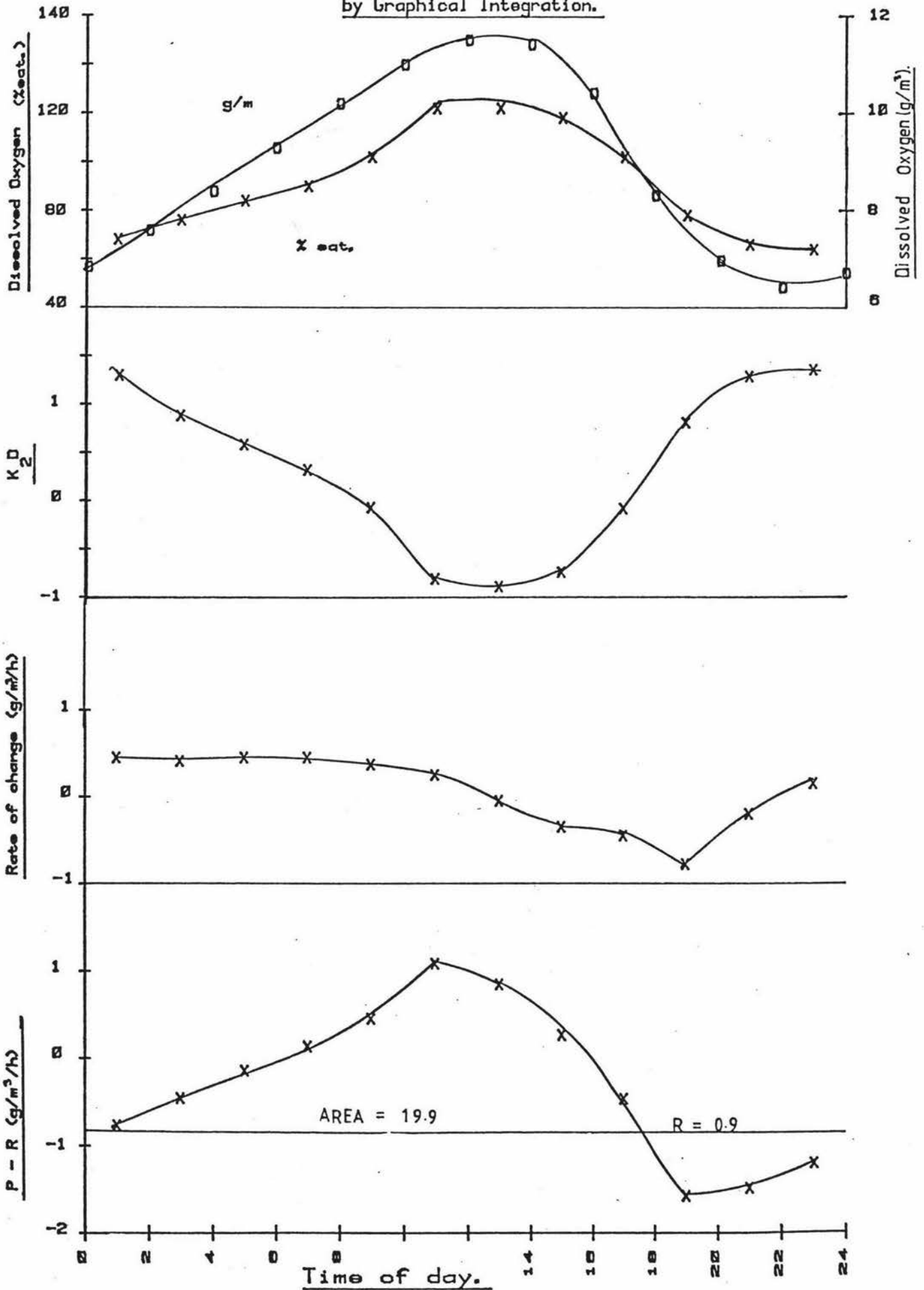


TABLE 29 PRODUCTIVITY DETERMINATION AT SITE F₄ BY THE
FINITE DIFFERENCE METHOD (21-22 MARCH 1978)

where C is the dissolved oxygen

$\frac{DC}{DT}$ is the hourly rate of change in dissolved oxygen

C_S is the saturation dissolved oxygen

K₂D is the rate of reaeration

P is the gross productivity

R is the gross respiration

K₂ is the reaeration coefficient

TIME	C	$\frac{DC}{DT}$	TEMP	C _S	C	C	K ₂ D	P-R	P
	g/m ³	g/m ³ /hr	°C	g/m ³	g/m ³	% Sat	g/m ³ /hr	g/m ³ /hr	g/m ³ /hr
0000	3.0								
		.50	14.6	10.3	3.3	32.0	2.34	-1.84	.19
0002	4.0								
		.56	14.0	10.4	4.4	42.3	1.99	-1.43	.60
0004	5.15								
		.60	13.7	10.5	5.6	53.3	1.61	-1.01	1.02
0006	6.35								
		.55	13.8	10.4	6.8	65.4	1.19	-.64	1.39
0008	7.45								
		.57	14.4	10.3	8.0	77.7	.77	-.20	1.83
0010	8.60								
		.53	16.8	9.7	9.4	96.9	.11	.44	2.77
0012	9.65								
		-.38	19.1	9.3	9.5	102.2	-.08	-.30	1.73
0014	8.90								
		-.80	20.1	9.2	8.2	89.1	.38	-1.18	.85
0016	7.30								
		-1.07	19.3	9.3	6.2	66.7	1.15	-2.22	-
0018	5.15								
		-.80	18.1	9.5	4.2	44.2	1.93	-2.73	-
0020	3.55								
		-.42	16.1	9.7	3.0	30.9	2.38	-2.80	-
0022	2.70								
		.15	15.5	10.0	2.7	27.0	2.52	-2.37	-
0000	3.0								
									10.38

$$K_2 = 3.45 \text{ (g/m}^3\text{/hr at 0\% saturation)}$$

$$R = -(-1.84 -1.43 -1.01 -2.73 -2.80 -2.37) \div 6 = 2.03$$

$$\text{GROSS RESPIRATION} = 2.03 \times 24 = 48.72 \text{ g/m}^3\text{/day}$$

$$\text{GROSS PRODUCTIVITY} = 10.08 \times 2 - 20.16 \text{ g/m}^3\text{/day}$$

FIGURE 31. Determination of Productivity at Site F4

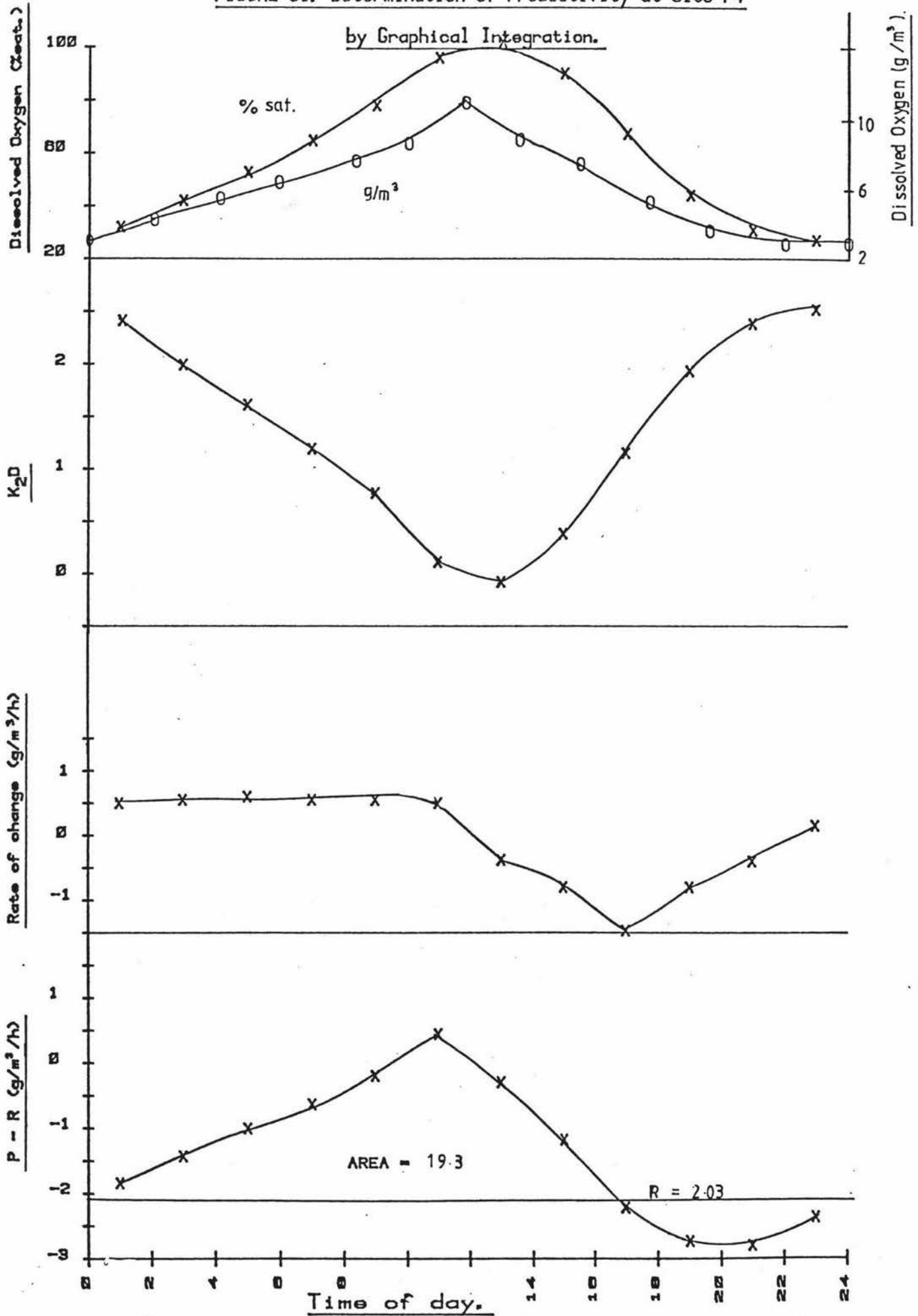


TABLE 30 GROSS PRODUCTIVITY AND RESPIRATION AT SITES IN
THE OROUA RIVER (21-22 MARCH 1978)

SITE	PRODUCTIVITY g/m ³ /day	RESPIRATION g/m ³ /day	Y g/m ³ /day	K g/m ³ /hr	K ₂ hr ⁻¹
B ₃	12.0	18.5	.01	3.1	.34
F ₂	19.9	22.6	.01	3.8	.42
F ₄	20.7	48.7	15.0	3.4	.38

Where Y is daily oxygen removal as indicated by the BOD

K is reaeration rate

TABLE 31 AVERAGE PRODUCTIVITY AND RESPIRATION RESULTS
AT SITES IN THE OROUA RIVER (21-22 MARCH 1978)

SITE	STREAM DEPTH (m)	P/R	K g/m ² /day	PRODUCTIVITY g/m ² /day	RESPIRATION g/m ² /day	Y' g/m ² /day
B ₃	.53	0.65	1.6	6.4	9.8	.01
F ₂	.57	0.87	2.2	11.3	12.9	.01
F ₄	.53	0.40	1.8	11.0	25.8	8.0

Where P/R is the ratio of Productivity to Respiration

K' is the average reaeration rate

Y' is the average deoxygenation by BOD

The ratio of productivity to respiration (P/R) is also given in Table 31. All the values are less than unity indicating heterotrophic conditions in the river and that the benthic algae is a liability in terms of the stream dissolved oxygen balance.

The diurnal dissolved oxygen data obtained during this study showed that at site F₄ the dissolved oxygen concentration in the river dropped to 3 g/m³ and less at night. These values are indicative of a polluted river and would stress any fauna living in the stream. The low dissolved oxygen levels are

a consequence of both respiration by algae and microbial oxidation of organic material as measured by total BOD_5 .

5.7

Biological Results

5.7.1

Qualitative description of the biota

A summary of the monthly biotic results is given in Appendix 4 while Table 33 is a checklist of all the macroinvertebrates identified in the Oroua River. Deleatidium was the dominant macroinvertebrate in the study area above the Feilding domestic sewage discharge. This genus was present on all sampling days and reached highest densities in the later months (February and March). Other Ephemeroptera, Nesameletus and Zephlebia, were rare and were recorded only in the later months. Only one plecopteran, Aucklandobius, was found in the Oroua River and its presence was only noted in November. Trichopterans living in the Oroua River above the domestic sewage discharge included the families Hydropsychidae, Polycentropodidae and Sericostomatidae. Numbers of trichopterans increased in the later months especially Hydropsychidae which abounded amongst the algae. Chironomidae and Simuliidae were the most important dipterans in the Oroua River and their numbers remained relatively constant throughout the sampling period. The coleopteran, Elmidae, was another important macroinvertebrate in the river and both larval and adult stages were represented.

The density of macroinvertebrates in the river was highest in February and March. This was due to a great increase in the number of Deleatidium while other macroinvertebrate numbers stayed the same.

The Borthwick's effluent did not affect the composition or density of the biotic samples. This was well illustrated by the presence of Aucklandobius below the Borthwick's discharge. Aucklandobius, a plecopteran, is an insect which is very susceptible to pollution. The Feilding domestic sewage greatly reduced the macroinvertebrate numbers. During moderate flows

TABLE 32 A CHECKLIST OF MACROINVERTEBRATES OBSERVED IN
THE OROUA RIVER (NOVEMBER 1977 - MARCH 1978)

Class	Order	Family	Genus/species
Insecta	<u>Plecoptera</u>	<u>Gripopterygidae</u>	<u>Aucklandobius</u>
	<u>Ephemeroptera</u>	<u>Leptophlebiidae</u>	<u>Deleatidium</u> <u>Zephlebia</u>
		<u>Siphonuridae</u>	<u>Nesameletus</u>
		<u>Trichoptera</u>	<u>Hydropsychidae</u>
		<u>Hydroptilidae</u>	-
		<u>Polycentropodidae</u>	-
		<u>Rhyacophilidae</u>	-
		<u>Sericostimatidae</u>	-
	<u>Coleoptera</u>	<u>Elmidae</u>	-
	<u>Diptera</u>	<u>Tipulidae</u>	-
		<u>Culicidae</u>	-
		<u>Tabanidae</u>	-
		<u>Chironomidae</u>	-
		<u>Simuliidae</u>	-
		<u>Muscidae</u>	-
<u>Hemiptera</u>		<u>Sigara arguta</u>	
Crustacea	<u>Decapoda</u>		<u>Paratya curvirostis</u>
	<u>Amphipoda</u>	<u>Eusiridae</u>	<u>Paracallope fluviatilis</u>
Gastropoda	<u>Pulmonata</u>		<u>Physca</u>
	<u>Prosobranchia</u>		<u>Potamypyrqus</u>

Deleatidium and Trichoptera were the only clean water groups present while in low flows all clean water species were eliminated. In February and March site F₂ was found to be completely devoid of biotic life while site F₄ only supported red chironomids and other dipterans typical of grossly polluted waters (Appendix 4).

5.7.2

Benthic macroinvertebrate diversity

The distribution of individuals and species at each site was found to follow the logarithmic series and these distributions are given in Figures 32-36. The slopes of these distributions indicate the species diversities (LDI). The diversity index based on the logarithmic series (LDI) was calculated from the nomograph of Williams (1964) which is reproduced in Appendix 1. Table 33 gives the diversity indexes (LDI) for the five month combined macroinvertebrate data (November-March) at each site as well as the individual monthly diversity. Generally the combined LDI was greater than the monthly LDI. This implies that the species present in the samples change during the study period. Thus although the ratio of number of species to total number

TABLE 33 LOGARITHMIC SERIES DIVERSITY INDICES FOR
MACROINVERTEBRATES OF THE OROUA RIVER

LDI	B ₁	B ₃	F ₁	F ₂	F ₄
Combined	2.5	3.5	3.4	4.4	4.4
November, 1977	2.4	2.9	2.0	1.0	3.7
December, 1977	-	-	2.4	1.5	2.0
January, 1978	2.3	2.8	2.3	2.0	-
February, 1978	1.5	1.4	2.1	1.0	1.4
March, 1978	1.9	2.8	3.0	0.6	1.2

of individuals in a monthly sample may be small this may be increased when the data is pooled and more species are introduced. This is particularly important at the sites below the Feilding domestic sewage discharge which changed from mildly polluted to grossly polluted waters during the study period and thus a corresponding change in macroinvertebrate type also occurred.

FIGURE 32. Logarithmic Series Distribution of Macroinvertebrates at Site B1.

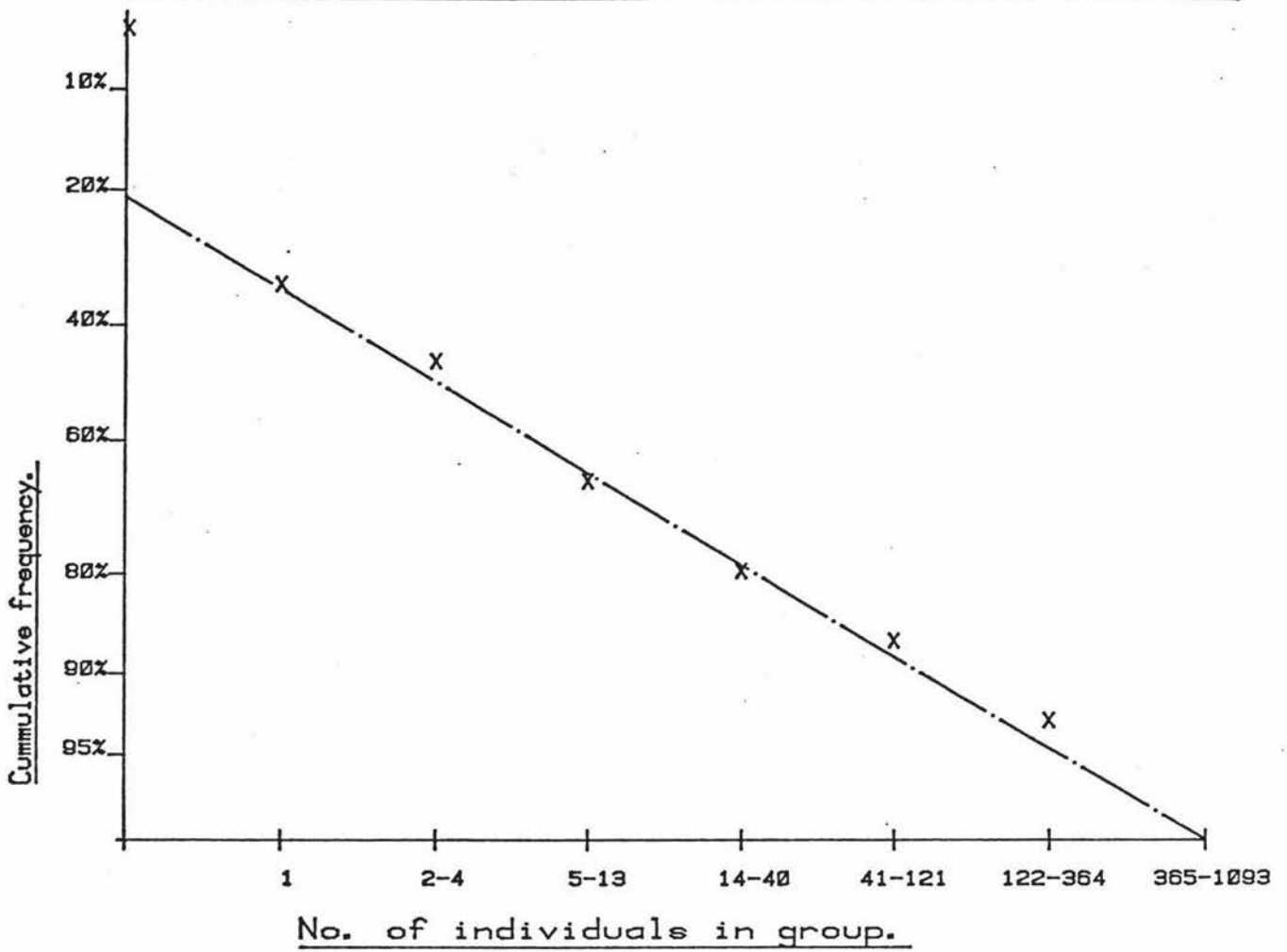


FIGURE 33. Logarithmic Series Distribution of Macroinvertebrates at Site B3.

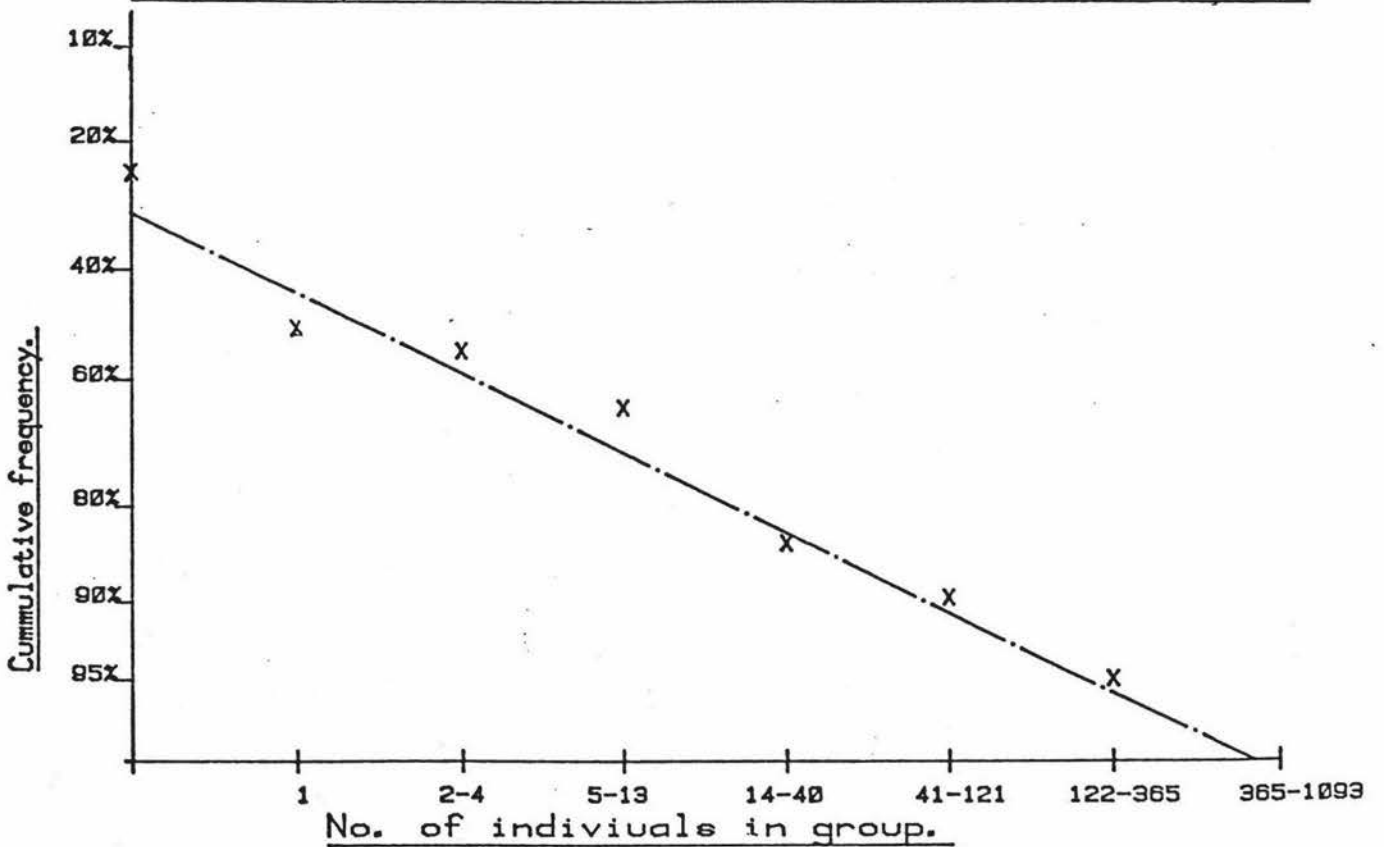


FIGURE 34. Logarithmic Series Distribution of Macroinvertebrates at Site F1.

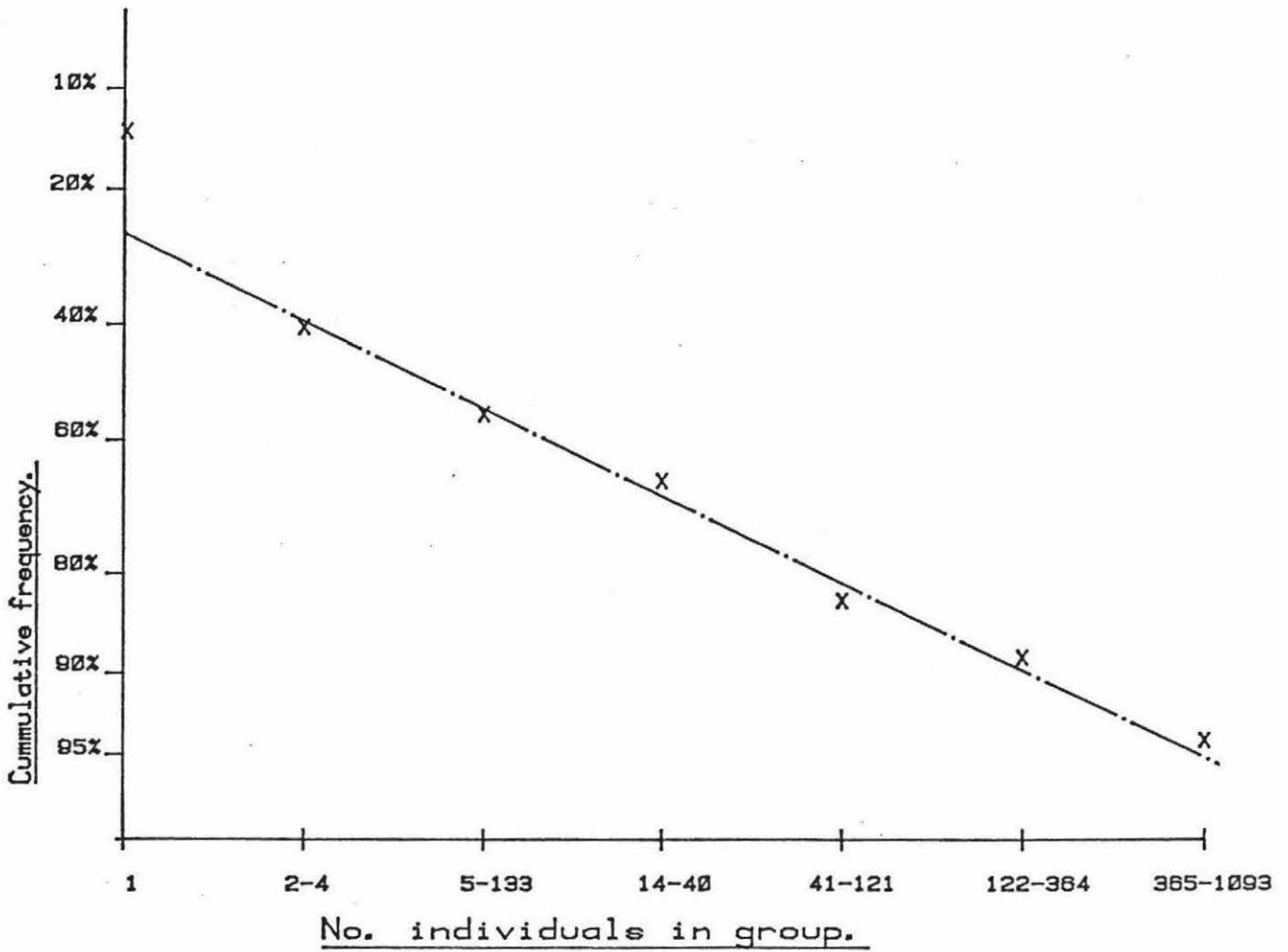


FIGURE 35. Logarithmic Series Distribution of Macroinvertebrates at Site F2.

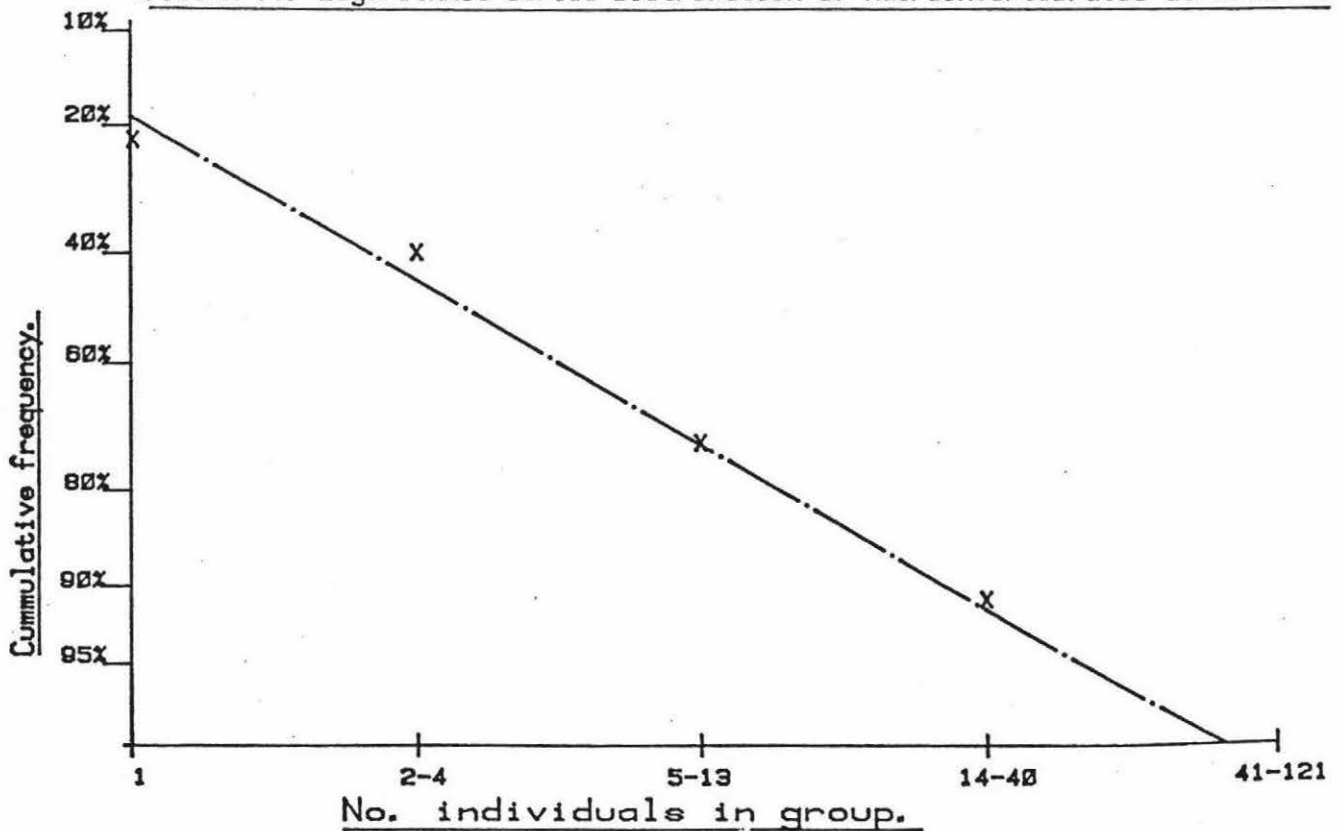
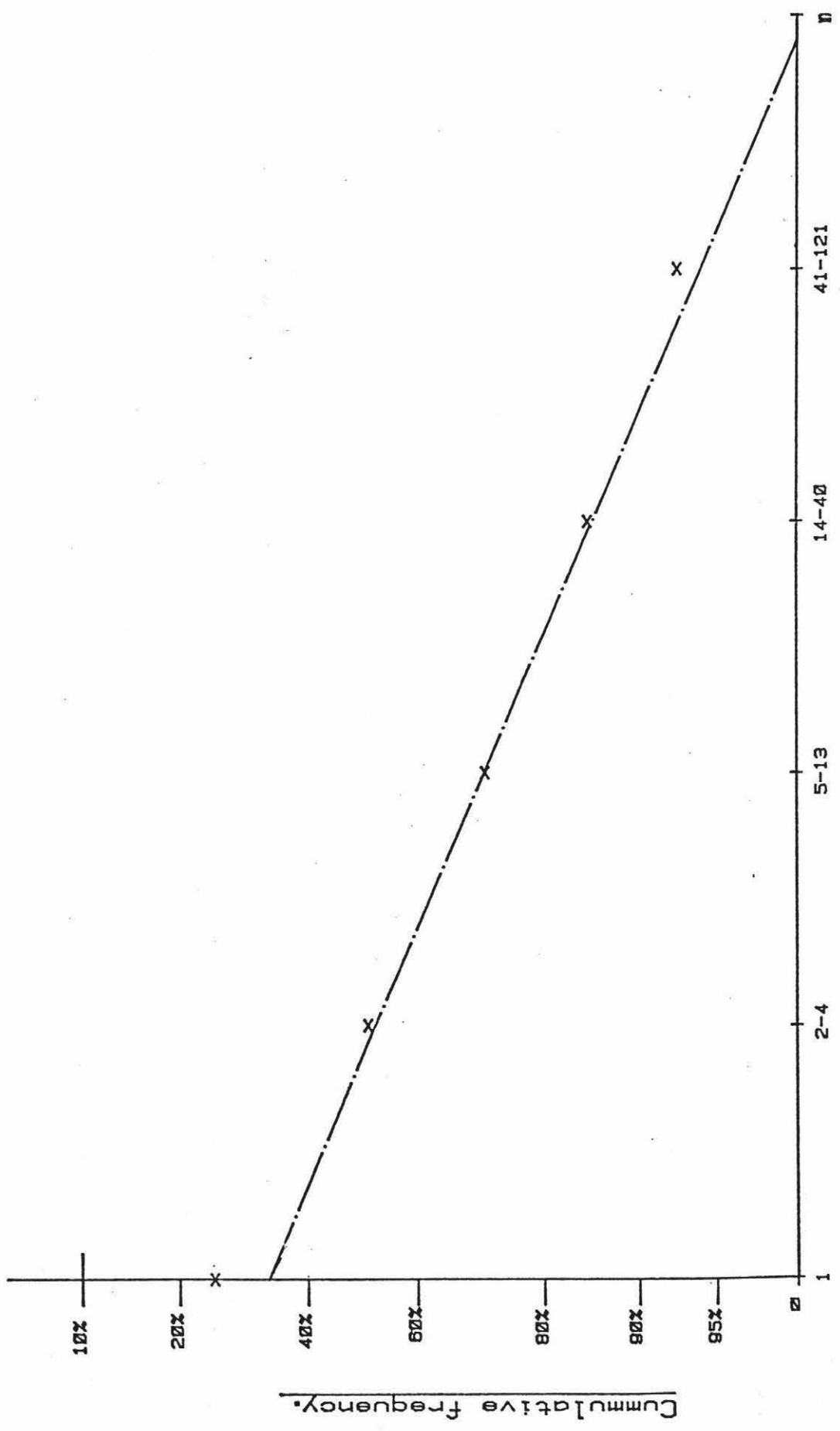


FIGURE 36. Logarithmic Series Distribution of Macroinvertebrates at Site F4.



No. of individuals in group.

All the diversity indices are compared in Table 34 which also includes the redundancy expression (r) derived from information theory. This indicates the dominance of one or more species. Good correlation (99.9% significance) existed between all the diversity indices indicating that all describe the situation to a similar extent.

The LDI diversity index was found to be the most easily applied index. This was because only the total number of macroinvertebrates and the number of different groups needed to be determined. This data was then readily converted to a diversity index by use of a nomograph. Figure 37 shows that the LDI diversity index was the only diversity index to correspond to the physicochemical and chemical results in March. Both the SCI and IDI diversity indices indicated that site F_2 was more diverse than site F_4 in March 1978. The LDI diversity index, however, showed F_4 to be more diverse than F_2 which thus corresponds to the physicochemical and chemical results. Before the LDI index can be applied, however, the macroinvertebrate distribution must be shown to fit the logarithmic series. The Biotic Index also corresponded well with the physicochemical and chemical results. The Biotic Index was particularly useful when very small samples were encountered or when a preponderance of one species developed. This occurred in February and March when a large Deleatidium population developed. This resulted in a marked decrease in the diversity indices although the composition of the other species had altered little. The Biotic Index, however, was not altered.

The diversity results showed that the Borthwick's effluent did not affect the macroinvertebrate community. In most cases the diversity downstream of the discharge was higher than the upstream diversity (Figure 37) and this was attributed to the action of shingle works causing an unstable riverbed at the upper site.

FIGURE 37. Changes in Diversity Indices along the Oroua River.

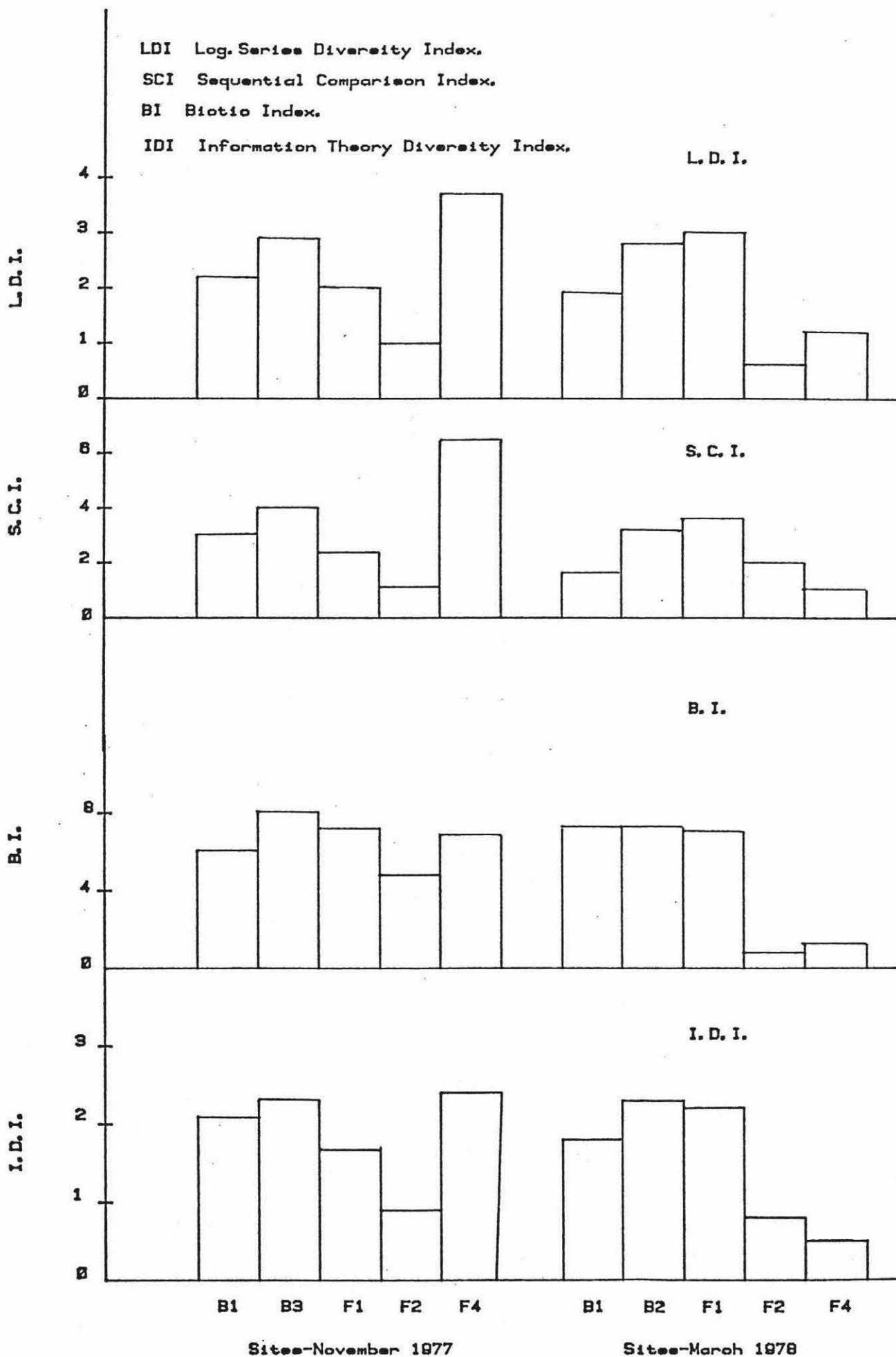


TABLE 34 COMPARISON OF DIVERSITY INDICES FOR
MACROINVERTEBRATES OF THE OROUA RIVER
(NOVEMBER 1977 - MARCH 1978)

MONTH	SITE	BI	LDI	SCI	IDI	R
November	B ₁	6	2.4	3.0	2.1	.35
	B ₃	8	2.9	3.9	2.3	.35
	F ₁	7	2.0	2.3	1.7	.47
	F ₂	5	1.0	1.1	0.9	.44
	F ₄	7	3.7	6.5	2.4	.18
December	F ₁	6	2.4	3.4	1.9	.39
	F ₂	5	1.5	2.0	1.6	.08
	F ₄	6	2.0	2.8	1.8	.28
January	B ₁	7	2.3	3.1	2.4	.29
	B ₃	8	2.8	3.1	2.5	.32
	F ₁	7	2.3	2.2	2.4	.31
	F ₂	3	2.0	3.1	1.5	.42
February	B ₁	7	1.5	1.2	1.8	.41
	B ₃	7	1.4	0.7	0.9	.70
	F ₁	7	2.1	1.5	2.2	.36
	F ₂	0	1.0	1.0	0	-
	F ₄	2	1.4	2.0	1.9	.13
March	B ₁	7	1.9	1.7	1.8	.44
	B ₃	8	2.8	3.2	2.3	.41
	F ₁	7	3.0	3.7	2.2	.41
	F ₂	1	0.6	2.1	0.8	1.0
	F ₄	2	1.2	1.0	0.5	1.0

LDI = Diversity index based on Logarithmic series
SCI = Sequential Comparison Index
IDI = Diversity index based on information theory
BI = Biotic Index
R = Redundancy expression

In contrast, the Feilding domestic sewage caused a major change in the stream biota especially in periods of low flow. In the earlier months the biotic composition had almost completely recovered by 3 kilometers below the discharge (i.e. by site F₄) where - as during low flow this site still had a diversity typical of a grossly polluted site (Figure 37).

6.

DISCUSSION

6.1

Background Water Quality and River Temperature

The concentrations of most of the measured components at site B₁ (the site above both the Borthwick's meatwork's discharge and the Feilding domestic sewage discharge) in the Oroua River are comparable to those measured in other New Zealand rivers (Scott, 1973; Gibbs and Penny, 1973; Davies and Shirley, 1976; Currie, 1977; Winterbourne *et al.*, 1971; Elam, 1971; Allen, 1951). The nitrate nitrogen and suspended solids concentrations were, however, slightly higher than has been measured in these other rivers. This may be because the Upper Oroua River catchment is very prone to erosion (Heerdegen, 1972). The suspended solids concentration is still comparably low and thus should not have an adverse effect on the aquatic biota (Hynes, 1963).

The BOD concentrations in the Oroua River at site B₁ corresponds to very clean water in the Royal Commission of Sewage Disposal 1915 classification (Holden, 1970). The COD and kjeldahl nitrogen concentrations are also low.

The dissolved oxygen concentration and pH of the Oroua River at site B₁ were uniformly high. The dissolved oxygen concentrations were higher than have been recorded previously (Pol. Adv. Council, 1957). This could be because the extreme drought conditions, which prevailed for most of the study period, promoted more algal growth and hence more oxygen production during daylight hours.

The average faecal coliform density measured at site B₁ was only slightly above the standard for bathing waters (Schedule to the New Zealand Water and Soil Conservation Act, 1967). The presumptive coliform densities were also low. These concentrations of presumptive and faecal coliforms were very similar to concentrations measured in 1956-1957 (Pol. Adv. Council, 1957) and

thus it appears that the microbiological quality has changed little since then.

The background quality of the Oroua River is thus typical of clean waters and has probably altered little in the last 20 years. This water should thus support an ecosystem that is typical of clean waters.

The average mid-morning temperatures in the Oroua River fitted a sinusoidal expression similar to that found by Walker and Lawson (1977) for mean monthly temperatures. This thus provides a water management tool. The highest water temperatures in the Oroua River occurred between 2 and 4.00 p.m. (New Zealand standard time) which is similar to the times of maximum temperature recorded in the Hinau Stream (Hopkins, 1971). As found in the Hinau Stream (Hopkins, 1971) the temperature in the Oroua River increased with downstream flow during daytime, while at night-time the temperature remained constant along the stream length.

In the present work the average composition of the Borthwick's effluent has been determined (see summary in Table 22) and it was found to consist of much lower concentrations of organic material than non treated meat wastes (Loehr, 1977; Nemerow, 1953; Hicks, 1959; see Table 5). The Borthwick's effluent quality was consistent to that of a biologically treated waste (Painter, 1971; see Table 6).

The average total BOD_5 and suspended solids concentrations measured in the influent during the study period were 1245 g/m^3 and 1618 g/m^3 respectively (Birch, pers. com). The average reduction of BOD_5 in the treatment system calculated from the mean influent value given above and the mean effluent concentration given in Table 22 is 98% while reduction of suspended solids is 97%. Comparison of the 1977-1978 influent data (Birch, pers. com.) and the 1956-1957 composition of screened Borthwick's wastes (Pol. Adv. Council, 1957) showed that the concentration of untreated Borthwick's wastes have increased by approximately 80 percent since 1957.

Cooke (1977) sampled the Longburn meatwork's effluent (see Table 3). This effluent was treated by primary sedimentation only and thus Cookes data may be compared with the present day Borthwick's effluent quality to show the effect of secondary treatment over and above that of primary treatment in two New Zealand meatwork's wastes. The secondary treatment of Borthwick's wastes decreased the BOD_5 by 96%, suspended solids by 75%, COD by 69% and faecal coliforms by 97% as compared to the primary treated Longburn meatwork's wastes. The ratio of COD:BOD was much higher in the Borthwick's meatwork's wastes than in the Longburn meatwork's wastes (10.8:1 and 1.3:1 respectively) which well illustrates the superior quality of Borthwick's effluent (A.P.H.A., 1971).

Further comparison of the Longburn (Cooke, 1977) and present Borthwick's data shows that nitrate concentration in both effluents are low while kjeldahl nitrogen and total phosphorus concentrations were of similar magnitude in both discharges. Borthwick's effluent had a higher orthophosphate:total phosphate ratio than the Longburn effluent because organic matter is converted to inorganic nutrients during secondary treatment (Painter, 1971). The total phosphorus concentrations are comparable in the two effluents because phosphorus is a conservative parameter (Thomann, 1972). Thus both effluents lost phosphorus during the sedimentation stage only. Comparable kjeldahl nitrogen in both effluents occur for similar reasons. Kjeldahl nitrogen consists of both organic nitrogen and ammoniacal nitrogen (A.P.H.A., 1975). During secondary waste treatment ammonia is formed from the deamination of organic matter and may be oxidized first to nitrite and then to nitrate (A.P.H.A., 1975). The low nitrate concentration in Borthwick's effluent indicates that little oxidation of ammonia has occurred and thus the majority of nitrogen is in the organic or ammoniacal form. Because of the high solubility of ammonia in water, the total nitrogen concentration in an effluent is considered conservative (Thomann, 1972). Thus during treatment of the Borthwick's and Longburn meatworks' effluents kjeldahl nitrogen concentrations are decreased mainly through sedimentation. The kjeldahl nitrogen concentration of Borthwick's effluent may be further reduced by release of ammonia to the atmosphere or by the oxidation to nitrate but these are probably minimal.

The effect that the Borthwick's effluent had on the Oroua River was found to be minimal and related only to the inorganic concentrations in the discharge. Sites below the discharge (B_2 - B_4 and F_1) all had BOD_5 values of very clean waters (Holden, 1970) and the only parameters notably affected by the discharge were the COD, kjeldahl nitrogen and orthophosphate concentrations. Bacteria numbers were also probably increased although the large standard deviation in the results meant that this increase was not

statistically significant.

In summary, the Borthwick's meatwork's discharge is of the high quality typical of biologically treated wastes (Painter, 1971). Most of the organic matter has been to inorganic nutrients and the faecal coliform content has been decreased by over 97 percent. As expected, this effluent had little effect on the quality of water in the Oroua River and the dissolved oxygen concentrations at sites below the discharge had increased considerably since 1957 while present day microbiological numbers were much lower than those previously recorded (Pol. Adv. Council, 1957, see Table 12).

6.3

Feilding Domestic Sewage

The concentration of components in the treated Feilding domestic sewage depended upon whether or not concentrated trade wastes were present. This is because the two major trade wastes, the Kawa Woolscour and the Feilding abattoir, do no pretreatment of their wastes. Wastes from the woolscour entered the treatment plant 24 hours a day, seven days a week during the study period. The waste flow varied over a wide range, and the maximum concentrations of total BOD₅ and suspended solids were approximately 5 times the minimum concentrations (Blakelock, pers. com.). Wastes from the Feilding abattoir entered the treatment plant between 7.00 a.m. and 3.00-4.00 p.m., 5 days a week during the study period. The flow rate and concentration of total BOD₅ and suspended solids were also highly variable in this effluent (Blakelock, pers. com.).

Comparison of the Feilding sewage treatment plant influent data (Blakelock pers. com.) with the effluent concentrations determined in the present study indicates that the total BOD₅ and suspended solids concentration are reduced by 32 and 46 percent respectively. These are extremely low reductions (McKinney, 1962) and data on the influent and effluent of the sewage treatment plant during a period when both the Kawa Woolscour and Feilding abattoir were closed down indicates that these low reductions occur primarily because of the trade wastes (Blakelock, pers. com.). The effluent flowing from the Feilding domestic sewage treatment plant thus bears no resemblance to biologically treated sewage (Painter, 1971; see Table 6) nor does it compare with Palmerston North's primary treated sewage (Cook, 1977, see Table 3). It corresponds best to a medium or strong raw sewage (Babbitt, 1947; Painter, 1971; see Table 2).

It must be noted that as the sampling of the effluent was conducted at the same daily time every fortnight, the average sample composition does not represent the average effluent composition. Visual observation of the rivers appearance suggested that the sewage was near its maximum concentration when the samples were collected. The average sample composition thus represents the average maximum sewage concentration which is a better river management figure.

Painter (1971) found that most of the organic material in domestic sewage was contained in the insoluble fraction. Significant correlations between the suspended solids concentrations and the total BOD₅, COD and carbohydrate concentrations suggests that this is also the case in the Feilding domestic sewage.

Proteins were found to constitute 90 percent (W/W) of the organic matter in the Feilding domestic sewage. This is an extremely high value, Hunter and Heukelekian (1965) found that amino acids accounted for only 19% of the total organic matter in sewages. The high protein content of meat wastes from the local abattoirs may have increased the protein concentrations (Loehr, 1977).

With the very high organic concentrations in the Feilding domestic sewage it is not surprising that it has a major effect on the Oroua River water quality. The average total BOD₅ at the first 2 sites downstream of the discharge (F₂ and F₃) indicated badly polluted river conditions while the last 2 sites (F₄ and F₅) had a total BOD₅ indicative of rivers of doubtful purity (Holden, 1970). The faecal coliform content at all sites monitored below the Feilding domestic sewage discharge were many times the densities specified for bathing waters in the New Zealand Water and Soil Conservation Act, 1967.

The Feilding domestic sewage was thus of very poor quality and this was primarily because of the discharge of very variable trade wastes to the treatment plant. This effluent hence produces an adverse effect on the water quality in the Oroua River which will thus affect the stream biota (Hynes, 1963).

6.4 Interactions In The Oroua River

6.4.1 Organic self purification

First order decay kinetics described the decline of organic material in the Oroua River after the Feilding domestic sewage discharge reasonably well and deviations from first order kinetics were attributed to river phenomena. Monod kinetics (Gates and Marljar, 1968; Gates et al., 1969; Rutherford and O'Sullivan, 1974) did not describe the decline in organic concentrations. The deoxygenation coefficients for the total BOD₅ decrease in the Oroua River were much higher than those specified as typical of shallow streams (Velz, 1970) but higher values have been recorded (Eckenfelder, 1970).

The high rate of organic decay is believed to be the result of accumulation of debris, sewage fungus and algae at riffle areas. This accumulation of matter provides shelter for a large population of heterotrophic organisms thus promoting rapid oxidation of organic material, a situation analogous to one postulated by Kittrell and Furfari (1963) to explain high microbial death rates in shallow streams. This can also explain the main deviation from first order kinetics. A high initial rate of decline occurs because the dense mat of sewage fungus immediately below the sewage discharge has a higher density of heterotrophic organisms than other parts of the river where there is no sewage fungus.

A high initial rate in the decline of total BOD₅ has been attributed to sedimentation of the suspended solids (Eckenfelder, 1970) but high velocities in the Oroua River means that in this river, sedimentation of suspended solids is negligible (Velz, 1970).

The in situ rate of decline of COD in the Oroua River below the Feilding domestic sewage discharge was also determined. The rate constants for COD decline were lower than the deoxygenation coefficients and no correlation existed between them. The low COD rate constants may result because COD includes recalcitrant components, such as cellulose, that are not readily oxidized biologically (A.P.H.A., 1975).

The rates of total BOD₅ and COD decline in the Oroua River were extremely variable and these variations did not correlate with any measured stream parameter. Probably the main factor influencing these variations was the amount of riffle areas and density of benthic growth on the riffles.

6.4.2 Nutrients in the Oroua River

Owens and Wood (1968) and Smith (1977) showed that land run-off was the most important source of nitrate in the waters they studied. Data on the nitrate concentration and flow at the uppermost site studied in the Oroua River (site B₁) indicates that land run-off is the most important nitrate source in reaches above effluent discharges. A gradual increase in nitrate concentration at sites below the Borthwick's meatwork's discharge and a lack of correlation between nitrate concentration and flow at these sites suggests that there is another important non-point source of nitrate. The Borthwick's effluent was estimated to have high ammonia concentrations. Oxidation of ammonia by Nitrosomonas and Nitrobacter in the river results in the production of nitrate (Klein, 1962) and thus this could provide a non point source of nitrate, originating from the ammonia in the Borthwick's discharge.

The orthophosphate concentrations in the Oroua River was influenced more by the point discharges of the Borthwick's effluent and the Feilding domestic sewage than non-point sources. Smith (1977) and Owens and Wood (1968) have

also found that phosphate in rivers originates from discharges rather than from land run-off or other non-point sources.

Jaworski (1969) modelled the decline of orthophosphate concentrations by first order kinetics. The orthophosphate concentration decrease in the Oroua River did not conform to first order kinetics possibly because of the many shallow algal covered riffles in the river.

6.4.3 Microbiological self purification

The rate of microbiological decline in the Oroua River conformed to the first order model first proposed by Chick (quoted by Velz, 1970). The actual bacterial death rate constants were more than 10 times those values given by Velz (1970) for medium sized rivers. Kittrell and Furfari (1963) found that in the shallow streams they studied 1.7 percent of the initial bacterial density remained after 24 hours flow time. The rate of bacterial decrease in the Oroua River was much greater than this and it took only 2.7 and 3.7 hours to get the same 98.3 percent reduction in the initial densities of saccharolytic and lipolytic bacteria respectively. Kittrell and Furfari (1963) postulated a trickling filter analogy to explain the high death rates occurring in the streams that they studied. This analogy was further considered by Wuhrmann (1972) who cited streams in which the initial density of bacteria was reduced to 10 percent in 2 hours flow time. This compares well with the Oroua River where flow times of 1.5 to 2.1 hours were recorded for a 90 percent decrease in initial bacteria numbers.

Studies on the Oroua River show that different bacterial groups die at different rates. This difference between death rates may be an important factor when faecal coliforms are used to model the interactions of human pathogens (Geldreich, 1972).

Unlike the rivers considered by Velz (1970), Kittrell and Furfari (1963) and Wuhrmann (1972) the microbiological decline in the Oroua River showed no lag phase prior to the logarithmic decline. This could have been because immediately after the sewage discharge the river flowed over a riffle completely covered in sewage fungus. The high number of bacterial predators presumed present within the sewage fungus would thus provide a rapid decline in bacteria numbers.

Velz (1970) found no correlation between the water temperature and the bacterial death rate constants and this was also illustrated in the Oroua River.

Absorption of bacteria to suspended particles in the river and the subsequent sedimentation of these particles is an important factor in microbiological self purification (Mitchell, 1968). In the Oroua River high velocities meant that such sedimentation was negligible (Velz, 1970) and thus it was not surprising that no correlations were found between the suspended solids decrease and the rate of bacterial decline.

The results of this study did not support the Kittrell and Furfari (1963) findings that the rate of bacterial decline varied with the initial concentration of the bacteria, nor did it support the theory that high concentrations of organics aided the self purification process (Wuhrmann, 1972).

Other environmental factors that were found not to affect the bacterial decline rates in the river were the stream flow and stream velocity.

It thus appears that biological factors are the most important influences on microbiological self purification in the Oroua River. Predation is probably

the most important. Predator action is aided by the many shallow riffles which were covered by either algae or sewage fungus (Kittrell and Furfari, 1963).

6.5

Algae In The Oroua River

The Oroua River was found to contain sufficient nitrate and orthophosphate to support dense populations of benthic algae. Many laucustrine studies (Hart, 1974; Schindler, 1977) have found that phosphate or nitrate concentrations limit the growth of algae. Neither the phosphate concentration nor nitrate concentration ranges present at sites in the Oroua River limited the growth of the benthic algae. However, stream velocity was found to influence algal development. At high stream velocities little algae developed while during low stream velocities dense algal populations occurred.

The benthic algae was found to be a liability to the stream in terms of oxygen demand. This has also been found by O'Connell and Thomas (1965). At unpolluted sites the effects of this liability was minimal and only a small night time dissolved oxygen concentration drop was recorded. At organically enriched sites the algal respiration and the oxygen demand resulting from the degradation of organic material resulted in a large night time drop in dissolved oxygen.

The average productivity measured at sites in the Oroua River ranged from 6-11 $\text{g/m}^2/\text{day}$ while the average respiration was 10-13 $\text{g/m}^2/\text{day}$ at non-polluted sites and 26 $\text{g/m}^2/\text{day}$ at the organically enriched site (F_4). These are typical productivity and respiration values (Odum, 1960) and are comparable to values found in rivers in other countries (O'Connell and Thomas, 1965; O'Connor and Di Toro, 1970; Edwards and Owens, 1962; Simonsen and Harremoës, 1978: see Table 8). The reaeration rates measured by the dissolved oxygen diurnal curve method (Odum, 1956) compared well with that calculated from theory (Owens, et al., 1964) and the values obtained are similar to those occurring in other shallow rivers (Odum, 1960).

The ratio of productivity to respiration (P:R) illustrates the streams trophic status (Cole, 1975). Non-polluted sites in the Oroua River had a P:R ratio slightly less than unity which indicates that these waters are slightly heterotrophic. The P:R ratio at the polluted site (F_4) was much less than unity and this indicates that heterotrophic, oxygen removing activities predominate (Cole, 1975). The productivity and respiration results thus show site F_4 to be more polluted than site B_3 (Hornberger *et al.*, 1977).

It is of interest to compare the Oroua River results with those obtained for the Truckee River (O'Connell and Thomas, 1965). Both rivers are shallow with similar background nitrate and phosphate concentrations, both received wastes from trickling filters and their nutrient concentrations downstream of the discharges were comparable. Large colonies of benthic algae developed in both streams. The productivity of both streams were similar but the Oroua River had a much higher average respiration. This was because oxygen removal through BOD exertion was ten times faster in the Oroua River than in the Truckee River ($0.56 \text{ g/m}^2/\text{hr}$ compared to $0.05 \text{ g/m}^2/\text{hr}$). A further comparison may be made with the River Havelse, Denmark, which is also a shallow stream receiving biologically treated wastes. The summer time productivity rates of the two streams compared well while again the respiration was greatest in the Oroua River.

The macroinvertebrate composition in the clean areas of the Oroua River was typical of that in other shingle bottomed New Zealand rivers (Allen, 1951; Stout, 1970, 1973 and 1975; McLay, 1968; Cadwaller, 1975; Winterbourne, 1974; Hopkins, 1965). The species present and the density of macroinvertebrates in the Oroua River at the site upstream of Borthwick's discharge have changed little in 21 years (Pol. Adv. Council, 1957; see Table 13) while sites B₃ and F₁ below the Borthwick's discharge have shown a vast increase in the numbers of clean water species since 1957. The 1977-1978 composition of macroinvertebrates at site F₂, downstream of the domestic sewage discharge illustrates a worse river condition than in 1956-1957 (Pol. Adv. Council, 1957). It thus appears that while treatment of Borthwick's wastes has improved the water quality in the upper reaches of the study area, the discharge of treated domestic sewage and trade wastes at Boness Road has lowered the water quality in the lower reaches.

Densities of macroinvertebrates in the Oroua River above the Feilding domestic sewage discharge measured in the present study varied between 352 and 2219 macroinvertebrates/m² and this is typical of other New Zealand rivers (Allen, 1951).

Of the diversity indices considered, the index based on the logarithmic series (Williams, 1953 and 1964) was found to correspond best with the physicochemical and chemical results (see Figure 37). Once the distribution of macroinvertebrates on the riffle areas was shown to fit the logarithmic series (see Figures 32-36) the diversity index could be obtained from the total number of individuals, the number of different species and the use of a nomograph (Williams, 1964; see Appendix 1). The diversity index based on information theory (Wilhm and Dorris, 1966) and the Sequential Comparison

Index (Cairns et al., 1968; Cairns and Dickson, 1971) deviated from the known water quality when gross pollution caused small sample size or when abnormally high populations of Deleatidium developed (see Figure 37). Mason (1977) has also found that when a preponderance of one specie develops and the community structure of other macroinvertebrates remains unchanged, there is a lowering in the value of the diversity index based on information theory, while Wilhm and Dorris (1968) prescribe caution when using small sample sizes.

The conformation of the macroinvertebrate community structure to a logarithmic series distribution implies that the stream macroinvertebrates occur in clumps that are distributed randomly throughout the riffle area (Hairston, 1959). Such clumping may occur through the laying of eggs at one site or through preferential site selection by the nymph or larvae (Elliott, 1977).

The Trent Biotic Index (Woodiwiss, 1964) was also applied to macroinvertebrate data gathered in the Oroua River. Gaufin and Tarzwell (1952) state that the life cycles and ecology of the macroinvertebrates must be considered when applying biotic indices. This was well illustrated in the Oroua River by the plecopteran, Aucklandobius. This macroinvertebrate exists only in very clean waters (Stout, 1975) and were identified in the Oroua River upstream of the Feilding domestic sewage discharge only in November 1977. This was not because of lower water quality in later months but because the adult Aucklandobius emerges in early summer (McLellan, 1975).

The Biotic Index compared well with the known physicochemical and chemical conditions (Figure 37) and adequately described the river condition in both very small samples and samples that contained very high densities of Deleatidium.

The biological results thus corresponded with the physicochemical and chemical finding and showed that while the Borthwick's meatwork's discharge did not affect the river quality, the Feilding domestic sewage had a major detrimental influence. The community structure of the macroinvertebrates on the riffle areas was found to be best described by the logarithmic series while the diversity index based on the logarithmic series and the Trent Biotic Index described the river condition better than the other diversity indices considered.

7.

CONCLUSIONS

1. The Oroua River above the Borthwick's discharge has changed little in the biological and microbiological parameters considered over the last 21 years. The macroinvertebrate types, density and diversity recorded in this study were very similar to those recorded in 1956 by the Pol. Adv. Council (1957) as were the faecal coliform densities and dissolved oxygen concentrations.

2. The Borthwick's meatworks effluent was found to be of exceptionally high quality and closely resembled the British 20:30 standards for sewage effluent. It was thus not surprising that this effluent was found to significantly increase only two components in the Oroua River. These were the COD and the orthophosphate levels. The majority of the COD measured in the Borthwick's effluent was from oxidation of the inorganic end-products of biological degradation. Thus the increase in COD and orthophosphate levels in the Oroua River indicates an increase in inorganic rather than organic composition. The orthophosphate level of the Borthwick's effluent was high because the conservative nature of phosphorus means that the only unit operations that could remove phosphorus in the Borthwick's treatment system were the primary and secondary sedimentations. The effluent discharge was found not to affect the macroinvertebrate community in the Oroua River which have improved greatly since 1957, while large variations in the fortnightly microbiological densities meant that no significant increase in bacteriological numbers could be found.

3. The Feilding domestic sewage was found to be of exceptionally poor quality and the actual concentration of components depended upon the presence or absence of concentrated trade wastes. When the concentrated trade

wastes were present the concentrations of components were greater than that of strong raw sewage. The effluent quality believed to represent mainly domestic sewage was typical of medium strength raw sewage. These high concentrations occurred even though the effluent had undergone secondary treatment by trickling filtration. It is thought that the large fluctuations in the influent quality, due to large variations in the quantity and concentration of the trade wastes caused shock loading of the trickling filter and hence greatly reduced its efficiency.

As would be expected, the Feilding domestic sewage discharge markedly affected the Oroua River. All the chemical and microbiological parameters studied, except the nitrate concentrations, were affected by this discharge. This discharge also brought about a large change in the macroinvertebrate community and at times it completely eliminated all macroinvertebrates from the reaches immediately below the discharge.

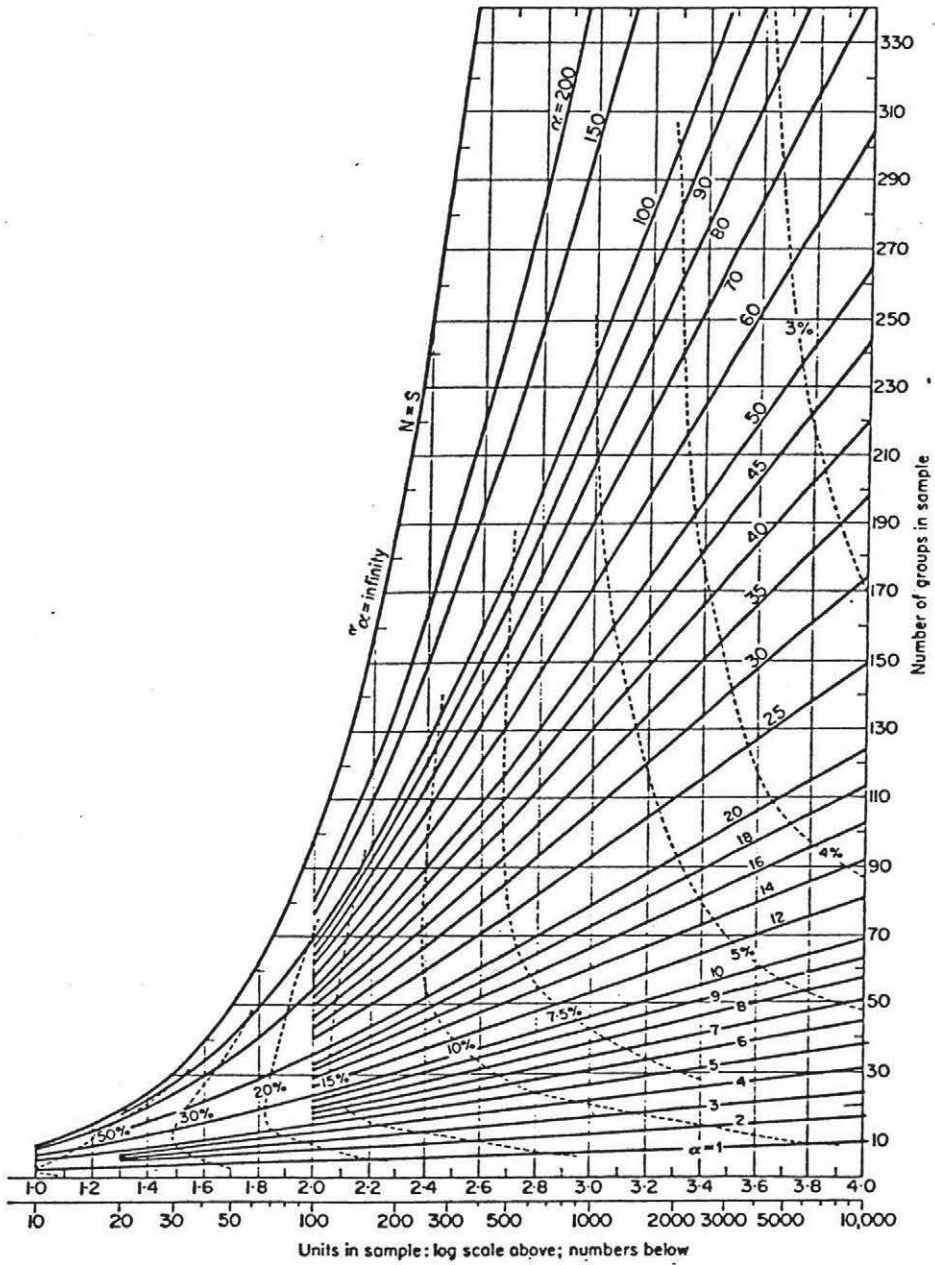
4. The Oroua River was found to have an exceptionally high self purification capacity in terms of both organic and microbiological decay. The rate of self purification was found to be up to 10 times the rates found in streams of comparable size. These high rates of self purification were attributed to the many shallow, algae or sewage fungus covered riffles that were present in this stretch of river. These probably promoted the accumulation of dense populations of heterotrophic microorganisms which thus resulted in rapid degradation of organic material and foreign bacteria.
5. The bacterial groups considered in the Oroua River were found to decrease at different rates. This thus causes concern when indicator organisms, such as faecal coliforms, are used to model the rate of decline of human bacterial pathogens.

6. The minimum orthophosphate concentrations found in the Oroua River were less than 10 mg/m^3 while concentrations of 60 mg/m^3 represented the lower range of the nitrate concentrations. Dense algal growth was found to preside during periods that represented both these minimum levels. The growth and decline of algae in the Oroua River was thus found not to be primarily influenced by the orthophosphate or nitrate concentrations occurring in the stream, nor was algal growth limited by the stream temperature. The most important factor found to influence the development of the algae was the stream flow. When the stream flow was greater than $2 \text{ m}^3/\text{s}$ little benthic algae was present in the river.
7. Deleatidium was found to be the most important macroinvertebrate in the non-polluted reaches of the Oroua River while Sericostomatidae, Elmidae and Hydropsychidae families were of lesser importance. In the polluted reaches of the river, chironomids and Elmidae dominated.

The distribution of macroinvertebrates in the river was found to fit the logarithmic series. The diversity index based on this logarithmic series was found to describe the river's condition better than the other diversity indices considered. The Trent Biotic Index was also found to adequately describe the Oroua River water quality provided that it was applied with a knowledge of the macroinvertebrate ecology.

APPENDIX 1

NOMOGRAPH SHOWING THE RELATIONSHIP BETWEEN THE NUMBER OF GROUPS (S), THE NUMBER OF UNITS (N), AND THE DIVERSITY (α) IN SAMPLES OF DIFFERENT SIZES FROM POPULATIONS ARRANGED IN A LOGARITHMIC SERIES



Source: Williams (1964)

APPENDIX 2

FLOW DATA, INFLUENT LOADING DATA AND WEATHER CONDITIONS

A2.1 RIVER FLOW, EFFLUENT FLOW AND WEATHER CONDITIONS

DATE	RIVER FLOW m ³ /sec	BORTHWICKS FLOW m ³ /day	SEWAGE FLOW m ³ /day	WEATHER
2/11/77	6.3	0	-	cloudy, cool, slight breeze
9/11/77	5.9	-	3395	sunny, cool, slight breeze
16/11/77	4.8	2357	-	overcast & cool, breezy
23/11/77	5.2	-	3681	overcast with gales
30/11/77	3.4	1351	-	wet and dull
7/12/77	3.1	-	3100	cloudy, warm & breezy
14/12/77	5.9	2855	-	overcast, windy & wet
21/12/77	6.2	-	4054	overcast & windy
11/1/78	4.5	3007	-	hot & sunny
18/1/78	2.9	-	3772	sunny & warm
25/1/78	1.8	2230	-	overcast, hot & breezy
1/2/78	2.9	-	3990	sunny & hot
8/2/78	5.5	2048	-	sunny & warm
15/2/78	1.6	-	3850	sunny & warm
22/2/78	2.0	2789	-	cloudy, warm & breezy
1/3/78	1.2	-	3645	cloudy & warm
8/3/78	1.1	-	3909	cloudy & warm
15/3/78	0.8	3367	-	sunny, breezy & warm
22/3/78	0.8	-	4018	sunny, breezy & warm
29/3/78	0.8	-	4550	overcast, windy & cool
5/4/78	1.0	2811	-	sunny & cool
12/4/78	2.2	-	3340	sunny & cool
19/4/78	3.1	-	4718	wet & cool with gales
26/4/78	5.0	686	-	overcast & cool

A2.2

FLOW-TIME DATA

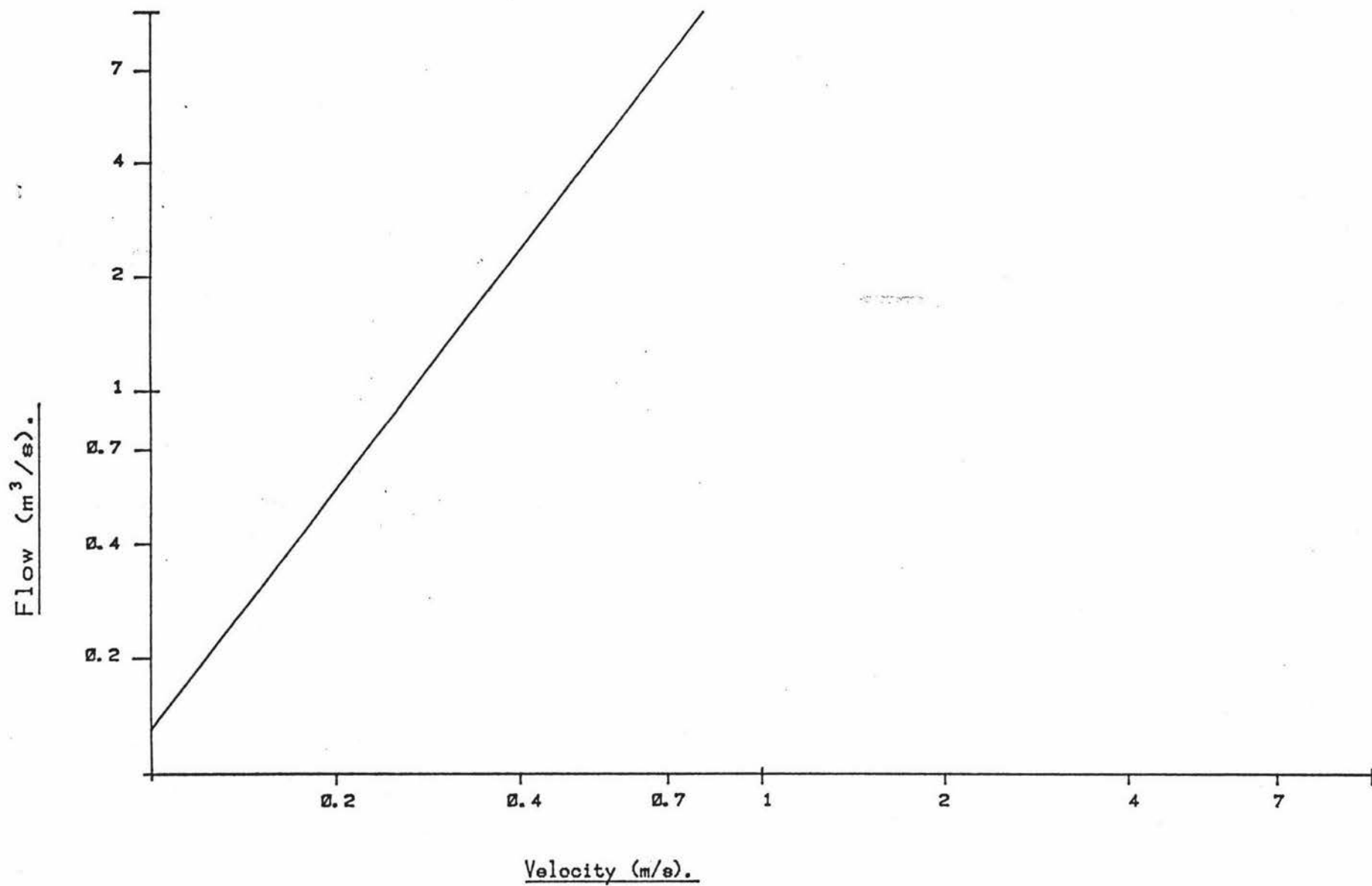
SITE	FLOW DISTANCE (m)	FLOW TIME (S)	AVE. VELOCITY (m/s)	SITE AVE VELOCITY* (m/s)	SITE AVE VELOCITY B ₄ AVE VELOCITY
KIWITEA STREAM CONFLUENCE					
B ₁	4000	4620	0.9	1.5	1.9
B ₂	700	360	1.9	1.6	2.0
B ₃	700	540	1.3	1.1	1.4
B ₄	600	660	0.9	0.8	1.0
F ₁	1300	2760	0.5	1.5	1.9
F ₂	600	300	2.0	1.8	2.3
F ₃	900	660	1.4	1.4	1.8
F ₄	2100	1500	1.4	1.3	1.6
F ₅	5400	4920	1.1	0.9	1.1
	3700	4440	0.8		

BARNABYS BRIDGE

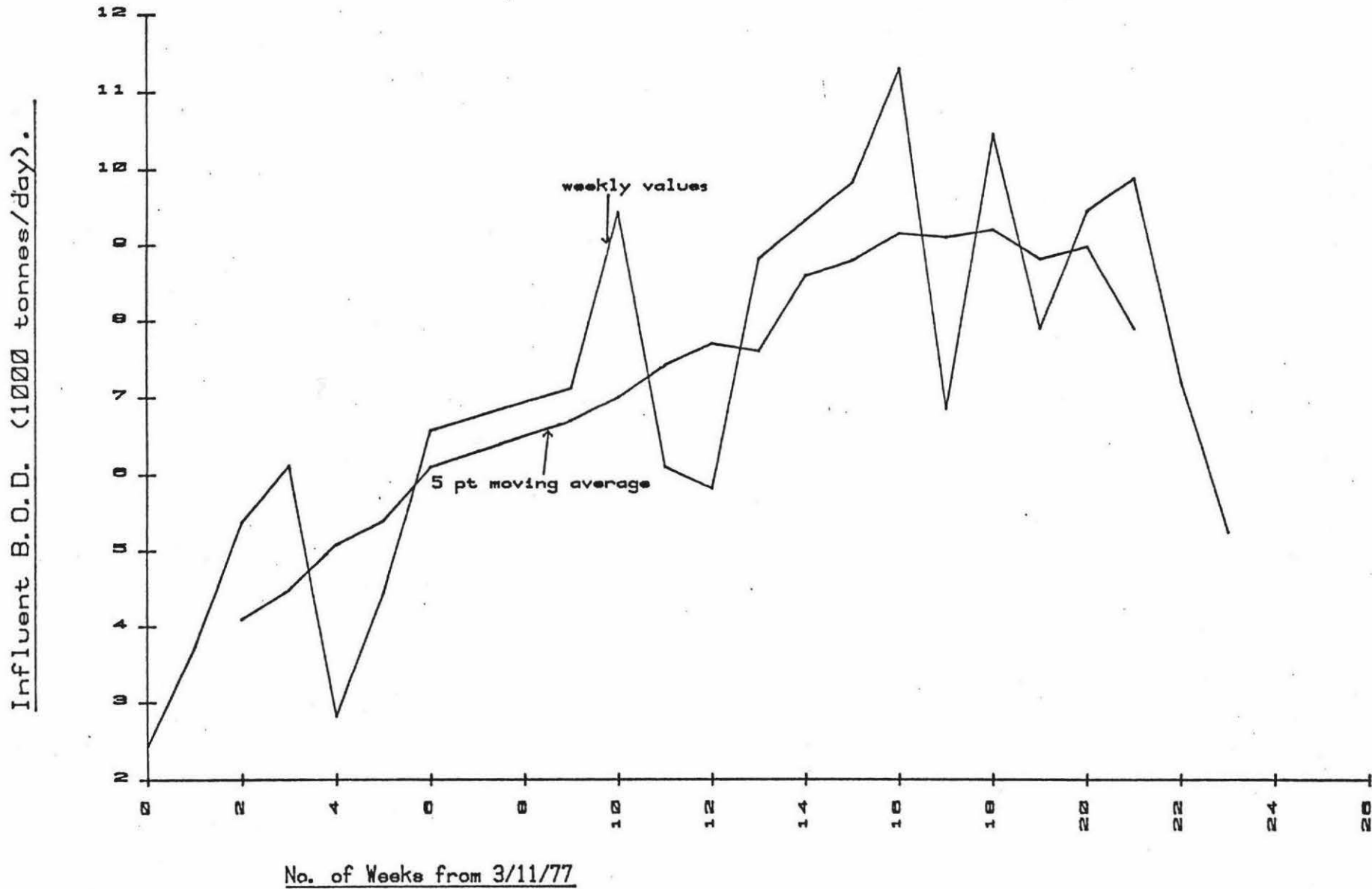
* SITE AVERAGE VELOCITY determined by a weighted average (based on nearness of adjacent sites) of the two river stretches immediately upstream and downstream of the site in question.

Source: This table is based on data supplied by the Manawatu Catchment Board and Regional Water Board.

A 2.3 Flow / Velocity Relationships for the Oroua River.



A 2.4 Influent B.O.D. to the Borthwick's Treatment System.



APPENDIX 3

3.1.1 PHYSICOCHEMICAL, CHEMICAL AND MICROBIOLOGICAL RESULTS

LIST OF ABBREVIATIONS, UNITS AND EXPERIMENTAL
ERROR FOR PARAMETERS CONSIDERED IN A3.1.2-A3.1.12

PARAMETER	ABBREVIATION	UNITS	EXPERIMENTAL ERROR		
			BORTHWICKS EFFLUENT	DOMESTIC SEWAGE	STREAM
Biochemical Oxygen Demand	BOD	g/m ³	±1	±10	±0.2
Carbohydrate Concentration	CARB	g/m ³	±5	±5	-
Chemical Oxygen Demand	COD	g/m ³	±10	±30	±5
Dissolved Oxygen Concentration	DO	g/m ³	±0.05	±0.05	±0.05
Kjeldahl Nitrogen Concentration	KN	g/m ³	±0.5	±0.5	±0.05
Nitrate Nitrogen Concentration	NO ₃	g/m ³	±0.01	±0.01	±0.01
Orthophosphate Phosphorus Concentration	PO ₄	g/m ³	±0.1	±0.1	±0.01
pH	pH	-	±0.05	±0.05	±0.05
Protein Concentration	PROT	g/m ³	±30	±30	-
Suspended Solids Concentration	SS	g/m ³	±0.4	±1	±0.1
Temperature	TEMP	°C	±0.2	±0.2	±0.2
Total Phosphorus	TP	g/m ³	±0.5	±0.5	±0.05
Heterolytic Bacterial Density	LB	no/100 ml	correct to characteristic number		
Autolytic Bacterial Density	PB	no/100 ml	correct to characteristic number		
Accharolytic Bacterial Density	SB	no/100 ml	correct to characteristic number		

A3.1.2

PHYSICOCHEMICAL, CHEMICAL AND MICROBIOLOGICAL RESULTSBORTHWICK'S EFFLUENT

DATE	TIME	TEMP	DO	pH	NO ₃	KN	PO ₄	TP	S ²⁻
21/11/77	1110	ND	ND	7.30	0.45	ND	0.43	ND	-ve
16/11/77	1010	15.5	6.20	7.45	0.04	ND	5.8	ND	-ve
30/11/77	1000	17.8	7.05	7.90	0.12	ND	6.0	ND	-ve
14/12/77	1045	17.0	6.10	7.91	0.04	72	7.1	5.2	-ve
11/1/78	1030	22.0	5.70	8.00	0.07	75	5.0	3.1	-ve
25/1/78	0935	24.0	4.70	8.00	0.17	54	3.9	8.4	-ve
8/2/78	1000	20.2	6.60	8.00	0.07	70	7.8	10.4	-ve
22/2/78	1000	21.5	5.20	7.75	0.15	72	7.3	11.0	-ve
15/3/78	1100	20.2	7.50	8.00	ND	ND	8.9	ND	-ve
5/4/78	1015	17.3	7.55	7.88	0.04	76	8.8	14.3	-ve
26/4/78	1000	16.7	8.30	7.70	0.05	72	7.3	5.5	-ve

DATE	BOD	COD	SS	PROT	CARB	PB	LP	SB	MPN
2/11/77	28	280	32	<100	31	ND	5.10 ⁴	ND	ND
16/11/77	10.5	240	18	ND	17	2.10 ⁵	3.10 ⁴	210 ⁵	3.10 ³
30/11/77	21	300	26	ND	14	5.10 ⁴	4.10 ⁴	610 ⁵	2.10 ³
14/12/77	26	269	35	245	16	2.10 ⁵	1.10 ⁶	710 ⁶	5.10 ²
11/1/78	22	222	39	ND	15	2.10 ⁶	1.10 ⁶	5.10 ⁶	2.10 ⁵
25/1/78	34	302	ND	352	13	2.10 ⁴	1.10 ⁵	4.10 ⁴	5.10 ⁶
8/2/78	24	290	63	261	19	1.10 ⁴	2.10 ⁵	7.10 ⁵	ND
22/2/78	37	282	78	326	24	3.10 ⁴	ND	8.10 ⁵	ND
15/3/78	25	349	77	ND	ND	ND	ND	ND	ND
5/4/78	25	265	66	343	27	ND	5.10 ⁴	7.10 ⁵	ND
26/4/78	32	304	68	364	24	ND	1.10 ⁵	3.10 ⁵	ND

A3.1.3

PHYSICOCHEMICAL, CHEMICAL AND MICROBIOLOGICAL RESULTSFEILDING DOMESTIC SEWAGE

DATE	TIME	TEMP	DO	pH	NO ₃	KN	PO ₄	TP	S ²⁻
9/11/77	1050	15.5	5.0	7.80	0.71	ND	2.2	ND	-ve
23/11/77	1040	16.2	2.5	7.70	0.69	ND	2.6	ND	-ve
7/12/77	1100	19.3	1.0	7.80	0.45	ND	4.4	ND	-ve
21/12/77	1215	17.0	1.8	7.20	0.83	81	4.2	3.6	+ve
18/1/78	1120	22.0	1.4	7.05	0.09	74	3.5	4.3	+ve
1/2/78	1035	22.0	1.2	6.92	0.36	50	42.1	4.9	+ve
15/2/78	1030	23.0	1.1	7.20	ND	ND	4.2	3.6	-ve
1/3/78	1030	21.0	0.9	7.25	0.02	30	1.7	3.3	-ve
8/3/78	1110	21.0	1.2	7.32	0.16	50	4.3	6.1	-ve
22/3/78	1050	21.2	1.0	7.2	<0.01	66	4.1	10.3	-ve
29/3/78	1205	20.5	1.3	ND	<0.01	64	3.2	5.9	-ve
12/4/78	1110	20.0	1.3	ND	<0.01	70	3.1	3.8	-ve
19/4/78	1110	19.5	3.4	7.2	<0.01	ND	4.2	5.5	-ve

DATE	BOD	COD	SS	PROT	CARB	PB	LB	SB	MPN
9/11/78	251	790	167	ND	27	ND	ND	ND	ND
23/11/78	260	>900	206	ND	26	3.10 ⁵	>3.10 ⁷	>1.10 ⁷	>2.10 ³
7/12/78	>700	2200	406	2122	55	1.10 ⁷	4.10 ⁵	7.10 ⁶	2.10 ⁵
21/12/78	ND	2150	404	ND	42	3.10 ⁸	1.10 ⁸	1.10 ⁸	2.10 ⁸
18/1/78	297	2025	ND	1931	52	ND	ND	9.10 ⁷	>2.10 ⁶
1/2/78	ND	1813	230	1545	42	1.10 ⁸	5.10 ⁷	3.10 ⁸	>2.10 ⁷
15/2/78	484	705	198	1030	38	3.10 ⁷	ND	1.10 ⁸	ND
1/3/78	280	495	131	577	24	5.10 ⁷	2.10 ⁷	2.10 ⁸	ND
8/3/78	371	1142	162	1071	35	8.10 ⁷	5.10 ⁷	4.10 ⁸	ND
22/3/78	782	1897	364	1666	57	ND	ND	ND	ND
29/3/78	633	1864	261	1704	48	ND	5.10 ⁷	6.10 ⁸	ND
12/4/78	420	1200	223	1121	34	ND	7.10 ⁷	4.10 ⁸	ND
19/4/78	327	766	220	910	29	2.10 ⁴	2.10 ⁷	3.10 ⁸	ND

A3.1.4

PHYSICOCHEMICAL, CHEMICAL AND MICROBIOLOGICAL RESULTS - B₁

DATE	TIME	TEMP	DO	pH	NO ₃	KN	PO ₄	TP
2/11/77	1040	ND	ND	7.05	0.23	ND	<0.01	ND
16/11/77	1100	14.5	11.50	7.90	0.20	ND	0.01	ND
30/11/77	1025	15.9	9.90	7.80	0.12	ND	<0.01	ND
14/12/78	1050	15.0	10.00	7.81	0.28	0.08	0.01	0.09
11/1/78	1045	21.5	10.20	8.00	0.06	0.10	<0.01	0.11
25/1/78	0945	21.0	9.15	7.80	0.07	0.25	0.02	0.17
8/2/78	1015	17.5	9.10	7.48	0.22	0.20	0.02	0.10
22/2/78	0945	19.2	9.45	7.60	<0.01	0.10	0.02	0.14
15/3/78	1100	19.5	10.40	8.40	ND	ND	0.01	ND
5/4/78	1045	16.0	10.30	7.96	<0.01	ND	<0.01	ND
26/4/78	1100	15.0	9.70	7.30	0.32	0.40	0.03	ND

DATE	BOD	COD	SS	PB	LB	SB	MPN
2/11/77	1.2	<10	2.0	ND	8.10 ³	ND	ND
16/11/77	0.8	<10	8.5	3.10 ³	2.10 ³	6.10 ³	5.10 ²
30/11/77	0.9	3	11.2	5.10 ²	1.10 ³	2.10 ⁴	5.10 ²
14/12/77	1.2	2	1.7	1.10 ⁴	4.10 ⁴	5.10 ⁴	9.10 ²
11/1/78	0.1	6	0.2	5.10 ³	2.10 ³	5.10 ³	1.10 ²
25/1/78	<0.1	ND	ND	4.10 ³	4.10 ³	3.10 ⁴	5.10 ²
8/2/78	0.6	6	2.1	6.10 ³	3.10 ³	5.10 ⁴	ND
22/2/78	0.3	8	0.4	2.10 ³	ND	2.10 ⁴	ND
15/3/78	<0.1	10	2.6	ND	ND	ND	ND
5/4/78	<0.1	6	3.9	ND	3.10 ²	2.10 ⁴	ND
26/4/78	0.2	7	4.7	ND	1.10 ³	1.10 ⁴	ND

A3.1.5

PHYSICOCHEMICAL, CHEMICAL AND MICROBIOLOGICAL RESULTS - B₂

DATE	TIME	TEMP	DO	pH	NO ₃	KN	PO ₄	TP
2/11/77	1130	ND	ND	7.00	0.17	ND	<0.01	ND
16/11/77	1015	13.5	10.20	7.75	0.19	ND	0.05	ND
30/11/77	1045	17.2	9.50	7.75	0.14	ND	0.03	ND
14/12/77	1120	15.0	9.40	7.79	0.28	0.41	0.03	0.05
11/1/78	1100	21.5	10.10	8.05	0.06	0.45	0.04	0.17
25/1/78	1010	21.9	9.00	7.90	0.07	0.35	0.02	0.19
8/2/78	1030	17.7	9.35	7.50	0.19	0.55	0.04	0.16
22/2/78	1015	19.1	9.15	7.60	0.02	0.10	0.05	0.15
15/3/78	1120	ND	ND	8.10	ND	ND	0.24	ND
5/4/78	1115	17.0	10.80	7.88	0.03	ND	0.12	ND
26/4/78	1045	15.0	9.85	7.42	0.29	0.20	0.05	ND

DATE	BOD	COD	SS	PB	LB	SB	MPN
2/11/77	0.7	<10	2.0	ND	1.10 ³	ND	ND
16/11/77	1.2	20	12.6	9.10 ³	2.10 ³	2.10 ⁴	8.10 ²
30/11/77	1.1	6	20.6	<1.10 ²	2.10 ³	2.10 ⁴	3.10 ²
14/12/77	1.0	5	2.3	1.10 ⁴	4.10 ⁴	4.10 ⁴	1.10 ³
11/1/78	0.4	10	0.8	1.10 ⁴	8.10 ³	4.10 ⁴	2.10 ³
25/1/78	<0.1	10	ND	2.10 ³	5.10 ³	2.10 ⁴	7.10 ²
8/2/78	0.6	5	15.2	5.10 ³	8.10 ³	5.10 ⁴	WD
22/2/78	0.8	11	1.4	5.10 ²	ND	8.10 ³	ND
15/3/78	0.5	23	6.5	ND	ND	ND	ND
5/4/78	0.5	11	1.3	ND	6.10 ²	4.10 ⁴	ND
26/4/78	0.6	9	6.4	ND	ND	ND	ND

DATE	TIME	TEMP	DO	pH	NO ₃	KN	PO ₄	TP
2/11/77	1210	ND	ND	7.10	0.17	ND	<0.01	ND
16/11/77	1030	13.5	9.10	7.75	0.20	ND	0.04	ND
30/11/77	1105	17.5	9.85	7.78	0.12	ND	0.03	ND
14/12/77	1140	15.0	9.35	7.77	0.03	0.20	0.03	0.06
11/1/78	1115	21.7	9.70	8.10	0.06	0.90	0.08	0.17
25/1/78	1025	22.0	9.55	7.85	0.11	0.06	0.09	0.26
8/2/78	1045	18.0	8.90	7.50	0.32	0.45	0.09	0.18
22/2/78	1030	20.0	10.00	7.57	0.10	1.60	0.21	0.36
15/3/78	1140	21.0	11.40	8.30	ND	ND	0.41	ND
5/4/78	1030	16.0	10.60	7.71	0.11	ND	0.10	0.14
26/4/78	1025	15.0	9.50	7.46	0.30	0.40	0.06	ND

DATE	BOD	COD	SS	PB	LB	SB	MPN
2/11/77	1.4	<10	1.7	ND	1.10 ³	ND	ND
16/11/77	1.0	20	8.4	2.10 ⁴	5.10 ²	1.10 ⁴	4.10 ²
30/11/77	1.0	5	27.8	1.10 ³	1.10 ³	2.10 ⁴	3.10 ²
14/12/77	1.2	5	2.6	3.10 ⁴	3.10 ⁴	6.10 ⁴	1.10 ³
11/1/78	0.6	13	1.7	1.10 ⁴	ND	3.10 ⁴	5.10 ²
25/1/78	0.3	16	ND	6.10 ³	1.10 ⁴	5.10 ⁴	1.10 ⁴
8/2/78	0.6	8	11.3	7.10 ³	4.10 ³	4.10 ⁴	ND
22/2/78	1.4	17	6.0	7.10 ⁴	ND	4.10 ⁴	ND
15/3/78	3.3	27	6.9	ND	ND	ND	ND
5/4/78	1.6	12	3.9	ND	3.10 ²	3.10 ⁴	ND
26/4/78	0.4	9	7.7	ND	ND		ND

DATE	TIME	TEMP	DO	pH	NO ₃	KN	PO ₄	TP
2/11/77	1150	ND	ND	7.05	0.18	ND	<0.01	ND
16/11/77	1130	14.7	10.40	7.80	0.20	ND	0.03	ND
30/11/77	1120	16.3	9.70	7.40	0.13	ND	0.03	ND
14/12/77	1030	15.0	9.70	7.80	0.29	0.35	0.04	0.11
11/1/78	1130	22.0	10.40	8.20	0.13	0.55	0.07	0.18
25/1/78	1045	22.7	10.20	8.00	0.18	0.45	0.09	0.18
8/2/78	1100	18.8	8.85	7.50	0.43	0.50	0.08	0.16
22/2/78	1045	20.1	10.40	7.76	0.34	1.30	0.16	0.36
15/3/78	1200	21.0	10.10	7.90	ND	ND	0.37	ND
5/4/78	1145	17.7	10.00	7.82	0.15	0.40	0.09	ND
26/4/78	1120	15.2	9.65	7.48	0.36	0.30	0.05	ND

DATE	BOD	COD	SS	PB	LB	SB	MPB
2/11/77	1.3	<10	1.8	ND	2.10 ³	ND	ND
16/11/77	1.1	25	9.4	2.10 ⁴	5.10 ³	2.10 ⁴	5.10 ²
30/11/77	1.2	7	17.9	3.10 ³	8.10 ²	3.10 ⁴	4.10 ²
14/12/77	1.0	4	2.9	2.10 ⁴	4.10 ⁴	5.10 ⁴	6.10 ³
11/1/78	0.8	14	1.8	3.10 ³	2.10 ⁴	2.10 ⁴	1.10 ³
25/1/78	0.3	16	ND	4.10 ³	2.10 ⁴	8.10 ³	5.10 ³
8/2/78	0.8	8	10.8	7.10 ³	7.10 ³	1.10 ⁵	ND
22/2/78	1.3	15	3.6	4.10 ³	5.10 ³	2.10 ⁴	ND
15/3/78	3.5	26	6.9	ND	ND	ND	ND
5/4/78	1.2	13	2.9	ND	4.10 ²	2.10 ⁴	ND
26/4/78	0.4	8	9.6	ND	2.10 ³	2.10 ⁴	ND

DATE	TIME	TEMP	DO	pH	NO ₃	KN	PO ₄	TP
9/11/77	1100	16.2	10.90	7.5	0.22	ND	0.02	ND
23/11/77	1050	16.2	9.80	7.7	0.08	ND	0.03	ND
7/12/77	1105	19.0	10.90	8.15	0.15	ND	0.04	ND
21/12/77	1215	19.0	9.45	7.82	0.16	0.55	0.03	0.16
18/1/78	1130	22.0	10.40	8.15	0.24	0.55	0.10	0.27
1/2/78	1045	21.0	9.90	8.20	0.35	0.30	0.10	0.18
15/2/78	1045	21.6	10.40	8.00	ND	1.90	0.24	0.39
1/3/78	1035	20.7	13.00	8.72	0.84	0.30	0.17	0.92
8/3/78	1125	18.0	16.05	9.20	0.79	0.45	0.18	0.37
22/3/78	1100	17.5	12.30	8.52	1.30	0.90	0.20	0.14
29/3/78	1210	17.2	13.60	ND	1.30	1.00	0.15	ND
12/4/78	1120	16.0	14.60	ND	1.40	1.65	0.22	0.29
19/4/78	1130	16.2	9.20	7.56	0.43	0.50	0.06	0.19

DATE	BOD	COD	SS	PB	LB	SB	MPN
9/11/77	0.9	20	4.8	<1.10 ²	5.10 ⁴	5.10 ³	ND
23/11/77	0.5	20	11.0	2.10 ³	2.10 ³	3.10 ⁴	3.10 ²
7/12/77	0.8	6	1.2	2.10 ³	<1.10 ²	2.10 ⁴	2.10 ²
21/12/77	ND	8	8.6	1.10 ⁴	1.10 ⁴	5.10 ⁴	1.10 ³
18/1/78	0.9	5	ND	5.10 ³	ND	1.10 ⁴	1.10 ³
1/2/78	ND	14	2.5	7.10 ⁴	9.10 ³	3.10 ⁵	8.10 ²
15/2/78	1.3	20	1.7	9.10 ³	6.10 ³	1.10 ⁵	ND
1/3/78	2.8	21	4.7	2.10 ⁴	1.10 ³	2.10 ⁵	ND
8/3/78	2.4	20	6.4	3.10 ³	1.10 ²	3.10 ⁴	ND
22/3/78	1.9	20	2.5	ND	ND	ND	ND
29/3/78	2.1	23	4.6	ND	4.10 ³	6.10 ⁴	ND
12/4/78	1.7	18	3.8	1.10 ³	9.10 ³	7.10 ⁴	ND
19/4/78	1.7	11	3.4	6.10 ²	3.10 ³	5.10 ⁴	ND

DATE	TIME	TEMP	DO	pH	NO ₃	KN	PO ₄	TP
9/11/77	1130	17.2	10.10	7.40	0.24	ND	0.21	ND
23/11/77	1105	15.8	8.80	7.65	0.13	ND	0.21	ND
7/12/77	1045	19.1	8.70	7.98	0.22	ND	0.18	ND
21/12/77	1145	18.5	8.25	7.60	0.22	2.35	0.18	0.23
18/1/78	1050	21.5	8.00	7.50	0.26	2.80	0.11	0.28
1/2/78	1025	20.3	8.00	7.50	0.25	1.20	0.11	0.24
15/2/78	1015	22.0	9.10	7.6	ND	4.40	0.34	0.49
1/3/78	1015	20.0	9.45	8.05	0.89	2.45	0.22	0.45
8/3/78	1045	18.0	12.15	8.39	0.64	3.50	0.51	0.57
22/3/78	1030	18.0	8.25	7.50	1.10	6.80	0.37	0.24
29/3/78	1150	17.9	8.70	ND	0.89	5.70	0.41	ND
12/4/78	1045	16.8	9.40	ND	1.04	5.65	0.47	0.33
19/4/78	1055	16.5	9.00	7.45	0.48	2.80	0.34	0.05

DATE	BOD	COD	SS	PB	LB	SB	MPN
9/11/77	>16	70	32	3.10 ⁴	ND	ND	ND
23/11/77	1.6	25	11.2	2.10 ⁴	1.10 ⁵	1.10 ⁶	>2.10 ²
7/12/77	30	81	14.0	4.10 ⁴	ND	ND	>2.10 ⁴
21/12/77	ND	87	20	2.10 ⁶	4.10 ⁶	5.10 ⁷	2.10 ⁷
18/1/78	26	83	ND	2.10 ⁶	ND	3.10 ⁶	>2.10 ⁵
1/2/78	ND	89	21	4.10 ⁶	1.10 ⁶	2.10 ⁷	>2.10 ⁵
15/2/78	30	87	16.2	9.10 ⁵	4.10 ⁵	8.10 ⁶	ND
1/3/78	12	57	12.0	2.10 ⁶	8.10 ⁵	8.10 ⁶	ND
8/3/78	39	124	32	3.10 ⁵	9.10 ⁴	1.10 ⁷	ND
22/3/78	56	225	38	ND	ND	ND	ND
29/3/78	108	302	46	ND	3.10 ⁶	4.10 ⁷	ND
12/4/78	55	165	29	1.10 ³	4.10 ⁶	8.10 ⁷	ND
19/4/78	20	40	12.2	1.10 ³	3.10 ⁵	2.10 ⁷	ND

DATE	TIME	TEMP	DO	pH	NO ₃	KN	PO ₄	TP
9/11/77	1000	15.5	10.80	7.50	0.24	ND	0.06	ND
23/11/77	1000	15.2	9.70	7.75	0.08	ND	0.09	ND
7/12/77	1005	18.0	9.70	9.95	0.22	ND	0.12	ND
21/12/77	1010	17.5	8.80	7.65	0.22	1.30	0.08	0.20
18/1/78	1000	20.2	8.10	7.60	0.27	2.00	0.11	0.27
1/2/78	0945	20.0	9.10	7.88	0.30	1.15	0.12	0.16
15/2/78	0930	20.8	9.50	7.52	ND	2.40	0.27	0.53
1/3/78	0935	20.2	8.55	7.52	0.82	1.60	0.18	0.33
8/3/78	1015	17.5	12.00	8.35	0.79	2.15	0.32	0.62
22/3/78	0945	16.2	6.90	7.42	1.20	2.80	0.32	0.24
29/3/78	1120	17.2	7.90	ND	1.10	2.20	0.18	0.19
12/4/78	1000	14.7	11.10	ND	1.40	2.26	0.29	ND
19/4/78	1010	16.1	8.50	7.30	0.54	1.80	0.16	0.05

DATE	BOD	COD	SS	PB	LB	SB	MPN
9/11/77	3.1	20	6.9	3.10 ⁴	ND	ND	ND
23/11/77	2.3	50	8.4	3.10 ⁴	1.10 ⁵	1.10 ⁶	>2.10 ³
7/12/77	>8	49	9.2	4.10 ⁴	5.10 ⁶	5.10 ⁶	>2.10 ⁴
21/12/77	ND	38	9.3	1.10 ⁶	2.10 ⁶	1.10 ⁷	9.10 ⁶
18/1/78	18	51	ND	1.10 ⁶	ND	2.10 ⁶	>2.10 ⁵
1/2/78	ND	44	7.3	2.10 ⁶	6.10 ⁵	4.10 ⁶	>2.10 ⁵
15/2/78	10	38	4.3	4.10 ⁵	2.10 ⁵	2.10 ⁶	ND
1/3/78	6.9	46	6.0	5.10 ⁵	4.10 ⁵	3.10 ⁶	ND
8/3/78	25	77	17.9	5.10 ⁴	ND	7.10 ⁶	ND
22/3/78	16	88	12.2	ND	ND	ND	ND
29/3/78	>40	140	28	ND	1.10 ⁶	8.10 ⁶	ND
12/4/78	19	68	11.7	1.10 ²	7.10 ⁵	7.10 ⁶	ND
19/4/78	13	41	8.1	3.10 ²	6.10 ⁵	7.10 ⁶	ND

DATE	TIME	TEMP	DO	pH	NO ₃	KN	PO ₄	TP
9/11/77	1030	15.9	10.60	7.45	0.20	ND	0.06	ND
23/11/77	1020	15.5	9.95	7.77	0.16	ND	0.12	ND
7/12/77	1020	18.2	10.40	8.02	0.25	ND	0.08	ND
21/12/77	1100	18.0	8.30	7.65	0.23	1.15	0.07	0.30
18/1/78	1030	21.0	9.90	8.15	0.25	1.20	0.10	0.24
1/2/78	1005	19.8	10.80	8.35	0.27	0.75	0.10	0.20
15/2/78	0950	20.9	8.80	7.45	ND	1.60	0.24	0.50
1/3/78	1000	20.3	9.00	7.69	0.69	1.70	0.14	0.29
8/3/78	1030	17.5	12.15	8.40	0.68	1.20	0.24	0.42
22/3/78	1010	16.7	8.55	7.58	1.10	2.50	0.25	0.24
29/3/78	1145	17.2	8.90	ND	0.97	1.00	0.17	ND
12/4/78	1030	15.4	12.20	ND	1.43	1.75	0.23	0.24
19/4/78	1040	16.0	8.20	7.25	0.66	1.30	0.14	0.19

DATE	BOD	COD	SS	PB	LB	SB	MPN
9/11/77	2.8	40	5.3	7.10 ³	ND	ND	ND
23/11/77	2.7	60	7.9	4.10 ⁴	1.10 ⁵	1.10 ⁶	>2.10 ³
7/12/77	>8	25	5.6	3.10 ⁴	2.10 ⁶	3.10 ⁶	>2.10 ⁴
21/12/77	ND	35	9.7	1.10 ⁶	1.10 ⁶	1.10 ⁷	4.10 ⁶
18/1/78	14	41	-	7.10 ⁵	ND	1.10 ⁶	>2.10 ⁵
1/2/78	ND	38	7.4	ND	ND	ND	ND
15/2/78	4.4	32	5.7	1.10 ⁵	4.10 ⁴	5.10 ⁵	ND
1/3/78	7.0	41	5.4	2.10 ⁵	2.10 ⁵	7.10 ⁵	ND
8/3/78	1.2	54	11.0	3.10 ⁴	4.10 ⁵	4.10 ⁵	ND
22/3/78	7.7	61	10.2	ND	ND	ND	ND
29/3/78	>20	102	24	ND	3.10 ⁵	6.10 ⁶	ND
12/4/78	8.5	43	12.2	1.10 ³	3.10 ⁵	2.10 ⁶	ND
19/4/78	8.2	33	13.2	4.10 ²	8.10 ⁴	2.10 ⁶	ND

DATE	TIME	TEMP	DO	pH	NO ₃	KN	PO ₄	TP
9/11/77	1200	17.5	10.80	7.60	0.22	ND	0.04	ND
23/11/77	1140	16.3	9.80	7.80	0.20	ND	0.06	ND
7/12/77	1135	20.0	12.50	8.57	0.25	ND	0.06	ND
21/12/77	1300	19.5	7.65	7.61	0.28	1.10	0.09	0.19
18/1/78	1200	22.2	15.00	9.10	0.18	0.90	0.07	0.20
1/2/78	1100	21.7	15.00	8.90	0.29	0.80	0.07	0.22
15/2/78	1100	21.5	9.50	7.70	0.34	0.55	0.17	0.40
8/3/78	1135	18.0	12.25	8.28	0.43	1.20	0.21	0.31
22/3/78	1120	17.9	12.60	8.22	0.63	1.20	0.27	ND
29/3/78	1230	17.2	10.00	ND	0.72	0.80	0.22	0.05
12/4/78	1130	16.0	12.20	ND	1.22	1.20	0.19	ND
19/4/78	1145	16.2	9.30	7.50	0.69	ND	0.11	ND

DATE	BOD	COD	SS	PB	LB	SB	MPN
9/11/77	2.6	35	6.9	2.10 ³	ND	2.10 ⁴	ND
23/11/77	1.8	30	11.8	3.10 ⁴	1.10 ⁵	1.10 ⁶	>2.10 ³
7/12/77	2.2	14	4.6	ND	1.10 ⁴	3.10 ⁵	>2.10 ⁵
21/12/77	ND	31	8.7	4.10 ⁵	4.10 ⁵	1.10 ⁷	6.10 ⁶
18/1/78	7.8	18	ND	4.10 ³	ND	2.10 ⁵	>2.10 ⁵
1/2/78	ND	43	20	2.10 ⁵	9.10 ⁴	4.10 ⁵	>2.10 ⁵
15/2/78	2.9	29	0.4	1.10 ⁵	3.10 ⁴	3.10 ⁵	ND
1/3/78	4.4	35	2.4	8.10 ⁴	5.10 ⁴	2.10 ⁵	ND
8/3/78	6.1	36	5.9	2.10 ⁵	9.10 ⁴	6.10 ⁵	ND
22/3/78	4.7	100	6.4	ND	ND	ND	ND
29/3/78	12.0	53	10.8	ND	3.10 ⁵	1.10 ⁶	ND
12/4/78	5.6	36	15.9	5.10 ²	2.10 ⁵	1.10 ⁶	ND
19/4/78	3.3	22	11.0	1.10 ³	6.10 ⁴	5.10 ⁵	ND

A3.2 CALCULATIONS FOR AMMONIACAL-NITROGEN AND FAT CONCENTRATIONS

A3.2.1 ESTIMATION OF AMMONIA CONCENTRATION IN BORTHWICK'S EFFLUENT

DATE	KJELDAHL-N (g/m ³)	PROTEIN (g/m ³)	PROTEIN-N (g/m ³)	AMMONIACAL-N (g/m ³)
14/12/77	72	245	39	33
25/1/78	54	352	56	-ve*
8/2/78	70	261	42	28
22/2/78	72	326	52	20
5/4/78	76	343	55	21
26/4/78	72	364	58	14

*negative result believed to be due to an error in the kjeldahl nitrogen value.

ABBREVIATIONS: KJELDAHL-N : KJELDAHL NITROGEN CONCENTRATION
PROTEIN : PROTEIN CONCENTRATION
PROTEIN-N : NITROGEN CONCENTRATION FROM PROTEINS
AMMONIACAL-N : AMMONIACAL NITROGEN CONCENTRATION

CALCULATION:

$$\text{AMMONIACAL-N} = \text{KJELDAHL-N} - 0.16 \text{ PROTEIN}$$

ESTIMATION OF FAT CONTENT IN THE FEILDING
DOMESTIC SEWAGE AND BORTHWICK'S EFFLUENT

I. FEILDING DOMESTIC SEWAGE

DATE	COD (g/m ³)	PROT (g/m ³)	COD-PROT (g/m ³)	CARB (g/m ³)	COD-CARB (g/m ³)	COD-FAT (g/m ³)	FAT (g/m ³)
7/12/77	2200	2122	1910	55	60	250	227
18/1/78	2025	1931	1738	52	57	230	209
1/2/78	1813	1545	1390	42	46	377	342
15/2/78	705	1030	927	38	42	-ve	-
1/3/78	495	577	519	24	26	-ve	-
8/3/78	1142	1071	964	35	38	140	127
22/3/78	1897	1666	1499	57	63	335	304
29/3/78	1864	1704	1534	48	53	277	251
12/4/78	1200	1121	1009	34	37	154	140
19/4/78	766	910	819	29	32	-ve	-

II. BORTHWICK'S EFFLUENT

DATE	COD (g/m ³)	PROT (g/m ³)	COD-PROT (g/m ³)	CARB (g/m ³)	COD-CARB (g/m ³)	COD-FAT (g/m ³)	FAT (g/m ³)
14/12/77	269	245	220	16	18	31	28
25/1/78	302	352	317	13	14	-ve	-
8/2/78	290	261	236	19	21	33	30
22/2/78	282	326	293	24	26	-ve	-
5/4/78	265	343	310	27	30	-ve	-
26/4/78	304	364	327	24	26	-ve	-

ABBREVIATIONS: COD : CHEMICAL OXYGEN DEMAND
 PROT : PROTEIN CONCENTRATION
 CARB : CARBOHYDRATE CONCENTRATION
 FAT : FAT CONCENTRATION

CALCULATION: FAT = (COD - 0.9 PROT - 1.1 CARB) ÷ 1.1

A3.3

PRODUCTIVITY DETERMINATIONS

A3.3.1

DISSOLVED OXYGEN (DO) AND TEMPERATURE (TEMP)LEVELS RECORDED IN THE OROUA RIVER DURING A24 HOUR SAMPLING RUN (21-22 MARCH 1978)SITE B₃

TIME	DO g/m ³	TEMP °C	% SATURATION
1315	11.3	17.2	116
1550	10.2	18.5	109
1750	8.7	17.8	92
2145	6.9	15.5	68
0330	8.7	14.0	84
0635	8.8	12.9	83
0855	10.3	13.9	99

SITE F₂

TIME	DO g/m ³	TEMP °C	% SATURATION
1255	11.6	18.2	122
1525	11.1	19.6	119
1810	8.25	18.0	87
2130	6.30	16.2	63
2345	6.75	15.0	66
0315	8.20	14.0	79
0625	7.30	13.0	69
0910	10.7	14.2	103

SITE F₄

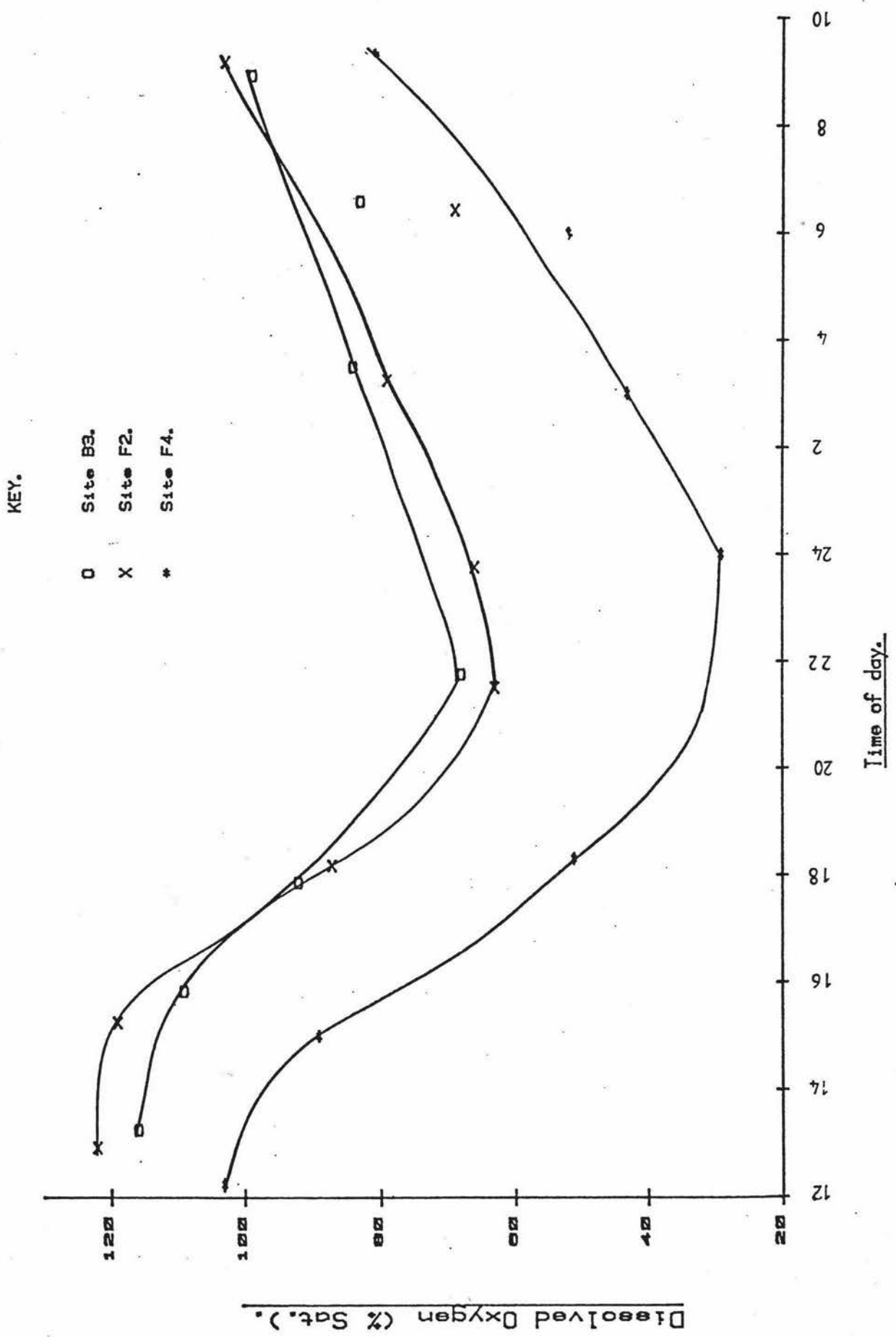
TIME	DO g/m ³	TEMP °C	% SATURATION
1215	9.7	18.5	103
1500	8.2	20.1	89
1820	4.75	18.5	51
2100	3.00	17.0	31
0000	3.00	15.0	29
0300	4.45	14.1	43
0600	5.50	13.0	52
0920	8.30	14.5	81

SITE F₅

2050	4.15	18.5	44
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These results are plotted in the accompanying diagram (Figure A3.1)

Figure A 3.1 .Dissolved Oxygen Levels in the Droua River 21-22 March 1978.



DETERMINATION OF THE REAERATION RATE BY THE DIURNAL
CURVE METHOD AND THE AVERAGE STREAM DEPTH

21-22 MARCH 1978

SITE	Q_m g/m ³ /hr	Q_e g/m ³ /hr	S_m % Sat	S_e % Sat	K g/m ³ /hr	v m/s	SAT g/m ³	T °C	H m	K_2 hr ⁻¹
B ₃	0.17	0.03	25.5	30.0	3.11	0.34	10.2	15	0.53	0.34
F ₂	0.44	0.02	26.0	37.0	3.82	0.55	10.2	15	0.57	0.42
F ₄	0.52	0.14	62.0	73.0	3.45	0.38	10.2	15	0.53	0.42

ABBREVIATIONS:

- Q_m rate of change in dissolved oxygen concentration at dawn
- Q_e rate of change in dissolved oxygen concentration at dusk
- S_m percentage saturation of dissolved oxygen at dawn
- S_e percentage saturation of dissolved oxygen at dusk
- K reaeration rate at 0% saturation
- v stream velocity
- SAT saturation dissolved oxygen concentration
- T stream temperature at dusk
- H average stream depth
- K_2 reaeration constant

CALCULATIONS:

$$K = \left(\frac{Q_m - Q_e}{S_e - S_m} \right) \times 100$$

$$H = \left(\frac{5.316 \times v^{.67}}{\frac{K}{SAT} \times (1.024)^{T-20} \times 24} \right)^{1/1.85}$$

$$K_2(20 \text{ } ^\circ\text{C}) = \left(\frac{5.316 \times v^{.67}}{H^{1.85}} \right) \div 24$$

A3.4 MASS BALANCES OF COD ABOUT THE FEILDING DOMESTIC SEWAGE DISCHARGE

DATE	FLOW-R m ³ /S	CONC-1 g/m ³	FLOW-S m ³ /S	CONC-S g/m ³	PCONC-2 g/m ³	OCONC-2 g/m ³	OCONC-4 g/m ³
7/12/77	3.1	6	0.036	2220	32	81	25
21/12/77	6.2	8	0.047	2150	24	87	35
18/1/78	2.9	5	0.044	2025	45	83	41
1/2/78	2.9	14	0.045	1818	42	89	38
15/2/78	1.6	20	0.045	705	40	87	32
1/3/78	1.2	21	0.043	495	39	57	41
8/3/78	1.1	20	0.045	1142	67	124	54
22/3/78	0.8	20	0.046	1897	139	225	61
29/3/78	0.8	23	0.053	1864	146	302	102
12/4/78	2.2	18	0.039	1200	39	165	43
19/4/78	3.1	11	0.055	766	25	40	33

ABBREVIATIONS:

- FLOW-R River Flow
- FLOW-S Sewage Flow
- CONC-1 Measured concentration of COD at F₁
- CONC-S Measured concentration of COD in domestic sewage
- PCONC-2 Concentration of COD at F₂ predicted by mass balance
- OCONC-2 Measured concentration of COD at F₂
- OCONC-4 Measured concentration of COD at F₄

CALCULATION: Since FLOW-R >> FLOW-S

$$PCONC-2 = \left(\frac{FLOW-S}{FLOW-R} \right) \times CONC-S + CONC-1$$

A3.5 t TESTS SHOWING SIGNIFICANT DIFFERENCES IN CONCENTRATION OF PARAMETERS BETWEEN THE SITES IMMEDIATELY UPSTREAM AND DOWNSTREAM OF BOTH THE BORTHWICK'S EFFLUENT DISCHARGE AND THE FEILDING DOMESTIC SEWAGE DISCHARGE

I. BORTHWICK'S SITES (B_1 AND B_2)

PARAMETER	X_1	S_1	N_1	X_2	S_2	N_2	t
COD	6	2.6	8	11	6	10	2.19
PO_4 -P	0.013	0.008	11	0.07	0.07	11	2.68

II. FEILDING SITES (F_1 AND F_2)

PARAMETER	X_1	S_1	N_1	X_2	S_2	N_2	t
DO	12	2	13	9	1	13	4.84
pH	8.1	0.5	11	7.7	0.3	11	2.27
SS	5	3	12	20	10	12	4.98
BOD	1.5	0.7	11	40	30	10	4.38
COD	16	6	13	110	80	13	4.22
KN	0.8	0.6	10	4	2	10	4.85
PO_4 -P	0.12 ⁴	0.08 ⁴	13	0.3 ⁶	0.1 ⁶	13	5.07
PB	1.10 ⁴	2.10 ⁴	10	1.10 ⁶	1.10 ⁶	11	3.09
SB	8.10 ⁴	9.10 ⁴	12	2.10 ⁷	3.10 ⁷	10	2.31

ABBREVIATIONS:

- DO : Dissolved oxygen concentration (g/m^3)
- SS : Suspended solids concentration (g/m^3)
- BOD : Biochemical Oxygen Demand (g/m^3)
- COD : Chemical Oxygen Demand (g/m^3)
- KN : Kjeldahl nitrogen concentration (g/m^3)
- PO_4 -P : Orthophosphate-P concentration (g/m^3)
- PB : Proteolytic bacterial density (no/100 ml)
- LB : Lipolytic bacterial density (no/100 ml)
- SB : Saccharolytic bacterial density (no/100 ml)
- X_1 : Mean value of upstream measurements
- S_1 : Standard deviation of upstream measurements
- N_1 : Number of upstream measurements
- X_2 : Mean value of downstream measurements
- S_2 : Standard deviation of downstream measurements
- N_2 : Number of downstream measurements
- t : the t statistic

CALCULATION:

$$t = (x_1 - x_2) \left(\frac{(N_1 - 1) S_1^2 + (N_2 - 1) S_2^2}{N_1 + N_2 - 2} \right)^{-\frac{1}{2}} \left(\frac{1}{N_1} + \frac{1}{N_2} \right)^{-\frac{1}{2}}$$

SELECTED + VALUES (at the 95% confidence level)

$N_1 + N_2 - 2$	$t_{(0.025)}$
24	2.064
16	2.120
8	2.306

APPENDIX 4

BIOLOGICAL RESULTS

A4.1

THE NUMBER OF ORGANISMS COLLECTED IN BIOTIC SAMPLES
IN THE OROUA RIVER (NOVEMBER 1977 - MARCH 1978)

GROUP NAME	NOVEMBER					DECEMBER			JANUARY				FEBRUARY					MARCH				
	B ₁	B ₃	F ₁	F ₂	F ₄	F ₁	F ₂	F ₄	B ₁	B ₂	F ₁	F ₂	B ₁	B ₂	F ₁	F ₂	F ₄	B ₁	B ₂	F ₁	F ₂	F ₄
<u>Aucklandobius</u>	0	b	a	0	b	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<u>Deleatidium</u>	d	e	e	c	c	c	c	d	e	e	e	a	f	f	f	0	b	e	e	e	0	0
<u>Zephlebia</u>	0	0	0	0	0	0	0	0	a	b	c	0	b	b	0	0	0	a	a	a	0	0
<u>Nesameletus</u>	0	0	0	0	0	0	0	0	0	b	0	0	0	0	a	0	0	0	0	a	0	0
<u>Hydropsyche</u>	a	a	0	0	0	d	c	c	c	c	c	0	d	c	e	0	0	d	d	d	0	0
<u>Hydroptidae</u>	0	0	a	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<u>Polycentropididae</u>	0	a	a	0	0	b	0	a	0	c	b	0	a	c	c	0	0	a	b	0	0	0
<u>Rhyacophilidae</u>	a	0	0	0	0	a	0	b	0	c	c	0	0	0	0	0	0	0	b	0	0	0
<u>Sericostamatidae</u>	d	d	0	b	0	a	0	0	a	c	0	0	a	0	b	0	0	b	0	b	0	0
<u>Elmidae</u>	d	d	c	b	c	d	b	c	d	e	d	a	d	d	d	0	c	d	e	d	a	a
<u>Tipulidae</u>	b	b	c	0	b	0	0	0	d	e	e	b	0	0	d	0	c	0	b	b	0	0
<u>Culicidae</u>	0	0	0	0	0	0	0	0	0	0	0	a	0	0	0	0	0	0	0	0	0	0
<u>Tabanidae</u>	0	0	0	0	0	0	0	0	0	a	0	0	0	0	0	0	0	0	0	0	0	0
<u>Chironomidae</u>	c	c	c	0	c	0	b	b	d	d	e	d	d	c	e	0	c	c	e	e	0	d
<u>Simuliidae</u>	0	c	c	0	b	c	0	0	c	b	c	c	d	c	c	0	0	b	b	0	0	0
<u>Muscidae</u>	b	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	a	b	0	0
<u>S. arguta</u>	0	0	0	0	0	a	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<u>P. fluviatilis</u>	a	0	0	0	b	0	0	0	0	a	0	0	0	0	0	0	0	0	0	0	0	0
<u>P. curvirostris</u>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<u>Physca</u>	0	a	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	b	a	0	0	0
<u>Potamypurgus</u>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	b	a	0
<u>Annelida</u>	0	0	0	0	0	0	a	0	0	0	0	a	0	0	b	0	c	0	0	0	0	0
<u>Unknown</u>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	a	0	0	b	b	b	0

Key

Number of Organisms

0	0
a	1
b	2-4
c	5-13
d	14-40
e	41-121
f	122-364
g	365-1094

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