Ecological studies on high-rate biological filters with special reference to microbial biosynthesis and nitrification.

Steven Norman Young

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Summary

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Pilot scale studies of high rate filtration were initiated to assess its potential as either a primary 'roughing' filter to alleviate the seasonal overloading of low rate filters on Hereford sewage treatment works - caused by wastes from cider production - or as a two stage high rate process to provide complete sewage treatment.

Four mineral and four plastic primary filter media and two plastic secondary filter media were studied. The hydraulic loading applied to the primary plastic media (11.2 $m^3/m^3.d$) was twice that applied to the mineral media. The plastic media removed an average around 66 percent and the mineral media around 73 percent of the BOD applied when the 90 percentile BOD concentration was 563 mg/l. At a hydraulic loading of 4 $m^3/m^3.d$ the secondary filters removed most of the BOD from partially settled primary filter effluents, with one secondary effluent satisfying a 25 mg/l BOD and 30 mg/l SS standard. No significant degree of nitrification was achieved.

Fungi dominated the biological film of the primary filters, with invertebrate grazers having little influence on film levels. Ponding did not arise, and modular media supported lower film levels than random-fill types. Secondary filter film levels were low, being dominated by bacteria.

The biological loading applied to the filters was related to sludge dewaterability, with the most readily conditionable sludges produced by filters supporting heavy film. Sludges produced by random-fill media could be dewatered as readily as those produced by low rate filters treating the same sewage.

Laboratory scale studies showed a relationship between log effluent BOD and nitrification achieved by biological filters. This relationship and the relationship between BOD load applied and removed observed in all filter media could be used to optimise operating conditions required in biological filters to achieve given effluent BOD and ammoniacal nitrogen standards.

Key Words: Two stage, Performance, Biosynthesis, Nitrification.

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1. The History and Principles of Biological Filtration

1.1 Early stages in the development of sewage treatment in Britain

The problem of waste disposal, which has been prevalent ever since man adopted community life, has been compounded in Britain since the Industrial Revolution of the late eighteenth and early nineteenth centuries. One of the results of the rapid urbanisation of the population at this time was that wastes began to accumulate in the streets. In 1832, Chadwick, working for the Poor Law Commission, recognised the health hazards involved and recommended that a unified sewerage system be introduced (Sidwick and Murray, 1976). While the water carriage system relieved the pollution of city streets, the newly built sewers discharged directly to watercourses, thus, coupled with the building of many factories on the banks of rivers into which they discharged untreated wastes, the rivers rapidly became little more than open sewers.

Due to public concern over the condition of waterways in industrial areas two Royal Commissions were set up in 1865 and 1868 to study River Pollution, their inception being justified by cholera outbreaks in London in 1866 and 1872 (Hawkes, 1965). Following Frankland's discovery in 1868 (Stanbridge, 1976) that organic matter could be oxidised if sewage were allowed to percolate through a sufficient depth of soil, the Commission recommended that sewage be treated on land before discharge to rivers. With the increasing populations of towns and the resulting increased water usage, the demands for land to be used for sewage treatment soon became excessive however and new methods of sewage treatment were sought.

1.2 The development of biological filtration

Several investigations were begun in an attempt to determine methods of treatment in which greater volumes of sewage could be oxidised on smaller areas of land. As a result of such experiments at the Lawrence Research Station in America, 1887 - 1890, (Stanbridge, 1976) it was found that gravel filled filters offered distinct advantages in the treatment of sewage over similar filters filled with soil. These results generated further interest in Britain and several filters were built at this time - including those of Stoddart, Garfield, Ducat and Latham - with various media and varying degrees of success (Stanbridge, 1976).

Dibden began to experiment with contact beds. These were filters which were flooded, allowed to stand for a few hours while solids adhered to the surfaces of the media, then drained and allowed to stand for a few hours when the accumulated solids were biologically oxidised, while at the same time Crimp investigated further the use of aerobic percolating filters. The Royal Commission on Sewage Disposal was appointed in 1898 to resolve the question of which treatment processes should be used and to set standards of effluent quality which should be attained by such processes.

Over the following seventeen years the Commission instigated detailed examinations of the treatment processes available, concluding that biological filtration was significantly superior to the contact bed process, being able to treat about twice the volume of sewage, having a longer operational life and being less susceptible to clogging. The Commission also set standards for effluent quality, the standard for suspended solids content being set at three parts per hundred thousand and the standard for the amount of dissolved oxygen absorbed over five days at 65°F of two parts per hundred thousand. These standards are the 20 : 30 standards of modern sewage treatment practice, i.e. 20 mg/l Biological Oxygen Demand (BOD) and 30 mg/l Suspended Solids content (SS).

The importance of several factors governing the efficiency of percolating filters was recognised at the time, e.g. retention period of the liquid in a filter, flow rate, organic loading, ventilation, temperature and surface area and void capacity of the media, while the biology of filters was of great interest to many naturalists. Johnson (1914) published the first detailed study of the biology of percolating filters, although at the time the full significance of the role of each organism found was not understood.

After this initial period of intensive research, the next 25 years have been described by Stanbridge (1954) as a period in which most of the country's biological filters were built and little new information was gathered from research developments.

1.3 The development of high-rate biological filtration

Sewage treatment in percolating filters was restricted to relatively low hydraulic loading until the work in America of Halvorson et al. (1936), Mohlmann (1936), Levine et al. (1936) and Jenks (1937) showed that high rates of application could be used to achieve good BOD removal rates, indicating also that high rate filters could be used as primary stages to reduce the organic load to secondary or further treatment stages, or as complete treatment where only partial purification was required, as when discharged to estuaries or the sea. The publication of these results aroused great interest in Britain, especially in the light of new legislation (Public Health Act 1937) under which sewage works were obliged to accept trade wastes for treatment for the first time, coupled with the onset of the Second World War and the ensuing increase in effluent production from war time industries. The combined results of these two factors caused many sewage works to become overloaded, and high rate filtration was seen as a possible solution to the problem.

Several pilot-scale investigations into the use of high rate filters were set up, notably at Huddersfield (Goldthorpe, 1938) - where Reynoldson (1941) studied the biology of high rate filters, Leeds (Thompson, 1942), Bradford (Beedham, 1947), Dewsbury (Oldroyd, 1951), Reading (Barraclough, 1954) and Cheltenham (Peach, 1957). Promising results were obtained although, generally due to ponding difficulties, no full-scale installations were built. Tomlinson and Hall (1950) had indicated the necessity of using large media to avoid ponding, but the problem remained and largely precluded further high rate filtration studies until the introduction of prefabricated plastic media from America in 1958.

The first experiments in Britain using plastic media to treat sewage at high hydraulic loadings were carried out by Imperial Chemical Industries at Brixham (Chipperfield, 1964). The media tested were 25 - 40 mm cubes of an expanded polyurethane foam which had a high void capacity. When compared with a filter filled with coke of similar size, the polyurethane filter produced effluents of equal quality even though it was operated at 50% higher hydraulic loading. Other plastic media were tested at Brixham, including 'Surfpac' a proprietary prefabricated modular medium, and it was in view of the results obtained that further studies were initiated into the performance of plastic media. Early pilot-scale studies involved the use of one medium type only (Eden et al., 1966) although later studies compared the performance of several different media (Bruce et al., 1970).

1.4 Outline of the principles and practice of biological filtration

Sewage is composed of 99.9% water with only 0.1% polluting substances, some of which may be easily removed by settlement as solids while others will remain in suspension or solution. Sewage treatment ensures that as much of this pollution as possible is removed before discharge to the receiving watercourse.

In British sewage treatment works the sewage enters the works via a sewer, from where it is screened to remove rags and large objects. Inorganic solids such as grit are removed in slow flowing grit channels before the sewage is passed into large primary sedimentation tanks. Here the settleable organic solids are removed after an average retention period of 2 - 10 hours. The effluent from the sedimentation tanks, known as settled sewage, is then passed on to the secondary treatment stage. In Britain this stage is either an activated sludge plant or a biological filter.

In biological filters the settled sewage is applied to the surface of the filter by either reciprocating or rotating arm distributor mechanisms with jets to release the sewage spaced between 15 and 45 cm apart. These jets may be either simple or fan types - in which a splash plate beneath the jet causes the sewage to spread evenly over the filter surface.

As the sewage flows downwards through the filter towards the collecting effluent channels it comes into contact with the surfaces of the medium The medium quickly becomes coated with a layer of saprobic micro-organisms, and this film or slime in the presence of oxygen brings about the oxidation of the soluble and suspended organic matter. This is achieved by a combination of adsorption, bioflocculation, digestion, absorption, bio-oxidation and biosynthesis, producing insoluble organic waste products, carbon dioxide, water and soluble, less noxious salts. As the film accumulates it is largely controlled by grazing of macro-invertebrates, although under certain conditions of loading, low temperature and poor ventilation the film may accumulate at a higher rate than it is being consumed, resulting in the clogging or ponding of the filter. If the filter ponds the film rapidly becomes anaerobic, causing effluent quality to deteriorate.

In many instances single stage filtration is used, but with particularly strong sewages or where stringent discharge consent levels are imposed, further treatment may be necessary. This usually consists of either further filters or activated sludge, which can be followed by tertiary treatment such as application to grass plots for solids removal.

Filter effluent is usually settled in humus tanks before discharge to the receiving watercourse, and humus sludges produced are admixed with the solids from the primary sedimentation tanks. The mixed sludge so produced is then dewatered by either application to large areas of shallow drying beds, anaerobic digestion in enclosed tanks and mechanical dewatering or mechanical dewatering alone. Many sludges are difficult to dewater and require preliminary addition of chemical conditioners to facilitate rapid water removal.

Several methods of operation have been developed for use in biological filtration, usually to allow treatment at increased hydraulic or organic loadings without increased capital costs or risk of ponding. A brief synopsis of standard biological filtration operational methods is given below:-

1 Low rate filtration - hydraulic loading up to 3 $m^3/m^3.d$, usually less than 1 $m^3/m^3.d$, organic loading up to 0.6 kg $BOD/m^3.d$, usually less than 0.3 kg $BOD/m^3.d$. Filters normally single pass,

approximately 2 m deep and filled with mineral media of up to 10 cm grading.

2. Recirculation - a given proportion of the filter effluent is returned and mixed with settled sewage prior to application to the filter. Recirculation rates (ratio of sewage : recirculated effluent) can be varied as required. This results in a greatly increased hydraulic loading to the filter, while the sewage strength is proportionately diluted. The tendency of filters to pond is reduced, primarily due to the flushing action of higher volumes of liquid, effluent quality is improved due to reduced film thickness. This method was used in many early high rate filtration studies (Jenks, 1937) and is used widely in Britain in order to treat increased organic loads on low rate filters without loss of effluent quality or risk of ponding.

3. Double filtration - two filters run in series, the first as a primary 'roughing' filter and the second as a 'polishing' filter. Early experiments by Goldthorpe (1938) were based on this principle. Under high organic loadings the primary filter may tend to pond.

4. Alternating double filtration - double filtration in which the order of filters is changed at regular intervals. Principle developed by Jenkins (1937) when working on the treatment of strong dairy wastes. He found that by altering the order of the filters, the secondary filter effluent had a cleansing effect on the heavy film accumulations associated with the primary filter. This method greatly increases the organic loading which can be applied to double filters without causing ponding.

5. Controlled frequency dosing - the rate at which the distributors traverse the filter surface is reduced, the increased instantaneous wetting rate reduces surface film level and can prevent ponding. Developed by Lumb and Barnes (1948), this is another

method by which existing filters can operate at organic loadings above their design capacity.

6. High rate filtration - by definition a high rate filter is either any filter hydraulically loaded in excess of 3 m^3/m^3.d and organically loaded in excess of 0.6 kg BOD/m^3.d (Bruce and Merkens, 1970) or any filter which is operated with the intention of removing as much of the organic load applied as rapidly as possible without regard to effluent quality (Bruce and Hawkes, in press). Existing low rate filters cannot usually be uprated to operate at high rates and specially constructed filters are required. These filters normally use either large mineral or prefabricated plastic media. High rate filters are usually employed as primary roughing filters to oxidise a great deal of the organic load before discharge to a further treatment stage (often low rate filtration) or directly to estuaries or sewers.

Factors influencing the performance of high rate filters are discussed in Chapter 2.

2 High rate filtration literature review

2.1 Media

As the oxidation of sewage in percolating filters depends on contact with biologically active slime which adheres to the surface of the medium (Tomlinson, 1942), the surface area of the medium used is of major importance in determining the purifying capacity of a filter. The primary criterion in choice of media is therefore that it should have a high surface area per unit volume, or specific surface area (SSA). Due to the high organic loadings employed in high rate filtration the film levels often tend to become excessive. The second factor governing media choice must therefore be that a high proportion of the volume occupied by the media must be void space. The dimensions of the void spaces must be such that they do not allow accumulated film to impede the passage of liquid, suspended matter or access of air for aerobic respiration, while the physical configuration of the medium should ideally cause the liquid applied to the filter to become uniformly distributed over the surfaces as it travels downwards. (Min. Tech., 1968).

The SSA and size of void spaces vary inversely with the size of clean media (Schroepfer, 1951). The choice of media therefore usually represents a compromise between these two factors, depending on the degree of treatment sought and the nature of the waste to be treated (Bruce, 1968). For example, Tomlinson and Hall (1950) concluded that it was necessary to use large mineral media when treating sewage at high rates at Birmingham. Although the media had reduced SSA compared to smaller media tested, the relatively large void spaces precluded ponding which had been frequent in smaller media. Alternatively Levine et al. (1936) when using Raschig rings in experimental high rate filters concluded that small rings with high SSA and small void spaces performed better than large rings with lower SSA and larger void spaces, ponding being largely absent from both filters.

Several other factors are important in the choice of filter media. The grading should be such that the size range is compact (Bruce, 1968) and the media should possess sufficient compressive strength and durability to avoid breaking up in use and consequent clogging of void spaces (Pike, 1976). The shape characteristics of the medium are also of importance, regular shapes with rough surfaces generally providing high SSA and large void spaces, while flaky media (particles with one excessively thin dimension) have high SSA but tend to clog the voids (Schroepfer, 1951) and are unsuitable. British Standard 1438 (1971) specifies strength, shape and grading characteristics of media for use in percolating filters.

Mineral media of less than 50 mm diameter are of little value in high rate filtration due to the small size of the void spaces (Bruce, 1968), although they may be useful in secondary or tertiary high rate filters where the organic load is lower and ponding less likely (Edmonson and Goodrich, 1943). Large mineral media have been used in full scale high rate filters at Leamington (Hawkes, Personal communication), Dunstable (Andrews, 1964) and Northampton (Anon, 1963), without ponding difficulties.

Due to the limitations of mineral media with respect to SSA and void capacity, and the concomittant restriction of the loadings which can be applied without ensuing ponding, synthetic plastic media have been developed specifically for use in high rate treatment of wastes.

Plastic media have roughly double the void capacity of conventional mineral media, with up to three times the SSA, as well as offering considerable reductions in bulk density (Min. Tech., 1968). They can support large quantities of films without clogging or restricting ventilation. The earliest commercially available plastic media were of a modular design

(Eden et al., 1966). These are usually formed from vertical corrugated plastic sheets of various geometrical designs bonded together to form stackable modules, eg Flocor E, Flocor M, Surfpac. Sewage is able to trickle down over the corrugations but lateral flow is prevented. Media produced since have included random-fill designs. Most makes consist of small open ring patterns with radial septa, eg Actifil (Biopac) 50 and 90, although corrugated tube patterns are also available eg Flocor R, Flocor RC (RS), Flocor R2C (R2S). These media allow comletely random flow through of liquids.

Bruce and Merkens (1970) have shown that while SSA and void capacity of filter media exert considerable influence on efficiency, with media of similar SSA and void capacities the physical configuration and surface texture can also contribute significantly to performance characteristics. Plastic media with corrugated surfaces are generally more efficient than those with smooth, while rough textured mineral media are more efficient than those with smooth surfaces. Särner (1981) found that performance could not be related to SSA, but could to the geometry of the plastic packings he studied.

The physical characteristics of several filter media are summarised in Table 2.1.1.

The advantages of plastic media over mineral media and their general characteristics have been outlined by Chipperfield (1966) and Hemming (1968). These include:-

1. High SSA:volume ratio, allowing higher hydraulic and organic loadings and greater weights of BOD per unit volume to be removed.
2. Sufficiently open structure to avoid blockage by accumulated bios, and, in random-fill media, even size distribution avoiding restriction of void spaces by smaller pieces of media.

3. Capable of withstanding shock organic loadings and widely fluctuating hydraulic loads, as well as treating comminuted sewage.
4. Void spaces are large enough to allow unrestricted ventilation.
5. Shape characteristics are such that applied liquids flow downwards in a thin film over the bios.
6. Lightweight but retaining compressive strength.
7. Biologically inert and chemically stable.
8. Civil engineering costs in the construction of filters is reduced.
9. Less land is required to treat a given volume of wastes.
10. Humus sludges produced settle readily.

The disadvantages inherent in plastic media include:-

1. High cost per unit volume of media.
2. At high hydraulic loadings continuous distribution over the filter surface may be required, while at lower hydraulic loadings recirculation may be necessary to attain the manufacturers specified minimum wetting rates.
3. Temperature losses through plastics media may be excessive.
4. Effluent quality is usually poor.
5. Humus sludges may be difficult to dewater, and more sludge is produced per volume of waste treated.

Research work has centred on the comparison of various plastic media with mineral media, and the performance of plastic media in general. This includes the studies of Eden et al. (1966), Bruce and Merkens (1970), Joslin et al. (1971), Hutchinson (1975) and Banks et al. (1976).

Most high rate plastic media filters in Britain have been installed as primary roughing filters partially treating industrial wastes (Askew, 1967 (2), 1969 (2)), while relatively few such filters have been built at municipal sewage works. Plastic media filters are in use however at Coisley Hill, Buckfastleigh, Whinburgh, (Anon, 1969), and Kingston Seymoor (Hemming, 1973), while more recently extentions to the Scaynes Hill STW have included the installation of an Actifil (Biopac) roughing filter (Anon, 1981). Plastic media are used more extensively in France, Germany and America (Pike, 1976).

The performance of high rate filter media vary, depending on the wastes they are used to treat, and it is apparent that media which exhibit distinct advantages in the treatment of a particular waste may be unsuitable in a different situation. The principle factors involved in determining performance being the amenity to treatment of the waste, operating variables such as hydraulic and organic loading, and temperature Factors affecting performance are outlined in the preceeding sections of this chapter.

Table 2.1.1 Summary of media characteristics.

Ref.	Medium and size (mm)		SSA (m^2/m^3)	% Voids	Bulk density (kg/m^3)	Medium type
1	Raschig rings	19.0	248.7	59.4	750.9	Random ceramic
	" "	25.5	171.2	58.1	796.5	" "
	" "	38.0	114.8	68.2	653.8	" "
	" "	57.0	74.5	74.9	485.4	" "
2	Slag	25.0	196.0	38.9		Random mineral
	"	63.0	108.0	42.0		" "
3	"	100.0-150.0	40.0	50.0		" "
2	Rounded gravel	25.0	146.0	42.8		" "
4	" "	63.0	122.6	46.2	1442.0	" "
5	Granite	25.0	194.0			" "
	"	63.0	75.5	50.0		" "
1	"	25.0-76.0	98.3	45.3		" "
2	Flocor E		85.0	98.0		Modular PVC
	Flocor M		135.0			" "
	Surfpac (Crinkle Close)		187.0	94.0		" "
4	Surfpac (Standard)		82.0	94.0	60.9	" "
	Cloisonyle		220.0	94.0		Tubular PVC
6	Actifil (Biopac) 50E		124.0	91.4	76.8	Random PVC
	Actifil (Biopac) 90E		95.0	93.8	55.4	" "
	Filterpak		120.0	93.0		" "
-	Flocor R		320.0	90.0		" "
	Flocor RS		240.0			" "
	Flocor R2S		140.0			" "

References :-

1 Levine et al. (1936)

2 Truesdale and Eden (1963)

3 Bruce and Merkens (1970)

4 Eden et al. (1966)

5 Dept. of the Environment, 'Specific surface area of media for biological filters.'

6 Pike (1976)

2.2 Hydraulic loading

One of the two criteria used in defining high rate filtration is that the hydraulic load should be equal to or greater than 3.0 cubic metres of waste per cubic metre of medium per day (Bruce and Merkens, 1970). Although this is an arbitrarily derived figure it is useful in delineating high rate filtration for comparative purposes.

The effect of increasing hydraulic loading at constant sewage BOD concentration has been well documented, and it is generally agreed that increased flow rates cause a gradual decrease in percent BOD removal efficiency and increase in the weight of BOD removed (Goldthorpe and Nixon, 1942, Tomlinson and Hall, 1950, Sorrels and Zeller, 1963, Eden et al., 1966, Germain, 1966, Middlebrooks and Coogan, 1969, Bruce and Merkens, 1970, Rincke and Wolters, 1971).

Fig 2.2.1 shows a generalised plot of hydraulic load vs BOD percent removal and load removed.

The gradual decrease in removal efficiency with increased hydraulic load is due to the fact that the liquid residence time in a filter varies inversely with hydraulic load (Germain, 1966). A certain proportion of the oxygen demanding constituents of any waste is rapidly oxidised near the surface of the filter, but removal of the less readily oxidisable matter requires longer residence times. Therefore with increased hydraulic loads and lower residence times the proportion of unoxidised waste in the effluent gradually increases (Bruce et al., 1970). The relationship between increased hydraulic load and decrease in removal efficiency is not linear due to the complex relationship between hydraulic load and residence time. Increased flows tend to cause a greater proportion of the media surfaces to be utilised, increasing the active surfaces of the biological slime and thus offsetting decreases in residence time to a certain extent.

The BOD load removed increases asymptotically until no further increase in BOD weight removed can be achieved by increasing the hydraulic load. This asymptotic or upper limiting load has been observed by Sorrels and Zeller (1963), Bruce and Merkens (1970), Bryan and Moeller (1963), and Schulze (1960), although in each instance the hydraulic load and BOD load removed levels differed at the asymptote. The differences in levels observed between these studies can be attributed to differences in waste treatability, temperature, media and the nature of the biological film present in each case. The authors reasoned that the asymptote was not caused by hydraulic loading alone, rather the biological film had become 'saturated' by the upper limit of the organic loading applied. This saturation level has been reported by Schulze (1960) to be 3.8 kg BOD/m^3.d, Sorrels and Zeller (1963) 1.1 kg BOD/m^3.d and Bruce and Merkens 3 kg BOD/m^3.d. As long as the product of BOD concentration and hydraulic loading did not exceed these upper limits the filters performed efficiently and were not overloaded.

Rincke and Wolters (1971) postulated that the observed saturation levels of hydraulic load versus BOD load removed are due to the reciprocal change in substrate concentration with increased hydraulic load. Thus if either the rate of diffusion of nutrients into the biological film or their adsorption on to the surfaces become limiting due to increased intensity of rinsing and velocity of flow over the film surfaces, a hydraulic load will be reached above which no further improvements in BOD load removed will be achieved. Eckenfelder and Barnhart (1963) also postulate that as the oxygen transfer coefficient K decreases with increased hydraulic load, the rate of oxygen diffusion into the film may reach saturation levels, thus limiting the extent to which further oxidation can occur at high flow levels.

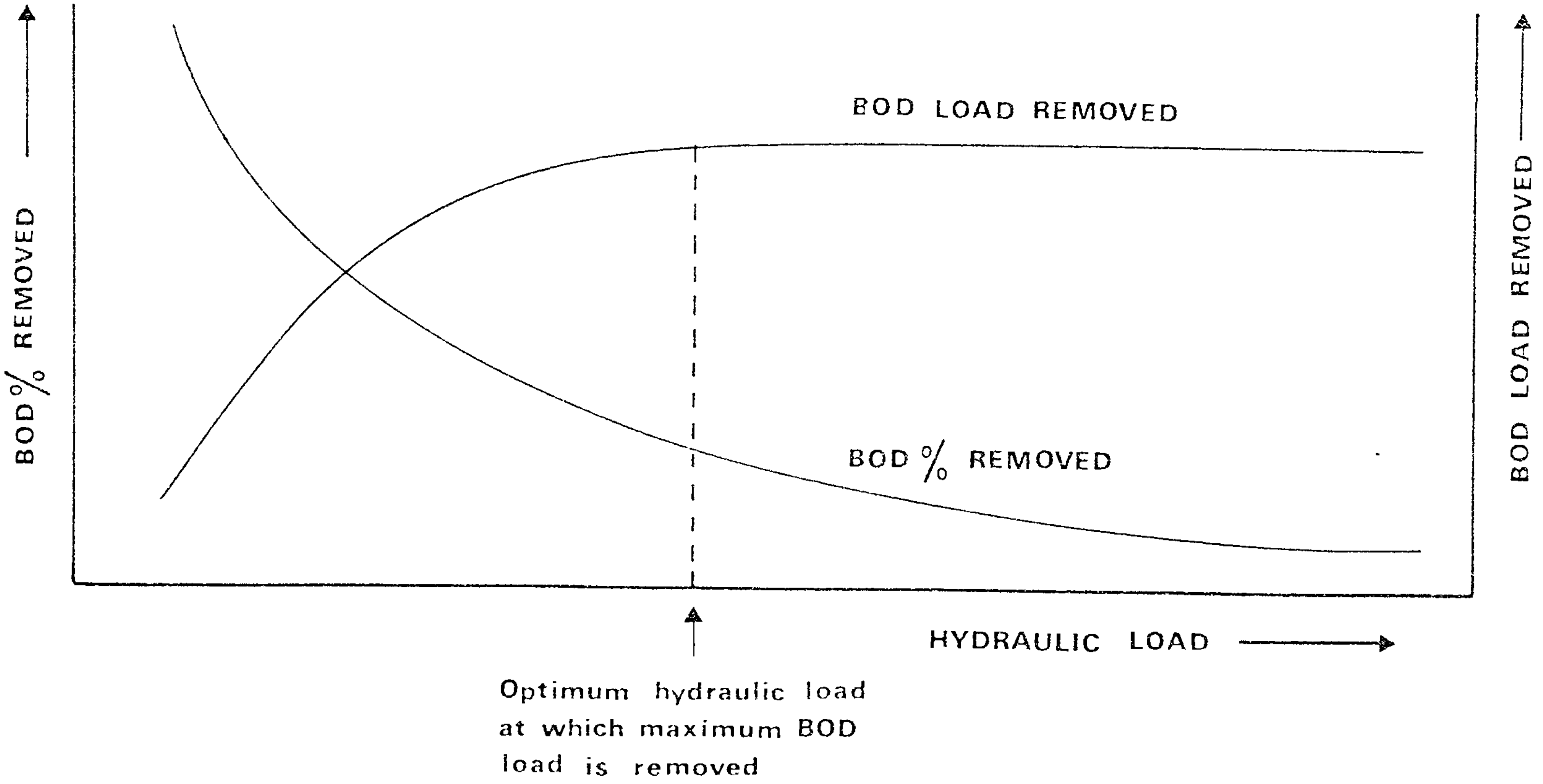
Schulze (1960) has shown that the % BOD removal obtained at a given hydraulic loading remains fairly constant over a wide range of feed strengths, therefore maximum efficiency is obtained at low hydraulic loadings and high feed BOD concentrations (Bruce and Boon, 1970, Särner, 1981). However, removal efficiency decreases at very low hydraulic loads. This is more marked with plastic media than with mineral, and is due to inefficient wetting of the media surfaces and a corresponding reduction of active bios available for oxidation. Manufacturers of plastic media stipulate minimum irrigation rates - minimum recommended flows per cross-sectional area of filter media - to ensure maximum utilisation of available media surfaces. In certain instances it may be necessary to employ recirculation to attain this irrigation rate, although experience has shown that dilution by recirculation at flows above the minimum wetting rate does not significantly improve effluent quality (Germain, 1966, Askew, 1969, Bruce and Boon, 1970), and may cause a deterioration in performance (Chipperfield, 1966).

The efficiency of a filter medium dosed at or above the minimum irrigation rate will also depend to some extent on the method used to distribute the flow to the filter surface. The distribution method can influence surface film levels (Hawkes, 1959), and also wetting efficiency. Wheatley and Williams (1981) for example showed that while all the media they examined exhibited distinct tendency towards channelling of liquids over their surfaces, maximum wetting efficiency was achieved with low surface loading rates and distributor jets fitted with splash plates. Continuous dosing in the form of a fine spray applied to the surface of high rate filters has been advocated by several researchers (Edmonson and Goodrich, 1943, Hemming, 1968, Askew, 1969) although in most instances intermittent dosing is effective (Bruce, 1976). Banks et al. (1976) have shown that provided sufficient attention is given to the use of efficient distribution methods, satisfactory performance can be attained at wetting rates significantly below the manufacturers minimum irrigation rate. At very high flows the volume of liquid applied, geometry of the medium, poor surface distribution and accumulated film can cause considerable channelling in the filter, causing a disproportionate reduction in removal efficiency (Eckenfelder and Barnhart, 1963). These factors, as well as those already mentioned, combine to determine the optimum hydraulic load for any filter medium.

The relatively high costs of the medium where plastic media are used in high rate filters places an initial prerequisite that the filter should oxidise at least as much waste per unit cost of medium as is possible with mineral media to be economically justifiable.

Although the relationship between hydraulic loading and filter efficiency can be reasonably well elucidated, no optimum hydraulic load can be specified for a particular medium for all applications, as this will depend on the physical and chemical composition of the waste to be treated and the degree of treatment sought.

Fig. 2.2.1 <u>Generalised plot of hydraulic load vs. BOD percent removal and BOD load removed at constant sewage BOD concentration.</u>



Optimum hydraulic load
at which maximum BOD
load is removed

2.3 Organic loading

Bruce and Merkens (1970) defined high rate filters as those which are operated at a hydraulic loading of equal to or greater than 3.0 $m^3/m^3.d$, although a second definition which describes more closely the mode of operation of high rate filters in Britain has been proposed. Bruce and Hawkes (in press) define a high rate filter as any filter which is operated with the intention of removing as much of the organic load applied as rapidly as possible, without regard to effluent quality. The fundamental requirement of high rate filters is therefore that they should offer the maximum work capacity in terms of weight of BOD removed per unit volume of filter (Askew, 1969), rather than the efficiency and extent of that removal as is the case in low rate filtration.

The growth rate of biological film in a filter is largely determined by the strength of the waste (Hawkes, 1965a). Very high organic loadings result in heavy film accumulation which can eventually cause the filter to clog and the removal efficiency to fall, as found by Eckenfelder and Barnhart (1963). In filters where the biological film is dominated by bacteria, the heavy film levels found when organic loading is high - particularly if the temperature is low - are due to the accumulation of adsorbed solids on the film surface which are not oxidised rapidly by the micro-organisms of the film. The accumulation of these solids, combined with the high demand for oxygen by the film in oxidising a strong waste can result in the rate at which oxygen can be transferred to the film limiting the amount of waste which can be removed by the filter (Ingram, 1959). This is particularly so in the early stages of purification close to the filter surface. Wastes havin a high carbon:nitrogen (C:N) ratio tend to result in the development of a biological film which is dominated by fungi (Jenkins, 1936). As fungi can synthesise a greater proportion of the oxidised wastes than bacteria (Water Pollution Research, 1955), the high accumulation of film found in such filters treating high BOD concentration wastes are usually mainly due to the mass of fungal mycelia and not to adsorbed solids. The thickness of the film itself in these filters is sufficient to impede the rate of transfer of oxygen to the cells below the film surface (Tomlinson and Snaddon, 1966) and this can limit the overall removal capacity of the filter.

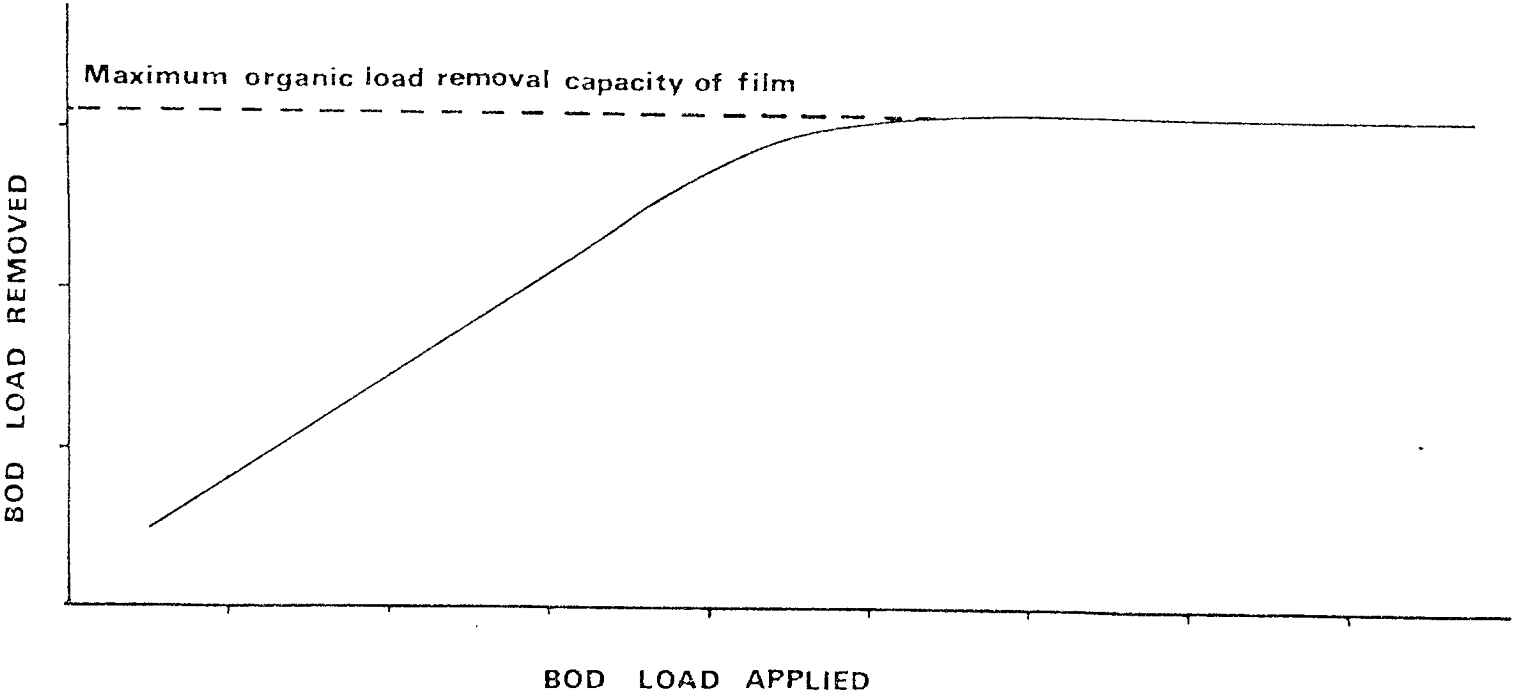
Under such conditions a maximum organic load removal capacity of the biological film would be expected, as shown in Fig 2.3.1. If this upper limiting organic load were reached further increases in the load applied would not result in an increase in the load removed because the supply of oxygen to the micro-organisms of the film would limit oxidation and the film would become 'saturated'. This was demonstrated by Bruce and Merkens (1970) at an organic loading of equal to or greater than 3.0 kg BOD/m^3.d, with a maximum removal capacity of 1.8 kg BOD/m^3.d when treating domestic sewage. They concluded that the maximum weight of BOD removed by a filter and filter efficiency would depend largely upon the medium SSA and the nature of the waste treated. Schulze (1960) found no upper limit to the removal capacity of a screen filter operated at 5 m^3/m^3.d hydraulic load and organic load of up to 6.5 kg BOD/m^3.d, but an upper limit was reached when the organic loading was further increased by raising the hydraulic load rather than the BOD concentration of the waste. Germain (1966) found no upper limit to the removal capacity of a filter operated at 8.0 kg BOD/m^3.d.

Several workers (Schulze, 1960, Germain, 1966, Middlebrooks and Coogan, 1969) have demonstrated a linear relationship between BOD applied and BOD load removed in filters in which no maximum organic loading capacity was reached. This shows that, within the loading capacity of a filter, the removal efficiency in percentage terms remains fairly constant over a wide range of feed strengths. Schulze (1960) and Bruce and Boon (1970) concluded that the real efficiency of high rate filters operated at a given hydraulic load therefore increases with feed strength, with the maximum weight of BOD removed occurring at low hydraulic loading and high BOD concentration wastes. Lower removal capacity results when the hydraulic load is increased and consequently the liquid residence time in the filter is decreased (as discussed in Section 2.2).

The effects of shock organic loadings have been reported by Middlebrooks and Coogan (1969) to be more pronounced and variable than shock hydraulic loadings when treating strong paper mill wastes, while Askew (1969) reports no more than a 10% fall in efficiency under such conditions. In industrial waste-water treatment shock organic loadings could have a more marked effect than shock hydraulic loadings. This is because the waste character and treatability is more likely to be changed by the sudden increase in the input level of a particular constituent of the waste than by a sudden increase in the volume of all of the waste constituents. Chipperfield (1966) reported an increase in sludge production rate with increased sewage strength.

The relationship between increased BOD load (induced by increasing BOD strength at constant hydraulic loading) and BOD load removed is therefore generally found to be linear, until a maximum weight of BOD removed per m^3 of filter is reached. The maximum removal capacity of filter media will vary, being influenced mainly by the treatability of the waste and the nature of the medium itself.

Fig. 2.3.1 Generalised plot of BOD load applied vs. BOD load removed at constant hydraulic loading.



2.4 Temperature

The influence of seasonal changes in temperature on biological filter performance is complex, and can be divided into direct and indirect effects. Temperature directly affects filter performance in that the organisms which are active in aerobic filters are usually mesophilic, having optima between 20 and 40°C depending on the species, and the rate at which the waste applied is biologically oxidised is therefore greater at high than at low temperature. Temperature indirectly influences filter performance through its affect on the ecology of the biological film. Macro-invertebrate grazing is severely restricted at temperature of less than 5°C, and this, coupled with an accumulation of solids which have been adsorbed on to the film surface but not yet oxidised because of a reduction in the oxidation rate of the micro-organisms, can lead to an increase in film to a level which may adversely affect performance (Shephard and Hawkes, 1975).

The direct and indirect influences of temperature on filter efficiency were observed by Shephard and Hawkes (1975) when studying experimental filters operated in the absence of grazing macro-invertebrates. On lowering the temperature from 20 to 5°C there was an initial fall in efficiency which was at least partly due to the direct influence of low temperature on microbial reaction rates. A subsequent decrease in efficiency was attributed to the fact that film levels increased at the lower temperature. The loss of efficiency at lower temperatures was more marked in filters having high levels of film, a fact which supported earlier work (Hawkes, 1961) which showed that of two identical filters, one operated at reduced dosing frequency and having low film levels, and the other operated at high dosing frequency and having high film levels, the adverse affect of low winter temperatures on efficiency was more pronounced in the filter with high film levels.

There is evidence to suggest that the method of filter operation may be an important factor in determining the influence of temperature on filter performance. In America, Schroepfer et al. (1952) found that the effect of low temperatures during winter months was less marked in filters treating high loads than in lightly loaded filters. The difference was particularly pronounced between filters treating high volumetric loads with continuous dosing and those treating low volumes of sewage with intermittent dosing. Bruce et al. (1970) reported results of experiments in which the effect of temperature on the performance of filters treating domestic sewage at 6 $m^3/m^3.d$ with intermittent dosing was very marked. Further examination of data presented in the same paper, when the filters were operated with continuous dosing of diluted domestic sewage at 12 $m^3/m^3.d$, shows that the effect of temperature was less pronounced at the higher hydraulic loadings. In these studies the dosing method used was not considered to directly affect filter performance, although there may have been an indirect affect in that the influence of temperature on filter efficiency appears to have been greater with intermittent dosing. Bruce and Boon (1970) reported, in direct contradiction to the findings of Schroepfer et al. (1952), that the effect of temperature increased with increased loading.

Low temperatures cause the dominance of fungi in biological film of filters operated under high organic loading conditions. In such filters the fungi may rapidly grow and clog the filter, leading initially to a loss of efficiency and eventually to the break down of the purification process. Although low winter temperatures in such filters are an important factor in determining the nature of the biological film which initially develops, the rate at which the film accumulates was found by Hawkes (1965a) to be more closely related to sewage strength than to temperature.

During the summer months the film levels in biological filters are usually low despite increased microbial growth rates at higher temperatures. This may be due to several factors, including the increased rate of oxidation of adsorbed solids, an increase in the rate of respiration leading to less cell synthesis, increased rate of lysis of fungal mycelia and increased grazing activity by macro-invertebrates (Hawkes, 1965, 1965a). These factors are influenced either directly or indirectly by temperature and their consequence is usually that the BOD removal efficiency of the filter increases during the summer months, as found by Schroepfer et al. (1952), Bruce et al. (1970), and others.

In practice sewage temperature does not influence filter performance as much as expected from consideration of basic principles such as the effect of temperature on biological reaction rates. This is because other factors tend to limit the oxidation process, particularly the rate at which nutrients can be transferred from the liquid to the film in low rate filters, and the rate at which oxygen can be transferred from the liquid to the film in high rate filters. The degree of influence which is exerted by temperature on filter performance depends on several other factors, including the level of film present, the dosing method and loading conditions used and also the design and construction of the filter itself. The effect of changes in temperature on BOD removal efficiency is most pronounced when the temperature of the sewage falls below about 10°C (Hawkes, Personal communication), regardless of filter operating conditions. The different conclusions drawn in the literature with respect to the effect of temperature on performance may be partly due to the difficulty inherent in dissociating the direct from the indirect influences of temperature, and partly due to the fact that the design and construction of some filters makes them more exposed and vulnerable to the effects of low ambient temperatures.

2.5 The ecology and biology of high rate filters

The organisms which inhabit biological filters may be split into those which form the film itself, and those which function as grazers of the film (Hawkes, 1965). Only a limited number of species can tolerate the specialised habitat presented by the filters, and these include truly aquatic micro-organisms and some moisture loving macro-invertebrates. The most commonly occurring species are listed by Hawkes (1965). The species composition of high rate filters is derived from that of low rate filters, although different species may dominate and species diversity is usually severely restricted. Reynoldson (1941) observed that in low rate filters at Huddersfield the macro-fauna consisted of ten species, while the fauna of a high rate filter treating the same waste was restricted to only two species, the number of individuals of each species also being greatly reduced in the high rate filter. This decrease in numbers was also observed by Usinger and Keller (1955) in experimental filters, where increased loading resulted in a marked reduction in the Psychoda population size.

Although a great deal of attention has been given to the study of the biology of low rate filters (Johnson, 1914, Tomlinson, 1939, Lloyd, 1945, Hawkes, 1963, 1965, Curds and Hawkes, 1975), comparatively little work has been carried out on the biology of high rate filters. Qualitative observations of biological film levels and dominant organisms present have been reported (Bruce et al., 1970), but quantitative studies are rare (Reynoldson, 1939, Rowlands, 1979).

The micro-organisms which successfully colonise biological filters include representatives of the bacteria, fungi, algae, Nematoda, Rotifera and protozoa. The meso-fauna includes enchytraeid worms, Collembola and mites, while the macro-fauna includes Lumbricidae and the larvae of Diptera (Hawkes, 1965). The role and interrelationships of the major representatives of the film micro-organisms and the grazing meso- and macro-fauna are briefly summarised below. Although very little work has been carried out on the biology of high rate filters, the organisms which commonly inhabit such filters are known, and this summary is based on literature concerning the biology of these organisms in low rate filters.

2.5.1 Bacteria

Bacteria form the basic trophic level and the major part of the biomass in biological filters. The dominant species are saprophytic, being responsible for the degredation of organic compounds in the wastes (Pike, 1975), and most active bacteria in filters are aerobic. Pike (1975) lists the aerobic bacteria species recorded in percolating filters, with the dominant genera appearing to be the Gram-negative rods *Zoogloea*, *Pseudomonas*, *Achromobacter*, *Alcaligeres* and *Flavobacterium*. Filamentous bacteria such as *Sphaerotilus natans* and *Beggiatoa* may also occur (Hawkes, 1965), and Bruce et al (1970) reported the bacterial population of experimental high rate filters treating domestic sewage to consist of zoogloeal and free-swimming bacteria and *Sphaerotilus*. The chemolithotrophic nitrifying bacteria *Nitrosomonas* and *Nitrobacter* often contribute significantly to the microbial population of filters, but high rate primary filters are not intended for use as nitrifying filters and the nitrifying bacteria do not contribute greatly to the bacterial activity of these filters.

The nature of the bacterial flora which develops in filters is largely determined by the nature of the waste (Hawkes, 1963), and as the bacterial population is largely sessile, microbial successions are induced through the depth of the filter in response to the conditions induced by the progressively purified waste (Pike, 1975). This microbial succession may be less pronounced in high rate roughing filters, as the loading is such that filter conditions may not improve greatly with depth.

The efficiency of filters in removing the coliform bacteria has attracted more attention than the study of the saprobic microbial population (Hawkes, 1965). Pike (1975) reported the faecal indicator bacteria to be universally present, but not indigenous, in biological filters. Low rate filters are capable of removing a very high proportion of the inflowing coli-aerogenic bacteria, but are ineffectual in removing virus particles (Pike, 1975), while the effectiveness of high rate filters was found by Bruce et al. (1970) to be at most 50% reduction of coli-aerogenic bacteria. As most high rate filters are used to either precede some secondary treatment facility, or prior to discharge to sea where dilution factors are high, this loss of coliform removal efficiency is not usually of importance.

2.5.2 Fungi

Most of the fungi which occur in biological filters are in direct competition with the heterotrophic bacteria as primary feeders on the organic waste in the sewage (Hawkes, 1963). In filters where fungi become dominant, luxuriant growths of mycelia may cause nuisance and loss of efficiency by impeding the flow of sewage through the filter and eventually by preventing adequate ventilation within the filter. This can lead to the break-down of the aerobic purification process and to ponding, Therefore, although saprophytic fungi have been shown to be as capable as bacteria in oxidising organic wastes (Water Pollution Research, 1955), they are generally considered as undesirable as dominant members of the film (Tomlinson and Williams, 1975). Saprophytic fungi have been shown to synthesise greater biomass for weight of nutrient utilised than certain of the bacteria important in purification (Water Pollution Research, 1955), and their dominance in the filter can therefore result in rapid film accumulation under favourable conditions.

The bacterial-fungal competition is therefore an important factor in the operation of biological filters, and the outcome of this competition is itself dependent on several operational factors. Low temperatures favour some fungal species, eg Sepedonium sp. as they have lower temperature optima than most other organisms found in filters (Tomlinson and Williams, 1975). Higher temperatures cause an increased rate of mycelial lysis (Tomlinson, 1942a, Hawkes, 1965a), as do starvation conditions (Hawkes, 1965a). Strong sewage, sewage having a high proportion of industrial effluent and sewage having a high carbon:nitrogen (C/N) ratio favour a fungal film (Hawkes, 1965a). Hawkes (1965a) found that although both low temperatures and strong sewage were important factors in determining whether fungi became dominant, the growth rate of Sepedonium sp. in pure culture was more closely related to sewage strength than to temperature. Fungi may dominate the surface layers of filters, where sewage strength is high, while bacteria may gradually become dominant within the depths of the filters as the waste is progressively purified (Hawkes, 1963). Fungi often dominate during the winter months, while bacteria may dominate in the summer, particularly if the sewage is weaker during the summer months.

As both bacterial lysis of fungal mycelia and invertebrate grazing activity are more severely restricted by low temperatures than are the growth rates of some fungi (Tomlinson and Williams, 1975), the film may accumulate without any external biological control during the winter. As temperatures rise during spring - an occurrence frequently coinciding with a reduction in sewage strength - the microbial lysis of mycelia increases, leading to an initial reduction in film levels due to the subsequent sloughing of the film (Hawkes, 1965a). The invertebrate grazing population can multiply once conditions in the filter have improved following the initial reduction in film levels, and through its activity can contribute to the control of film levels through the summer (Hawkes, 1965).

The control of fungal film accumulation through the biological activity of the microbial and invertebrate grazing populations of the filter is therefore possible during the warm summer months. During the winter however the inherent biological control mechanisms frequently break down. A great deal of research work has therefore been directed towards developing operational techniques for use in the control of film accumulation, largely to enable high organic loadings to be treated on conventional filters without risk of ponding in the winter months (Hawkes, 1965). Alternating double filtration (ADF), recirculation and low periodicity dosing are all reasonably successful in controlling film levels in such filters, all of these techniques exerting a degree of nutritional control on the film (Hawkes, 1961). In high rate filters however there has been little research on film control measures, the large void spaces of media used in such filters often providing sufficient capacity to accomodate the heavy film accumulations expected when treating high organic loadings, thus avoiding ponding and loss of efficiency.

2.5.3 Protozoa

Three main groups of protozoa have been recorded in biological filters - ciliates, flagellates and amoebae. The ciliated protozoa are usually the most abundant group, and most of these feed on bacteria suspended in the liquid waste, although some are carnivorous, feeding on other ciliates (Min. Tech., 1968). Curds (1975) gives a comprehensive list of the protozoan species recorded in biological filters.

The role of protozoa in biological filters is considered to be of secondary importance to the operation of the plant. Curds et al. (1968)

reported experiments in which the introduction of ciliated protozoa to experimental activated sludge plants previously operated in the absence of protozoa resulted in an improvement in effluent quality. Effluent turbidity also decreased - due mainly to a large reduction in the numbers of suspended bacteria. The protozoa are therefore important in clarifying the effluents of activated sludge plants, and their role in biological filters may be the same. The removal of suspended bacteria by ciliated protozoa is mainly through predation (Curds, 1975).

Different protozoa have been reported as predominating at certain levels in biological filters operated at conventional rates. The species most tolerant of polysaprobic conditions being prevalent in the surface layers where the sewage is strongest, eg amoebae and flagellates. In some filters the middle regions of filters are colonised by a more varied fauna, mainly comprising of ciliates, while the protozoa at the base may be restricted to peritrichous ciliates (Hawkes, 1965). Barker (1946) has shown that the zonation within filters is modified by sewages of different strengths. With weak sewage the surface population is larger and more diverse, while the basal population is more restricted. With strong sewage the fauna of the surface and middle layers is severely restricted, while the basal fauna is diverse and numerous. Several workers (reviewed by Curds, 1975) have attempted to explain the vertical distribution of protozoa in filters by the association of each species with different levels of saprobity found in the habitat.

In high rate filters the zonation of protozoa may not be as pronounced as reported in low rate filters. This may be due to the greater turbulence induced by the larger volume of sewage passing through the filter, combined with the fact that high rate filters are normally used to partially treat strong wastes and great differences in saprobity may not exist between the surface and basal layers, especially in cases where the effluent BOD is high.

2.5.4 Grazing fauna

Micro-organisms which actively graze on the film include Tardigrada, Rotifera and Nematoda. Enchytraeid worms are common meso-fauna, as are Collembola and mites, while the macro-fauna are represented by Lumbricidae and Dipteran larvae (Hawkes, 1965).

Nematode worms are probably the most important grazing micro-organisms. Schiemer (1975) lists nematode species found in biological filters. Most of the species inhabiting filters are bacteria feeders, while some feed on other nematodes and rotifers. Enchytraeid worms are found in most biological filters (Hawkes, 1965), although Bruce and Merkens (1970) reported that they were absent from high rate filters treating domestic sewage at Stevenage. Other high rate filters, treating municipal sewage at Northampton, supported healthy populations of enchytraeids. Literature demonstrating the ability of annelid worms to control the biological film levels by grazing in experimental filters is reviewed by Solbē (1975).

Collembola and mites are not normally major representatives of high rate filter fauna, nor are lumbricid worms. Some of the earthworms have been reported to prefer small grade media, possibly due to their strong thigmotactic response, and they are therefore unlikely to become established on high rate filter media. The flushing action of sewage in high rate filters may also be too great for the larger worms to withstand (Solbē, 1975).

The larvae of Diptera are the most abundant representatives of the high rate filter grazing macro-fauna, with Psychoda frequently dominating to the virtual exclusion of all other fly larvae. The biology and seasonal incidence of flies in low rate filters has been studied by Lloyd (1937, 1945). While in low rate filters the emergence of filter flies has caused considerable nuisance in the vicinity of some sewage works in the past (Hawkes, 1965), Bruce and Merkens (1970) reported that no adult *Psychoda* were seen to leave the surface of high rate filters operated at 6 m^3/m^3.d, although their larvae were plentiful in the filters. Learner (1975) attributes this to the method of operation of high rate filters, with the high volumes of sewage applied to the filter preventing the adults from gaining ready access to the filter surface. *Psychoda* spp. can mate within the confines of the filter under such conditions.

Diptera which are most commonly found in biological filters, together with *Psychoda* spp., include *Hydrobaenus minimus* and *Metriocnemus hygropetricus* (Chironomidae) and *Sylvicola fenestralis*. The frequent dominance of high rate filter film by *Psychoda* spp. can be attributed to biological factors. The chironomid larvae are not normally found in filters having thick biological film, possibly because these larvae have a closed tracheal system and can only obtain oxygen by diffusion through the body surface. Both *Psychoda* and *Sylvicola* larvae have respiratory siphons, enabling them to draw oxygen from the air while feeding from thick film (Learner, 1975). Tomlinson and Hall (1950) showed that increasing the hydraulic load to a level above 1.8 m^3/m^3.d resulted in a decline in the *S. fenestralis* population, while Bruce and Merkens (1970) reported that *Psychoda* sp. larvae were plentiful in filters operated at 6 m^3/m^3.d hydraulic load. Hawkes (1965) considered that strong sewage restricted the flies present in filters to *P. alternata* and *Spathiophora hydromyzina*, while *S. fenestralis* was found to be the dominant species in some filters treating industrial sewages.

The extent to which the grazing fauna is capable of controlling the level of film in filters has been the subject of considerable debate (Hawkes, 1965). In filters operated under conventional conditions, the grazing fauna have been shown to be very important in preventing the filters from ponding (Reynoldson, 1939, Hawkes, 1965, Williams and Taylor, 1968), particularly if the film is dominated by bacteria. Under heavy loading conditions however, and where the film is dominated by fungi, the grazers cannot control film levels when temperatures are low. In such filters, during the winter months, it is possible that the levels of film accumulation controls the incidence and abundance of the grazing population, rather than vice versa (Hawkes, 1965). Bruce and Merkens (1970) concluded that the activity of the insect grazers was not important in affecting the degree of treatment obtained in high rate filters having low levels of film.

Williams and Taylor (1968) report a further contribution made by the invertebrate grazing fauna to the satisfactory operation of biological filters. In experimental filters they found that the solids in effluents from filters containing Psychoda larvae as the sole macro-invertebrate, or Psychoda and Lumbricillus, settled more rapidly than solids in effluents from filters without macro-invertebrates. This was attributed to the greater density of animal fragments and faecal material in the effluent solids.

2.6 Humus sludge production and characteristics

Humus sludge consists principally of solids formed within the filter by biological synthesis, together with flocculated and partially oxidised suspended solids from the incoming waste. The rate at which humus sludge is discharged by the filter is usually expressed in terms of the weight of solids produced per weight of BOD removed - either g/g BOD removed or kg/kg removed, and this rate has been found to be higher in most high rate than low rate filters (Goldthorpe and Nixon, 1942, Bruce et al., 1975). The average sludge production rate of low rate filters treating domestic sewage at Stevenage was reported by Bruce and Boon (1970) to be 0.22 g/g BOD removed, whilst high rate filters treating the same waste produced between 0.63 and 1.0 g/g BOD removed. The rate at which sludge is produced also depends on the nature of the waste being treated (Bruce and Boon, 1970). Seasonal variations in sludge production rate are more marked in low rate filters, due to the spring offloading of film - a phenomenon not generally observed in high rate filters.

As the humus sludge is principally of biological origin, changes in the biology of the filter could be expected to exert some influence on the character of the sludge produced. Williams and Taylor (1968) showed that the effluent solids produced by experimental filters settled more readily if invertebrates were present in the filters than if they were absent. The biology of the filter has also been reported to affect the volume of sludge produced, with sludge production rates being higher if the film is dominated by fungi than if the film is largely bacterial (Water Pollution Research, 1955). This conclusion was contradicted by the work of Hawkes (1965a) who found that *Sylvicola fenestralis* larvae produced less humus when feeding on biological film which consisted mainly of fungal mycelium than when feeding on activated sludge which consisted mainly of flocculated bacteria. This difference in sludge production rate was attributed to the fact that fungal autolysis tends to produce a soluble discharge and hence film dominated by fungi produces less humus sludge.

Dewatering the humus sludge produced is frequently the most capital intensive process in sewage treatment by biological filtration, and is employed to reduce the sludge to a solid cake which can be readily handled and disposed of. In the past the most common method used was to dry the sludge on open sand beds fitted with under-drains. There is an increasing trend in Britain towards the use of mechanical dewatering however, particularly in urban areas where land is expensive and where drying beds cannot be used without prior anaerobic digestion of the sludge to prevent odour nuisance (Gale, 1968).

The main types of mechanical dewatering equipment used in Britain are filter presses, rotary vacuum filters and rotary sludge concentrators, while centrifugation is also used both in the USA and on the continent (Gale, 1968). For satisfactory operation of mechanical dewatering plant the specific resistance to filtration ($\bar{r}$) of the sludge must be around 1.0×10^{12} m/kg (Gale and Baskerville, 1970). As the $\bar{r}$ of undigested mixed primary sludge is frequently between 100 and 200×10^{12} m/kg (Gale, 1971), conditioning of the sludge to reduce $\bar{r}$ is required before mechanical dewatering can be effectively used. In Britain the most commonly used conditioning method is chemical flocculation, although heat treatment, slow freezing and thawing and anaerobic digestion can also be effective conditioning techniques (Gale, 1971).

The chemicals used in conditioning sewage sludges are either inorganic salts, such as lime, ferrous sulphate, aluminium chloride or aluminium chlorohydrate, or more recently synthetic organic polyelectrolytes (Gale, 1977). The mode of action of these chemicals - which act as flocculants of dispersed particles of sludge held in suspension, thus allowing more rapid and complete settlement and mechanical dewatering - is outlined by Gale and Baskerville (1970) and in the case of polyelectrolytes by Thomas (1966). Gale and Baskerville (1970) concluded that it was not possible to give a generalised ranking of chemicals in order of their merit in conditioning sludges of different origins, and that experimental work was needed to find the best product and dose for each sludge.

Although several different conditioners may effectively flocculate a sludge, the flocs formed by the act of conditioning can vary in mechanical strength. Weak flocs can break down under mechanical shear forces exerted on the sludge during stirring and pumping, thus losing the conditioning effect of the chemical. Conditioned sludge floc strength has been shown to be affected by both the type and dose of chemical used in conditioning (Min. Tech.,1967, Gale et al., 1967). Gale and Baskerville (1970) reported that of the sludges they tested, those conditioned with aluminium chlorohydrate were in many cases more resistant to shear than those treated with polyelectrolytes. As increased susceptibility of flocs to disruption by shear forces increases the amount of coagulant required to achieve satisfactory dewatering characteristics, the effect that each conditioner has on the mechanical strength of the resulting flocs is an economically important factor in the choice of chemical conditioner. The choice of conditioner is therefore dependent on both the cost and effectiveness of the chemical and dose chosen and on the affect of that chemical dose on floc strength.

Several authors have concluded that high rate filter humus sludges are more difficult to dewater than low rate filter sludges (Bruce and Merkens, 1973; Bruce et al., 1975, Banks et al., 1976, White et al., 1977). White et al. (1977) also found that high rate filters - treating domestic sewage - produced sludges which were very unstable, settled poorly and staled quickly. Other workers however have concluded that high rate filter sludges are no more difficult to dewater than low rate sludges

(Eden et al., 1966, Hemming, 1968, Askew, 1969, Joslin et al., 1971), while Chipperfield (1966) and Askew (1969) reported that high rate filter sludges settled more readily than low rate sludges. The differences observed in the dewaterability of high rate sludges may in part be due to differences in the wastes being treated, although further study of this problem is required.

2.7 Nitrification in biological filters

2.7.1 Introduction

The presence of ammoniacal nitrogen in sewage effluents discharged to a watercourse, where either the dilution factor is low or water is to be abstracted downstream, can cause severe problems with regard to both the biology of the watercourse and the cost of treatment of the water for potable use. Ammonia is toxic to fish in its dissociated form, and the degree of dissociation is very sensitive to the pH of the water, with dissociation increasing at high pH. Toxicity also increases if the oxygen content of the water is low (Merkens and Downing, 1957). In addition ammonia can cause considerable deoxygenation due to its subsequent oxidation in the water (Pike, Personal communication). Duddles et al. (1974) reported that 75% of the total oxygen depletion within a 16 km downstream stretch of the Grand River at Lansing, USA, was caused by nitrogenous oxygen demand. Ammonia also forms chloramines, increasing the chlorine demand in treating water abstracted for potable use.

The presence of ammoniacal nitrogen is therefore of considerable ecological and economical importance. Consequently many Water Authorities now impose ammoniacal nitrogen discharge standards in addition to the traditional 20 mg/l BOD and 30 mg/l SS standards. These standards are usually of the order of 5 mg/l NH_3-N in summer months (May - October) and 10 mg/l NH_3-N in winter months (November - April), although in some instances a single standard is imposed throughout the year (Bruce et al., 1975).

A brief survey of the literature on nitrification, including the environmental factors known to affect the process in sewage treatment plant and the chemistry and biology involved, follows.

2.7.2 The biology and chemistry of nitrification

Two chemolithotropic bacteria are responsible for nitrification in sewage treatment plants (Painter, 1970), these bacteria being of the same species as found to be responsible for nitrification in soils (Barritt, 1933). The oxidation of NH_4^+ to NO_2^- is carried out by Nitrosomonas, and the subsequent oxidation of NO_2^- to NO_3^- by Nitrobacter. The energy produced by these reactions is then utilised by the bacteria to reduce CO_2 to carbohydrates and other carbon compounds used in cell synthesis. Oxygen is required for the oxidation of both NH_4^+ and NO_2^- ions and the bacteria are therefore aerobic, although they can survive long periods of anaerobicity during which time growth ceases (Painter, 1970).

The basic reactions of nitrification are (Downing et al., 1964)

$$2NH_4^+ + 3O_2 \xrightarrow{\text{Nitrosomonas}} 4H^+ + 2H_2O + 2NO_2$$

$$2NO_2^- + O_2 \xrightarrow{\text{Nitrobacter}} 2NO_3^-$$

Production of hydroxlamine is known to be an intermediate step in the oxidation of NH_4^+ to NO_2^-, and it is believed that there may be another intermediate oxidation product in this reaction although it has yet to be identified. No intermediates in the oxidation of nitrite to nitrate are known to exist (Painter, 1977).

The complete oxidation of 1 mg NH_4^+ ion to NO_3^- ion has been calculated to consume between 4.5 (Sharma and Ahlert, 1977) and 4.6 mg O_2 (Bliss and Barnes, 1981), and as the nitrifiers can only grow by utilising oxidative reactions their oxygen consumption rates are high. Most research into the dissolved oxygen (DO) requirements for complete nitrification has been carried out with either activated sludge or culture techniques. Knowles et al. (1965), working with mixed nitrifying cultures, found that nitrification was inhibited at DO concentrations of less than 0.6 mg/1, while Downing et al. (1962), working with activated sludge found no nitrification below a critical DO of between 0.5 and 0.7 mg O_2/1. Downing et al. (1962) and Wild et al. (1971) concluded that there was no inhibition above a DO concentration of 1 mg/1, although Wuhrmann (1963, reported in Painter, 1970) reported that nitrification in activated sludge plants proceeded to a lesser degree at a DO concentration of 1 mg/1 than at corresponding concentrations of 4 and 7 mg O_2/1. For complete nitrification a requirement for dissolved oxygen in mixed liquor at a greater concentration than 1 mg/1 is generally accepted as necessary, while many activated sludge plants are operated at 2 mg O_2/1.

The carbon source used by nitrifiers for cell sythesis can be either gaseous CO_2, carbonates or bicarbonates in solution, or possibly the by-products of heterotrophic bacterial respiration (Barritt, 1933). These sources are all readily available in sewage treatment plants and are not considered likely to become limiting. Nitrifying bacteria have been grown on glucose in the absence of their specific energy sources, either NH_4^+ or NO_2^-, when dialysis was used to remove toxic substances (Pan and Umbreit, 1972), although organic compounds cannot replace CO_2 as the carbon source for Nitrobacter (Delwiche and Finstein, 1965). While the growth of Nitrobacter can be stimulated by the addition of compounds such as acetate (Delwiche and Finstein, 1965), there is little evidence of a basic requirement for organic carbon (Painter, 1970).

Growth rates of nitrifying bacteria are very low in comparison to those of the heterotrophic bacteria in sewage. The generation time of Nitrosomonas is estimated to lie between 8 and 36 hours, while the generation time of Nitrobacter lies between 12 and 59 hours (Sharma and Ahlert, 1977). Generation time varies depending on several environmental factors, including temperature, oxygen supply, pH etc. As a result of these slow growth rates nitrification in sewage treatment processes usually develops slowly, and in newly commissioned filters there may be a considerable time lag before significant nitrification is achieved.

2.7.3 Environmental factors affecting nitrification in biological filters

Biological filters operated at low loading rates, with no inhibitory substances present in the sewage, usually produce well nitrified effluents under favourable temperature conditions. Increasing the loading rates leads to more erratic nitrification performance however, and quantification of the factors which are responsible for this loss of efficiency is difficult.

The effects of increasing the organic loading in filters where nitrification was previously taking place have not been fully quantified in the past, although Grantham (1951) and Sorrels and Zeller (1956) showed that the degree of nitrification achieved generally decreased with increased organic loading. It was once thought that the presence of organic matter in the waste was directly inhibitory to the nitrifying bacteria, although several workers have since demonstrated that both nitrification and carbonaceous oxidation can take place simultaneously in filters (Jenkins, 1931, Heukelekian, 1947, Tomlinson and Snaddon, 1966). Organic matter is not now generally believed to be inhibitory (Painter, 1977). Nitrifying bacteria are unable however to compete successfully with heterotrophs if substantial quantities of organic matter are present in the waste. Wild et al. (1971) recommended a feed BOD of 40 - 50 mg/l for nitrifying stages. The oxidation of stronger wastes by heterotrophs could result in oxygen concentrations in the film which are below the level required by nitrifying bacteria (Barritt, 1933, Heukelekian, 1947, Tomlinson and Snaddon, 1966), while if the sewage is strong, with a high carbon:nitrogen ratio, the rapidly growing heterotrophs would tend to take up much of the ammonia required by Nitrosomonas and hence reduce the nitrification rate (Painter, 1970). For these reasons nitrification is unlikely in either high rate roughing filters, which usually have high BOD effluents, or in the surface layers of low rate filters. Hawkes (1957) has suggested that the most biologically efficient means of obtaining fully nitrified effluents would be to employ two stage biological filtration, in which the primary filter serves to remove most of the organic matter in the waste, leaving the secondary filter to act purely as a nitrifying stage. This is supported by the findings of Bruce and Merkens (1970) who reported good nitrification in a two stage filtration plant in which the primary filter was high rate. Later research (Bruce et al., 1975) at Stevenage using a similar two stage system to treat domestic sewage produced poor quality effluents.

The effect of hydraulic loading on nitrification in biological filters is also difficult to quantify. If the flow rate is sufficiently low substantial nitrification is usually obtained, as it is increased however the degree of nitrification has been shown to decrease (Grantham, 1951, Balakrishnan and Eckenfelder, 1969). The removal of ammonia by nitrification is believed to be in accordance with a zero-order or concentration independant reaction, as the saturation concentration for the oxidation of ammonia by Nitrosomonas is only approximately 1 mg/l (Bruce et al., 1975). For ammonia concentrations of greater than 5 mg/l, the reduction in concentration (and not the percentage removal) during treatment is therefore believed to be inversely proportional to hydraulic loading and to the specific surface area of the filter medium (Pike, Personal communication). Because of the low growth rates and activity of the nitrifying bacteria, filters designed specifically for nitrification therefore usually have a medium of high specific area relative to the volumetric loading, allowing the necessary prolonged period of contact between the waste and the biological film (Pike, Personal communication).

Solbē et al. (1974) showed that the effect of temperature changes on filter efficiency was more marked in the case of nitrification than for carbonaceous oxidation. This was attributed to the beneficial effect of increased temperature on the activity of nitrifying bacteria, interacting with other temperature dependant factors controlling bacterial numbers. These include the increased biological control of film levels at higher temperature which leads to a decrease in film depth, an increase in active surface area of the filter and in the access of oxygen to the film and consequently to an increase in the numbers nitrifying bacteria available (Tomlinson and Snaddon, 1966). The direct influence of higher temperatures on microbial reaction rates combined with the indirect influences of lower film levels and improved filter conditions therefore contribute to the enhanced nitrification usually achieved by biological filters during the summer months.

The direct influence of temperature on the growth rate of <u>Nitrosomonas</u> in activated sludge plants was demonstrated by Downing et al. (1964) who calculated that the growth rate roughly doubled for each ten degree increase in temperature in the range 6 - 25°C. Although nitrifying bacteria have been shown to grow at temperatures considerably below 10°C in pure culture studies (Painter, 1970), the nitrification rate in biological filters is significantly reduced as temperature falls below 10°C (Bruce et al., 1975). Poor nitrification performance in the second stage of a pilot scale two stage filtration plant - in which the primary stage was high rate - was attributed in part to a 4 - 5°C fall in liquid temperature through the pilot plant in the winter, which resulted in final effluent temperatures being well below 10°C. The rate of removal of ammonia by the two stage plant increased by 4.5 mg N/m^2. day for each degree rise in temperature between 6 and

$20^{\circ}C$ (Bruce et al., 1975).

Nitrifying bacteria, particularly Nitrosomonas, are also susceptible to a large number of inhibitors (Painter, 1977). Substances inhibitory to nitrification in the activated sludge process are listed by Downing et al. (1964), Tomlinson et al. (1966) and Wood et al. (1981). Inhibition can occur by interference with either the general metabolism of the cell or with the primary oxidation reactions, and the phenomenon has been reviewed by Painter (1970, 1977). While the activated sludge process is very sensitive to the presence of inhibitors, biological filters in general have been shown to be rather less sensitive (Downing et al., 1964). High rate filters were found to remove most of the inhibitory material present in municipal sewage which included chemical industry effluents, enabling a greater degree of nitrification to be achieved in a second stage activated sludge plant (Downing et al., 1964). Hawkes (in discussion to Downing et al., 1964) attributed the removal of these inhibitory materials to the activity of the organisms of the biological film in the surface layers of the filters.

3 Introduction

Hereford Sewage Treatment Works (STW) receives a sewage which changes markedly in composition and strength throughout the year, mainly due to the wastes produced in the highly seasonal industry of cider production. Wastes from a vegetable canning works have also contributed to the seasonally high organic load received by the works in the past. Both of these industries produce wastes rich in organic matter and of high BOD, although they contain little nitrogenous matter. The resulting high C:N ratio encourages the development of very heavy fungal growths on the existing biological filters, particularly during the low temperature period between October and January when apple crushing during cider production is at its peak.

Pilot scale studies were therefore initiated with the objectives of investigating the possibility of introducing two stage biological filtration with a high rate primary stage and intermediate secondary stage to alleviate the problem and increase the capacity of the works, and to determine whether two stage high rate filtration could be used to produce Royal Commission standard effluents when treating seasonally strong municipal sewage.

The pilot plant provided the facilities for detailed study of the biology and physico-chemical performance of various high rate filtration media, as well as to study the dewaterability of the humus sludges produced by each of these filter media. Field laboratory facilities provided the opportunity to determine the nitrifiability of the secondary filter effluents and to examine the relationship between the degree of nitrification achieved in biological filters and organic loading.

The primary filtration units of the pilot plant were first commissioned in 1974 and early data concerning their performance - at lower hydraulic loadings than those reported here - are presented elsewhere (Rowlands, 1979). The secondary filtration unit was commissioned during the period of study with which this thesis is concerned (September 1978 - May 1981).

3.1 Aims and objectives

The aims and objectives of the work reported here were as follows

i) To observe and monitor the performance of single and two stage high rate biological filters with reference to BOD, SS, COD and NH_3-N removal and sludge production under conditions of seasonal variations in sewage strength and composition.

ii) To observe and compare the performance of four plastic and four mineral biological filter media as high rate primary filtration media, and to observe and compare the performance of two plastic biological filter media as secondary filtration media.

iii) To observe and monitor seasonal changes in the levels of accumulated film and to observe the effects of changing the periodicity of dosing on film distribution and filter performance in high rate biological filters.

iv) To observe and monitor the ecology and biology of primary and secondary stage high rate biological filters.

v) To characterise the humus sludges produced by primary and secondary high rate filters, to monitor any seasonal changes in the conditionability of such sludges, to investigate the effectiveness of various chemical conditioning agents in assisting the dewatering of humus sludges and to compare the dewaterability of high and low rate humus sludges.

vi) Using laboratory scale filters - to ascertain whether the effluents from the second stage of a two stage high rate biological filtration system could be fully nitrified, and to investigate the relationship between organic loading and nitrification in biological filters.

4 Methods and materials

Pilot plant

The pilot-scale filters, situated at the Eign Road sewage treatment works (STW), Hereford, consisted of two brick-walled octagonal 'primary' filters which had been used in previous high rate filtration work (Rowlands, 1979), and an adjacent steel-walled Braithwaite tank converted for use as a secondary filtration unit. One of the octagonal filters contained four different mineral media in separate sectors, while the other contained four different plastic media, again in separate sectors. The secondary filter was divided into two equal sections, each containing a plastic filter medium. Table 4.1.1 lists sector numbers and filter media used, while Figs 4.1.1, 4.1.2a and 4.1.2b are diagrammatic representations of the primary and secondary filter units. The three structures were all constructed entirely above ground level and are shown in Plates 4.1.1 and 4.1.2. Each stage of the pilot plant was protected from the accumulation of fallen leaves from a nearby oak tree by the construction of chicken wire cages above each filter. These cages can be seen in the pilot plant photographs.

4.1 Primary filters

The two octagonal primary filters were each divided into sectors, each sector containing one type of filter medium and having a separate effluent drain and sump (to facilitate easy sampling of effluents). Plate 4.1.3 illustrates the design of these effluent sumps

The first of the primary filters contained mineral media, and was divided into eight sectors (Fig 4.1.1 and Plate 4.1.4), with diagonally opposed sectors filled with the same filter medium. Duplication in this manner was used to provide greater statistical confidence in any differences observed between the performance of different filter media.

One of each of the duplicated sectors had three perforated galvanised steel shafts inserted as shown in Fig 4.1.1 and Plate 4.1.5. Each shaft was 1.8 m deep and 225 mm internal diameter (ID) with 19 mm diameter perforations to allow unrestricted lateral flow of wastes both into and out of each shaft. Five baskets constructed from 19 mm mesh 'Netlon' plastic garden netting, four of which were 400 mm deep and one 200 mm deep (all had a diameter of 210 mm), were filled with the appropriate filter medium and lowered into each shaft by means of nylon twine tied to the top of each individual basket. The 200 mm basket was used as the top basket in each shaft. These shafts were used to study the biology of each filter, using the methods described in Section 4.6.1.

A 2 metre deep, 37.5 mm ID, 16 SWG wall thickness duralumin access tube was installed in each of the sectors (Fig 4.1.1 and Plate 4.1.5), each tube having the base blanked off with a rubber bung and a removable rubber bung in the top used to prevent the tube filling with sewage. In addition to the rubber bung, a plastic sleeve was placed over the top of each tube to keep the inside of the tube completely free from moisture. The tubes were positioned in such a way that they were surrounded by a radius of at least 300 mm of the filter medium, and each was placed in the same position within the filters. These tubes were used in the determination of the percentage of voids in the filter media which were saturated, using the neutron moisture meter technique, as described in Section 4.6.2.

The base of each sector was raised slightly and drainage tiles were used to prevent the accumulation of standing effluents. Each sector had a 63.5 mm ID uPVC pipe inserted to facilitate adequate ventilation, the upper end extending to above the level of the filter retaining walls and the lower end terminating at the level of the drainage tiles (Plate 4.1.5).

The temperature within each sector of the filter was monitored using a resistance probe from a Foster Cambridge Clearspan continuous temperature recorder. This recorder was fitted with 17 such probes, one of which was inserted into the side of each of the 16 sectors of the two primary filters at a distance of 1600 mm from the surface (each probe being 570 mm long), while one was used to continuously record the temperature of the sewage in the primary filter header tank. Continuous recording of the output from three of the probes was possible, and the sectors recorded were changed daily so that the temperature of each sector of the primary filters was recorded continuously for at least 24 hours once in every ten working days.

Settled sewage from one of the primary settlement tanks on the Eign Road STW was pumped at a constant rate (approximately 500 m^3/d) to the 2.4 m^3 capacity header tank on the pilot plant (Fig 4.1.1), from where the sewage gravitated to the distributor arms serving each of the primary filters through valves used for flow control. The distribution mechanism supplying sewage to the mineral medium filters consisted of a mechanically driven four-armed Simon Hartley distributor, each arm fitted with 6 x 19 mm jets with splash plates (Plates 4.1.4 and 5). In order to maintain a reasonable flow of sewage on to the splash plates, two of the distributor arms were blocked, only allowing sewage to pass through the jets of the remaining two arms. A distributor motor was used, fitted with chain drive and the facility to change cog sizes - thereby allowing direct control of the periodicity of dosing.

The flow rate applied to each sector was assumed to be equal, and estimates of this volume were obtained from tipping troughs placed under the overflow of two of the effluent sumps of the mineral media filter (Sectors 1 and 5), as shown in Plate 4.1.3. These troughs, designed by Water Research Centre, could be calibrated to determine the volume of effluent required to cause them to tip (approximately 10 l in the case of primary filter tipping troughs). Each trough was fitted with a 'Maglock' magnetic reed switch, connected to an electrical counter, and each tip of the trough was therefore automatically registered. This method of flow recording was considered to provide approximately a ten percent under-estimation of the total flow over the weirs of the effluent sumps, as the troughs did not return to the upright position immediately after they had discharged their contents and hence some of the flow was lost.

Each sector of the mineral medium filter had an average depth of 2.0 m and provided a surface area of 1.9 m^2 and volume of 3.8 m^3. The two grades of slag and granite media used and their positions and sector numbers within the bed are shown in Fig 4.1.1 and Table 4.1.1, while the medium sizes used in the grading of the mineral media are given in Table 4.1.2.

Table 4.1.2 Grading used for each of the primary filter mineral media

Sieve size (mm)	% Stone passing through sieve	
	125/75 Grading	89/50 Grading
150	100	
125	75 - 85	
100	35 - 45	100
76	0 - 10	45 - 55
63.5	0	0 - 10

The second octagonal filter contained four types of plastic media and was divided into six sectors (Fig 4.1.1, Plate 4.1.6). Two of these sectors were each twice as large as the other four, with the four smaller sectors being filled with random-fill media (Biopac 50 and Biopac 90 - Plate 4.1.7, Fig 4.1.1). The small diagonally opposed sectors were again filled with the same media. These small filters were exactly the same size, shape and volume as those of the mineral media and contained ventilation shafts, temperature probes, biological sampling shafts and neutron probe shafts in the same positions (Plate 4.1.8). The two larger sectors contained the modular Flocor M and Flocor E media respectively (Plate 4.1.6, Table 4.1.1). The modular nature of these media precluded their use in separate duplicated filters, and the decision was therefore taken to provide a single sector of similar volume to two of the smaller sectors, with two separate effluent drain points for each of the modular media. The total volume of the Flocor E medium used in the single large sector was 7.6 m^3, while the total volume of the Flocor M medium used was 6.84 m^3, with the reduction being achieved by raising by 200 mm the floor of the Flocor M sector. The lower volume of Flocor M was used so as to provide the same total available surface area of medium in this filter as was available in the Biopac 50 filters.

The use of biological shafts in the modular medium filters was not possible due to the nature of the medium itself, and the biology of these filters was therefore studied by the extraction of small modules of the medium from pre-set depths within each filter. The depths used were 0 - 200 mm, 600 - 800 mm and 1200 - 1400 mm, while the size of the modules used were 300 x 300 x 200 mm (Flocor E) and 300 x 200 x 200 mm (Flocor M). Four units were used, side by side, at the surface (allowing recolonisation between sampling periods). The (four) units positioned at 600 - 800 mm depth were not placed directly below the surface units and access to these units was gained by the removal of a complete standard module of medium from the top of the filter. Access to the single unit which was used to study the biology at 1200 - 1400 mm depth was gained through a rectangular hole cut through the filter wall brickwork. Only one unit was used at this depth due to the difficulties associated with placement and access. The hole in the brickwork was covered after use by refitting polystyrene insulation and wooden shuttering.

The two modular medium filters contained temperature probes, neutron probe access tubes and ventilation shafts in the same positions as in the mineral medium filters and flow rates were estimated using two tipping troughs (beneath sectors 12 and 16) as in the mineral medium filters.

The mechanically driven, four-arm, Simon Hartley distributor mechanism supplying sewage to the plastic filters was identical to that which supplied sewage to the mineral medium filters, although all four arms were used to deliver the sewage (as the flow to the plastic medium filters was always maintained at twice the level of that applied to the mineral medium filters). As all four arms were used on the plastic medium filters, the speed of rotation was set at half that used on the mineral medium filters, producing a frequency of dosing of two minutes on each filter.

Through most of the experimental period the hydraulic loading applied to the primary filters was nominally 5.6 and 11.2 $m^3/m^3.d$ on the mineral and plastic medium filters respectively (with Flocor M loaded at 11% higher hydraulic load per m^3 of filter medium than the other plastic medium filters because of the lower volume of this medium in the filter). The volume of settled sewage supplied to the pilot plant as well as that applied to the filters was maintained at a constant level with no diurnal variations.

The effluent from each of the primary plastic and mineral medium filters drained to a common effluent sump (Fig 4.1.1, 4.1.2b, Plate 4.1.9) where mixing took place. A portion of the effluent (approximately 70 m^3/d) from this sump was pumped to the settlement tank serving the secondary filters using the small Mono pump shown in Plate 4.1.9, while the remainder flowed over the weir and was returned as waste to the STW.

Table 4.1.1 List of sector numbers and media types used in the pilot plant

Sector No.	Medium	Specific Surface Area (m^2/m^3)
Primary Filters		
1	89/50 Granite (Biol)	53.7
2	125/75 Slag (Biol)	34.6
3	89/50 Slag	61.7
4	125/75 Granite	38.3
5	89/50 Granite	53.7
6	125/75 Slag	34.6
7	89/50 Slag (Biol)	61.7
8	125/75 Granite (Biol)	38.3
9	Biopac 50 (Biol)	124
10	Biopac 90 (Biol)	85
11	Flocor E	85
12	Flocor E	85
13	Biopac 50	124
14	Biopac 90	85
15	Flocor M	135
16	Flocor M	135
Secondary Filters		
17	Flocor R2S (Biol)	140
18	Flocor RS (Biol)	240

Where:- '(Biol)' refers to sectors having biological sampling shafts

Fig. 4.1.1 Diagram of pilot plant primary filters and associated pipework.

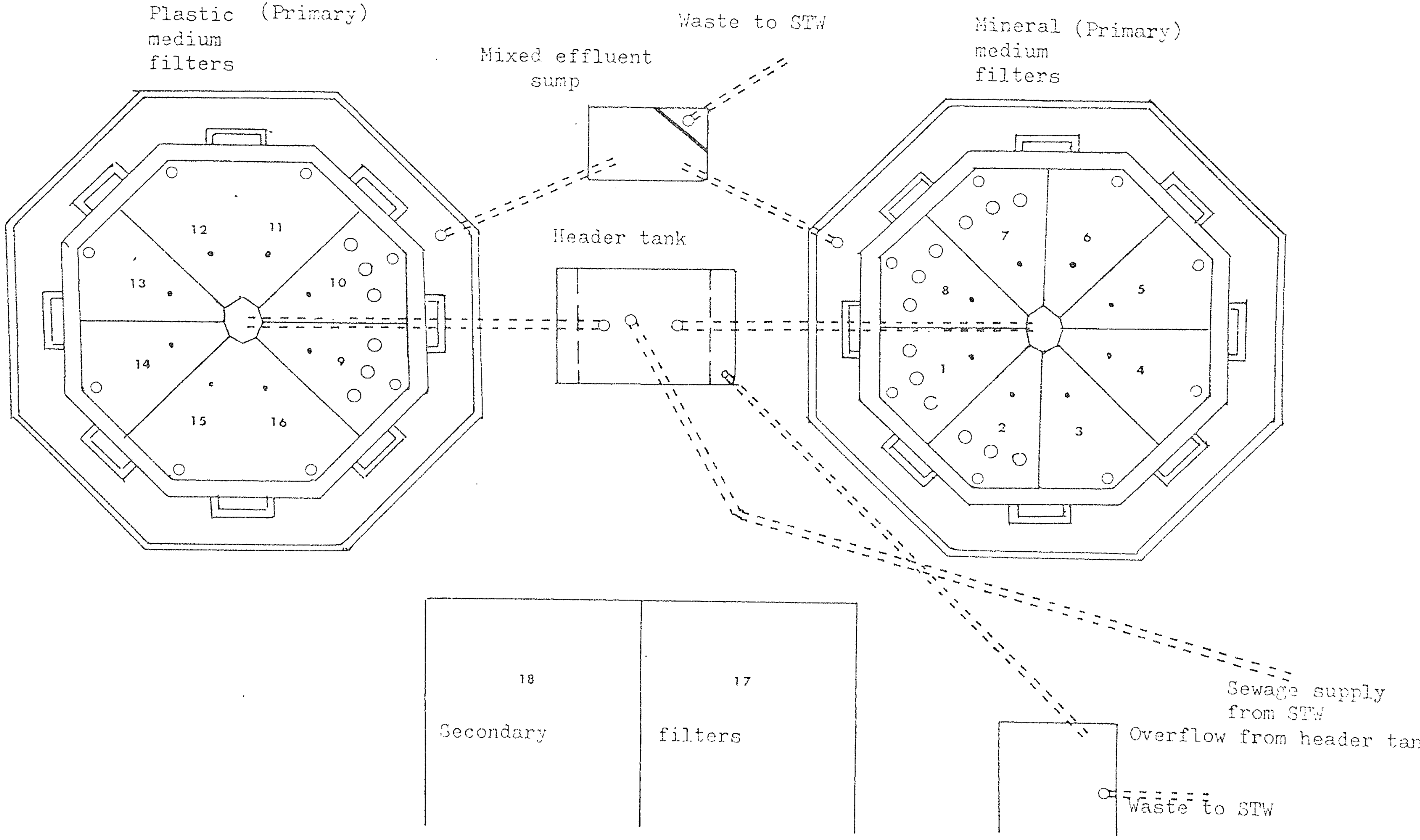


Fig. 4.1.2a Diagram of secondary filters and associated pipework.

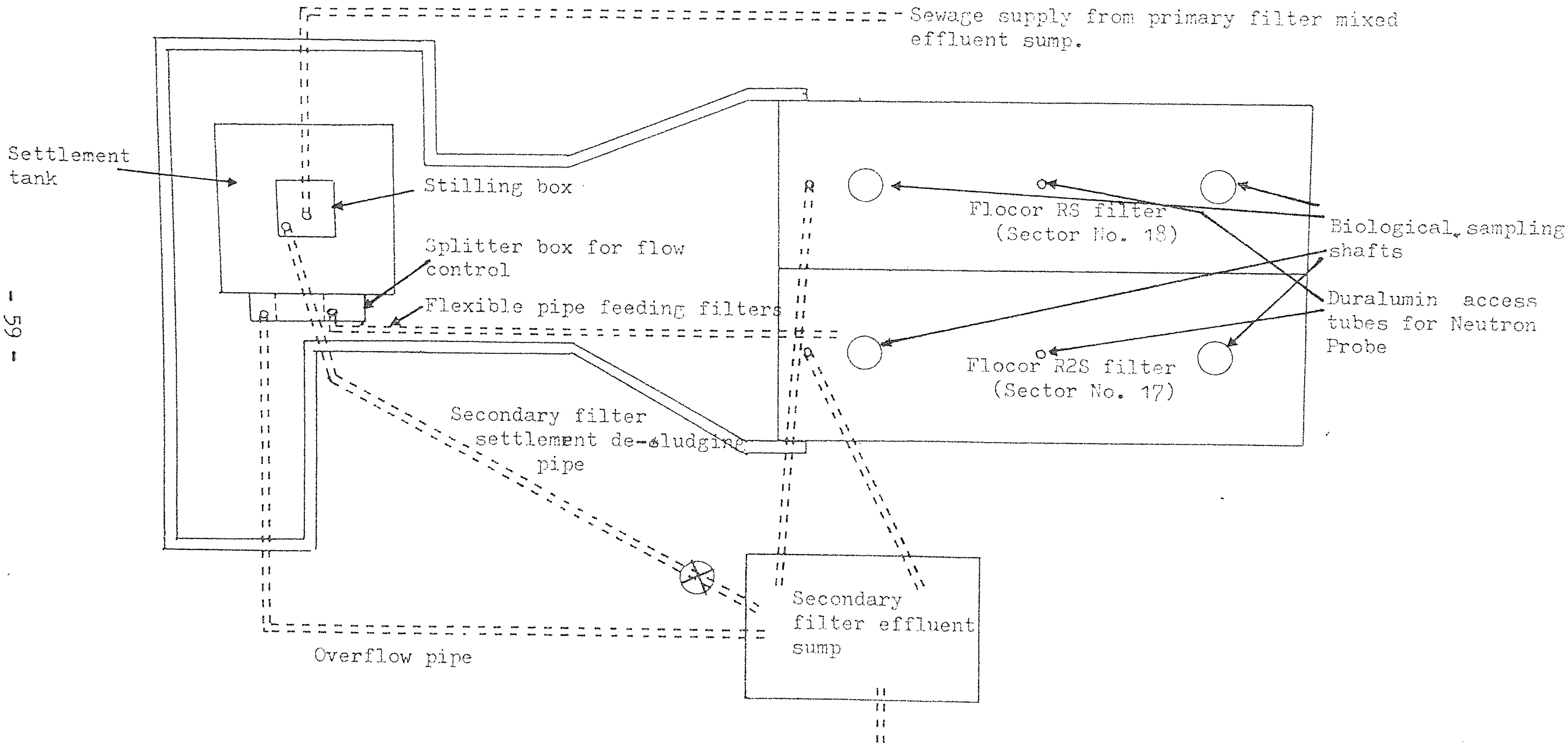
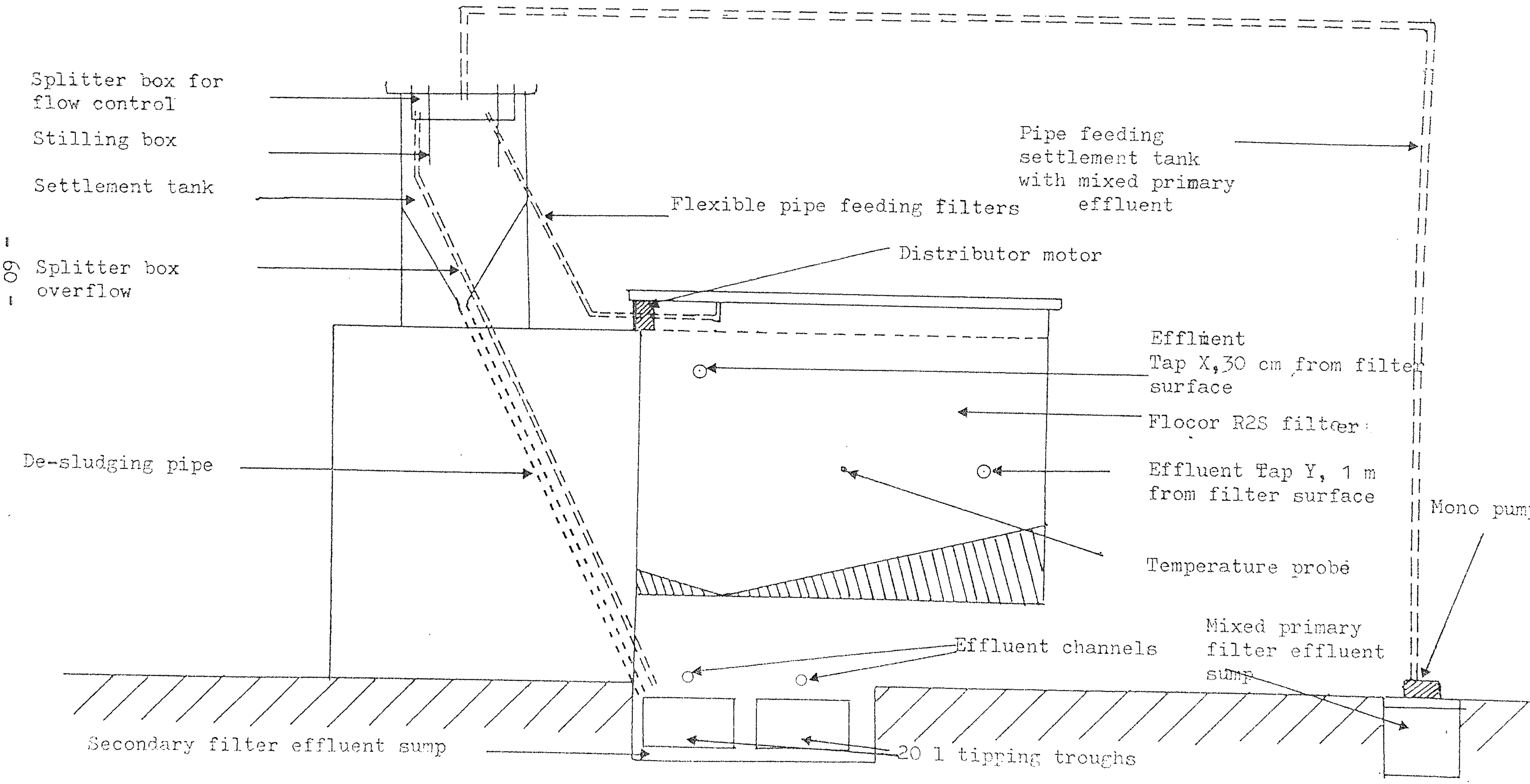


Fig. 4.1.2b Plan of secondary filters.



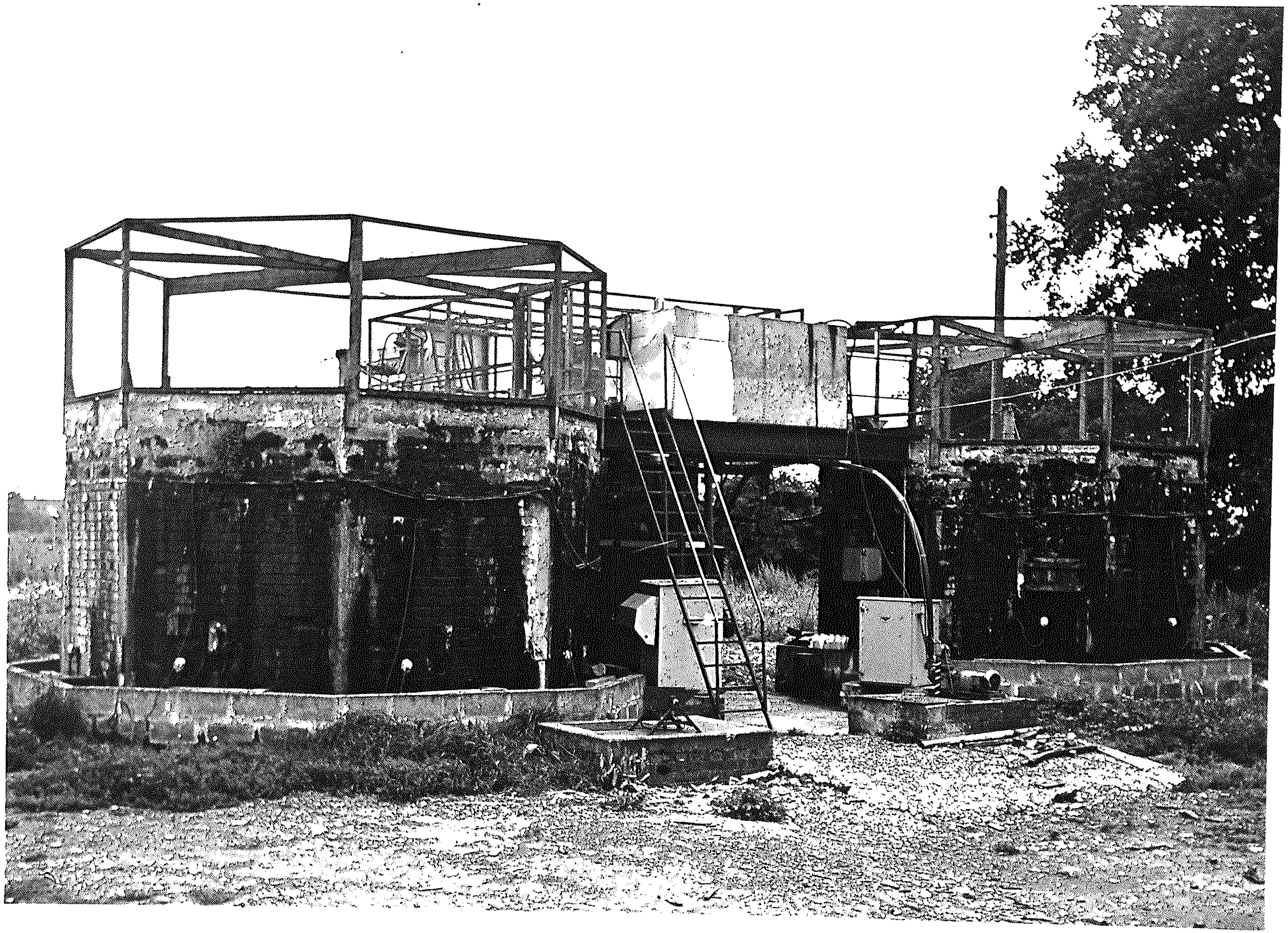


Plate 4.1.1 View of pilot plant. Showing primary filter sewage header tank, octagonal primary plastic and mineral media filters and part of secondary filters (to rear).

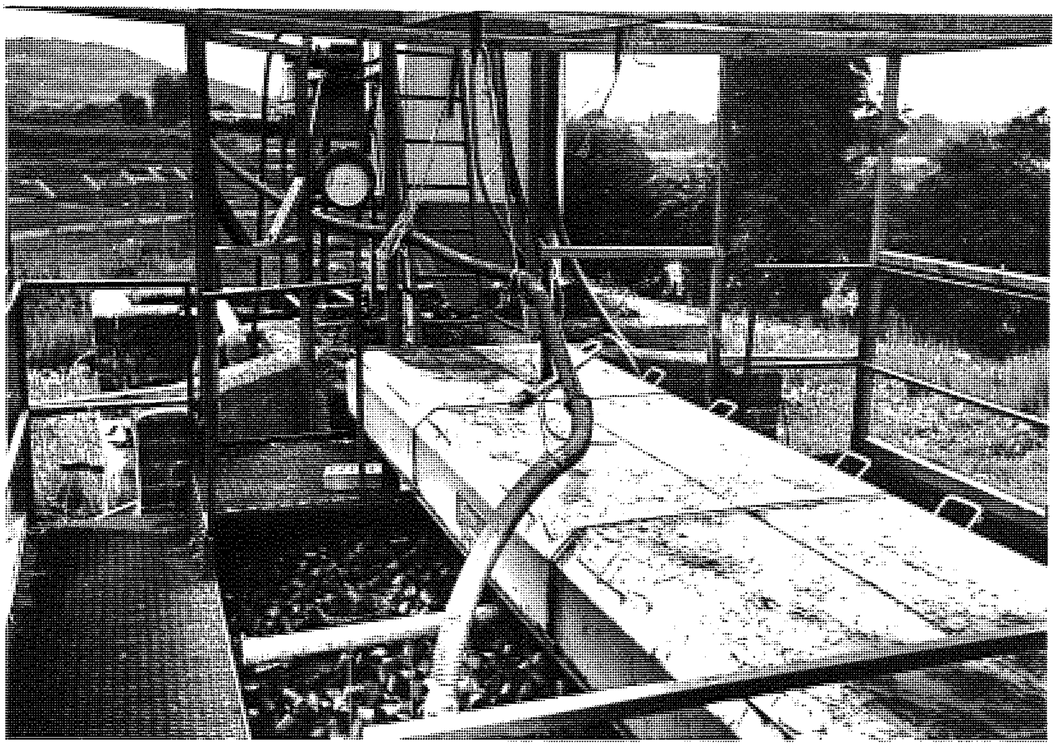


Plate 4.1.2 View of secondary filters. Showing secondary filter feed settlement tank with splitter box and associated pipework, circular temperature recorder, distribution mechanism and surface of Flocor R2S filter.

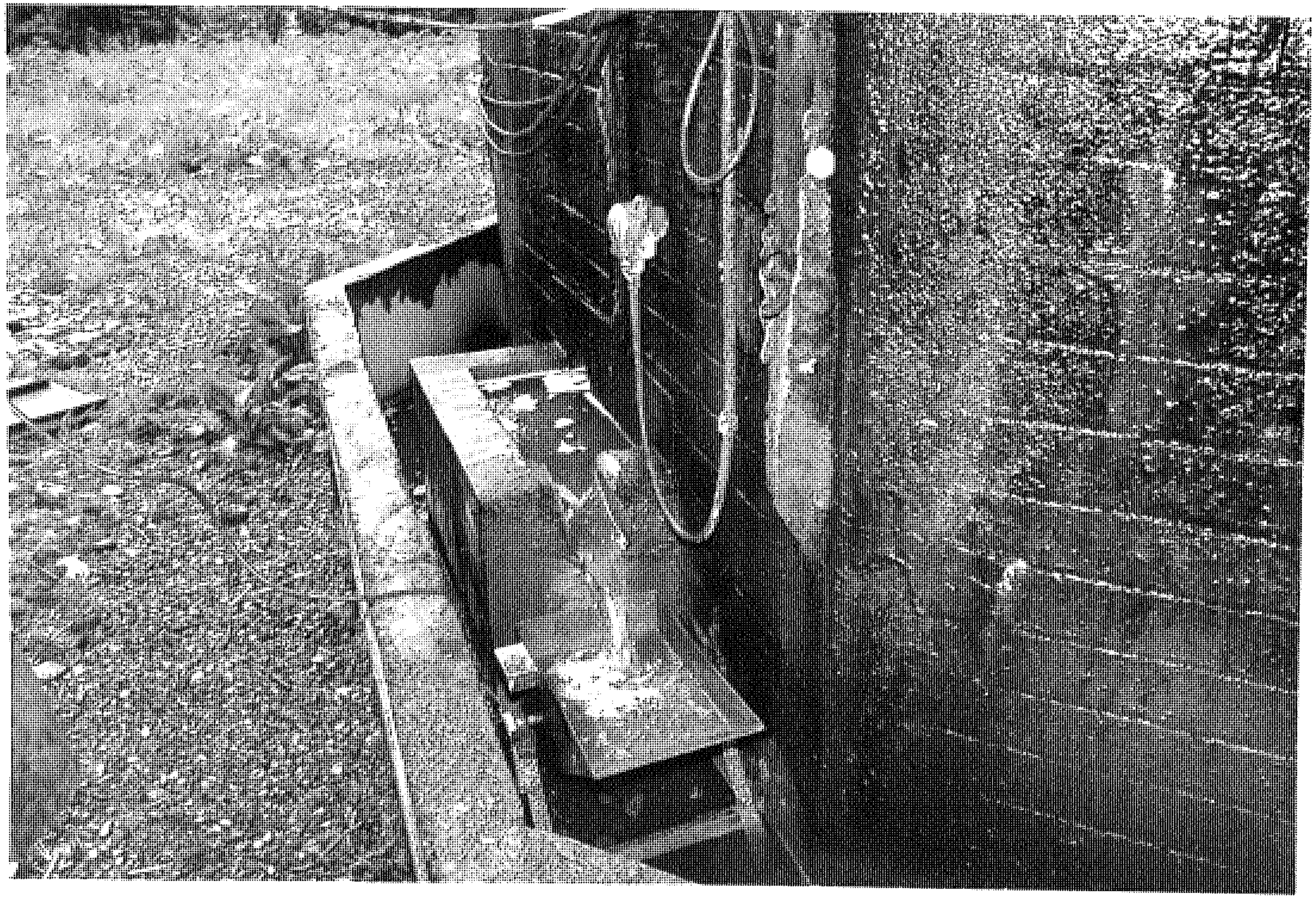


Plate 4.1.3 Primary filter effluent drain, sump and tipping trough used in flow recording. Showing Foster Cambridge temperature probe positioned in filter wall.

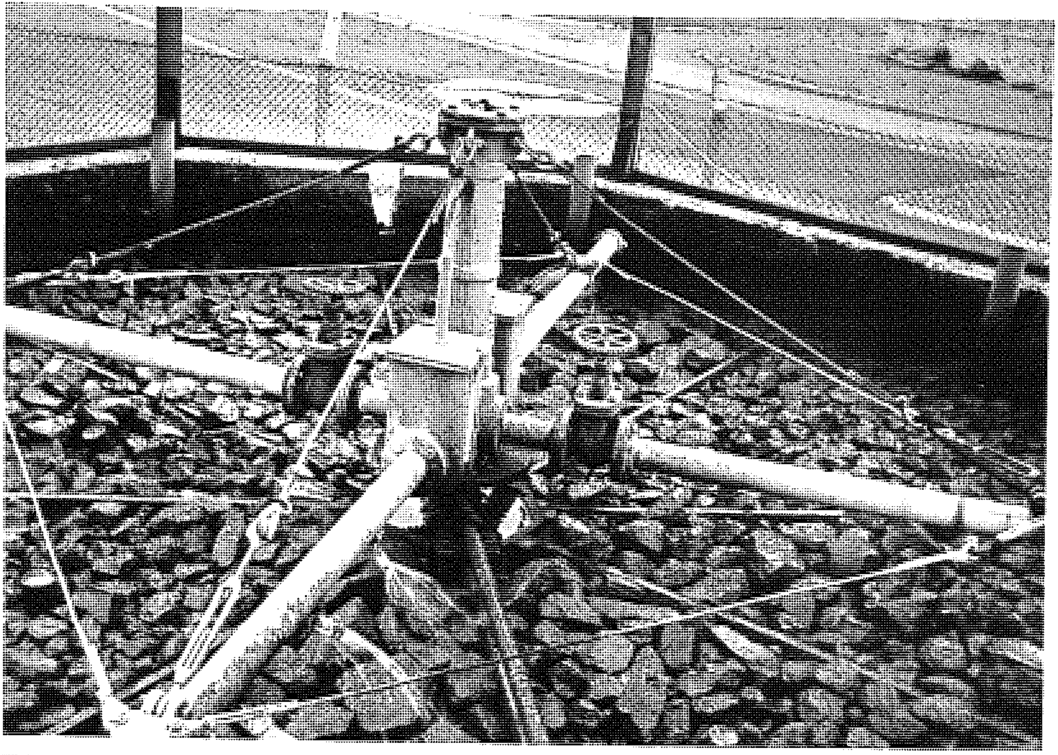


Plate 4.1.4 Surface of primary mineral media filter. Showing eight separate sectors filled with various filter media and four-armed Simon-Hartley distribution mechanism.

Plate 4.1.5 Surface of 125/75 Granite filter. Showing three perforated galvanised steel biological sampling shafts, neutron moisture meter access tube (centre left of Plate) and ventilation shaft.

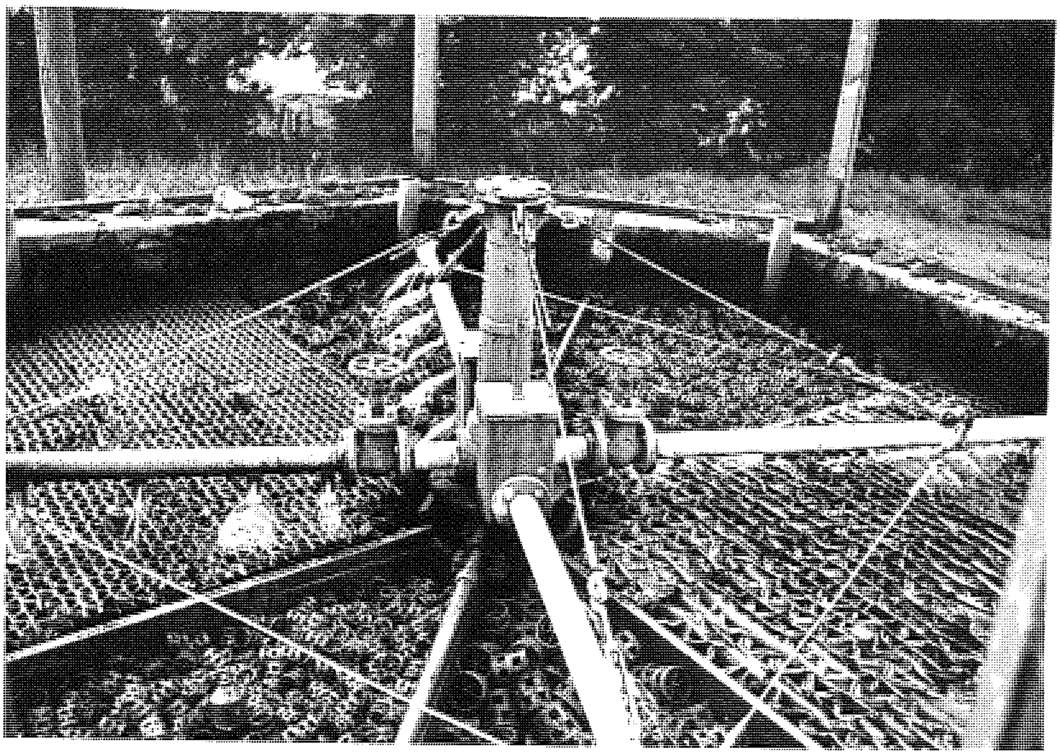


Plate 4.1.6 Surface of primary plastic media filter. Showing six separate sectors filled with various filter media (Flocor M to the left, Flocor E to the right) and four-armed Simon-Hartley distribution mechanism.

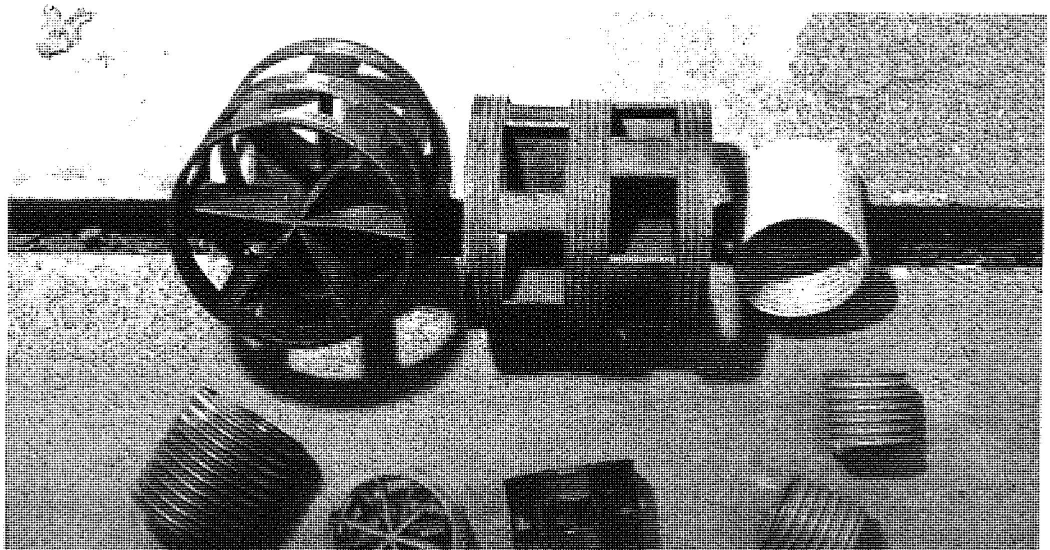


Plate 4.1.7 Random-fill plastic media used in pilot plant. Showing :- Top, left to right, Biopac 90 top and side views, Flocor R2S side view. Bottom, left to right, Flocor R2S side view, Biopac 50 top and side views and Flocor RS side views.

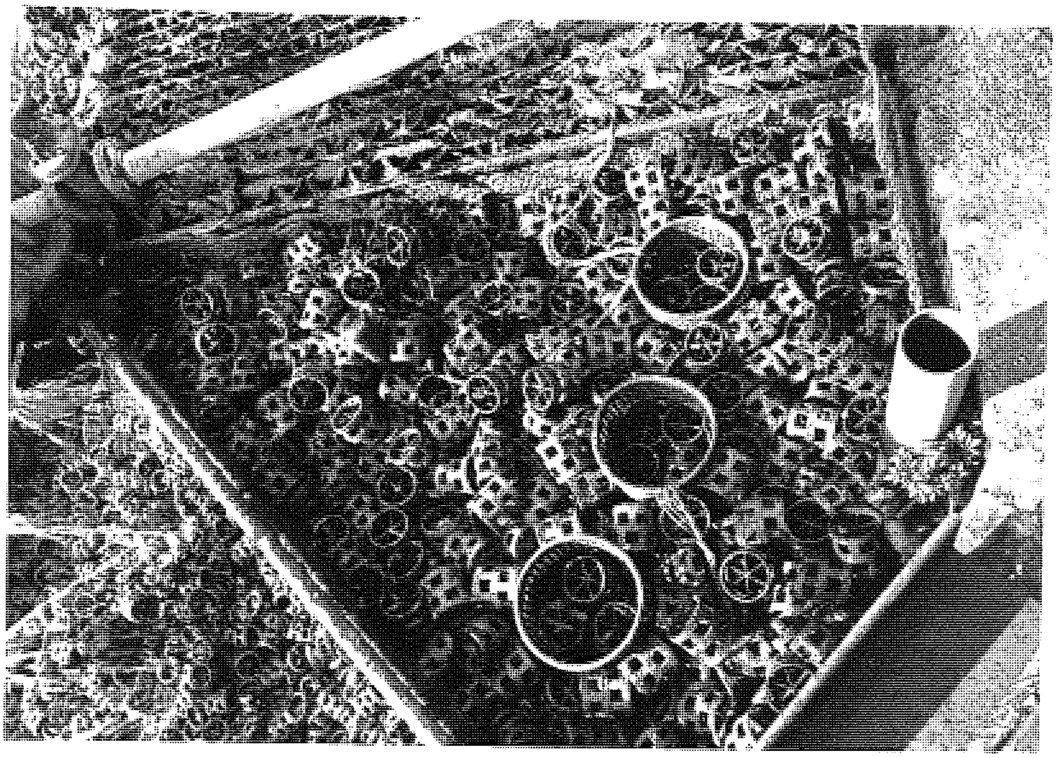


Plate 4.1.8 Surface of Biopac 90 filter. Showing three perforated galvanised steel biological sampling shafts, neutron moisture meter access tube (centre left of Plate) and ventilation shaft.

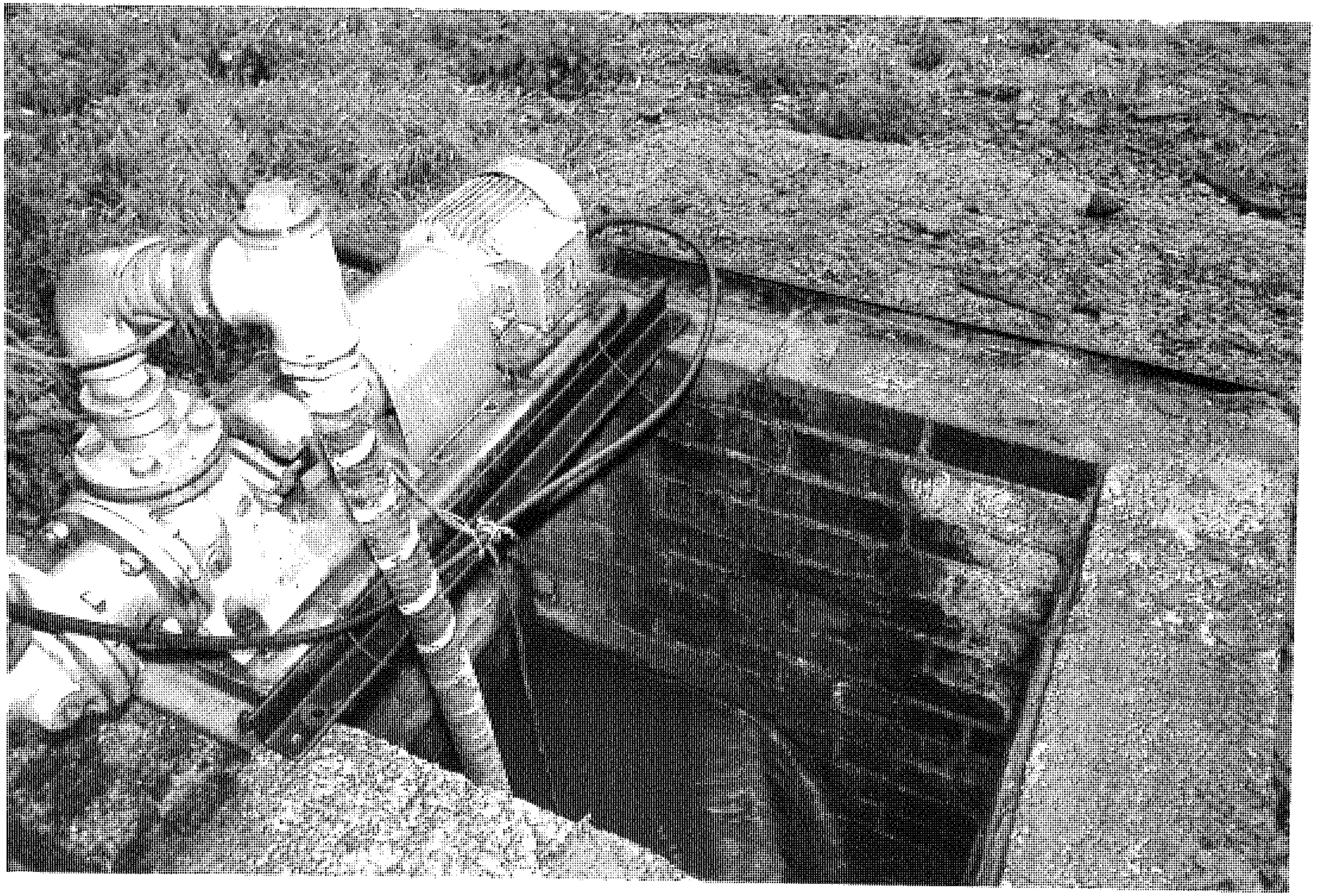


Plate 4.1.9 Primary filter common effluent sump and Mono pump supplying liquor to secondary filter settlement tank.

4.2 Secondary filters

The Braithwaite tank was converted for use as a secondary filtration unit by the installation of a longitudinal division, allowing for comparison of the performance of two different plastic filter media (Flocor RS and Flocor R2S, Plate 4.1.7, Fig 4.1.2a, Table 4.1.1). The total volume of the Braithwaite tank was 18 m^3, while the effective volume of each of the two secondary filters was 8.64 m^3, each having an average depth of 2 m^3 and surface area of 4.32 m^3 (length 3.6 m, breadth 1.2 m). Plate 4.1.2 shows part of the Flocor R2S filter, together with the distribution mechanism and secondary filter settlement tank.

Mixed primary filter effluents were pumped from the common sump (Plate 4.1.9, Fig 4.1.2b) to the intermediate settlement tank situated above the secondary filters where the wastes received partial settlement before application to the secondary filters. The settlement tank is visible in Plates 4.1.2 and 4.2.1. The total volume of this tank was 2.0 m^3 and the desludging pipework can be seen in Plate 4.2.1. The tank was desludged daily and the period of settlement afforded to the secondary filter feed was approximately 40 minutes. While a splitter box was installed for the purpose of flow regulation, this box was never used for this purpose and all of the sewage overflowing from the settlement tank was applied to the filters through the 63.5 mm ID flexible pipe shown in Plates 4.1.2 and 4.2.1. The splitter box served as a small reservoir of the sewage applied to the filters which was sampled for physico-chemical analysis using the small pump and Foster Cambridge clockwork circular temperature recorder shown in Plate 4.2.1.

The shape of the filters necessitated the use of a reciprocating arm distribution mechanism. This consisted of two distributor arms, each having six plain 12.5 mm jets feeding sewage to each half of the

Braithwaite tank. The distributor was chain driven by a small electric motor (situated under the metal covers shown in Plate 4.1.2), and as the total travel of the drive chain was 3.6 m the equipment had to be specially designed for the filter by W. E. Farrer Ltd. As the distributors were of reciprocating type, the sewage supply pipe from the settlement tank to the arms had to be flexible to accomodate the long distributor travel. The arms took 90 seconds to cover the length of the filters and sewage was discharged through them continuously.

Each of the secondary filters was fitted with biological sampling shafts and neutron probe access tubes as in the primary filters (Fig 4.1.2a), with the exception that only two biological shafts were used in each filter. Unfortunately these shafts were installed after the filters had been filled with media, and as they were made from perforated aluminium alloy three of them buckled at the base as attempts were made to force them into the filters. Consequently one of the shafts in sector 17 (Flocor R2S) contained only three baskets while the other contained only four, and one of the shafts in sector 18 (Flocor RS) contained only four baskets while the other shaft was complete with five baskets. In all cases the small surface basket was one of those installed and basket and shaft sizes were as used in the primary filters.

Temperature was recorded in only one of the two secondary filters, as it was considered that temperature differences between two adjacent sections of a filtration unit would not be significant - in the light of previous work (Rowlands, 1979) and experience with the high rate primary filters. Continuous temperature recording was achieved using a Foster Cambridge circular clockwork temperature recorder, with the thermistor inserted to a depth of 18 cm into sector 17, at a distance of approximately 1 m from the filter surface.(Fig 4.1.2b).

Separate effluent drain pipes were used for both sectors of the filter

(Plate 4.2.2, Fig 4.1.2b), each discharging to a 20 l tipping trough which was used to estimate flow rates as with the 10 l troughs of the primary filters. These troughs tipped into a common sump (together with the overflow from the primary filter header tank and the sludge from the secondary filter settlement tank) before flowing back as waste to the head of the STW.

To supply sewages for the nitrification experiments discribed in Section 4.4, two taps were inserted in the side of the Flocor R2S filter (Sector 17, Fig 4.1.2b, Taps X and Y). These taps enabled partially treated wastes to be obtained from the filter without causing undue disturbance within the filter. The taps were constructed from a 125 mm diameter uPVC drain pipe, 1.4 m long, which had been cut longitudinally in half to produce an open drain for 1.2 m of its length (Fig 4.2.1). The open drain end of the pipe was inserted through a 125 mm diameter hole cut through the wall of the Braithwaite tank so that it ran the width of the filter itself. The closed end of the pipe was then bonded to the hole in the tank wall producing a water tight seal, while a 40 mm diameter uPVC pipe was inserted through a hole in the base of the closed end of the drain pipe which protruded from the filter wall, enabling a constant flow of partially treated wastes to be drawn off. The two taps used were installed at 30 cm and 1 m from the filter surface, and other wastes used in nitrification experiments were drawn from the reservoir of settled sewage in the splitter box (using the small pump shown in Plate 4.2.1), and from the Flocor R2S effluent pipe.

The secondary filters were operated at a nominal hydraulic loading of 4.0 $m^3/m^3.d$ throughout the experimental programme, although as no active control was exercised over the flow rate applied the hydraulic load tended to fluctuate - largely depending upon the mechanical condition of the Mono pump feeding the settlement tank with mixed primary filter effluents. The filters were commissioned on 29.5.79, and were operated until the complete closure of the pilot plant on 8.6.81.

Fig. 4.2.1 Design of taps used to obtain partially treated wastes from the Flocor R2S filter.

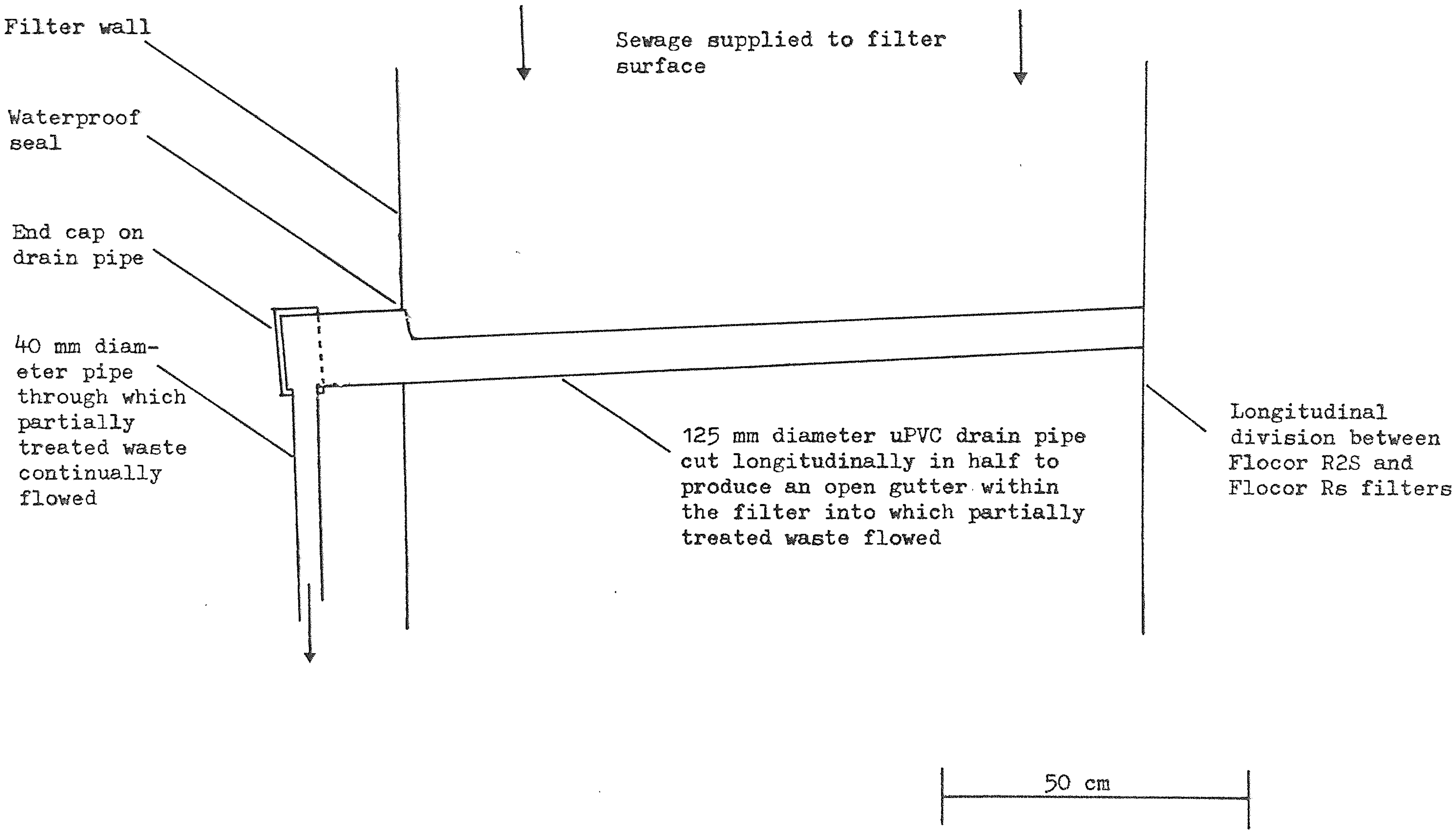


Plate 4.2.1 Secondary filter settlement tank and associated pipework, splitter box and physico-chemical sampling equipment. Showing small pump and Foster Cambridge circular temperature recorder used for sampling settled filter feed liquor.

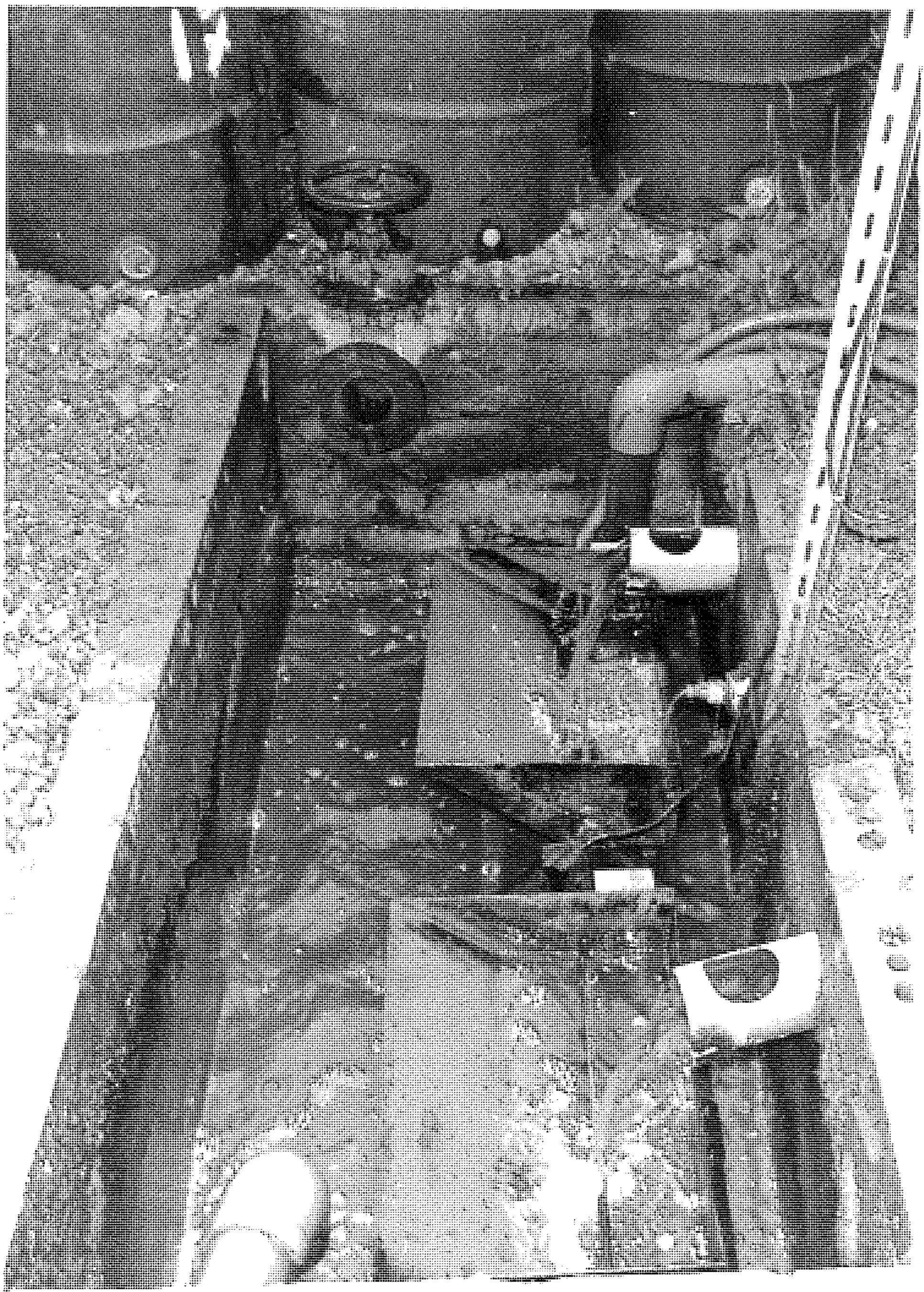


Plate 4.2.2 Secondary filter effluent drain pipes, waste sump and tipping troughs. Showing secondary filter feed settlement tank de-sludging valve (top left) and primary sewage header tank overflow pipe (bottom left).

4.3 Experimental programme and chemical analyses

4.3.1 Sampling methods for routine physico-chemical analyses of sewage and effluents from the pilot plant

As the composition and strength of municipal wastes varies throughout the day, composite samples of sewage and effluents were used for routine chemical analyses to provide accurate estimates of filter performance. The constant flow rate applied to the filters allowed samples of equal volume to be taken instead of weighting for flow, and these samples were taken every hour between 10 am and 4 pm. Although automatic (Bestel-Dean 24 hour) samplers were available on site, it was found that the solids in the effluent samples, and occasionally those in the sewage, tended to clog the mechanisms and samples were therefore usually taken manually. The volume of each sample was 70 ml and these were compounded in 500 ml glass stoppered sample bottles. The primary filter sewage (Primary Feed) was sampled from the surface of the primary filter header tank, while the primary filter effluents were individually sampled from the effluent drain leading into each effluent sump. The secondary filter feed (Secondary Feed) was sampled by pumping waste from the small reservoir formed as the settled feed flowed through the splitter box before draining to the secondary filters, using the small pump shown in Plate 4.2.1. A period of at least one minute was allowed for this pump to purge itself of any stale waste before samples were taken. Secondary filter effluents were sampled from the effluent drain pipes as they discharged into the tipping troughs (Plate 4.2.2).

Samples for BOD, COD and SS analysis were stored in darkness overnight at $4^{\circ}C$, while samples for nitrogen analysis were first preserved as outlined in Section 4.3.3.1. Sewage and filter temperatures were recorded using the equipment and methods outlined in Sections 4.1 and 4.2.

4.3.2 Sampling programme

The sampling programme used during the period of study for sampling the physico-chemical composition of the feeds and effluents was divided into three separate phases. These phases differed in terms of sampling intensity and have been termed Full, Half and Reduced sampling periods. The chronology of these periods is given in Table 4.3.2.1. The sampling programme employed varied mainly in terms of the number of primary filter effluent samples which were taken, as the intensity of secondary filter feed and effluent sampling was never reduced from Full sampling.

Full sampling, as used on the primary filter feed and effluents between September 1978 and March 1980, and on the secondary filter feed and effluents for the whole period of their operation (with one small change between January and May 1981, as outlined later), consisted of sampling on Mondays and Thursdays. During this period every effluent (including duplicated filter effluents) and both feeds were sampled hourly on sample days, and the samples analysed for BOD, COD, SS and nitrogen content (with only occasional samples being taken for primary filter feed and effluent nitrogen analyses).

Half sampling was employed between June and September 1980 on the primary filter effluents. This initially consisted of sampling only one effluent from each of the duplicated primary filter media twice weekly with compounded samples as in Full sampling (during June and July), and eventually of sampling all mineral medium filter effluents on Mondays and all plastic medium effluents on Thursdays. Full analysis of samples for BOD, COD, SS and occasionally nitrogen content were performed on all samples during this period, and the secondary filter sample analyses were not affected by the changes.

Reduced sampling was employed between October 1980 and May 1981. During this period the sampling of the primary filter effluents was minimal, with only the performance of filters 1 and 9 monitored regularly. Samples were taken on Mondays and Thursdays between October and December 1980 and Tuesdays and Thursdays between January and May 1981. COD analyses were not performed during this period of Reduced sampling, although the sampling of primary and secondary feed and secondary effluents was not otherwise affected during this period.

Table 4.3.2.1 lists the full chronology of the sampling and analysis programmes employed during the study. Owing to the seasonal changes in the nature of the sewage at Hereford (see Chapter 3) the performance figures obtained from the pilot plant have been divided into quarterly sets. Each quarter has been identified by two numbers, the first of which represents the calender year (year 1 = 1978, year 2 = 1979 etc), while the second represents the time of year (1 = winter, 2 = spring etc). Table 4.3.2.1 also lists the months in which long plant shutdowns occurred. The dates, duration and reasons for the plant shutdowns are given in Appendix 4.3.1.

4.3.3 Chemical analyses

BOD, COD, SS and nitrogen analyses were performed as determined by the experimental programme. BOD, COD and SS analyses were carried out using the methods given in Analysis of Raw, Potable and Waste Waters (HMSO, 1972), using the modification to the method of BOD determination given by Rowlands (1979). NH_3-N, NO_2-N and NO_3-N concentrations were determined using a Technicon Auto-analyser, by the methods outlined by Chapman et al. (1967).

Samples of feeds and effluents were analysed as soon as possible after collection, with analyses being carried out on either shaken or settled samples. Settlement entailed a 30 minute quiescent settlement period in a 500 ml sample bottle.

Samples taken on Mondays were sub-sampled and analysed for COD and SS content on Tuesdays, following overnight refrigeration. Owing to the difficulties involved in performing the five day BOD analysis, the samples taken on Mondays were not analysed for BOD until Wednesdays, allowing the fifth day of the test to fall on a Monday rather than a Sunday. Samples were refrigerated between Monday night and Wednesday. Samples collected on Thursdays were analysed for BOD, COD and SS contents on Fridays following overnight refrigeration.

4.3.3.1 Preservation of samples prior to nitrogen analyses

As facilities for inorganic nitrogen analysis were not available at Hereford, suitable methods for preserving samples for transport to, and analysis at Aston University had to be evaluated. It was expected that the maximum storage period required would be three weeks, with an average of two weeks. Preservation tests were therefore carried out using a number of preservation techniques commonly used for storage of water samples for nitrogen analysis, and a storage period of up to thirty days.

For the investigation, sieved one litre samples of the settled sewage (T1), secondary filter feed (T2), and secondary filter effluent (17 - Flocor R2S) were taken and stored overnight in dark glass bottles at 5°C before transportation to Aston. The samples were taken the previous day and stored overnight because diurnal variation in sewage composition would have caused early morning samples to be unrepresentive of the sewage composition at the proposed future sampling times. These three samples were chosen to provide a wide range of BOD concentrations, so that the effects of different levels of organic matter on each preservation method could also be evaluated.

At Aston each one litre sample was divided into eight aliquots of 125 ml and each aliquot was given a separate preservation treatment. The treated samples were then thoroughly mixed and each sub-divided into 8 x 15 ml sub-samples, placed in screw topped 25 ml universal bottles and stored in darkness under the temperature regime described below.

The preservation techniques used were :-

1 Acid - acidification with conc. HCl to a pH of less than 2 (5.9 ml conc. HCl/l sample). Plus refrigeration at 5°C.

2 Min Acid - acidification with conc. HCl to a pH of 2 (1.2 ml conc. HCl/l sample). Plus refrigeration at 5°C.

3 Frozen - freezing to -15°C. Samples for this technique were sub-divided and stored frozen in 24 x 2 ml plastic capped analyser cups, one cup to be thawed and used for each analysis for NH_3-N, NO_2-N and NO_3-N carried out on each day of the investigation.

4 Alkali - addition of NaOH to a pH of more than 12 (7.0 ml 1.2 M NaOH/l sample). Plus refigeration at 5°C.

5 Mercury - addition of $HgCl_2$ (4 ml 1.25% $HgCl_2$Sol/l). Plus refrigeration at 5°C.

6 Chloroform - addition of $CHCl_3$ (1 ml $CHCl_3$ per 15 ml sample). Plus refrigeration at 5°C.

7 Fridged - refrigeration at 5°C.

8 Room temp - storage at 20°C.

The 2 ml plastic cups were used for the Frozen preservation because the samples could be thawed relatively quickly at room temperature, without recourse to the use of a possibly harmful external heat source.

Immediately after the treatments had been administered the first sample was analysed (day 0). Subsequent analyses after 1, 6, 9, 16, 23 and 30 days storage were carried out on a fresh sample bottle, the contents of the bottle were discarded after the analysis was completed. Separate universal bottles were used for each analysis because it was felt that the disturbance caused by the sub-sampling of a preserved sample after a period of storage might cause extra variation in the results. The Frozen sample was not frozen and thawed on day 0 prior to analysis, merely stored at 5°C. The initial concentration of each parameter measured was obtained by averaging the Frozen and Fridged sample concentrations at day 0. Analyses were also carried out after 60 days storage to evaluate the effects of long term storage.

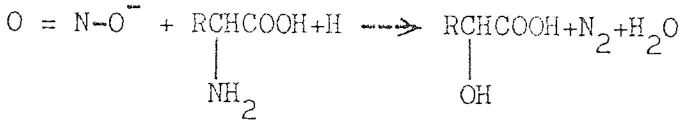
Analyses were carried out using the Technicon Auto-analyser, and the results of these analyses are presented graphically in Figs 4.3.3.1 - 3. Statistical analysis of the data consisted of a two way blocked analysis of variance to determine whether the treatments differed significantly in their effects on the samples and whether sample composition deteriorated with time. Students t-tests were used to determine whether the average concentration for each parameter and each technique obtained over 30 days storage differed from the initial concentration determined at day 0. The results of these analyses are presented in Tables 4.3.3.1 - 3, while the basic data are presented in Appendix 4.3.3.

Analysis of variance of the NH_3-N data show that the concentration of ammonia in the samples did not change with the period of storage, but differences between treatments were significant at the 1% level (Table 4.3.3.1). The treatments included in the analysis of variance were Acid, Min Acid, Chloroform, Mercury, Alkali and Frozen. With the exception of the Alkali and Frozen samples, each treatment gave very stable ammonia concentrations with storage period (Fig 4.3.3.1). However t-tests indicate that only the Alkali and Frozen sample averages were not significantly different from the initial concentrations.

Due to the very low concentrations of nitrite and nitrate found in the T1 sample statistical analyses were not carried out on the data. Analysis of variance of the NO_3-N data from T2 and 17 shows that there were significant differences (@ 1% level) due to both the treatments and storage period. This indicates that at least one of the techniques is unsuitable for nitrate storage over a 30 day period. Graphical presentation of the data from samples of 17 (Fig 4.3.3.2) indicates that only the Acid and Alkali gave good preservation on storage. T-tests however show that the average concentration from these techniques was significantly different (@ 1% and 5% levels respectively) from the initial concentration. Only Mercury produced reliable results in this respect, although after six days storage the results became erratic.

It was decided that for convenience a single preservation technique should be used for both NH_3-N and NO_3-N analyses. Freezing was not considered appropriate due to the difficulties involved in freezing in glass containers. Addition of NaOH, although giving an overall average NH_3-N concentration which was close to the true concentration, produced erratic results, especially towards the end of the experiment where a possible deterioration in the samples was evident. Although adding chloroform produced stable NH_3-N results, the NO_3-N storage characteristics were more erratic and this technique tended to cause a greater overestimation of nitrate concentrations than the other treatments. Mercuric chloride produced good overall storage characteristics for both parameters, but there was a tendency to an underestimation of NH_3-N content. As underestimation of any parameter was considered less desirable than overestimation,this technique was not used. Min. Acid addition gave good storage characteristics, but NH_3-N concentrations were overestimated by slightly more than by the addition of the greater volume of Acid. Because of the stability of the samples stored by the addition of Acid, this technique was chosen as suitable. It is recognised that this preservation method overestimates nitrate concentration quite seriously at low concentrations, while at higher concentrations both NH_3-N and NO_3-N are overestimated by an approximately steady 11%. This sample stability over the storage period is considered to outweigh the disadvantage of slight overestimation.

The addition of acid to samples for NO_2-N preservation is obviously an unacceptable method (Fig 4.3.3.3). There is an exponential fall in NO_2-N concentration on storage after acid addition. This decrease has been observed in the past, and has been attributed to the Van Slyke reaction by Brezonik and Lee (1966). In this reaction nitrite reacts with amino groups and with ammonia to produce nitrogen gas, as described by the formula.



$$O = N\text{-}O^- + \underset{\substack{| \\ NH_2}}{RCHCOOH} + H \longrightarrow \underset{\substack{| \\ OH}}{RCHCOOH} + N_2 + H_2O$$

This reaction occurs at significant rates only in low pH solutions. Samples for nitrite analysis would therefore require a different preservation technique to that chosen for NO_3-N and NH_3-N analysis.

Statistical analysis of the nitrite -N data indicates that nitrite samples cannot in fact be satisfactorily preserved for long periods. This finding has also been reported by Wagner (1976) and by the German Working Party on Stabilisation of Samples (1981). However the Frozen samples were reasonably well preserved with an acceptable level of accuracy, and the t-tests showed that of all treatments the average concentration of nitrite is least significantly different from the true concentration in the Frozen sample.

As a result of this investigation the following sample preservation methods were used. For NH_3-N and NO_3-N analyses, freshly taken samples were settled before a 25 ml sub-sample was taken and preserved by the addition of six drops conc. HCl from a micropipette (1 drop = 0.025 ml).

These samples were then stored in screw capped 25 ml universal bottles at 5°C and in darkness until analysed. Separate sub-samples for NO_2-N analysis were taken and frozen in 2 ml capped plastic analyser cups, each being thawed for approximately 1 hour at room temperature prior to analysis.

The inaccuracies induced by the use of these preservation techniques were considered to be acceptable and constant.

Table 4.3.2.1 Chronology of sampling programme employed.

Key given overleaf.

Quarter	Month	Routine sampling used	No. of samples taken	Months with plant shutdowns of greater than 1 day	Biological sampling	Neutron moisture probe	Sludge conditioning	Nitrifying tower experiments
1.4	S 78	F	2	P				
	O	F	5					
	N	F	4	St				
2.1	D	F	2		F			
	J 79	F	3	P				
	F	F	5					
2.2	M	F	2		F	F		
	A	F	5	P				
	M	F	4	P				
2.3	J		0	P		F,S		
	J	F,S	6	S	F,S	F,S		
	A	F,S	7	S		F,S		
2.4	S	F,S	5			F,S	F,S,A	
	O	F,S	4		F,S	F,S		
	N	F,S	3	S		F,S	F,S,A	
3.1	D	F,S	3			F,S	F,S,A	
	J 80	F,S	4	P	F,S	F,S	F,S,A,Z	
	F	F,S	7	S		F	F,S,A,Z	
3.2	M	F,S	4	P		F	F,S,A,Z	
	A		0		F,S		F,S,A	
	M		0	P		F,S	F,S,A	
3.3	J	H,S	9	S		F,S	F,S,A	1
	J	H,S	1	Pl	F,S	St,S	H,S,L,A,Z	1
	A	H,S	3	P		F,S	St,S,L,A,Z	1
3.4	S	H,S	7	P		F,S	F,S,L,A,Z	2
	O	R,S	5		F			2
	N	R,S	7					2
4.1	D	R,S	2					2
	J 81	R,S	8					3,5
	F		0	P				3,5
4.2	M	R,S	6	Pl				3,5
	A	R,S	6					4,5
	M	R,S	2					4,5

Key to Table 4.3.2.1

F - Full routine sampling, with sewage and effluents sampled as outlined in Section 4.3.2, or, in the sludge characterisation work, full characterisation of primary filter sludges.

H - Half routine sampling, with half of the primary filter effluents being sampled on each sampling day. Sewage sampled in full.

R - Reduced routine sampling, with only the 89/50 Granite (Biol) and Biopac 50 (Biol) filters of the primary filters being sampled. Sewage sampled in full.

S - Secondary filters - sampling regime never reduced.

P - Complete pilot plant.

Pl - Primary plastic media filters only.

St - Primary mineral media filters only.

A - Sludge conditioning using aluminium chlorohydrate.

Z - Sludge conditioning using a polyelectrolyte conditioner.

L - Sludge conditioning using a low rate filter humus sludge from the Rotherwas STW, Hereford.

1 - First nitrification experiment, to test the nitrifiability of Flocor R2S filter effluent.

2 - Second nitrification experiment, using wastes of various BOD strengths and flow rate of 2.0 $m^3/m^3.d$.

3 - Third nitrification experiment, using wastes of various BOD strengths and flow rate of 4.0 $m^3/m^3.d$.

4 - Fourth nitrification experiment, using wastes of various BOD strengths, fortified with 20 mg/l NH_3-N and flow rate of 4.0 $m^3/m^3.d$.

5 - Fifth nitrification experiment, using wastes of various BOD strengths and flow rate of 6.0 $m^3/m^3.d$.

Table 4.3.3.1 Sample preservation investigation - Statistical summary.

Ammoniacal - Nitrogen sample preservation.

Analysis of variance.

Sample origin	Significance level Treatments	 Storage time
T1 - Primary feed	1%	N.S.
T2 - Secondary feed	1%	N.S.
17 - Flocor R2S effl.	1%	N.S.

Effects of preservation techniques.

Preservation method used :-

Primary feed.

Initial conc. :- 4.9 mg NH_3-N/l

	Acid	Min. Acid	Chloroform	Mercury	Alkali	Frozen
Ave. conc. over 30 days storage	5.5	5.6	5.3	4.5	4.8	4.5
% of initial conc. remaining	113.1	114.1	108.2	91.2	97.1	92.7
Standard deviation	0.1	0.1	0.2	0.1	0.5	0.5
Significance level of t	1%	1%	1%	1%	N.S.	N.S.

Secondary feed.

Initial conc. :- 5.0 mg NH_3-N/l

	Acid	Min. Acid	Chloroform	Mercury	Alkali	Frozen
Ave. conc. over 30 days storage	5.6	5.7	5.4	4.8	4.8	5.0
% of initial conc. remaining	112.6	114.8	107.4	96.0	95.4	99.8
Standard deviation	0.1	0.1	0.2	0.1	0.6	0.2
Significance level of t	1%	1%	1%	1%	N.S.	N.S.

Flocor R2S effluent.

Initial conc. :- 5.45 mg NH_3-N/l

	Acid	Min. Acid	Chloroform	Mercury	Alkali	Frozen
Ave. conc. over 30 days storage	5.9	6.0	5.5	5.1	5.1	5.4
% of initial conc. remaining	108.1	109.4	101.1	93.4	94.3	99.8
Standard deviation	0.1	0.1	0.1	0.1	0.4	0.1
Significance level of t	1%	1%	N.S.	1%	N.S.	N.S.

Table 4.3.3.2 Sample preservation investigation - Statistical summary.

Nitrate - Nitrogen sample preservation.

Analysis of variance.

Sample origin	Significance level Treatments	Storage time
T1 - Primary feed	N/A	N/A
T2 - Secondary feed	1%	1%
17 - Flocor R2S effl.	1%	1%

Effects of preservation techniques.

Preservation method used :-

Secondary feed

Initial conc. :- 0.225 mg NO_3-N/l

	Acid	Min. Acid	Chloroform	Mercury	Alkali	Frozen
Ave. conc. over 30 days storage	0.33	0.32	0.40	0.28	0.29	0.26
% of initial conc. remaining	146.7	141.3	177.8	125.3	130.2	116.0
Standard deviation	0.03	0.04	0.07	0.05	0.05	0.04
Significance level of t	1%	1%	1%	5%	2%	5%

Flocor R2S effluent

Initial conc. :- 1.000 mg NO_3-N/l

	Acid	Min. Acid	Chloroform	Mercury	Alkali	Frozen
Ave. conc. over 30 days storage	1.10	1.12	1.20	1.08	1.07	1.06
% of initial conc. remaining	110.4	112.0	120.0	107.5	106.8	106.4
Standard deviation	0.03	0.08	0.12	0.10	0.06	0.07
Significance level of t	1%	1%	1%	N.S.	5%	5%

Table 4.3.3.3 Sample preservation investigation - Statistical summary.

Nitrite - Nitrogen sample preservation.

Analysis of variance.

Sample origin	Significance level Treatments	Storage time
T1 - Primary feed	N/A	N/A
T2 - Secondary feed	1%	1%
17 - Flocor R2S effl.	1%	1%

Effects of preservation techniques.

Preservation method used :-	Acid	Min. Acid	Chloroform	Mercury	Alkali	Frozen
Secondary feed						
Initial conc. :- 0.245 mg NO_2-N/l						
Ave. conc. over 30 days storage	0.06	0.09	0.21	0.22	0.22	0.21
% of initial conc. remaining	24.1	36.7	84.1	90.6	89.0	87.3
Standard deviation	0.04	0.05	0.02	0.01	0.01	0.02
Significance level of t	1%	1%	1%	1%	1%	1%
Flocor R2S effluent						
Initial conc. :- 0.246 mg NO_2-N/l						
Ave. conc. over 30 days storage	0.07	0.10	0.22	0.23	0.22	0.22
% of initial conc. remaining	26.4	39.4	89.8	91.5	89.9	88.2
Standard deviation	0.05	0.05	0.01	0.01	0.01	0.02
Significance level of t	0.1%	0.1%	0.2%	0.1%	0.1%	1%

Fig. 4.5.5.1 Ammoniacal - N sample preservation data.

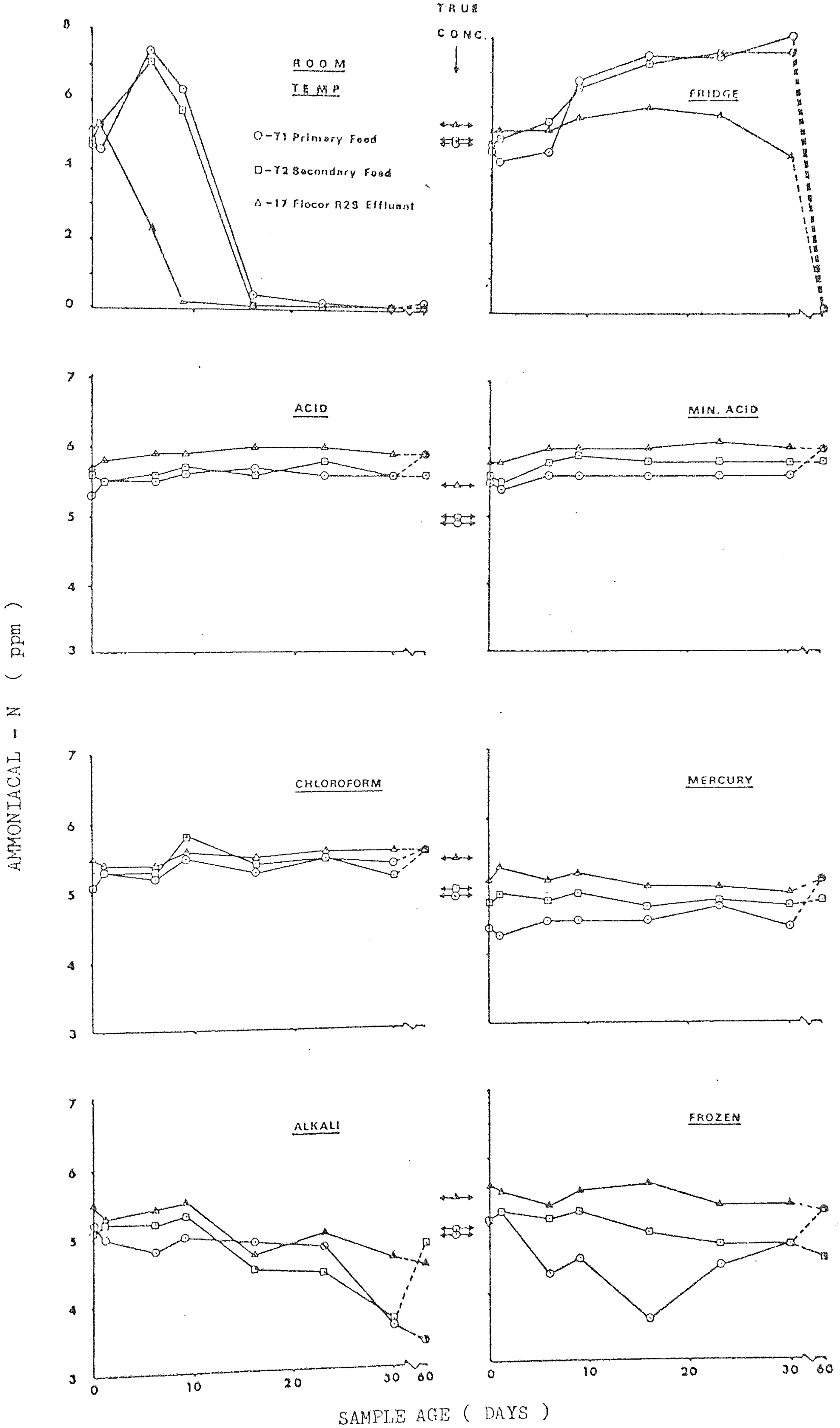


Fig. 4.3.3.2 Nitrate - N sample preservation data.

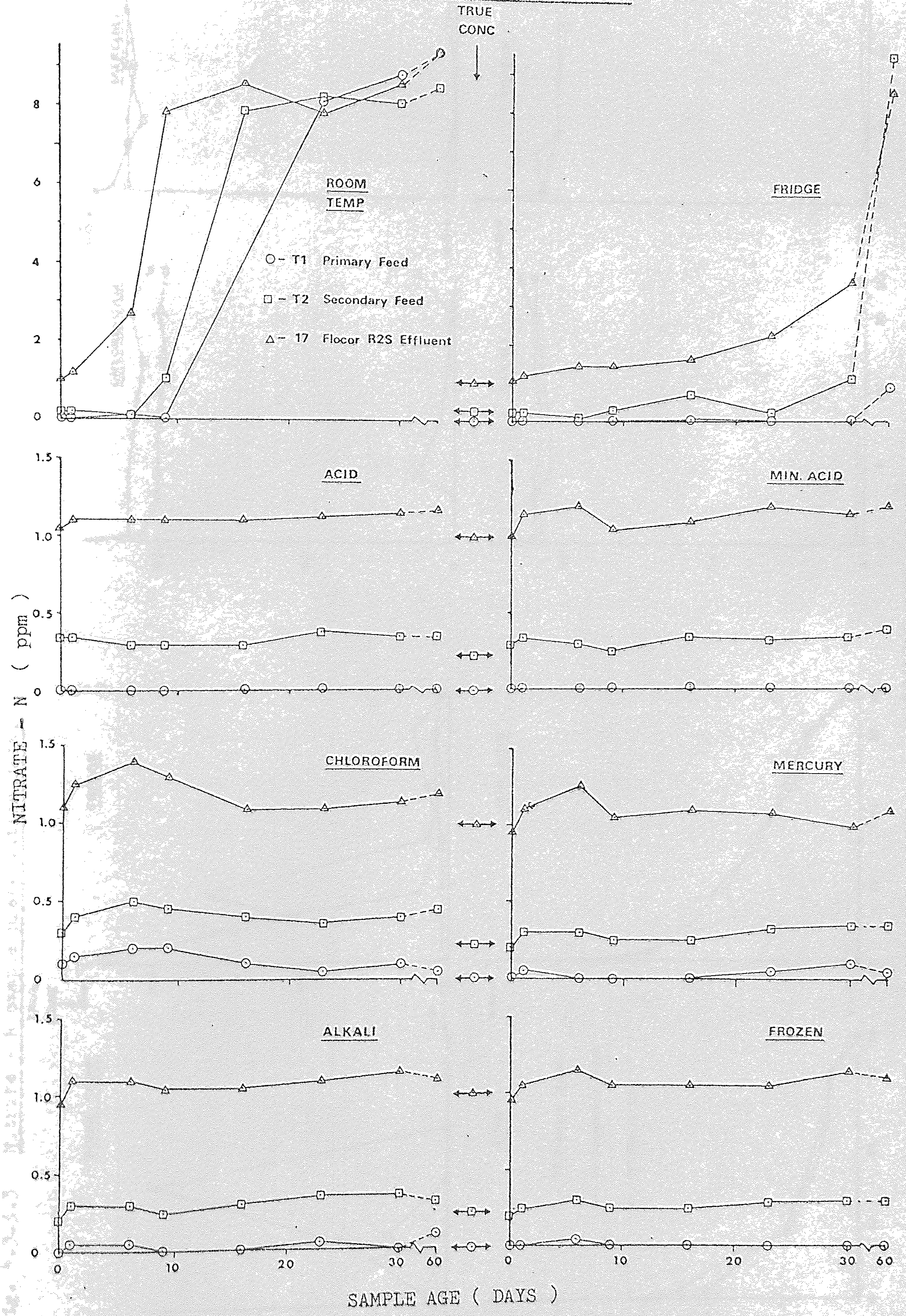
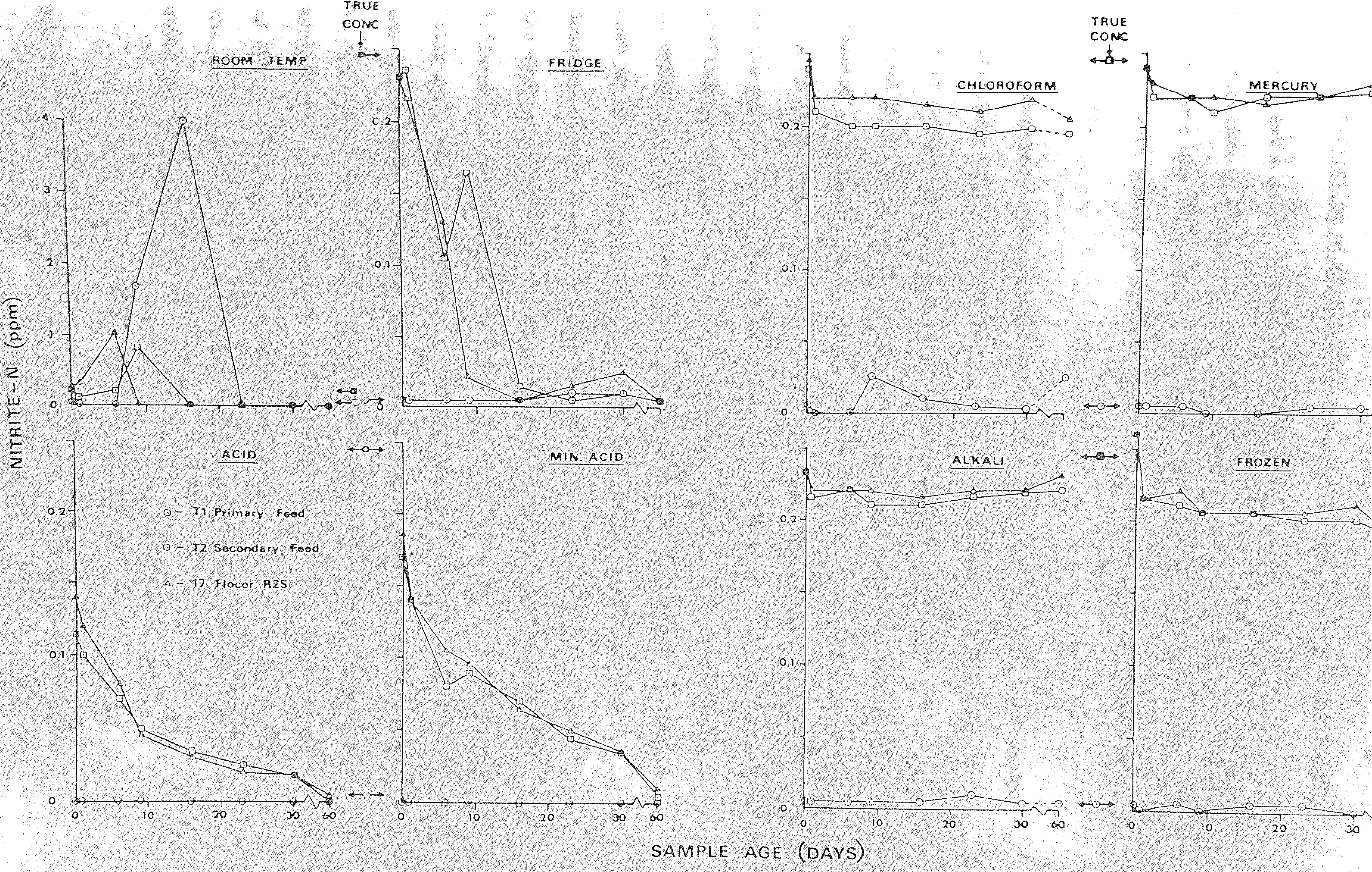


Fig. 4.3.3.3 Nitrite - N sample preservation data.



4.4 Nitrification of sewage effluents in relation to loading conditions

To carry out a study of the effects of various loading conditions on nitrification in biological filters, a series of laboratory scale experiments was designed in which groups of identical filters could be supplied with wastes of different organic content and at predetermined flow rates.

Small laboratory scale filters were used for the experiments, each having an effective volume of 0.75 litres. The size of these filters was largely determined by the amount of sewage needed to maintain the desired flow rates. The filters were constructed from 65 mm internal diameter (ID) glass tubing, being tapered to an effluent drain pipe of 1 cm ID at the base (Fig 4.4.1). A small side arm was inserted close to the base to facilitate ventilation, which was further aided by the positioning of an airtex practice golf ball at the base of each filter. In order to maintain identical conditions within each of the 21 filters used in the experimentation, each was filled with 0.75 litre 6 mm diameter spherical glass beads which acted as the filter medium. As the exact measurement of a volume of glass beads is difficult due to differential packing in measuring cylinders, the measurement was carefully made once, this volume of beads was then weighed and each filter was filled with that weight of beads. The 6 mm beads were used because in order to minimise the effects the wall of the filter might have on treatment the media must have a diameter of less than one tenth that of the filter itself (Dept of Environment, 19). Spherical beads have the advantage of having easily determined specific surface area (SSA) which is calculated from the formula

$$SSA = \frac{3690}{d} \quad \text{Where } d = \text{diameter of the spheres (mm)}$$

therefore the beads have a SSA of 615 m^2/m^3. While it is appreciated that this is around three times as high as might reasonably be used in sewage works tertiary treatment plants, it is felt that, provided ponding can be avoided, the small beads effectively remove any performance constraints which may operate due to lack of nitrifying capacity of a filter filled with larger media.

Each filter was wrapped with black polythene to exclude light, shaken twice to allow settlement of the medium, and placed in the vertical position above an open drain which served to carry away to waste the portion of the effluents not required for samples.

An inverted petri dish with a small hole drilled in the centre served to hold a sewage supply tube in position over the surface of the media. The silicone supply tubing used had a 3 mm ID and 5 mm outside diameter (OD), each filter having the same length of tube to feed it with. Sewage was metered to the filters by one of three Watson Marlow peristaltic pumps which were fitted with either 12 or 24 tubing induction rotors. Two of these pumps were variable speed, one fixed speed. All rotors were initially fitted with 3.0 mm ID, 3.5 mm OD silicone rubber tubing which was liberally lubricated with olive oil twice daily to prolong the effective life. Despite regular lubrication it was found that the tubes required frequent replacement, often after only five days use, if flow rates were to be accurately controlled. All supply tubes were cleaned each week, using tap water, to prevent them blocking with accumulated solids.

The fixed speed peristaltic pump was found to deliver a greater volume of sewage to the filters than was required when fitted with 3.0 mm ID tubing, the volume delivered by this pump was therefore controlled by the use of a time switch which automatically switched off the electric supply for approximately 10 seconds every 30 seconds. To maintain identical dosing regimes for all filters, the two variable speed pumps were also attached to (separate) time switches, each having the same on/off periods, and the speed of these pumps was varied accordingly.

The filters were housed in a small shed (3 m x 2 m) close to the pilot plant to facilitate the transport of the large volumes of sewage required daily during the experiments. This shed was insulated using expanded polyurethane foam clad to the roof and inner walls. Temperature was controlled using a 3 kw Xpelair fan fitted with a thermostat. The temperature was maintained as accurately as possible at 20°C, being continuously monitored by a Foster Cambridge Temperature recorder, the thermistor of which was positioned at a level half way down the side of one of the filters. Fresh wastes were collected daily between 10.15 and 11.15 am, these were then sieved through a 150 micron sieve and placed in 20 litre containers. The containers were positioned close to the relevant Watson Marlow pump and filter supply tubes positioned inside the containers with the ends about 2 cm from the base. The experimental equipment is shown in Plate 4.4.1 and diagrammatically in Fig 4.4.1.

Prior to the taking of any effluent sample a period of one hour was allowed, during which time fresh waste displaced any of the previous days supply from the filter. The effluents from each filter were then collected individually in 250 ml bottles fitted with funnels, for a period of four hours. Each feed liquor was individually sampled by taking a spot sample of at least 100 ml, from as close to the ends of the supply tubes inside the feed containers as possible without causing undue turbulence, at the start of the effluent sampling period. Flow rates were measured on each sampling day by direct measurement of the volume of effluent collected over the four hour period. Each sample was shaken and allowed 30 minutes settlement before taking a 25 ml sub-sample for NH_3-N and NO_3-N analysis and a 2 ml sub-sample for NO_2-N analysis. These sub-samples were immediately preserved as described earlier. The remainder of each sample was stored overnight at 4°C prior to analysis for BOD (ATU suppressed), each analysis was carried out after 30 minutes settlement.

Fifteen of the filters were commissioned in May 1980 and initially seeded with nitrifying populations using settled final effluent from the Eign Road sewage works, applied at a flow rate of 2 m^3/m^3.d for a period of five weeks. The feed supply was then changed to the effluent from the Flocor RS filter of the pilot plant. This effluent was sieved through a 150 micron sieve prior to use. Filtering the effluent in this way removed invertebrates and gross solids. This was recognised as placing an artificial condition on the filters, but it is believed that the removal of invertebrates can be justified on the grounds that the prevention of differential population development between filters could reduce variations in performance. In the absence of grazing invertebrates the removal of gross solids becomes necessary to prevent ponding of the filters.

Following a four week period of acclimation to the secondary filter effluent, a series of experiments was commenced in which sewages of various BOD concentrations were applied to the filters at predetermined flow rates in order to observe the effects of loading conditions on nitrification. The sewages used were collected from different points on the pilot plant, as shown in Table 4.4.1, each being applied to a small group of filters.

Prior to the start of each experiment a period of at least two weeks was allowed for acclimation to any new operating conditions imposed. Excluding this period, each experiment ran for ten consecutive sampling days (approximately five weeks), samples being taken twice weekly where possible.

The first of the experiments was designed to determine the nitrifiability of the secondary effluent when applied to all 15 filters collectively. Following this experiment the filters were randomly assigned to groups of three. These groups were used for all subsequent experiments and served to provide reliable estimates of within group variations during each experiment.

Details of the operating conditions imposed and feed liquors applied to each group of filters during the subsequent experiments are presented in Table 4.4.2.

Table 4.4.1 Origin of feeds used in nitrification experiments.

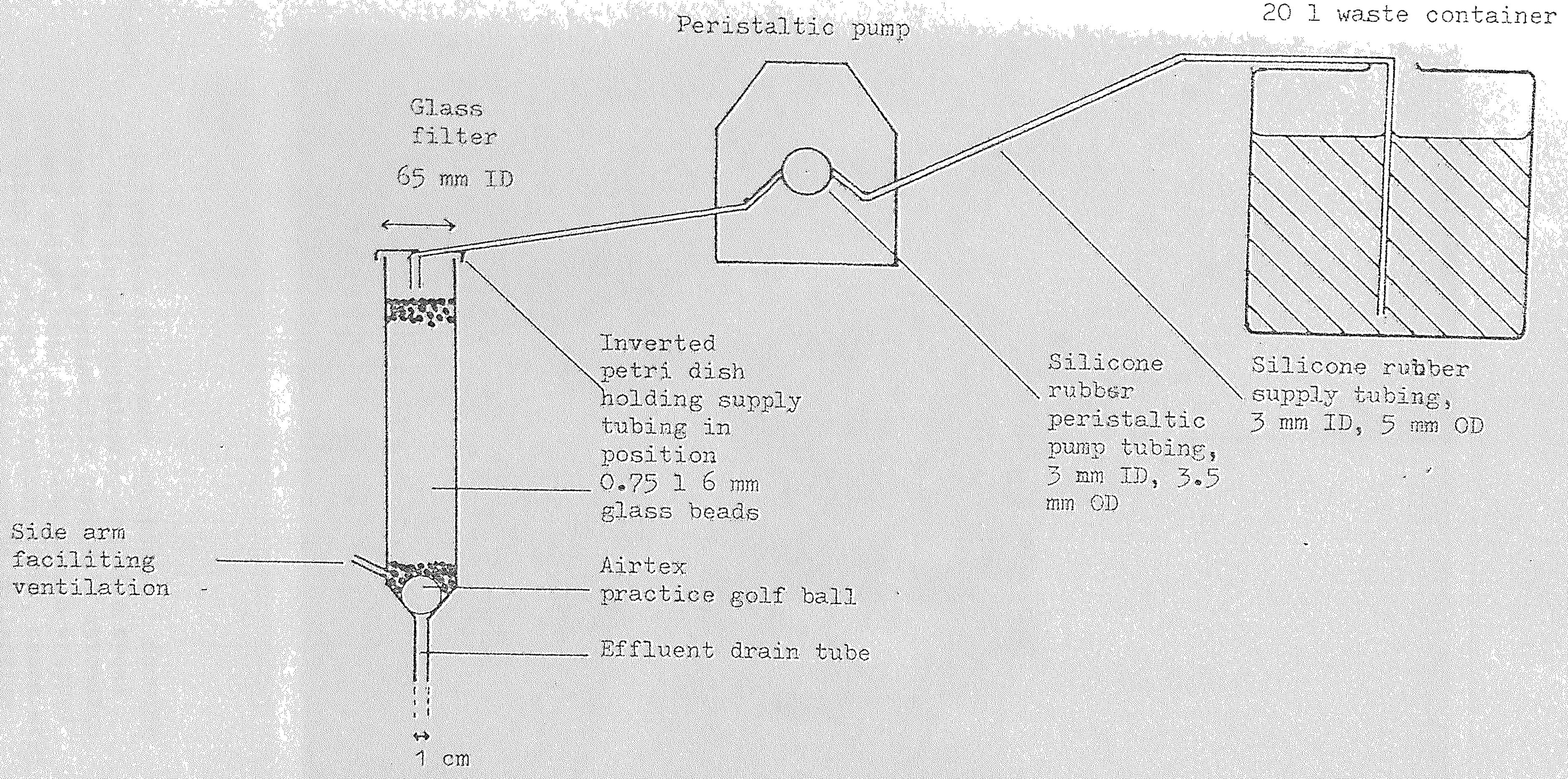
Label used	Origin of feed
W	The splitter box feeding settled mixed primary filter effluents to the secondary filter (T2).
X	The tap placed 30 cm below the surface of the Flocor R2S filter.
Y	The tap placed 1.0 m below the surface of the Flocor R2S filter.
Z and V	The effluent from the Flocor R2S filter (17).
W II	Settled sewage (T1) fortified with 20 mg NH_3-N/l by the addition of ammonium sulphate solution.
X II	Settled sewage (T1) and secondary filter feed (T2) mixed to produce a BOD of approx. 150 mg/l, fortified with 20 mg NH_3-N/l as above.
Y II	Settled sewage (T1) and secondary filter feed (T2) mixed to produce a BOD of approx. 120 mg/l, fortified with 20 mg NH_3-N/l as above.
Z II	Settled sewage (T1) and secondary filter feed (T2) mixed to produce a BOD of approx. 90 mg/l, fortified with 20 mg NH_3-N/l as above.
V II	Effluent from the Flocor R2S filter (17), fortified with 20 mg NH_3-N/l as above.

All feeds were sieved through a 150 micron sieve prior to application to the filters.

Table 4.4.2 Nitrification experiments - experimental programme.

Experiment no.	Filter group	Feed applied	Flow rate applied
1	All	Z	2.0 $m^3/m^3.d$
2	B	W	2.0 $m^3/m^3.d$
	C	X	" "
	D	Y	" "
	E	Z	" "
	A	V	" "
3	B	W	4.0 $m^3/m^3.d$
	C	X	" "
	D	Y	" "
	E	Z	" "
	A	V	1.4 $m^3/m^3.d$
4	B	W II	4.0 $m^3/m^3.d$
	C	X II	" "
	D	Y II	" "
	E	Z II	" "
	A	V II	1.4 $m^3/m^3.d$
5	B	W	6.0 $m^3/m^3.d$
	C	X	" "
	D	Y	" "
	E	Z	" "

Fig. 4.4.1 Diagrammatic representation of nitrification experiment equipment.



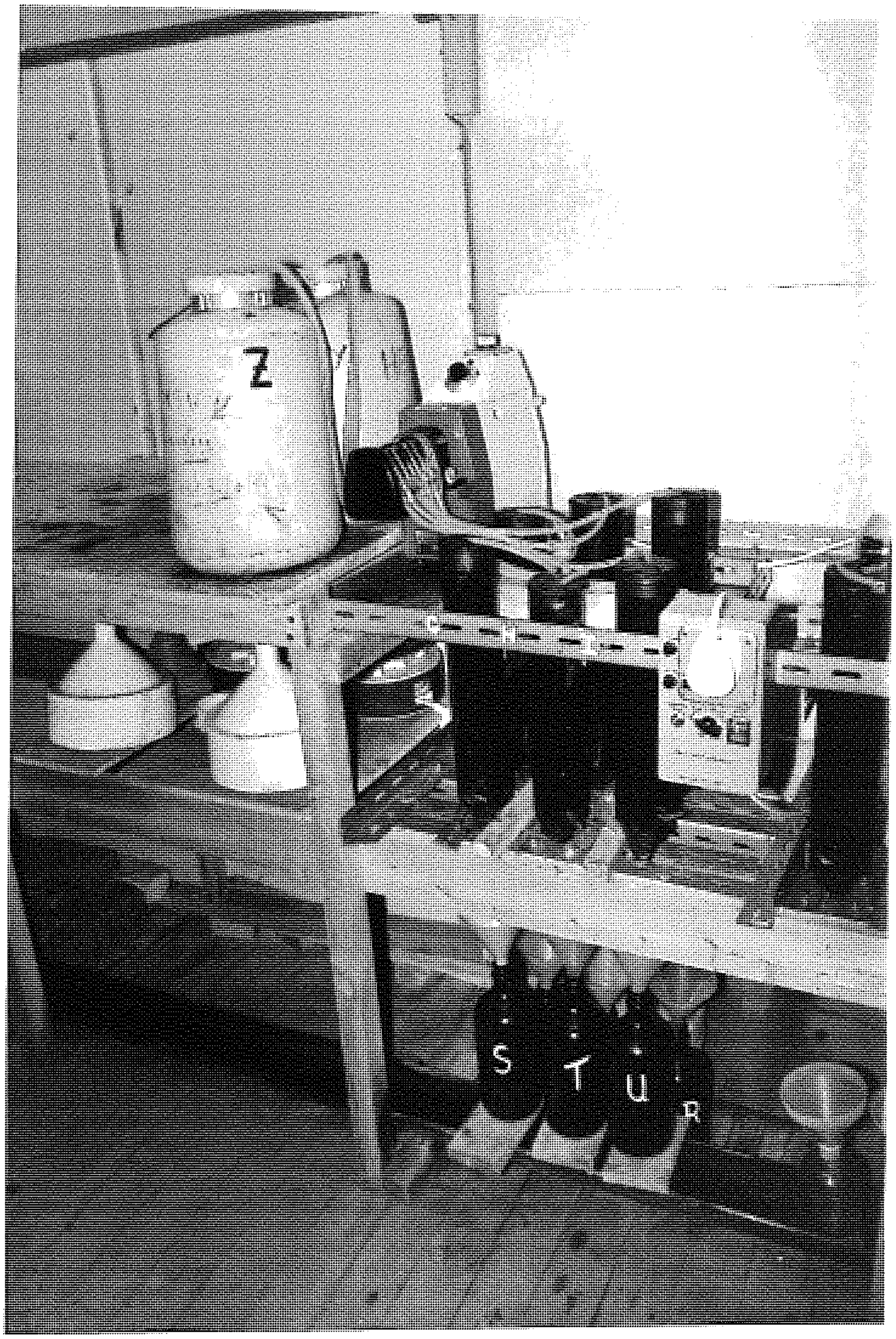


Plate 4.4.1 Nitrification experiment equipment. Showing two feed liquor containers, variable speed Watson Marlow peristaltic pump with automatic on/off switch, six nitrifying towers wrapped in black polythene to exclude light, associated supply tubes and effluent sample collection bottles.

4.5 Sludge collection and conditioning

To characterise the humus sludges produced by the primary and secondary filter media and to compare their dewaterability with humus sludges produced by the low rate biological filters of the Rotherwas STW, Hereford, a technique for the separate collection of the sludges produced by each filter medium had to be developed.

The effluents from the primary filters passed through a small sump (described in Section 4.1) before discharge to a common effluent channel. Each sump was of low capacity (less than 15 l) and did not provide the opportunity for substantial settlement of humus solids, although the fact that the effluent collected in a small pool before discharge to the effluent channel provided an ideal sampling point for the collection of effluent from which humus solids could be settled. Two sets of the apparatus shown in Fig 4.5.1 were used in the collection and settlement of sludge from each filter effluent. Effluent collection was continuous over a 24 hour period, with the effluent from two different filter media being collected simultaneously. Sludge collection was carried out over a two week period during each of the months shown in Table 4.3.2.1.

The effluent from each primary filter medium was collected by pumping from the sump, using a small peristaltic pump fitted with 9 mm ID, 11 mm OD silicone rubber tubing, at a rate of 500 ml/min. The tubing used to convey the effluent from the sump to the pump, and from the pump to the standard household dustbin converted for use as a settlement vessel, was also of 9 mm ID, although this tubing had rigid walls. This tubing was used as it was considered that the internal diameter would be large enough to allow the passage of gross humus solids without causing any change in their nature through the action of compressive forces.

The dustbin was fitted with a baffle to promote rapid settlement and a drain tap and overflow pipe. Excess effluent passing out of the overflow pipe was run to waste. The volume of each dustbin was approximately 68 l, with average diameter 44 cm and height to the drain tap 45 cm. With the pump used the retention time of the effluent in the dustbin was therefore approximately 135 minutes and the upward flow velocity approximately 0.2 m/hr. This was considered to provide sufficient time for complete humus sludge settlement.

At the end of the 24 hour collection period the drain tap was opened and the supernatant drained off. The dustbin was then tipped with considerable care so that as much of the supernatant was drained from the surface of the sludge layer as possible without losing any of the fine solids of the sludge. A small amount of supernatant liquid was always left on top of the sludge layer to ensure that fines were not lost and this supernatant was discarded after laboratory thickening. Using this technique the sludges collected were considered to be representative of those which would have been collected from full scale settlement tanks had they been available.

The secondary filter sludges were settled from effluent drawn from the effluent drain pipes shown in Plate 4.2.2. Two sets of settlement apparatus were used for each effluent as in the primary filters, but as there were no effluent sumps on the secondary filters the effluents were collected by placing the collection tube in the hole cut in the top of each effluent drain pipe (shown in Plate 4.2.2). Each drain pipe had the bottom half of its outlet blocked off to form a small weir, and the small pool of effluent formed behind this weir was used as the reservoir from which effluent collection was made. Settlement and supernatant withdrawal were as for the primary filter sludges.

Settled sludge from the Rotherwas STW low rate biological filters was collected from the desludging valve of one of the humus settlement tanks during one of the two desludging periods of the day. The sewage treated by these filters was the same as that treated by the filters of the pilot plant, and comparisons between the low and high rate sludges were made during three consecutive months as outlined in Table 4.3.2.1. The high rate filter humus sludges were collected and characterised during each of 12 consecutive months.

Sludges were thickened after collection using a WRC laboratory settlement apparatus and their condition and response to the addition of various doses of chemical conditioners was assessed using the methods recommended by Gale (1977). Observations of differences in the conditionability of sludges collected and changes in conditionability with season were then made.

For the comparison of the conditionability of different sludges the concentrations of chemical applied per tonne sludge dry solids during sludge conditioning tests should ideally be maintained at a constant level. In order to simplify the preparation of solutions of chemical conditioning agents however and to remove the need to determine the sludge dry solids content before commencing conditioning tests, the same concentrations of chemical were applied to each thickened sludge regardless of sludge solids content. The cost of the chemical dose used therefore varied with the sludge solids content.

Two methods were used in the treatment of the data for the comparison of the condition and conditionability of the sludges. The first method involved estimation of the cost dosage of aluminium chlorohydrate required to reduce the specific resistance to filtration ($\bar{r}$, measured at 500 g/cm^2 and 20°C) of each sludge to 4.0×10^{12} m/kg after 40 sec shear - which is standard practice in comparative studies on sludge conditionability. A second method of treating the data was developed to take into account two aspects of sludge conditioning tests which became apparent during this investigation. These were:-

1 Although reducing $\bar{r}$ to 4.0×10^{12} m/kg was relatively easy in all of the sludges tested, the coagulant demand required to reduce this figure further increased progressively and varied between sludges. As the aim of the chemical conditioning of sludges is usually to reduce $\bar{r}$ to below 1.0×10^{12} m/kg to produce satisfactory dewatering characteristics, the coagulant demand required to reduce $\bar{r}$ to 4.0×10^{12} m/kg may be too lax a standard for use in comparative studies. The minimum economically achievable $\bar{r}$ through conditioning may therefore be a more precise indicator of sludge conditionability.

2 During comparative tests on conditioner effectiveness it was noted that the conditioners occasionally caused instability of some sludges to the influence of shear forces. Maintainance of sludge stability is considered by Gale (1977) to be an important consideration in the selection of pumping gear and chemical conditioner, as $\bar{r}$ is known to increase with increased shear forces applied to the sludge. If a chemical conditioner therefore destabilises a sludge, $\bar{r}$ could increase on sludge pumping and pressing, therefore producing unsatisfactory dewatering characteristics.

It is therefore felt that the characterisation of any humus sludge should include a measure of the degree to which that sludge can be conditioned, and that the inclusion in this characterisation of an assessment of the change in sludge stability to shear forces induced by conditioning may be of use in both the comparison of sludges and in conditioner selection. In view of this opinion a 'Cost/dose'index has been calculated from the basic data provided by the routine conditioning tests recommended by Gale (1977).

The 'Cost/dose' index has been calculated as follows:-

Cost/dose index =

Cost x $\bar{r}$ x (Conditioned Stability/Initial Stability)

Where:-

Cost = Cost of the chemical dose used in conditioning test (£/Tonne dry sludge solids)

$\bar{r}$ = Specific resistance to filtration of the sludge after conditioning with the above chemical dose and 40 sec stirring in a WRC high speed stirrer (40 sec shear, $\bar{r}$ measured at 500 g/cm^2, in units of x 10^{12} m/kg)

Conditioned Stability = Stability of the sludge to shear after the addition of the above chemical dose

Initial Stability = Stability of the sludge to shear forces after the addition of 20 ml water to 100 ml sludge

and:-

$$\text{Sludge Stability to shear} = \frac{(\bar{r}\text{ after 10 sec shear} + \bar{r}\text{ after 100 sec shear})\ /2}{\bar{r}\text{ after 10 sec shear}}$$

The specific resistance to filtration of the sludge after conditioning and 40 sec shear has been used as a measure of the dewaterability of the sludge after conditioning as it has been shown that this is approximately equivalent to the shear forces experienced by the sludge in a well-designed full scale mixing system. The index is so calculated that it becomes simply the product of the cost of the chemical dose used and the specific resistance to filtration that dose produces in the sludge if the conditioner does not destabilise the sludge.

By taking the 'minimum' achievable Cost/dose index for any particular sludge the index provides an estimate of how cost effectively the sludge can be conditioned, with low values only being possible for sludge which can be successfully conditioned to around 1.0 x 10^{12} m/kg without any severe loss of stability. The 'minimum' achievable value is obtained by examination of the specific resistance to filtration after conditioning. If doubling the chemical dose used resulted in only a slight improvement in $\bar{r}$, the lower chemical cost would be used in the calculation, together with the $\bar{r}$ that chemical dose produced in the sludge.

Sludges were conditioned each month using a 1% solution of aluminium chlorohydrate, while the polyelectrolyte conditioners Zetag 51 and Zetag 88 were used, in 1% and 0.4% solutions respectively, for three consecutive months to compare conditioner effectiveness.

CST values were correlated with specific resistance data using the calibration curve of Fig 4.5.2. The calibration curve was constructed using the methods recommended by Gale (1977) using Gales Simplified Buchner Funnel Apparatus to determine specific resistance to filtration.

Fig. 4.5.1 Humus sludge collection and settlement apparatus.

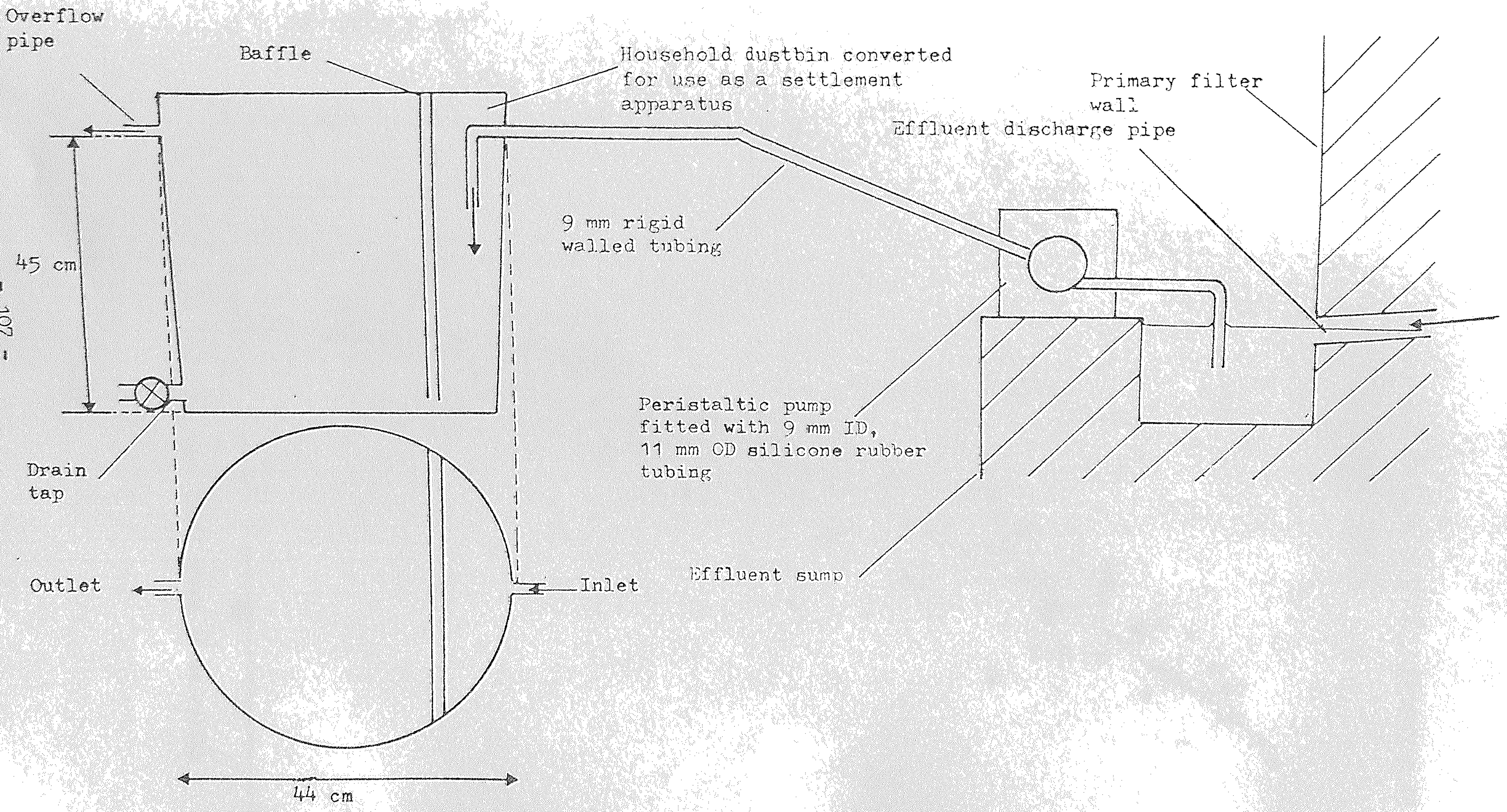
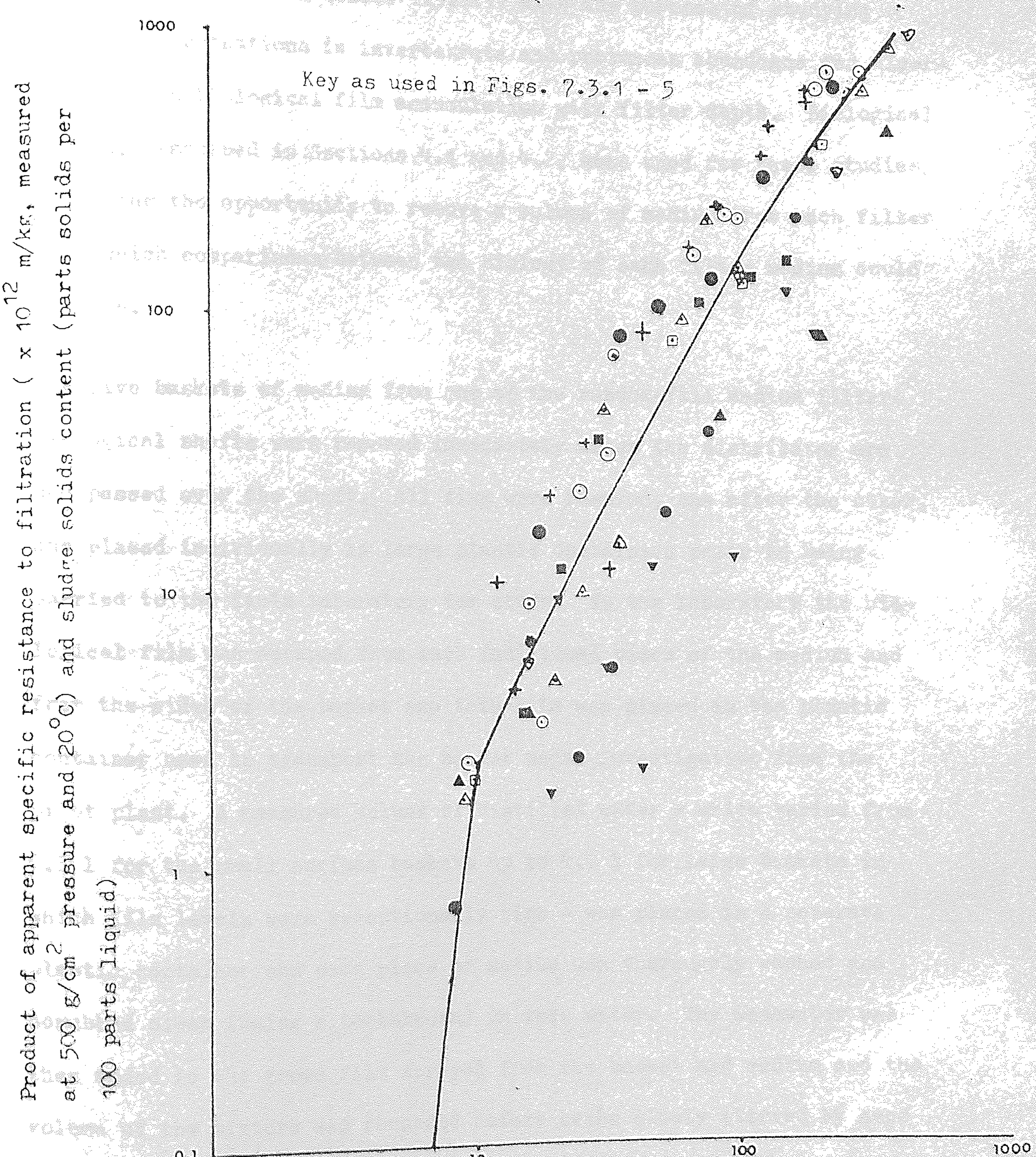


Fig. 4.5.2 CST of humus sludges vs. product of specific resistance to filtration and suspended solids content.



4.6 Biological sampling methods

4.6.1 Biological sampling

Biological sampling was undertaken every three months on both the primary and secondary filters (Table 4.3.2.1) with the purpose of studying seasonal fluctuations in invertebrate and protozoan abundance and diversity and in biological film accumulation with filter depth. Biological shafts, described in Sections 4.1 and 4.2, were used for these studies, providing the opportunity to remove a column of medium from each filter from which comparisons between the biology of each filter medium could be made.

The five baskets of medium from one of the random-fill medium filters' biological shafts were removed immediately after the distributor arm had passed over the shaft. All five were removed, one after the other, and placed individually in large plastic containers prior to being carried to the field laboratory for study. In the laboratory the biological film was scraped from each individual piece of the medium and from the sides of the basket and this film was placed in the plastic container used to transport the basket under investigation from the pilot plant. A measured volume of distilled water - which varied from 0.5 l for the small surface baskets up to 4.0 l for large baskets in which film levels were exceptionally high - was placed in a separate plastic container and each piece of medium was thoroughly washed and scrubbed clean (using a toothbrush) in this water. The washwater was then added to the gross film scraped from the basket and medium and the volume of the mixture was recorded before being slowly stirred by hand to ensure complete homogenisation. After stirring random samples of 100, 25 and 20 ml were taken. The 100 ml sample was oven dried at 105°C to determine dry solids content, followed by ashing at 650°C to determine volatile solids content. The 25 ml sample was diluted to 100 ml using distilled water, and then aerated for one hour prior to the preparation of two microscope slides (after the mixture had been stirred) which were then used to estimate protozoan numbers and species diversity. The 25 ml sample was emptied on to a tray and diluted to enable the identification and counting of invertebrate species present. As the volume of each basket was known (0.00693 and 0.01385 m^3 for the small and large baskets respectively) the numbers of invertebrates and the weight of dry and volatile solids per m^3 filter medium could then be calculated as follows:-

Film dry wt (kg/m^3) =

$$\text{Dry wt in sample(kg)} \times \frac{\text{Vol film and washwater(ml)}}{100} \times \frac{1}{\text{Basket Vol}(m^3)}$$

Film volatile solids wt (kg/m^3) =

$$\text{Volatile solids in sample(kg)} \times \frac{\text{Vol film and washwater(ml)}}{100} \times \frac{1}{\text{Basket Vol}(m^3)}$$

No. invertebrates per m^3 filter medium ($\times 10^6/m^3$) =

$$\text{No. invertebrates in sample} \times \frac{\text{Vol film and washwater(ml)}}{25} \times \frac{1}{\text{Basket Vol}(m^3)}$$

The study of the biology of the modular media entailed the removal of one of the surface units of medium, together with one of the units at 600 - 800 mm from the surface and the only unit at 1200 - 1400 mm from the surface as outlined in Section 4.1. The film was then scraped off and the unit scrubbed clean in a measured volume of washwater as for the random-fill media. The procedure followed was the same as in the random-fill media, although the volume of the units was not the same as in the baskets and therefore the calculations used in estimating film weights and invertebrate numbers were altered accordingly.

The biological shafts of the modular medium filters were removed for study in rotation, therefore nine months were allowed for recolonisation before resampling in the primary and six months in the secondary filters. Although four units were available for use at the surface and middle of the modular medium filters, in practice only three were used, allowing nine months recolonisation before resampling. Three months recolonisation was allowed in the case of the units at 1200 - 1400 mm, and while it is accepted that this is a relatively short period of time, the practical difficulties involved in the placement of more than one unit at this depth outweighed the benefits of replication.

During biological sampling periods the study of the biology of each medium took one whole day, and each period therefore lasted for two weeks. During this time routine chemical analysis of the feeds and effluents was rarely possible due to the work load involved, although at no time was the running of the pilot plant disrupted by the biological sampling as the distributor arms were left running while each medium was studied.

4.6.2 Neutron moisture meter technique

Use of the neutron moisture meter enables estimation of the percent saturation of filter medium voids at different depths without having to disrupt the filter itself, and the results obtained can be used as a rough guide to the condition of the film and to the liklihood of ponding at any depth. Low percent saturation of voids generally indicate that the film is in good condition while high percentages could indicate that ponding is likely and the condition of the filter is poor.

The Wallingford Neutron Moisture Meter used in these studies consists of a probe housing a radioactive source (Berryllium-Americium) of fast neutrons, a counter detecting reflected and moderated neutrons and a rate scaler. When lowered into the access tube (described in Section

4.1) positioned in one of the filters the neutrons emitted by the probe are moderated by collisions with hydrogen atoms in water trapped in the biological film. The density of the moderated neutrons which are reflected back to the probe is detected by the scintillation counter giving a reading which is proportional to the amount of liquid held in the filter film and which can give a rough estimate of the volume of film present through the estimate of the extent to which the void spaces of the medium are saturated with wet film.

To enable the figures obtained by the use of the moisture meter to be converted to percent saturation of voids in the filter medium, calibration was required. Each of the mineral filter media studied was calibrated individually during each of the monthly studies with the meter (months in which analysis was carried out are listed in Table 4.3.2.1), as Marais and Smit (1960) had found - when studying the moisture content of different soils - that different materials require separate calibration. For the mineral media calibration consisted of filling a clean 180 l oil drum with the medium to be calibrated. The moisture meter probe was then lowered into an access tube positioned centrally in the drum and a reading taken with the medium dry. The drum was then filled completely with water and a second('saturated') reading taken. All subsequent readings obtained from the corresponding filter were then converted to the percent of total available voids which were saturated by the following equation

$$\%\ \text{saturation of voids} = \frac{\text{Reading obtained from filter}}{\text{Saturated drum reading-dry drum reading}} \times 100$$

Calibration of the readings obtained from the plastic media was achieved by filling a 60 l polythene container - having a centrally placed moisture meter access tube - with water and using the readings obtained when the probe was lowered into the tube as the 100% saturation figure. It was felt that this method of calibration would be suitable for plastic media in which the percent voidage was greater than 90%, although to achieve true calibration of moisture meter readings with actual percent saturation of voids in a high rate filter having heavy fungal film would be very difficult owing to the differences in moisture content of film which is in good condition and film in poor condition.

Neutron moisture meter readings were taken from each filter on one day of each month (as outlined in Table 4.3.2.1). The flow to the filter to be studied was shut off for one hour before readings were started to allow excess sewage to drain from the filter. Two readings were taken at each depth, with 20 cm intervals between depths. No readings were taken at depths of less than 20 cm from the surface as it has been found that the moisture meter can produce inaccurate results if the probe is used any closer to the surface (Marais and Smit, 1960). Care was taken not to allow sewage to enter any of the access tubes in the filters of the pilot plant or in the calibration vessels, and sewage flow was resumed as soon as readings were completed.

5 Pilot plant performance

5.1 Seasonal fluctuations in sewage strength

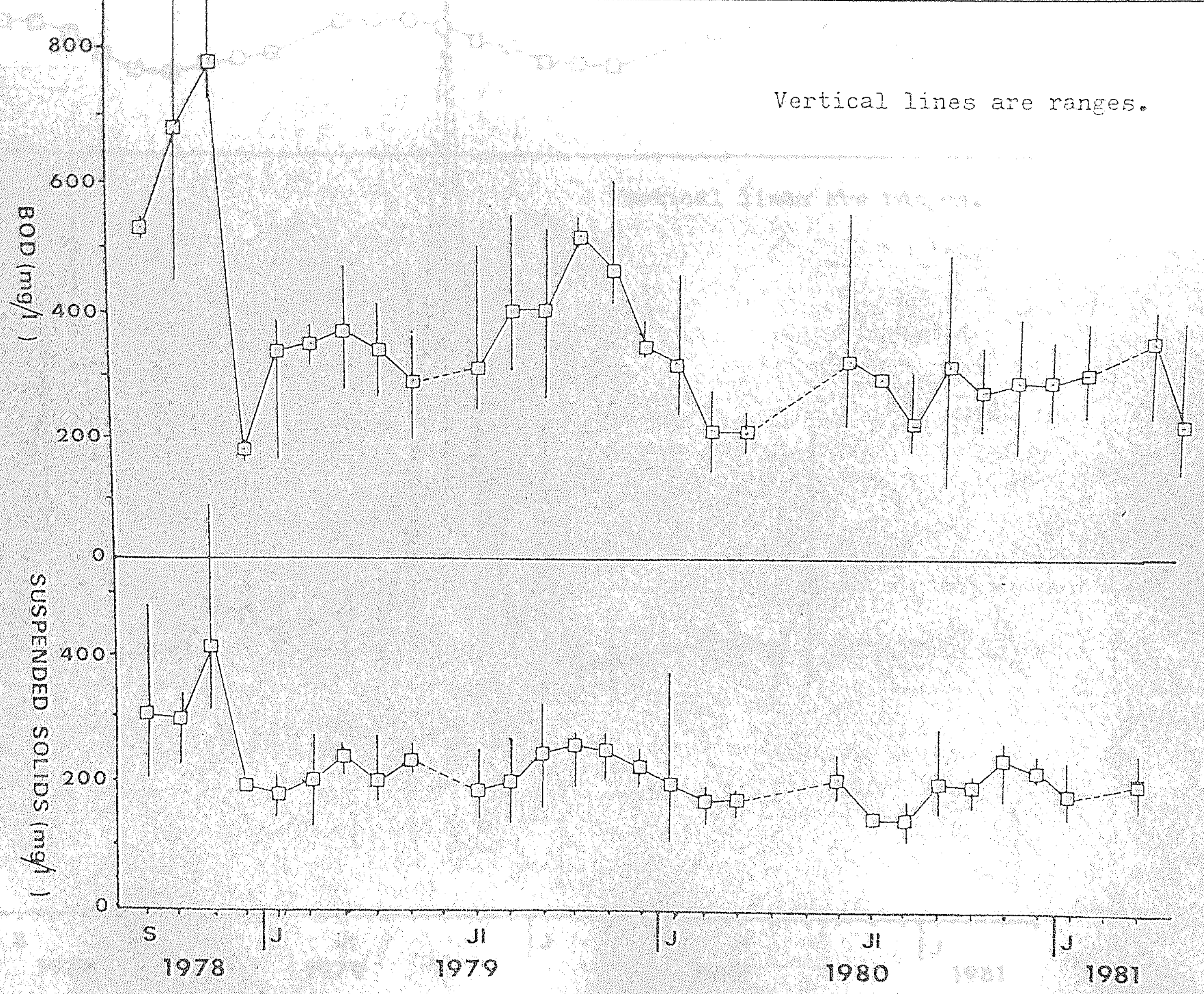
The nature of the sewage received by the Hereford STW changed quite markedly between 1978 and 1981. Figs 5.1.1 - 3 show the monthly averaged physico-chemical composition of the sewage during this period. It can be seen that while there was a very high peak in sewage BOD, SS and COD during the period September - November 1978 when the apple crushing phase of cider production was in progress, subsequent peaks attributable to the discharge of cider wastes during the autumn of 1979 and 1980 were far less marked. The apple crop of 1978 in Herefordshire reached a record level and the tonnage of apples crushed for cider production during the autumn of this year was increased accordingly. While the level of BOD and SS increased during the period September - November 1979 the increase was less than during the previous year, and there was virtually no seasonal increase in these parameters during the same period of 1980. The peak in COD concentration of 2000 mg/l during October 1980 was probably caused by the input of non-biologically oxidisable material to the sewage system as the sewage BOD during this month was not correspondingly high.

Results from the occasional analysis of the sewage for nitrogen content are shown in Fig 5.1.3. The monthly averaged NH_3-N concentration was very low during the whole period of study, with the maximum recorded concentration being 18.4 mg N/l, in April 1981. The total oxidised-N figures are very variable at Hereford, with samples occasionally having quite high concentrations, as seen during the period November 1980 - April 1981. These figures are largely influenced by the practice of tankering liquid sludges and wastes to the Eign Road STW from outlying areas of Herefordshire. These wastes are discharged to the head of the works and can affect the nitrogen content of the settled sewage quite markedly.

The fall in the magnitude of the seasonal fluctuations in sewage strength over the three year period can be attributed to several factors. The installation of improved pre-treatment facilities at the cider production works for the removal of some of the oxidisable material prior to discharge to the sewerage system, following the revision of trade effluent charges levied by Welsh Water Authority, greatly reduced the load to the sewage works. The closure of the vegetable canning factory in May 1979 and the fact that many industries were affected by economic recession also reduced the load considerably. Despite these reductions in load the sewage at Hereford is still strong for mixed domestic and industrial wastes, and the fact that the nitrogen content of the sewage is low (averaging less than 15 mg N/l) results in a high C:N ratio which tends to promote fungal growth in the existing biological filters, and this can lead to ponding and its associated problems.

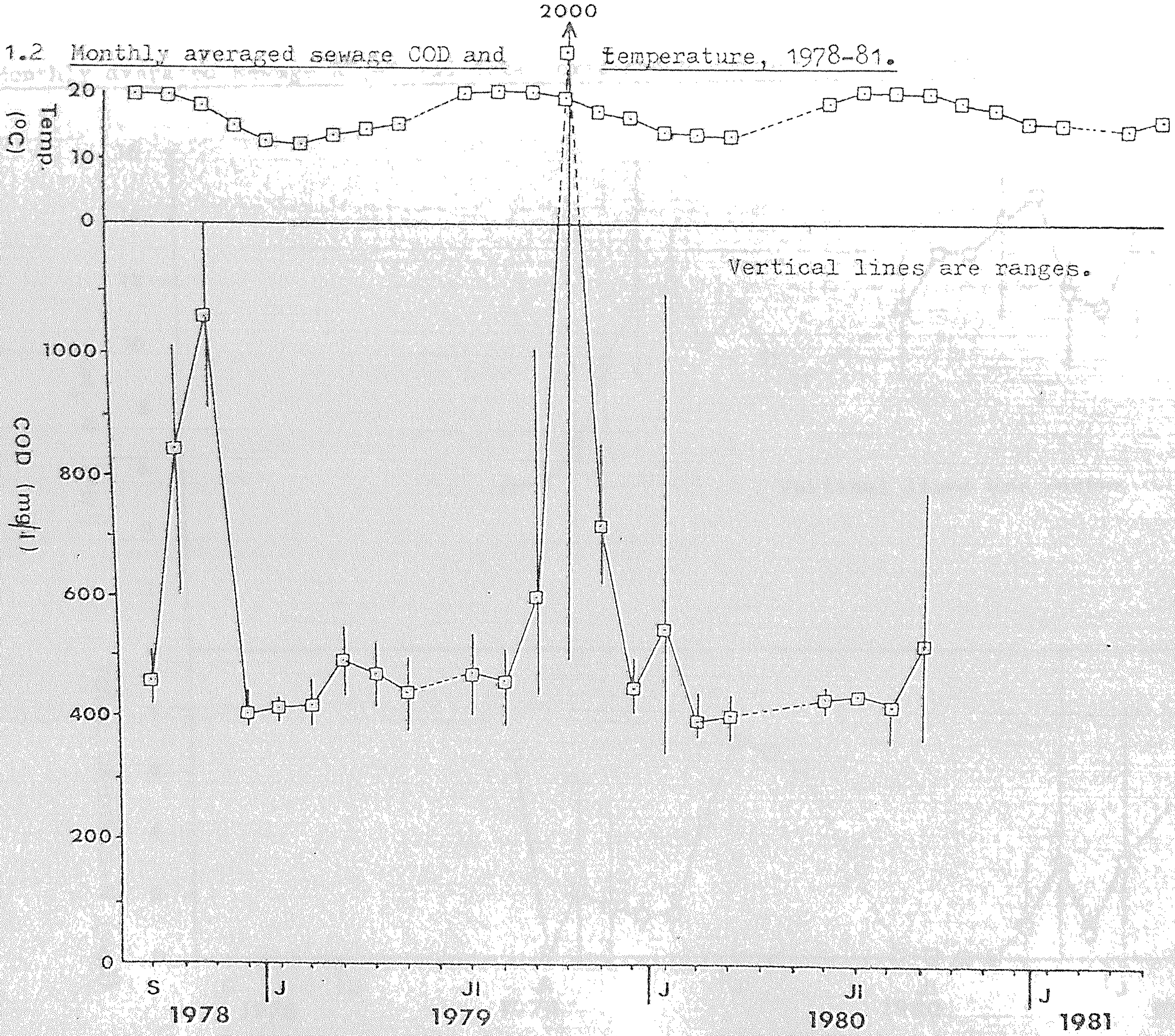
Detailed study of the physico-chemical performance and biology of two stage high rate biological filters when treating a municipal sewage with such characteristics would therefore be of value from two aspects. Firstly such studies would be useful in generally quantifying the performance characteristics and capabilities of two stage high rate filtration, and secondly they would provide an assessment of whether high rate filtration could be used as an efficient alternative to seasonally overloaded low rate biological filters, similar to those installed at the Eign Road and Rotherwas sewage treatment works at Hereford.

Fig. 5.1.1 Monthly averaged sewage BOD and suspended solids (Shaken sample), 1978 - 81.



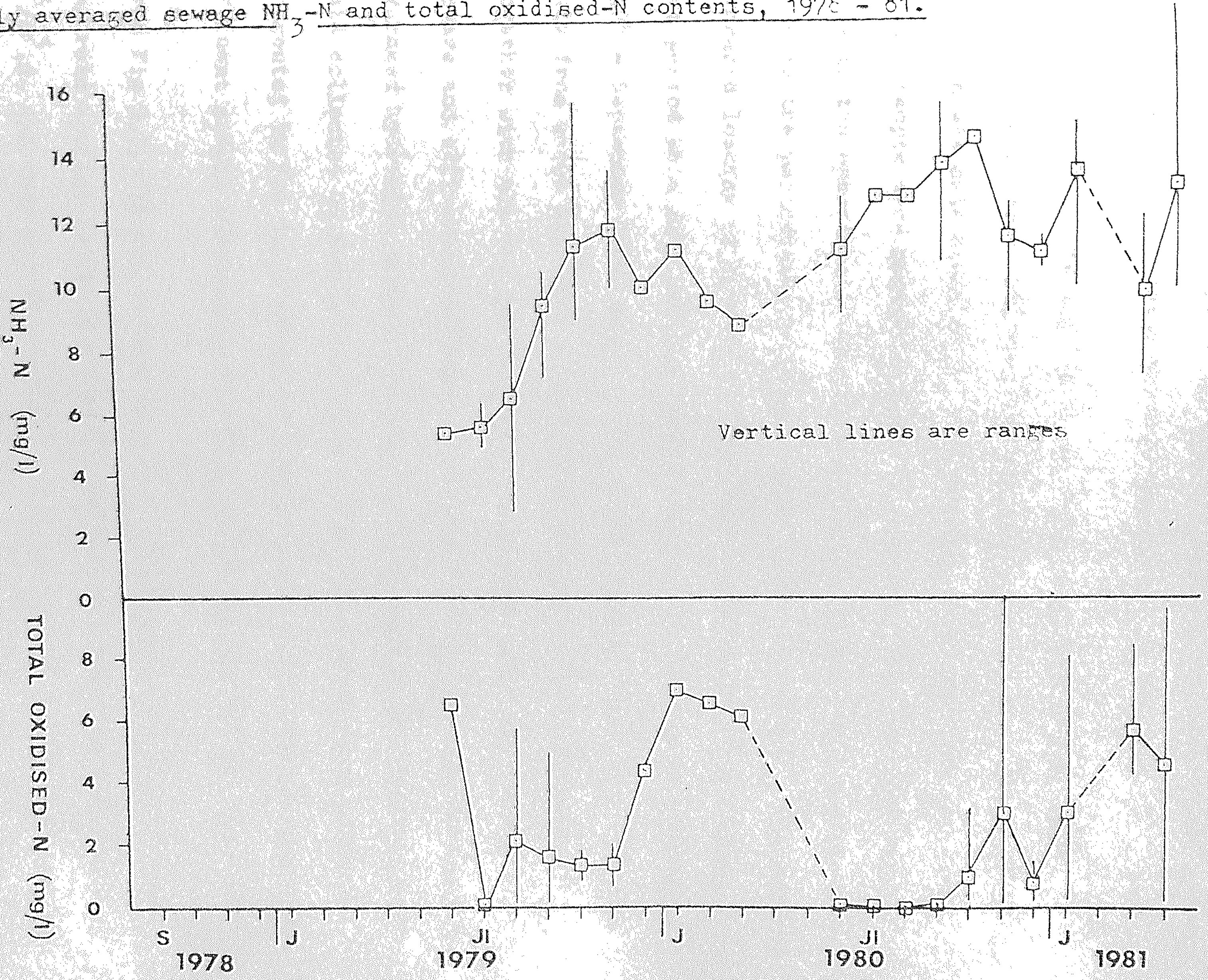
Vertical lines are ranges.

Fig. 5.1.2 Monthly averaged sewage COD and temperature, 1978-81.



Vertical lines are ranges.

Fig. 5.1.3 Monthly averaged sewage NH_3-N and total oxidised-N contents, 1978 - 81.



5.2 Mineral medium filter results

The mineral medium filters are described fully in Section 4.1, while the media used and their specific surface area (SSA) are listed in Table 4.1.1. These filters had been in operation for three years before the research project began and were therefore fully matured.

The nominal flow rate applied to the filters during the nine month period to September 1978 when the research project began was 5.6 $m^3/m^3.d$, and this was maintained as accurately as possible until December 1980 when attempts were made to increase it (Section 5.6). The only change made in the operation of the filters prior to December 1980 was a reduction in the periodicity of dosing in May 1979 (Section 5.4). The monthly averaged loading of conditions applied to the primary filters during the period when full effluent sample analysis was maintained (September 1978 - September 1980) are presented graphically in Fig 5.2.1. The raw data from which the BOD and COD loading rates have been calculated, together with all the raw data from the analysis of primary filter sewage and effluents, are presented in Appendices 5.1.1 - 9. The monthly averaged hydraulic loading rates have been calculated from the flow rate data collected on sample days only, and the BOD and COD loading rates presented in Fig 5.2.1 therefore apply directly to the monthly averaged effluent sample composition data which are presented in Figs 5.2.2 - 6.

From Fig 5.2.1 it can be seen that the monthly averaged hydraulic loading rate applied to the mineral filters fluctuated between 3.68 and 8.13 $m^3/m^3.d$, and that the flow generally increased as the project proceeded. The distributor jets supplying sewage to the primary filters tended to be susceptible to blockage by gross solids which accumulated within the distributor mechanism unless the flow rate was maintained at a reasonably high level. Months in which the hydraulic loading applied to the filters fell are indicative of either periods in which the distributor jets became badly blocked (despite daily clearance of any such blockages), or periods in which the Mono pump supplying settled sewage to the pilot plant was not operating at full capacity due to mechanical problems. Periods in which the sewage supply to the filters was lost completely are listed in Appendix 4.3.1.

The peak BOD and COD loads applied to the mineral filters correspond to the peaks in sewage BOD and COD shown in Figs 5.1.1 and 2, and, with the exception of the extremely high COD loading applied during October 1979 which was mentioned in Section 5.1, can be generally attributed to periods of apple crushing at the cider works. Most of the monthly averaged BOD loading figures were between 1 and 2 kg/m^3.d, while most of the COD loadings were between 1.8 and 3.5 kg/m^3.d.

Data from the period when full effluent analysis was maintained are presented in Figs 5.2.2 - 6 as monthly averages. While each filter medium was duplicated in the mineral media filter, statistical analysis (Students t-tests) of effluent quality showed that there were no differences between duplicates and in order that presentation of the results may be simplified the data from each pair of filters has therefore been averaged on a monthly basis. The data were treated separately however in the comparison of filter performance by statistical analysis, presented in Section 5.7. Unfortunately no samples were taken during June 1979 or April and May 1980.

The effluent BOD concentrations of the mineral media filters (Fig 5.2.2) were all very similar during the two year study period, and followed the seasonal fluctuations in sewage BOD quite closely. The very high sewage BOD's recorded during October and November 1978 resulted in correspondingly high effluent BOD concentrations, although the fact that good quality effluents were produced as soon as the sewage BOD dropped sharply (as in December) indicates that the filters had not been overloaded to the point where efficiency was badly impaired. Fig 5.3.6 shows that while BOD removal efficiency, based on percent BOD removal, was maintained at around 70% during October and November, it fell to around 62% during December and increased to over 80% in January. This seems to indicate that although the filters have the capacity to treat heavy organic loadings, if the BOD concentration falls suddenly there will be a lag period before they re-adjust to the lower loadings, during which time removal efficiency will be slightly impaired. Although the temperature of the sewage fell between November and December as shown in Fig 5.1.2, this is not considered to be a contributory factor to the change in filter efficiency, especially as temperature fell again between December and January while filter efficiency improved during this time. Sewage and effluent monthly averaged temperature data are presented in Appendix 5.1.7. Due to fluctuations in sewage strength during the experimental period it is impossible to determine whether any changes in filter efficiency were due to changes in sewage temperature alone, although it is not believed that temperature played any major role in directly determining filter efficiency.

The effluent COD concentrations (Fig 5.2.3) were also very similar, with no filter medium proving to be consistently more efficient than any other. Effluent concentrations did not follow the sewage concentrations as closely as in the BOD data and this may reflect the fact that the sewage varies in chemical composition and that the readily oxidisable fraction of the COD is occasionally small.

Figs 5.2.4 and 5.2.5 show the settled and shaken sample effluent suspended solids contents respectively. The shaken solids concentrations varied between filters and duplicates, although this can be reasonably expected as the continuous sloughing of film by the filters increases the possibility that gross solids will appear in the samples. As gross solids were continuously discharged by the filters, and as these solids were occasionally of a very fibrous (fungal) nature it was often difficult to obtain representative samples for the determination of effluent shaken sample suspended solids content. Great care was taken to ensure that samples were as representative as possible although it was decided that very large solids should not be included in any sample. Pieces of material which were considered large enough (greater than about 8 cm in length) to block the automatic effluent samplers had they been in use were therefore discarded and a fresh sample drawn. Less than one percent of effluent samples had to be discarded in this way. No filter medium appears to have consistently discharged greater amounts of suspended solids than the others. The settled solids contents of the effluents were closely grouped throughout the experimental period, illustrating that the solids produced by the filter media were all readily settleable to approximately the same suspended solids concentrations. There was a peak in settled solids content of the effluents in May 1979, despite the fact that there was no such peak in shaken solids content, suggesting that the settleability of the solids had deteriorated during this month. There were no obvious periods of heavy sloughing of film and it appears that film is normally sloughed continuously in small quantities.

Sludge production rate data are shown in Fig 5.2.6. The filter media all produced similar quantities of sludge with no medium consistently producing either more or less than the others. Two distinct peaks in sludge production occurred. The first was during December 1978, when sewage BOD fell dramatically after having been extremely high during the two preceeding months. The peak during this month is therefore attributed to the fact that excess film accumulated while the BOD load was very high was sloughed as soon as the sewage BOD fell dramatically. The second peak grew gradually from December 1979 to March 1980 and may have been due to the sloughing of film, as the percent saturation of voids recorded monthly during this period (Fig 5.5.1) showed a gradual decline from the extremely high values which had been recorded in December 1979.

Data from the analysis of samples for NH_3-N content are presented in Appendix 5.1.8 as monthly averages. From this data it can be seen that the effluent samples almost invariably contained greater quantities of NH_3-N than found in the sewage. As the samples were effectively fixed and preserved prior to analysis (see Section 4.3.3.1), the increases in NH_3-N concentration are real and reflect the changes occurring on passage through the filters rather than experimental or analytical error. The increases are believed to be due to the death and subsequent lysis of cells within the filter film. This is a continuous process within the film, with massive cell death occurring in anaerobic areas which develop when the film thickness increases to levels which are too great to allow the passage of oxygen by diffusion through the whole of the film. If the base of the film dies in this way it can become detached from the filter medium and the possibility of sloughing through the action of hydrualic scour is increased. If the film does slough there is a tendency for it to accumulate in small areas of the filter, where the medium can become clogged and the film fully anaerobic. Lysis of the cells in these areas of anaerobicity then releases the cell contents to the sewage and hence increases the NH_3-N content. As the filter film tends to become anaerobic in small localised areas, the dead film tends to be flushed from the filter by hydraulic scour once the dead material has been partially decomposed. The result is that at any time some areas of the filter are undergoing periods of active film growth and regeneration to fill the space left by the flushing out of dead film, while others are dying due to the development of anaerobicity. The areas of active film growth will take up some of the cell NH_3-N released by lysis of cells from the dead film in areas higher up in the filter, and will therefore affect the amount of NH_3-N released in the effluent. This uptake of NH_3-N will be by actively growing fungi during periods of low temperature and high sewage BOD when the grazing invertebrate population is suppressed by the influence of envir onmental factors, and by fungi, invertebrates and protozoons at other times of the year. If the film at the base of the filter dies and is sloughed following lysis, the dead cells contents cannot be used by actively grazing cells within the filter and are discharged in the effluent, resulting in an increase in effluent NH_3-N content. There appears to be no seasonal discharge of NH_3-N by the filters and this correlates with the observation (made earlier) that the sloughing of biological film is continuous throughout the year.

Fig. 5.2.1 Monthly averaged loading conditions applied to the primary filters, September 1978 - 80.

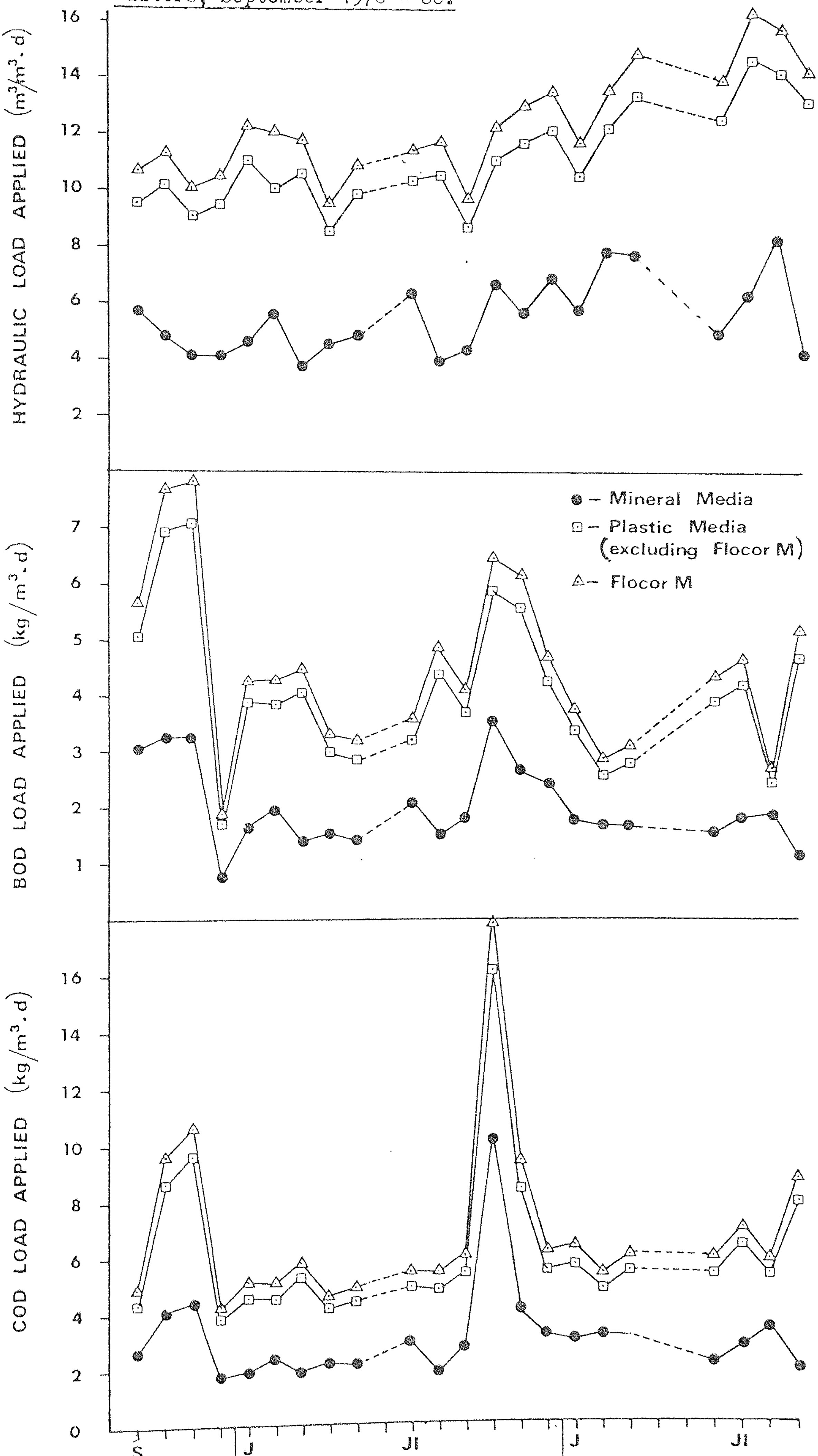


Fig. 5.2.2 Monthly averaged BOD data. Mineral medium filters.

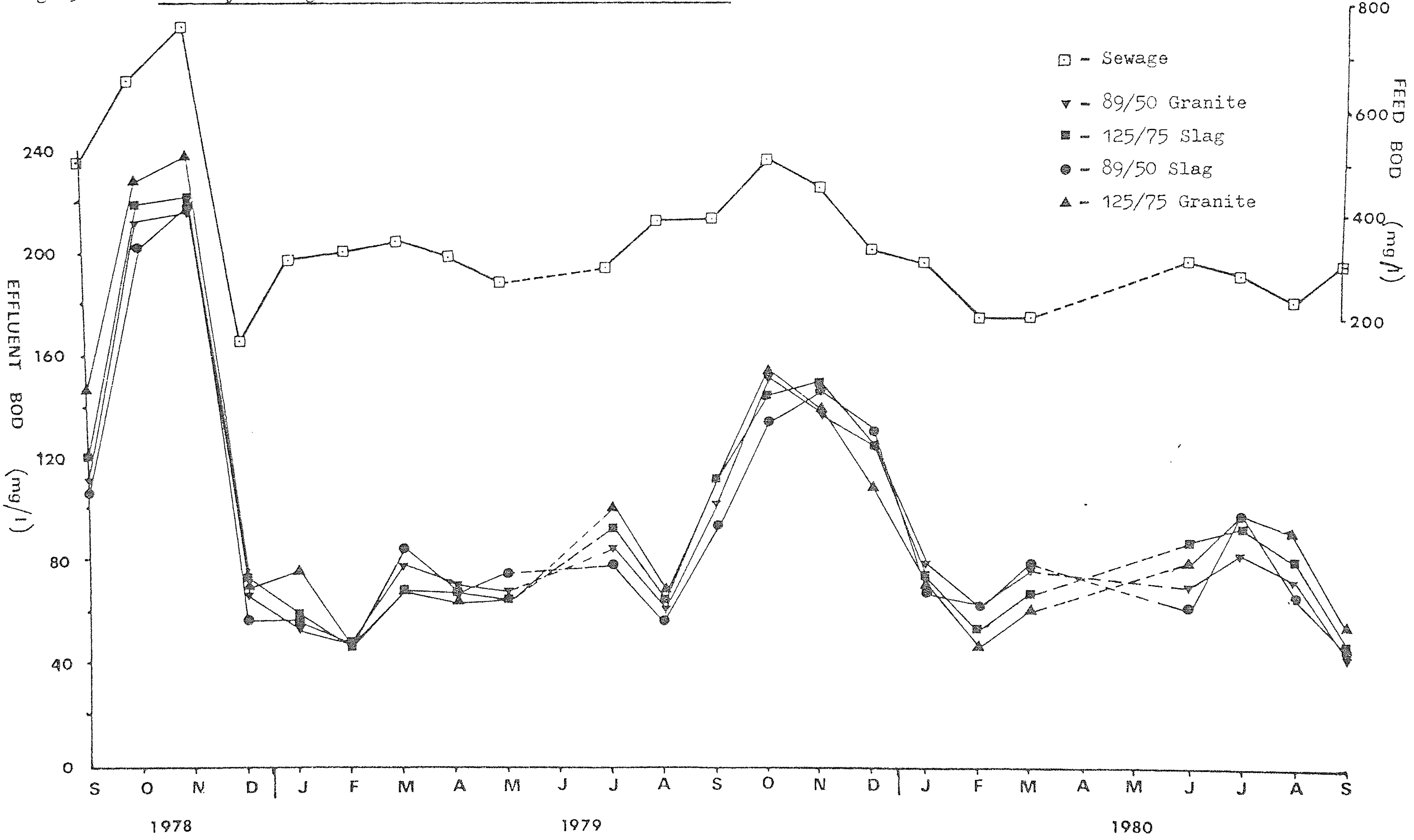


Fig. 5.2.3 Monthly averaged COD data. Mineral medium filters.

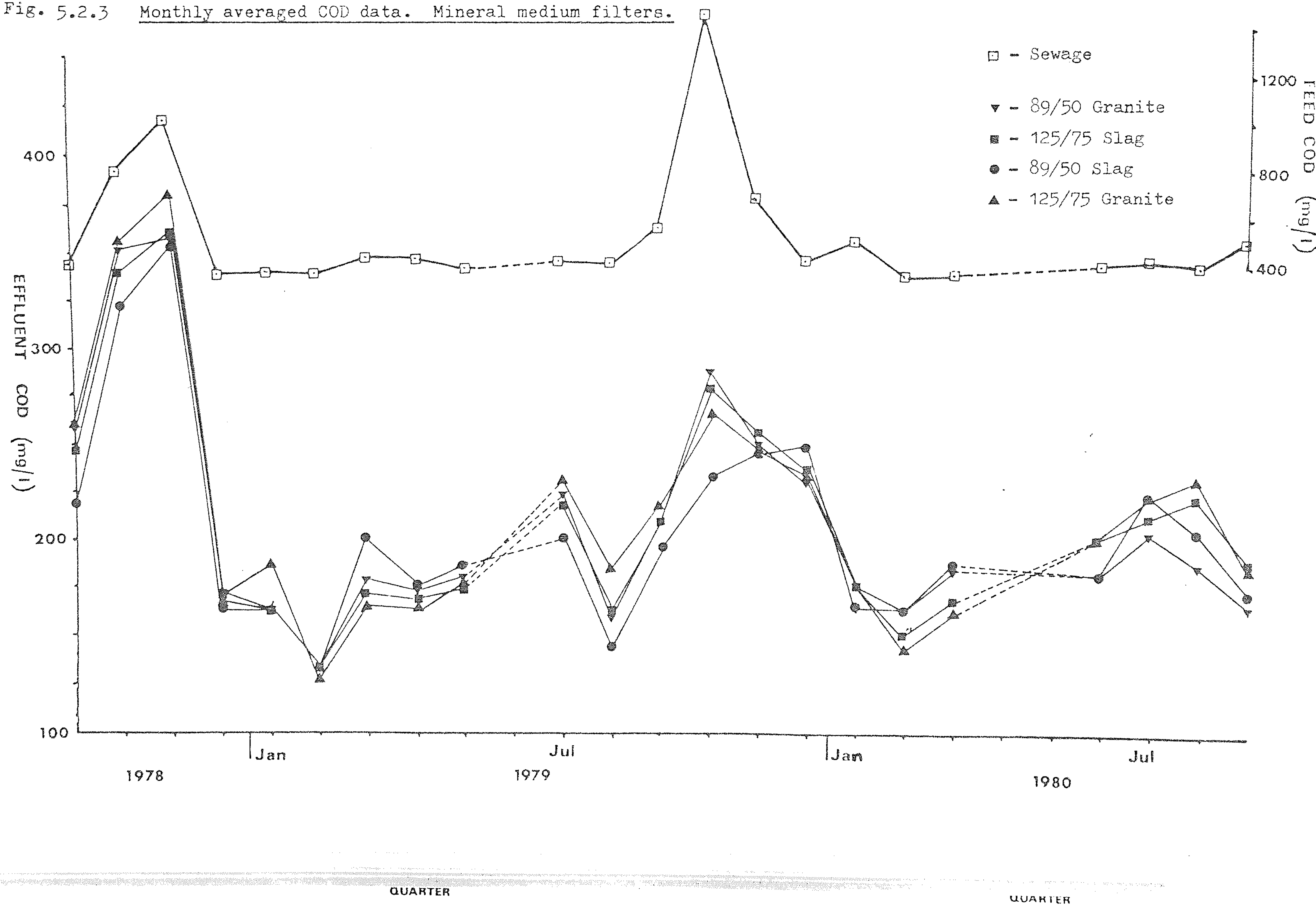


Fig. 5.2.4 Monthly averaged suspended solids (settled sample) data. Mineral medium filters.

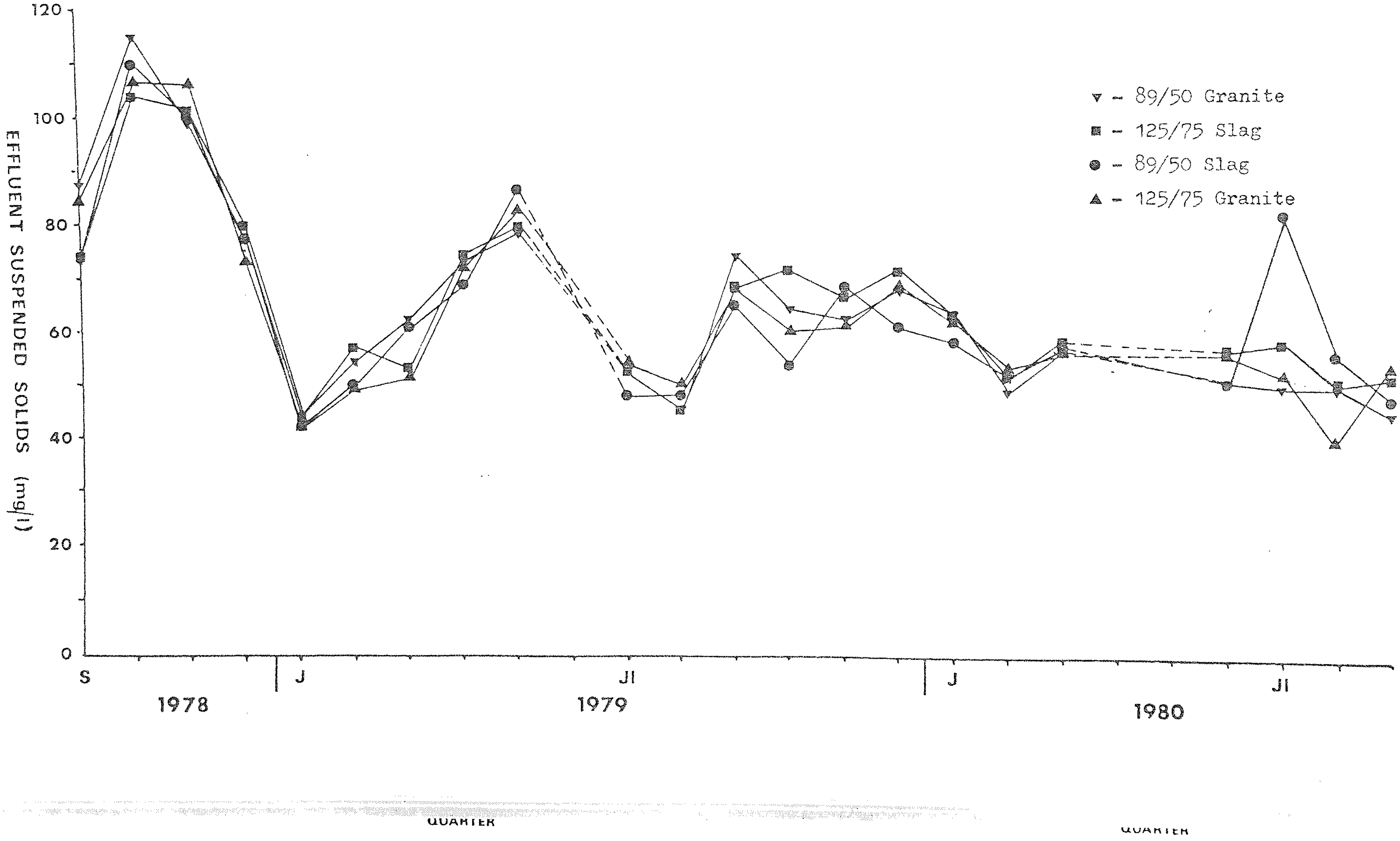


Fig. 5.2.5 Monthly averaged suspended solids (shaken sample) data. Mineral medium filters.

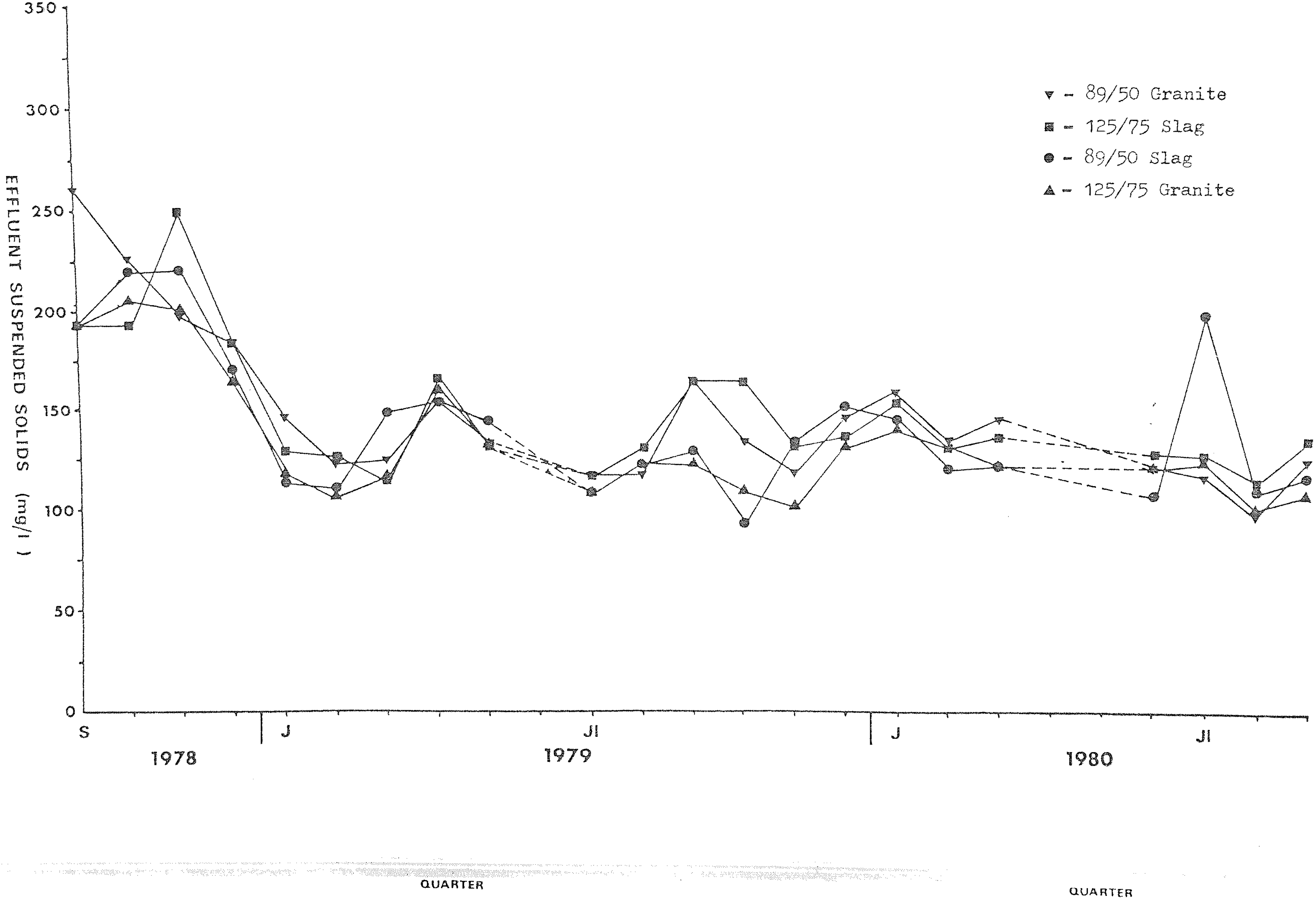
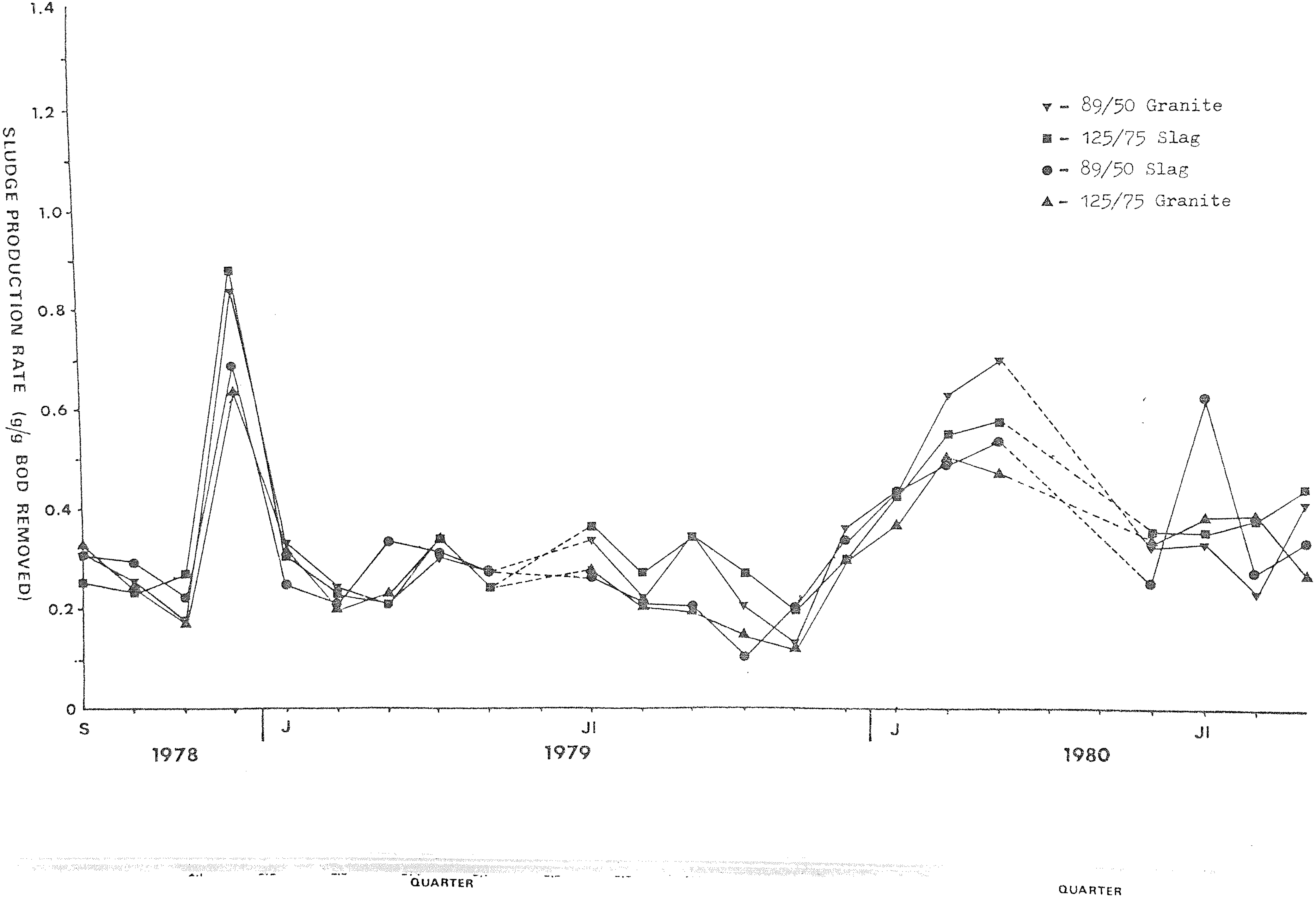


Fig. 5.2.6 Monthly averaged sludge production rate data. Mineral medium filters.



5.3 Plastic medium filter results

The plastic medium filters are described fully in Section 4.1, while the media used and their specific surface area (SSA) are listed in Table 4.1.1. These filters had been in operation for the same length of time as the mineral filters and were therefore also fully matured at the begining of the research project.

The nominal flow rate applied to the filters during the nine month period to September 1978 was 11.2 $m^3/m^3.d$ and this was maintained until December 1980 with the same operational changes as reported for the mineral medium filters (Section 5.2). The monthly averaged loading conditions applied to the plastic medium filters during the period September 1978 - September 1980 are presented in Fig 5.2.1. The raw data pertaining to the operation of the plastic filter are presented in Appendicies 5.1.1 - 9, and the loading rates have been calculated as for the mineral filters.

The monthly averaged hydraulic loading applied to the plastic medium filters ranged from 9.54 - 16.21 $m^3/m^3.d$ for the Flocor M filter and from 8.59 - 14.59 $m^3/m^3.d$ for the other plastic medium filters. Fluctuations in the hydraulic loading applied were caused by the same factors as outlined for the mineral medium filters, although the gradual increase in loading as the project proceeded was more marked in the plastic than in the mineral medium filters.

The peak BOD and COD loads applied to the plastic filters again generally corresponded to the peaks in sewage BOD and COD. Most of the monthly BOD loading averages lay between 2.5 and 6.0 $kg/m^3.d$ (2.75 and 6.70 $kg/m^3.d$ in the case of the Flocor M filter), while most of the COD monthly averaged loadings lay between 4.25 and 5.60 $kg/m^3.d$ (4.70 and 6.25 $kg/m^3.d$ in the Flocor M filter).

Data from the period September 1978 - 1980 have been averaged in the same way as those from the mineral media filter and are presented in Figs 5.3.1 - 5. Students t-tests again showed no significant differences between the effluent quality from duplicated filters and data from each pair of filters have been presented as averages for simplicity. No samples were taken during June 1979 or April and May 1980.

The monthly averaged BOD data (Fig 5.3.1) show that while the effluent concentrations followed the seasonal fluctuations in sewage strength quite closely, as in the mineral media, there was a greater spread in the quality of the effluents achieved by the different filter medium types. It should be noted that the Flocor M filter was filled with 11% less medium than the other filters and therefore received an 11% greater load per unit volume of medium, as shown in Fig 5.2.1. From Fig 5.3.1 it is not immediately apparent which filter produced the best overall performance, and it appears that the relative performance of each medium changed with the seasonal fluctuations in sewage strength. Statistical analysis of the data shows this to be true (Section 5.7).

In months where the sewage BOD and COD reached peak values (October and November 1978, October and November 1979), the Flocor M filter tended to produce effluents of lower quality than those produced by the other plastic media. However, as the biological film levels were low in this filter at all loading rates (and the risk of ponding was therefore always low (Section 5.5)), and the loss of efficiency at high organic loadings was only slight (Fig 5.3.1, 2 and 6), higher loadings could be applied to this medium in situations where effluent quality is not of prime importance.

The suspended solids data (Figs 5.3.3 - 4) show that the Flocor M filter tended to produce greater concentrations of both suspended and settled solids than the other filters for much of the experimental period. All media showed peaks in both shaken and settled solids which roughly followed those observed in sewage strength, although there was a slight increase in both of these parameters between January and May 1979 which did not correspond to any changes in sewage composition. There is no evidence from these data of any regular seasonal offloading of film.

The sludge production rate data (Fig 5.3.5) followed a similar pattern to that observed in the mineral medium filters although there were greater differences between sludges and there was a third peak in August 1980. This peak corresponded to a marked improvemnent in the settlement characteristics of the effluent solids at this time - the settleable proportion of the effluent solids increased from approximately 60% to approximately 70% between July and August 1980 - causing an increase in the sludge production rate figures.

Data from the analysis of samples for NH_3-N content (Appendix 5.1.8) again show that effluent samples regularly contained greater concentrations of NH_3-N than those found in the sewage. This phenomenon was more pronounced in the random-fill Biopac medium filters than in the modular Flocor filters. The greater release of NH_3-N to the effluents through cell lysis in the random-fill media can be attributed to the fact that the void spaces in these media, although constituting a similar percentage of the total volume occupied by the media as those of the modular media, are smaller in size. The high levels of biological film supported by the random-fill media therefore tended to clog the void spaces more regularly than in the modular medium filters where biological film levels were lower (see Section 5.5). The resulting localised areas of anaerobicity which developed caused cell death and lysis in the random-fill medium filters, releasing NH_3-N to the effluents (as described in Section 5.2). The lower film levels supported by the modular media did not block the void spaces of the media as regularly, and the release of NH_3-N through cell lysis was therefore less marked. Another factor in the development of anaerobic areas within the filters is the ease with which biological film which has become detached from the filter medium is washed from the filter. In the random-fill media the cross-septae of each unit of medium tend to trap film as it is washed down the filter, while the fixed and more open structure of the modular media allows quite large pieces of sloughed film to be washed directly from the filter without causing any localised blockages. Only large pieces of sloughed film therefore become lodged and subsequently anaerobic within the Flocor filters, and the resulting levels of cell lysis produces less of an increase in effluent NH_3-N concentration than that observed in the random-fill filters.

Operational shutdowns affecting the plastic medium filters are listed in Appendix 4.3.1.

Fig. 5.3.1 Monthly averaged BOD data. Plastic medium filters.

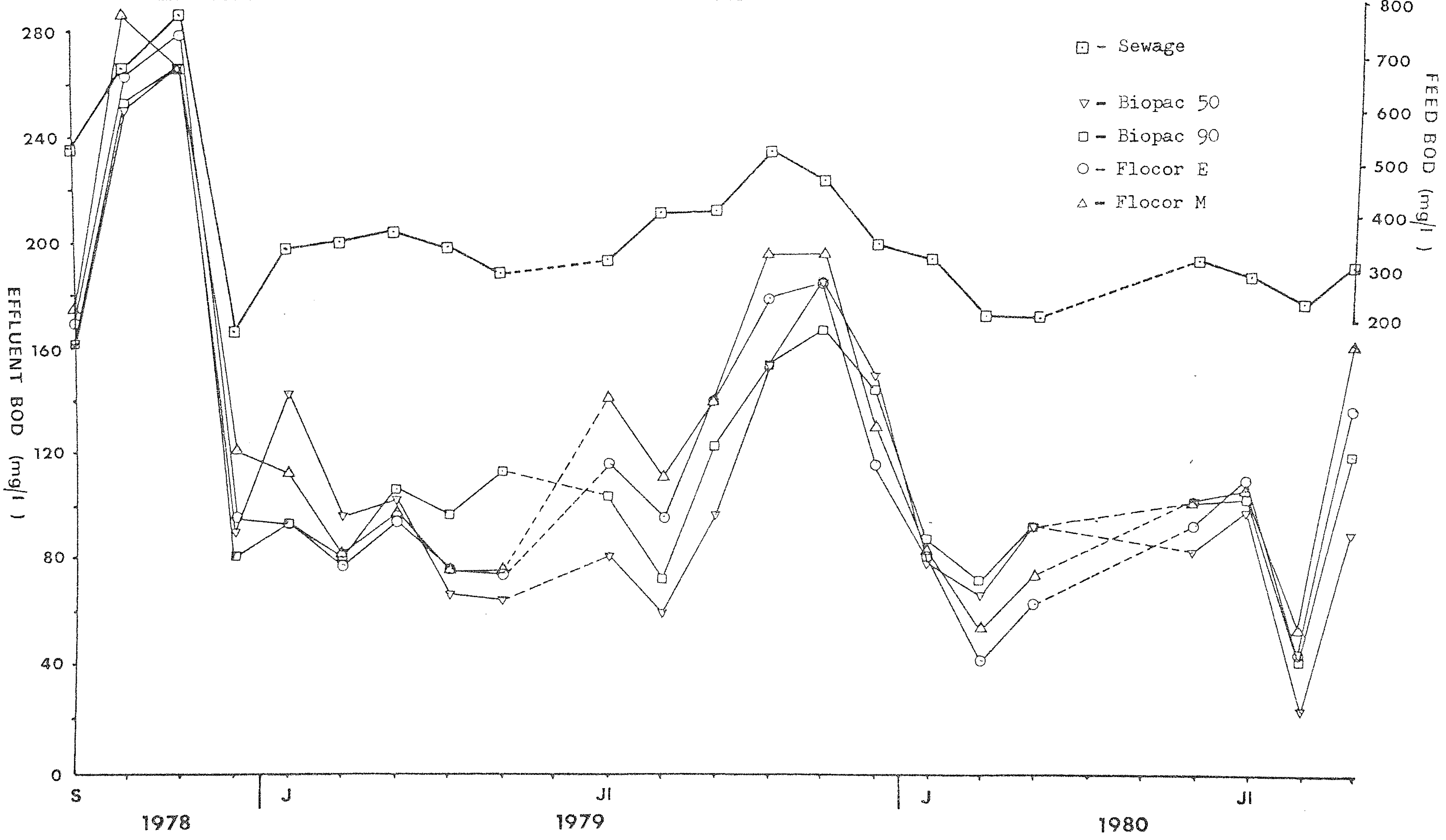


Fig. 5.3.2 Monthly averaged COD data. Plastic medium filters.

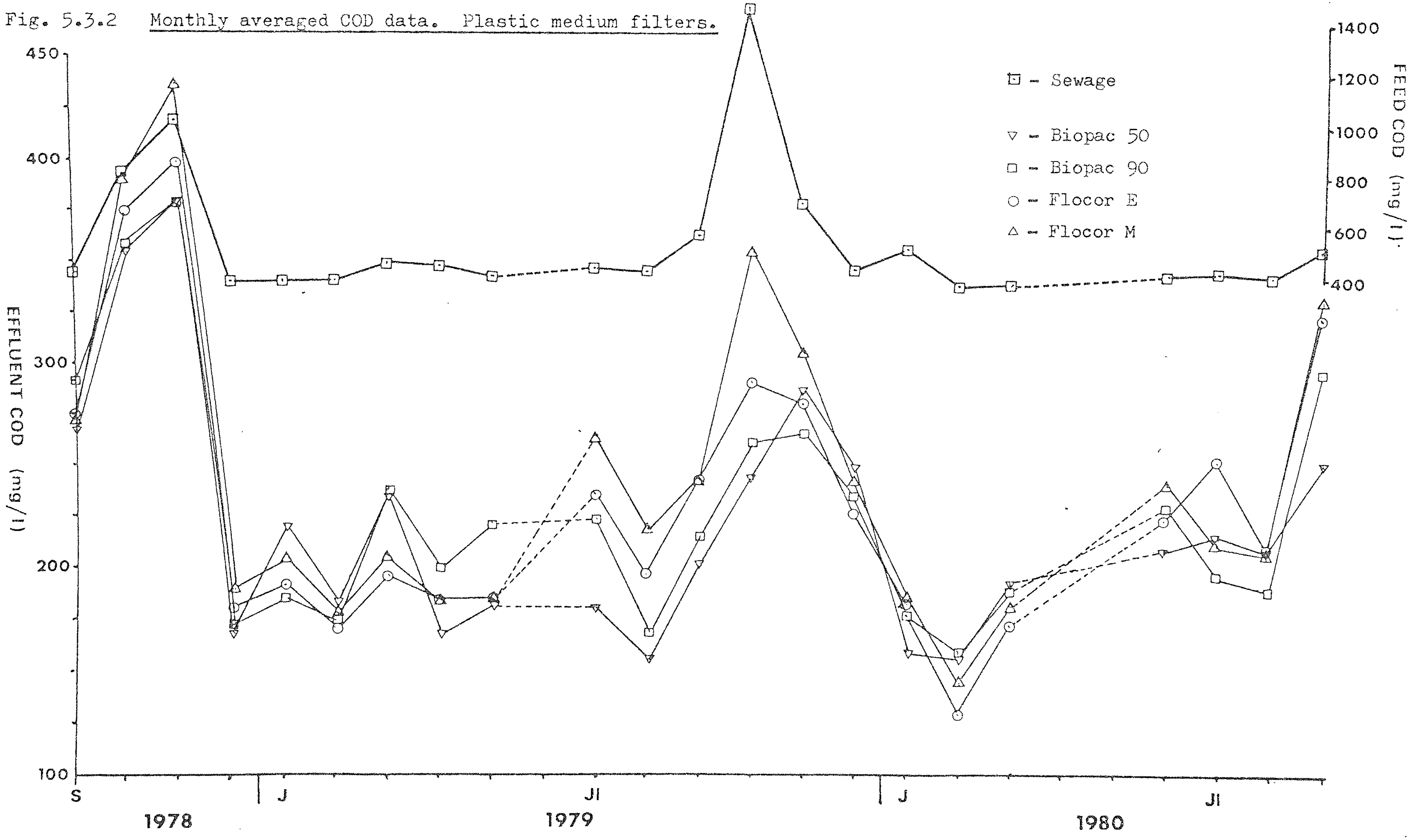


Fig. 5.3.3 Monthly averaged suspended solids (settled sample) data. Plastic medium filters.

Fig. 5.3.4 Monthly averaged suspended solids (shaken sample) data. Plastic medium filters.

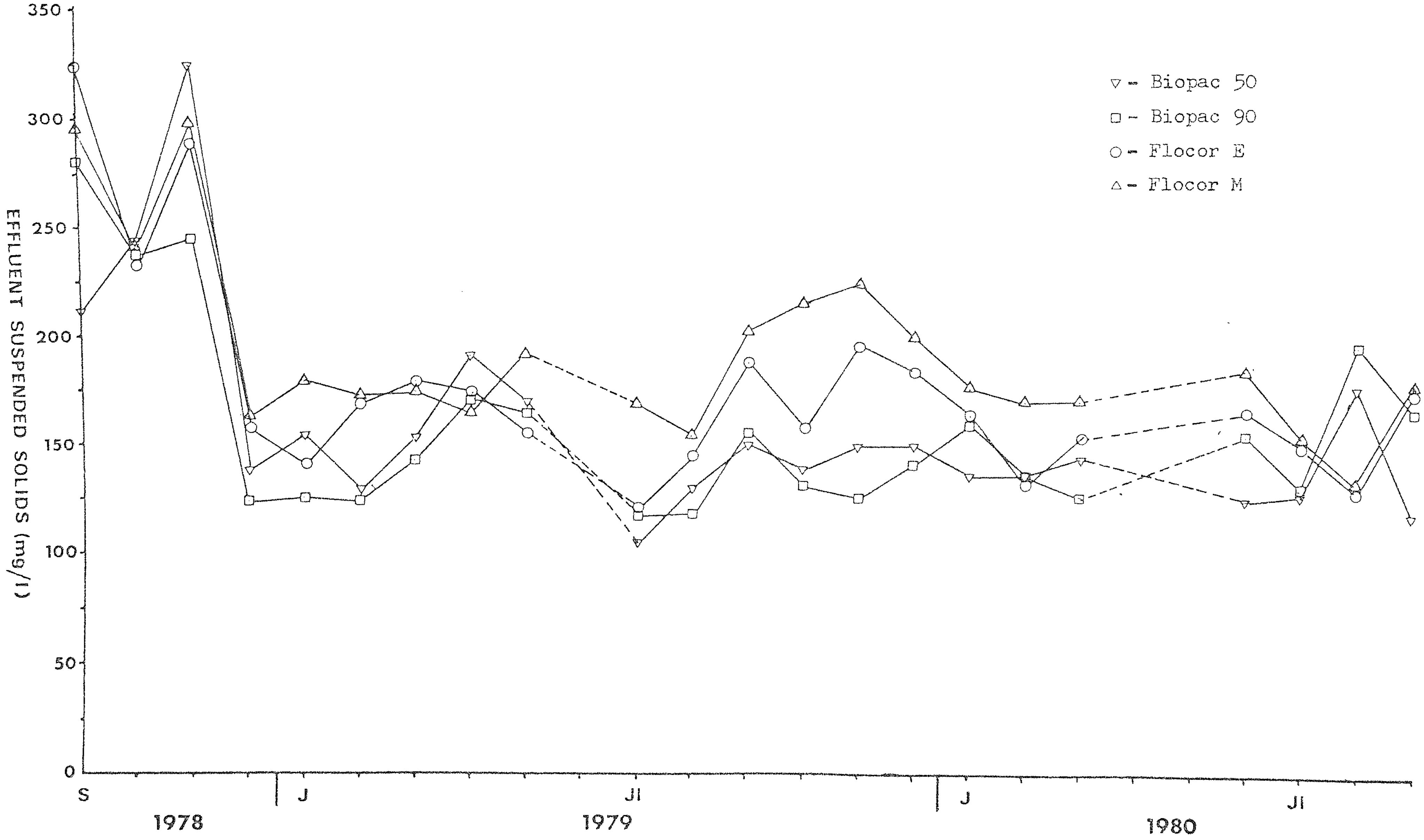


Fig. 5.3.5 Monthly averaged sludge production rate data. Plastic medium filters.

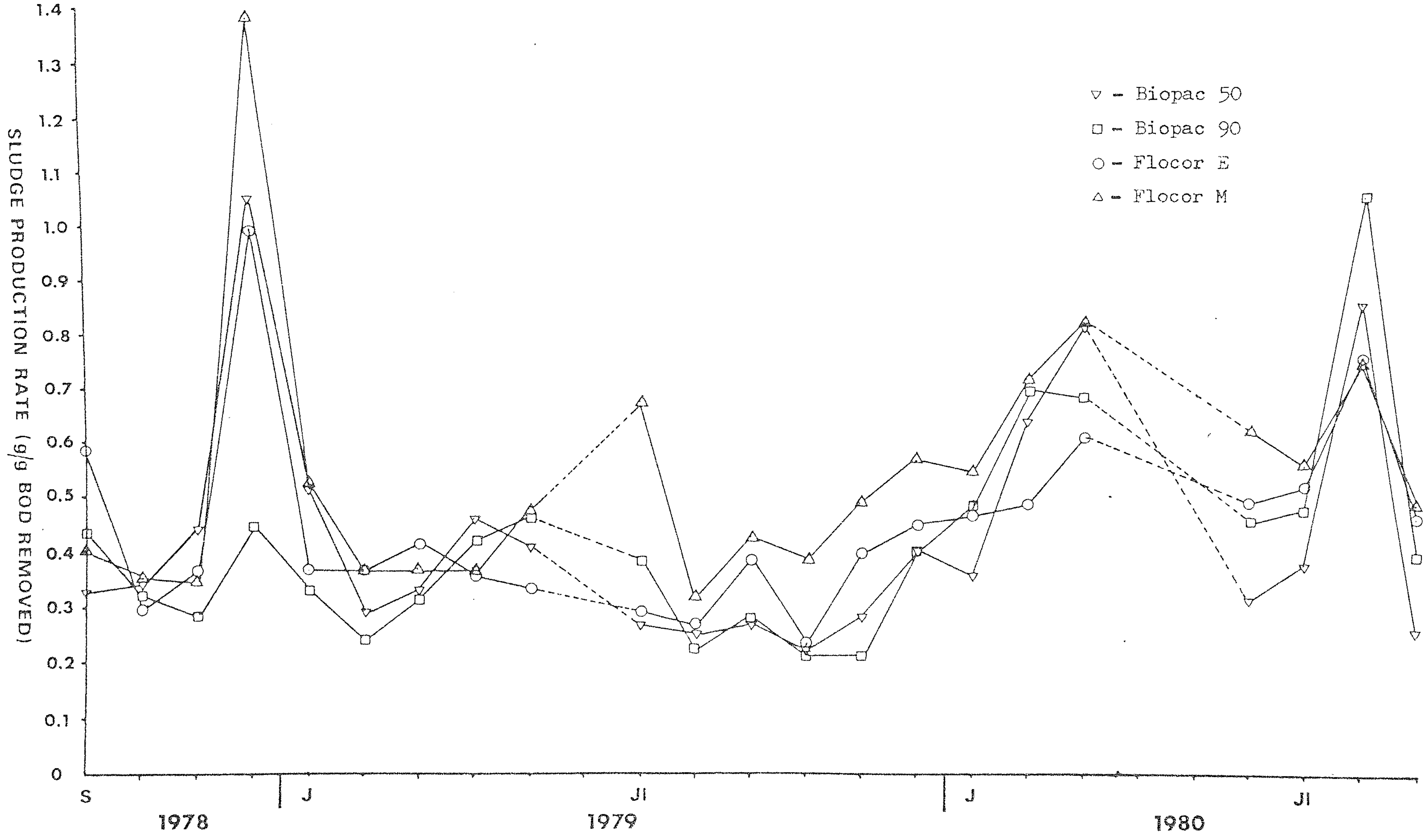
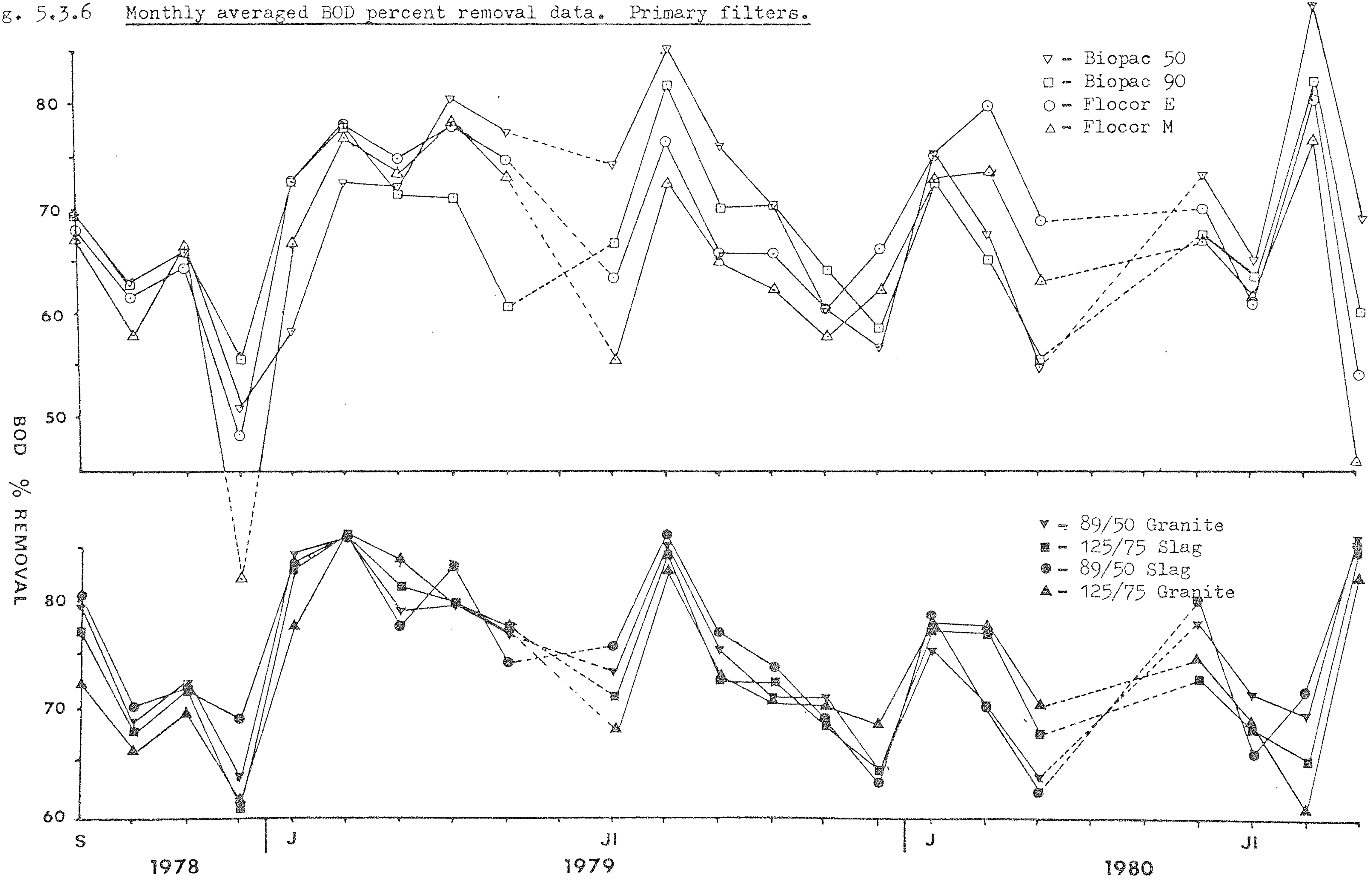


Fig. 5.3.6 Monthly averaged BOD percent removal data. Primary filters.



5.4 The effect of changing the periodicity of dosing on primary filter biological film levels and performance

While the effect of changing the periodicity of dosing on low rate and A.D.F. filters has been well documented (Lumb and Barnes, 1948, Tomlinson and Hall, 1955, Hawkes, 1955, Hawkes and Shephard, 1970 and 1972), with respect to both ecological and performance factors, very little quantitative research has been carried out to determine the effects of such changes on high rate filters. Results of experiments at the Minworth STW, Birmingham (reported by Eden et al., 1966), showed that in high rate filters treating a municipal waste which tended to promote luxuriant fungal growth in the biological film, a reduction in the periodicity of dosing from four to eight minutes resulted in a reduction in ponding difficulties at the longer dosing interval. Detailed studies of the biology of high rate filters following changes in the periodicity of dosing have not been made in the past however and efforts were therefore made to undertake such a study at Hereford.

The periodicity of dosing to the filters was reduced by 50 percent during May 1979, changing the dosing frequency from two to three minutes on each filter bed. This reduction was chosen as it was considered great enough to induce a change in film distribution if the lowering of the periodicity of dosing was to affect high rate filters in the same way as in low rate filters (i.e. to result in a more even distribution of film with filter depth, as reported by Hawkes and Shephard, 1972), without resulting in the peak hydraulic loading applied each time the distributor arm passed overhead being sufficient to cause a loss of filter efficiency.

Prior to the reduction in periodicity of dosing the biological film levels in all filters other than Flocor E were high following the heavy organic loading applied during late 1978. This is shown by the biological sampling results of Quarter 2.2 (Figs 5.5.3 - 8) and by the neutron moisture meter readings of March 1979 (Figs 5.5.1 - 2). Unfortunately it had not been possible to carry out long term biological surveillance work on the filters prior to the change being made and it is therefore difficult to dissociate the effects of the reduced dosing frequency from normal seasonal variations in film levels and distribution. It should also be mentioned that although the neutron moisture meter is believed to provide valuable data regarding relative changes in the level of film present in any one filter, doubts are raised in Section 5.5 with respect to whether the data provide a true representation of the percentage of void spaces of each medium which is saturated with film.

It is not possible from the data available from the mineral medium filters (Figs 5.5.1 and 3) to dissociate the effects of the change in dosing frequency from seasonal variations in film level. Although one month after the change had been made the average and maximum recorded percent saturation of voids had fallen in each medium, and a further fall was recorded during the following month, a similar though less steep fall in film levels occurred during the same period of 1980 when dosing frequency remained unchanged. Therefore, while it is possible that the reduction in dosing frequency may have assisted in accelerating the loss of the high film levels present in the spring of 1979, it is not possible to draw firm conclusions from the data available.

The biological surveillance data gathered before and after the change in periodicity of dosing was made on the plastic medium filters are presented in Figs 5.5.2 and 4. The weight of film supported by the Flocor media was always low, and while the maximum film dry weight in the Flocor M filter during Quarter 2.2 (Fig 5.5.4), before the change in dosing frequency was made, of 25 kg/m^3 was the highest recorded in this medium no discernable operational problems were caused by this weight of film. The fact that large numbers of enchytraeid worms were present in this filter at all depths at the time (Fig 5.5.8) shows that the film was in good condition. The reduction in film levels in this filter and also in the Flocor E filter following the reduction in dosing frequency was probably the result of a normal seasonal decrease in film accumulation associated with increased temperature and decreased sewage strength, followed by a further decrease caused by increased invertebrate grazing activity, rather than as a direct result of the change in periodicity of dosing.

Film levels in the two Biopac filters were extremely high before the change in dosing frequency was made (Figs 5.5.2, 4 and 7), and in both of these filters (but particularly Biopac 50) large areas of the medium were completely clogged with film which had developed anaerobicity. This was the direct result of the very high organic loadings applied during late 1978, with the Biopac 50 being particularly badly affected due to the fact that the dimensions of the void spaces of this medium are less than those in Biopac 90 and are therefore more susceptible to clogging. The poor conditions prevalent in these filters before the change was made are apparent through the very low numbers of invertebrates found in Quarter 2.2 (Fig 5.5.7). These low numbers show that the control of film levels through invertebrate grazing was impossible at the time.

Reducing the periodicity of dosing had a rapid and pronounced affect on the Biopac 50 filter film. The maximum percent saturation of voids within the filter was reduced by 60% from a value of 75% to one of 30% between March and June 1979 (Fig 5.5.2). The distribution of film within the filter was more even in Quarter 2.3 (Fig 5.5.7) following the change, and invertebrate numbers had increased to a level where they could contribute to the control of the film level by their grazing activity. The beneficial effects of the change in periodicity were short lived however, with film levels increasing by September 1979. The changes observed in film levels and distribution with depth in the summer of 1979 are attributed mainly to the change in dosing frequency, as the neutron meter data show that over the period March - June 1980 the maximum percent saturation of voids actually increased slightly when the periodicity of dosing remained unaltered, while a decrease in the maximum (and the average) percent saturation recorded was apparent during the same period of 1979 when the periodicity of dosing was reduced. The change in periodicity did not appear to affect the performance of the filter, although due to the lack of performance data for June 1979 firm conclusions are difficult to reach.

The effect of the change is difficult to assess in the case of the Biopac 90 filter, as the heavy film accumulated during the winter of 1979 - 80 (Fig 5.5.7) was controlled in the following spring over a similar time scale as in 1979, without any change in filter operation. The observed reduction in film levels after the change in dosing frequency may therefore have been due mainly to normal seasonal variation.

As the effects of the change were short lived in the Biopac 50 filter, the method of control over biological film levels appears to have been purely physical. Biological film which was either detached from or only weakly attached to the filter medium because of anaerobic film conditions must have been flushed from the filter by the increased hydraulic scour. The Biopac 50 filter was more markedly affected by the change in dosing frequency than were any of the other filters because the level of anaerobicity within the Biopac 50 film was greater than in any other filters before the change was made. It is therefore evident that for this method to be successful in reducing film levels a very high proportion of the filter film must be anaerobic before any reduction in dosing frequency is made. Once excess anaerobic film had been washed from the filter the regular seasonal cycle of increased fungal growth during the autumn months would begin. It is believed that while the beneficial effects of the change in distribution rate were short term, the fact that film levels were reduced early in 1979 allowed invertebrate grazing to continue for a longer period of time during the summer than normal, and this may have prevented the level of film accumulation in the following winter from reaching a level where ponding could have occurred.

The mechanism of control of film levels by changing the periodicity of dosing therefore differs between high and low rate filters. In low rate filters the control may be nutritional, while in high rate filters it appears to be purely physical. If any degree of control over film levels in high rate filters is to be exerted by this method either more than one alteration in the dosing frequency would be required (i.e. lowering the periodicity of dosing during periods when the film became particularly heavy and anaerobic and raising it during subsequent periods when film levels were lower) or the distributor could be slowed severely for a relatively short period of time when film levels became excessive. The short term loss of efficiency which would accompany the latter method would be balanced by the longer term benefits accrued by the prevention of future ponding difficulties, although - as previously stated - a very high proportion of the biological film must be anaerobic and largely detached from the filter medium before this method could be used with any degree of success.

5.5 Ecology and biology of the primary filters

5.5.1 Film accumulation measurements

Two methods were used in assessing the level of film accumulation with depth in the filters, as described in Section 4.6. The results of these assessments are presented in Figs 5.5.1 - 12 and Appendices 5.5.1 - 9.

It is believed that the data from the neutron moisture meter (Figs 5.5.1 - 2) cannot be directly correlated with film thickness in any of the high rate filter media studied, nor can they be used to compare accurately film levels between different filter media. The readings are useful however in appraising relative changes in film level and condition with time in any particular medium, with very high readings probably indicating very heavy film accumulation with the film being in poor condition.

The film on all of the primary filter media was dominated throughout the study by fungi, and it developed to great thickness on several occasions in all of the random-fill media. The fungi present were identified by Mrs I. L. Williams of Aston University, with the major representatives being Fusarium aquaeductuum, Geotrichum candidum, Subbaromyces splendens, Sepedonium sp. and Ascoidea rubescens.

Figs 5.5.3 - 4 illustrate the seasonal fluctuations in film accumulation in the primary filters, with marked increases in the weight of film present apparent during late winter - early spring in all media except Flocor M and E. Figs 5.5.5 - 8 show variations in film dry weights with depth in each filter during the two year study period, together with sewage temperature data. From these figures it can be seen that the greatest levels of film generally occurred during periods with the lowest temperatures. These low temperature periods tended to coincide with periods of strong sewage however, and from these data it is therefore impossible to ascertain which of these two factors exerted the greatest influence on the rate of film accumulation. As the film was found to be dominated by fungi it is possible that the sewage strength was more important than temperature in determining film growth rates (Hawkes, 1965a).

Comparison of the data from biological sampling of the mineral medium filters (Figs 5.5.5 and 6) shows that the film of the two small media tended to be more evenly distributed with depth and less variable with season than the film of the two large media. There was a slight tendency for film levels to be higher close to the surface of the filters (level 2, 20 - 60 cm depth), although this did not always occur. The heaviest recorded film level in the mineral media occurred in the 125/75 Slag filter during January 1980 (Quarter 3.1, Fig 5.5.3 and 6) at a depth of 60 - 100 cm (level 3). This accumulation of film was exceptionally high and almost blocked the filter, although BOD removal efficiency was not adversely affected and the film accumulation may have been localised in the area of the biological sampling shaft.

The Flocor M and E filters were never found to support heavy film accumulations (Figs 5.5.4 and 8), although the Flocor M modules occasionally exhibited a slight tendency towards the blockage of effluent channels with sloughed film pieces, leading to localised ponding. This blockage was never observed in more than two adjacent channels through any module. The reason for the comparatively low film levels found in the two Flocor media is the open, ordered structure of these modular media. This structure allows the film to be readily sloughed if it becomes too thick, and the sloughed film can be removed by the rapid downward flow of the sewage without accumulating in the filter. Biopac 50 generally supported the greatest quantity of film (Fig 5.5.7) of any of the media studied, and was more susceptible to the developement of anaerobicity in localised areas of very heavy film. Conditions within this filter were occasionally found to be foul, and considerable short-circuiting of wastes through the filter must have occurred on these occasions to avoid complete ponding. As with the mineral media there was a tendency for the greatest film accumulation to occur in the top 60 cm of medium in the two Biopac filters, while the two Flocor media tended to support the greatest volume of film at 60 - 80 cm depth. With the exception of the Flocor E filter (Fig 5.5.8), the film was generally less evenly distributed with depth in the plastic media than in the mineral media, and seasonal changes were more pronounced in the plastic medium filters.

Although complete ponding was never observed in any filter medium during the study there were periods when the sewage drained only slowly from the surface of the filters. If the sewage did not drain completely by the time the second distributor arm had moved over the surface of the filter this was logged as 'slow drainage'. Table 5.5.1 lists the periods of 'slow drainage' observed in the primary filters. On one occasion (15.12.80), the drainage on both Biopac 50 and 89/50 Slag filters became so slow that 70 percent of the filter surfaces remained under 5 cm of sewage after each pass of the distributor arm. This occurred after very heavy sewage solids loadings had tended to block the distributor mechanisms during late November and early December.

The slow drainage observed in the Biopac 50 filter is believed to have been due to exceptionally heavy film levels frequently found between 20 and 60 cm from the filter surface. Biopac 90 did not show any periods of slow drainage, and while the volume of film supported by this medium reached excessive levels on two occasions (Quarters 2.2 and 3.1, Fig 5.5.4) the film rarely became anaerobic. Although both Biopac 50 and 90 filters tended to support very heavy film levels, the proportion of the dry weight in Biopac 90 film which was volatile was greater than in the Biopac 50 film, and therefore contained a greater proportion of living material.

Despite the seasonally high accumulation of film in the filters due to high organic loadings and low temperatures, in no instance was drainage so slow as to badly affect filter efficiency, although efficiency relative to other filter media was often affected (Section 5.7), and there were no problems associated with odour.

5.5.2 The occurrence, abundance and distribution of invertebrate species and micro-organisms of the film

5.5.2.1 Invertebrate populations

The quarterly analyses of invertebrate abundance and diversity showed that in all filter media there was a very low species diversity, with *Psychoda alternata* and enchytraeid worm spp. dominant throughout the study. Despite this very low species diversity the fly population remained under control and no fly nuisance problems were encountered. The only other invertebrate species recorded in the filters were *Tubifex* sp. (found in low numbers in some of the mineral medium filters during Quarters 3.1 and 3.2), *Sylvicola fenestralis*, Naid worm sp. and Chironomid sp. larvae (single representatives found at the base of the Flocor M filter during Quarter 3.2). The larvae of *Eristalis tenax* were occasionally recorded in the effluent sumps and twice in the primary sewage header tank, but never in the filters themselves. Results of the quarterly estimation of invertebrate abundance are presented in Figs 5.5.5 - 8 and Appendices 5.5.1 - 8.

Figs 5.5.5 - 8 show that the numbers of invertebrates present in the filters did not follow any regular seasonal pattern. In most of the random-fill filters the numbers of invertebrates present was lowest when the film dry weight levels were highest, which would suggest that they cannot survive well in heavy film accumulations. An exception to this observation was the 125/75 Granite filter (Fig 5.5.6). During Quarter 2.2 the number of invertebrates present was very high, while film dry weight levels were also high, indicating that they can not only survive heavy film accumulation but that they can reach sufficient numbers under such conditions to actively contribute to film control by grazing. During Quarters 3.1 and 3.2 in the same filter the number of invertebrates present was very low, although the film dry weight level was also low. The fall in the Psychoda and enchytraeid worm spp. populations observed in most of the filters as film levels increased cannot therefore be attributed simply to the increase in film volume. However, the fluctuations observed in the invertebrate population size are believed to have been caused by changes in the biological film, rather than vice versa.

Filter media in which the film was observed to have been anaerobic at some section of the filter depth are listed below.

Quarter during which anaerobicity of biological film was observed (using the biological sampling technique)	Filter medium affected
3.2	89/50 Granite
2.2, 3.2	125/75 Slag
3.2	89/50 Slag
3.1, 3.2	125/75 Granite
2.2, 3.1, 3.3.	Biopac 50
2.2	Biopac 90
---	Flocor E
---	Flocor M

The periods in which anaerobicity was observed within the filters can be seen to correspond closely with periods of low invertebrate numbers. It therefore appears that the condition of the film was more important in determining invertebrate numbers than the actual film level or film dry weight content. Heavy film accumulation in which the film remains healthy with high solids content and low water content encourages invertebrate grazing activity, while heavy film accumulation in which the film begins to decompose, with low solids content and high water content, discourages invertebrate activity.

The size of the invertebrate population of each filter was therefore largely controlled by the volume and condition of the biological film, and also by temperature. In circumstances where the film was in good condition and under favourable temperature conditions, the invertebrate populations could increase to a point where control of the film accumulation rate was possible through grazing activity. Under most circumstances however the role of the invertebrates in film control is considered to have been minor. In the modular Flocor filters where film levels were always low and the condition of the film relatively good, the grazing invertebrate population may have been able to exert a greater controlling influence over the accumulation of film.

5.5.2.2 Protozoan and other micro-organism populations

The biological sampling of the primary and secondary filter films included microscopical examination to determine the species diversity and relative abundance of the protozoan population, together with an assessment of the abundance of other micro-organisms such as nematode and naid worms and rotifers. These studies showed that both species diversity and abundance were frequently high, and while no species dominated, nematode worm spp., Opercularia microdiscum and flagellate spp. were almost universally present. Table 5.5.2 lists the species found, while Figs 5.5.9 - 12 illustrate the composition of the micro-organism population of the film with filter depth over a twelve month period. The relative abundance of the flagellate population was not assessed, and is not included in Figs 5.5.9 - 12.

The list of species found in the pilot plant (Table 5.5.2) is extensive. Several of these species have not been reported as occurring in biological filters (Curds, 1975). These are *Pseudoglaucoma muscorum*, *Zoothamnion pygmaeum*, *Climacostomum virens*, *Aspidisca sulcata*, *Podophrya carchesii* and *Tokophrya quadripartita*. Curds (1969) reports the saprobic conditions under which ciliated protozoa have been found in activated sludge plants, with *P. muscorum* classified as polysaprobic, *Z. pygmaeum* of unknown saprobic preference, and *C. virens*, *A. sulcata*, *P. carchesii* and *T. quadripartita* usually found in β-mesosaprobic conditions. *P. muscorum* was found only twice in the pilot plant, once in the 125/75 Slag filter and once in Biopac 50, under relatively poor film conditions. *Z. pygmaeum*, *P. carchesii* and *T. quadripartita* were only recorded in those filters supporting low volumes of film and during periods when that film was in good condition. *C. virens* and *A. sulcata* were found in very low numbers and too few representatives were recorded to discuss their saprobic preferences. Most of the ciliated protozoa recorded in the filters were usually found under the conditions of saprobity expected from the saprobic classification given by Curds (1969). It was found however that areas of healthy, freely draining film were occasionally adjacent to areas of heavy anaerobic film. Under such film conditions the use of ciliated protozoan species to indicate the general condition of filter film may lead to inaccurate conclusions.

Different numbers of species were recorded in the different media of the pilot plant (Table 5.5.2). The random-fill priamary filter media all exhibited similar species diversity, although the two Biopac media contained marginally more of the species which are usually found in poor conditions in activated sludge plants. Table 5.5.2 and Figs 5.5.9 - 12 show that the species diversity and abundance of the micro-fauna of the Flocor media were higher at all times during the study than in any of the random-fill primary filter media. The two Flocor media were found to be the only primary filter media which did not exhibit a marked tendancy toward the development of anaerobicity of heavy film accumulations (Table 5.5.1), and this is believed to have been an important factor in determining the size and composition of the protozoan population. Of the two modular media, Flocor M supported the heaviest film levels and also supported the lowest numbers of protozoans (Fig 5.5.12). In the random-fill media there was also a general inverse relationship between protozoan numbers present and film volume and condition. This was particularly pronounced during Quarter 3.1, when film condition was found to be poor in most of the filters and protozoan numbers were correspondingly low. The ciliated protozoan population was completely eliminated from the middle sections of the Biopac 90 filter during this period, with the only protozoa present being flagellates.

While there were generally more peritrichs close to the base of each filter, and occasionally greater numbers of amoebae close to the surface, the protozoan zonation with depth was not as pronounced as it has been reported to be in low rate filters (Barker, 1946). This is due to the fact that film conditions frequently did not improve from the surface to the base of the filters because of the high organic loadings used and the resulting high BOD effluents.

Table 5.5.1 Periods of Poor Drainage Observed in the Primary Filter Media

Month in which 'Slow drainage' observed	Media Affected
Dec 1978	Biopac 50, Flocor M (Slight, localised) 89/50 Slag
Jan 1979	Biopac 50, Flocor M (Slight, localised)
Feb	Biopac 50, Flocor M, 89/50 Slag, 89/50 Granite, 125/75 Granite (During period of severe cold weather)
Mar	Biopac 50
Apr	Biopac 50
Oct	89/50 Slag
Nov	89/50 Slag
Jan 1980	Biopac 50
Feb	Biopac 50, 89/50 Slag
Sep	89/50 Slag
Oct	89/50 Slag, Flocor M (Slight, localised)
Nov	Biopac 50
Dec	Biopac 50, 89/50 Slag
Jan 1981	Biopac 50

Table 5.5.2 Protozoan species found in pilot plant filter film

	PRIMARY FILTERS								SECONDARY FILTERS	
	MINERAL				PLASTIC					
Species	89/50 Slag	89/50 Granite	125/75 Slag	125/75 Granite	Biopac 50	Biopac 90	Flocor M	Flocor E	Flocor RS	Flocor R2S
Flagellate spp.	+	+	+	+	+	+	+	+	+	+
<u>Amoebae</u>										
Amoeba guttula								+		
A. proteus						+	+		+	
Vahlkampfia limax	+	+	+	+	+	+	+	+	+	+
Amoeba sp.									+	
<u>Holotrichia</u>										
Hemiophrys fusidens	+	+	+	+			+	+	+	+
H. pleurisigma	+		+	+					+	
Litonotus carinatus									+	
L. fasciola	+								+	+
L. lamella							+		+	
Spathidium spathula			+							
Trachelophyllum pusillum		+		+	+		+	+	+	+
Chilodonella cucullulus								+	+	
C. uncinata		+	+	+	+	+	+	+	+	+
Colpoda cucullus							+			
C. inflata							+	+		
Colpidium campylum	+	+	+	+	+	+	+	+	+	+
Colpidium colpoda	+	+	+	+	+	+	+	+		
Glaucoma scintillans		+	+				+		+	+
Pseudoglaucoma muscorum			+		+					
Tetrahymena pyriformis							+		+	
Uronema nigricans	+	+				+	+	+	+	+
Cinetochilum margartaceum							+	+		
Paramecium aurelia					+		+			

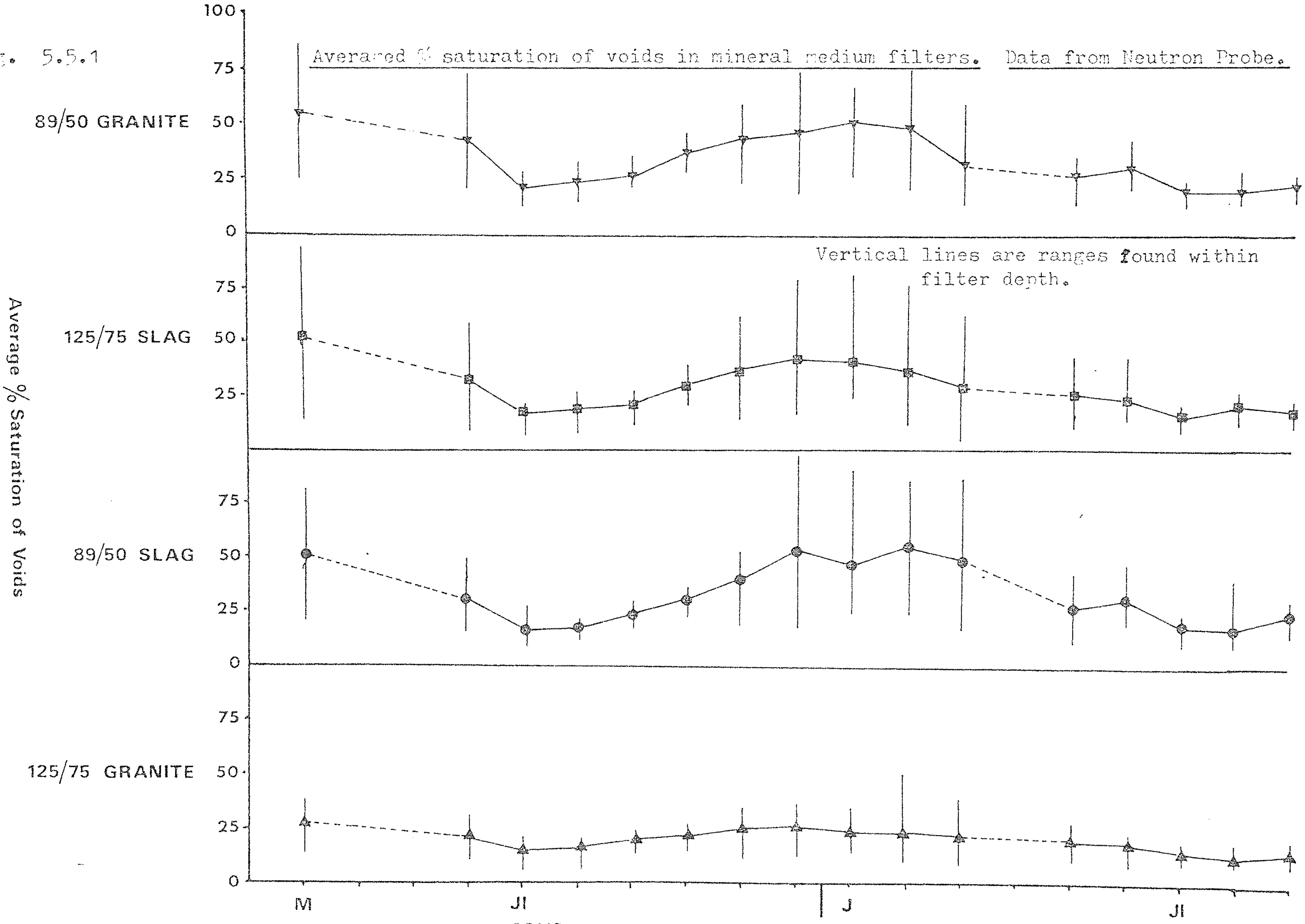
Table 5.5.2 (Cont.)

	PRIMARY FILTERS								SECONDARY FILTERS	
	MINERAL				PLASTIC					
Species	89/50 Slag	89/50 Granite	125/75 Slag	125/75 Granite	Biopac 50	Biopac 90	Flocor M	Flocor E	Flocor RS	Flocor R2S
P. caudatum	+	+		+				+	+	+
Species X	+	+	+	+	+	+	+	+	+	+
Species Y	+	+	+	+	+	+	+	+		
<u>Peritrichia</u>										
Carchesium polypinum						+	+	+	+	+
Epistylis plicatilis		+	+	+	+		+		+	
E. rotans	+	+	+	+	+	+	+	+	+	+
Opercularia coarctata	+	+	+	+	+	+	+	+	+	+
O. curvicaula				+					+	+
O. microdiscum	+	+	+	+	+	+	+	+	+	+
O. minima	+	+	+	+	+	+		+	+	+
O. phryganeae					+	+		+		
Vorticella aequilata	+	+		+				+	+	+
V. alba							+			
V. campanula										+
V. convallaria		+	+	+	+	+	+	+	+	+
V. fromenteli							+	+		+
V. hamata									+	
V. microstoma	+	+	+	+				+	+	+
V. striata									+	+
Vorticella sp.		+				+	+	+	+	
Zoothamnion pygmaeum				+			+	+	+	+
<u>Spirotrichia</u>										
Climacostomum virens					+					
Aspidisca costata		+	+	+		+	+	+	+	+
A. lynceus					+		+			
A. sulcata					+				+	
Euplotes moebuisi							+		+	+
Opisthotricha similis									+	
Oxytricha sp.							+			
Oxytricha ludibunda									+	

Table 5.5.2 (Cont.)

Species	PRIMARY FILTERS								SECONDARY FILTERS	
	MINERAL				PLASTIC					
	89/50 Slag	89/50 Granite	125/75 Slag	125/75 Granite	Biopac 50	Biopac 90	Flocor M	Flocor E	Flocor RS	Flocor R2S
Tachysoma pellionella							+	+	+	+
Spirotrich sp.									+	
<u>Suctoria</u>										
Podophrya carchesii								+	+	
P. fixa										+
P. maupasi							+		+	+
Sphaerophrya magna							+			
Tokophrya mollis							+			
T. quadripartita									+	+
<u>Other micro-organisms</u>										
Nematode worm spp.	+	+	+	+	+	+	+	+	+	+
Naid worm spp.	+	+	+	+		+	+	+	+	+
Rotifera spp.	+	+		+		+	+	+	+	+
Total no. of species recorded	20	25	22	25	21	21	39	33	45	33

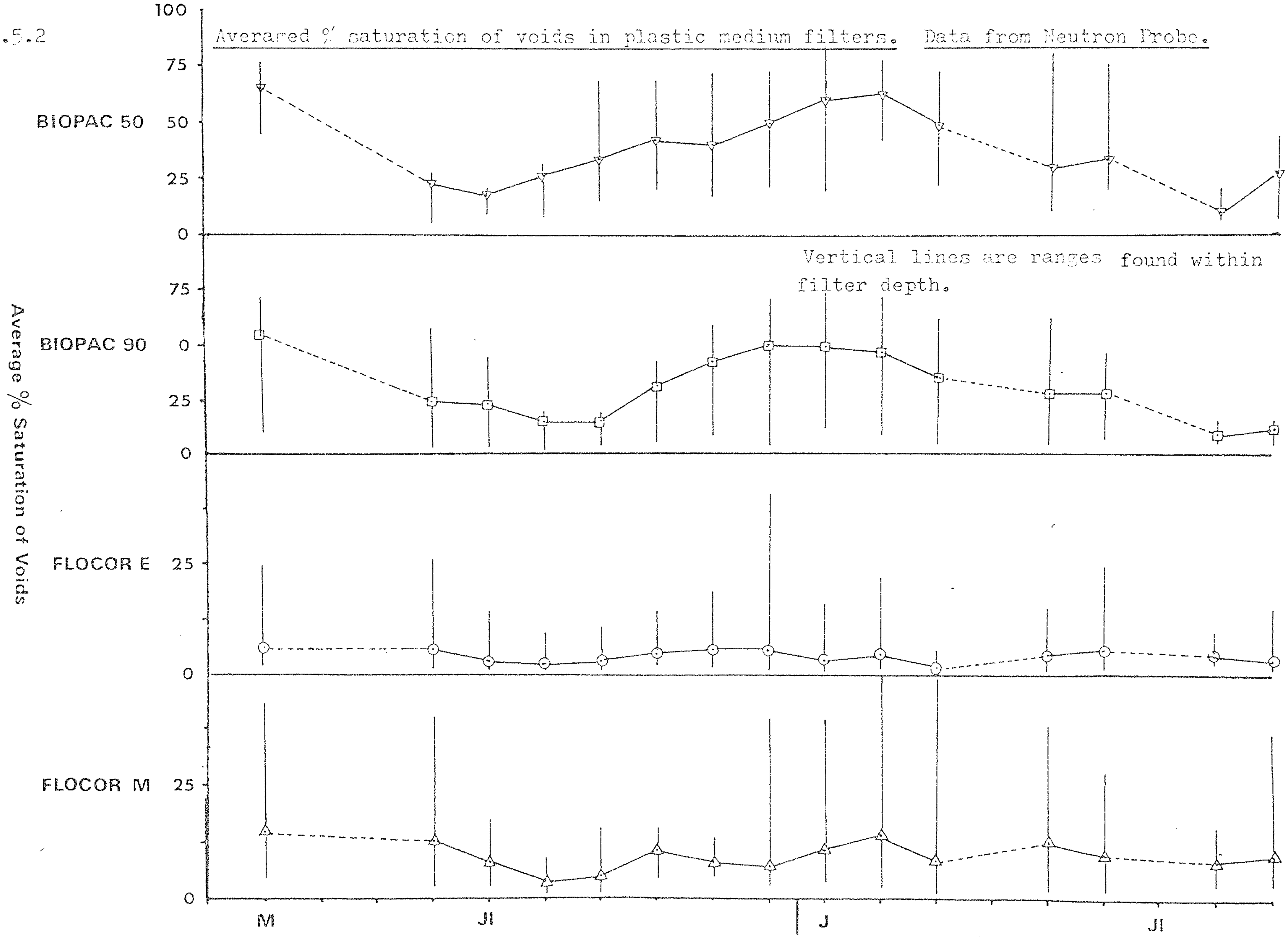
Fig. 5.5.1



Averaged % saturation of voids in mineral medium filters. Data from Neutron Probe.

Vertical lines are ranges found within filter depth.

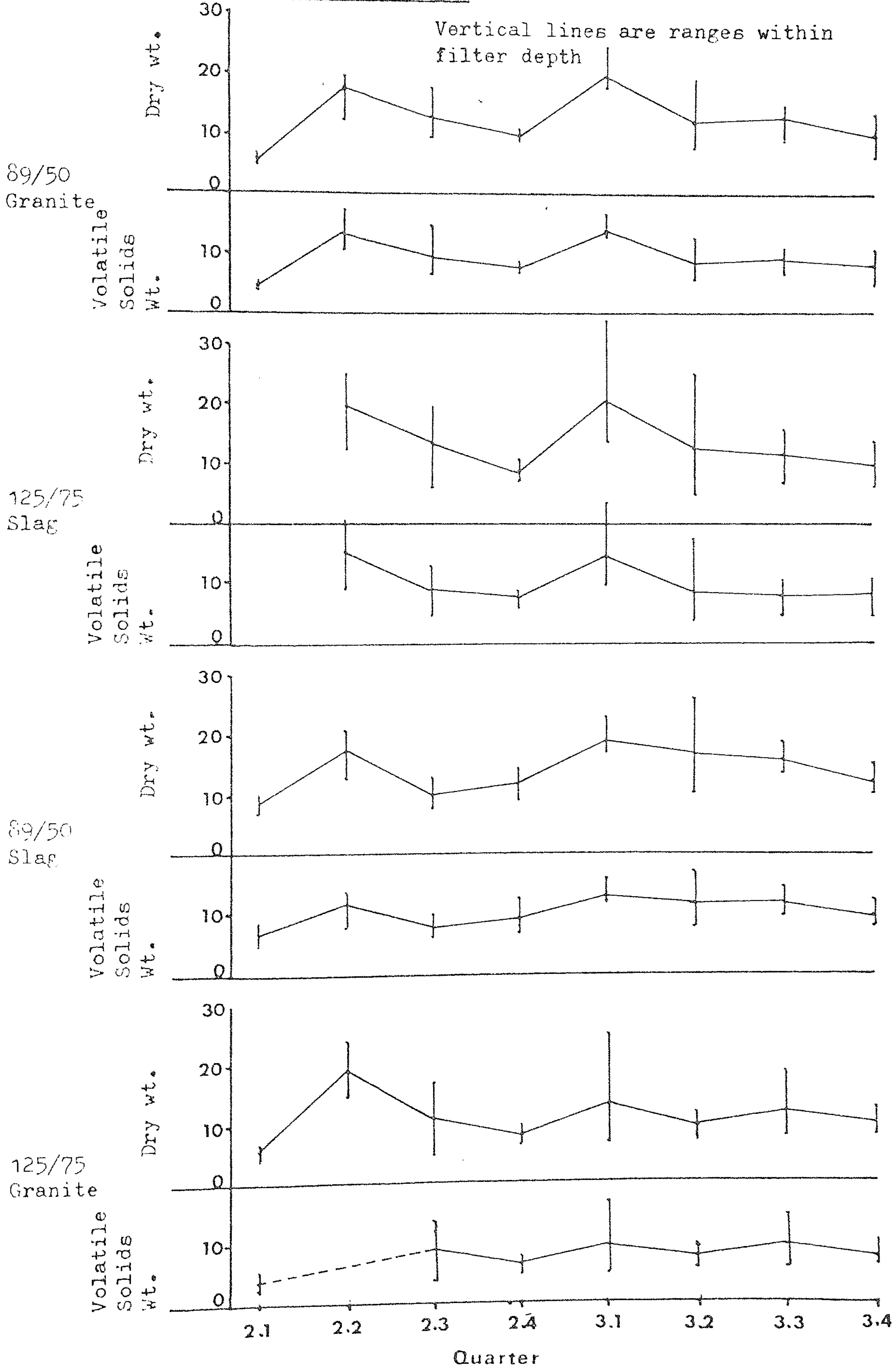
Fig. 5.5.2



Averared % saturation of voids in plastic medium filters. Data from Neutron Probe.

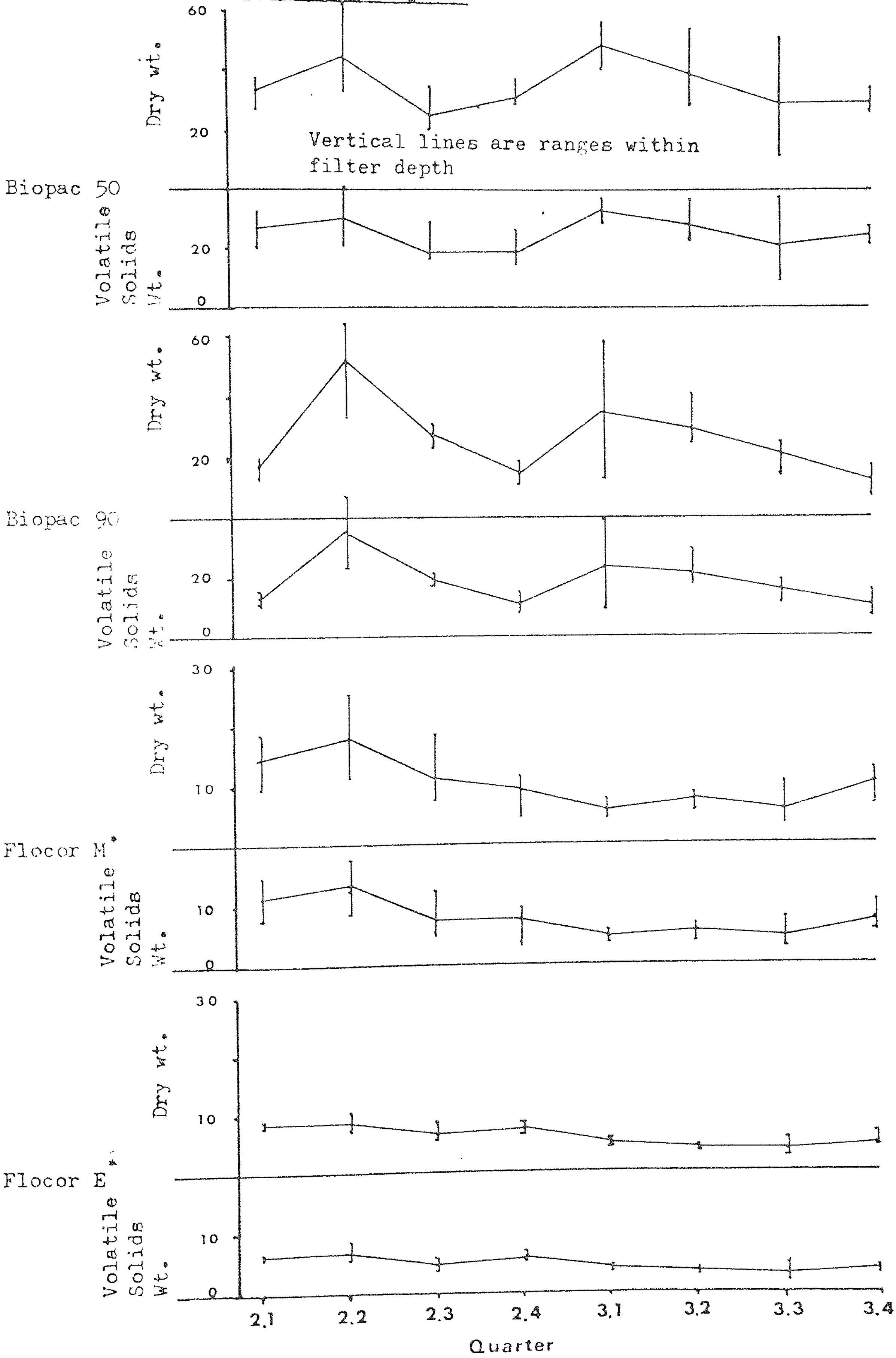
Vertical lines are ranges found within filter depth.

Fig. 5.5.3 Biological sampling results. Mineral medium averaged biological film weights.


Vertical lines are ranges within filter depth

All data expressed as kg biological film per m^3 filter volume.

Fig. 5.5.4 Biological sampling results. Plastic medium averaged biological film weights.



All data expressed as kg biological film per m^3 filter medium.

* - Note different scale used for the Flocor media.

Fig. 5.5.5 Biological sampling results. Distribution of biological film and invertebrates

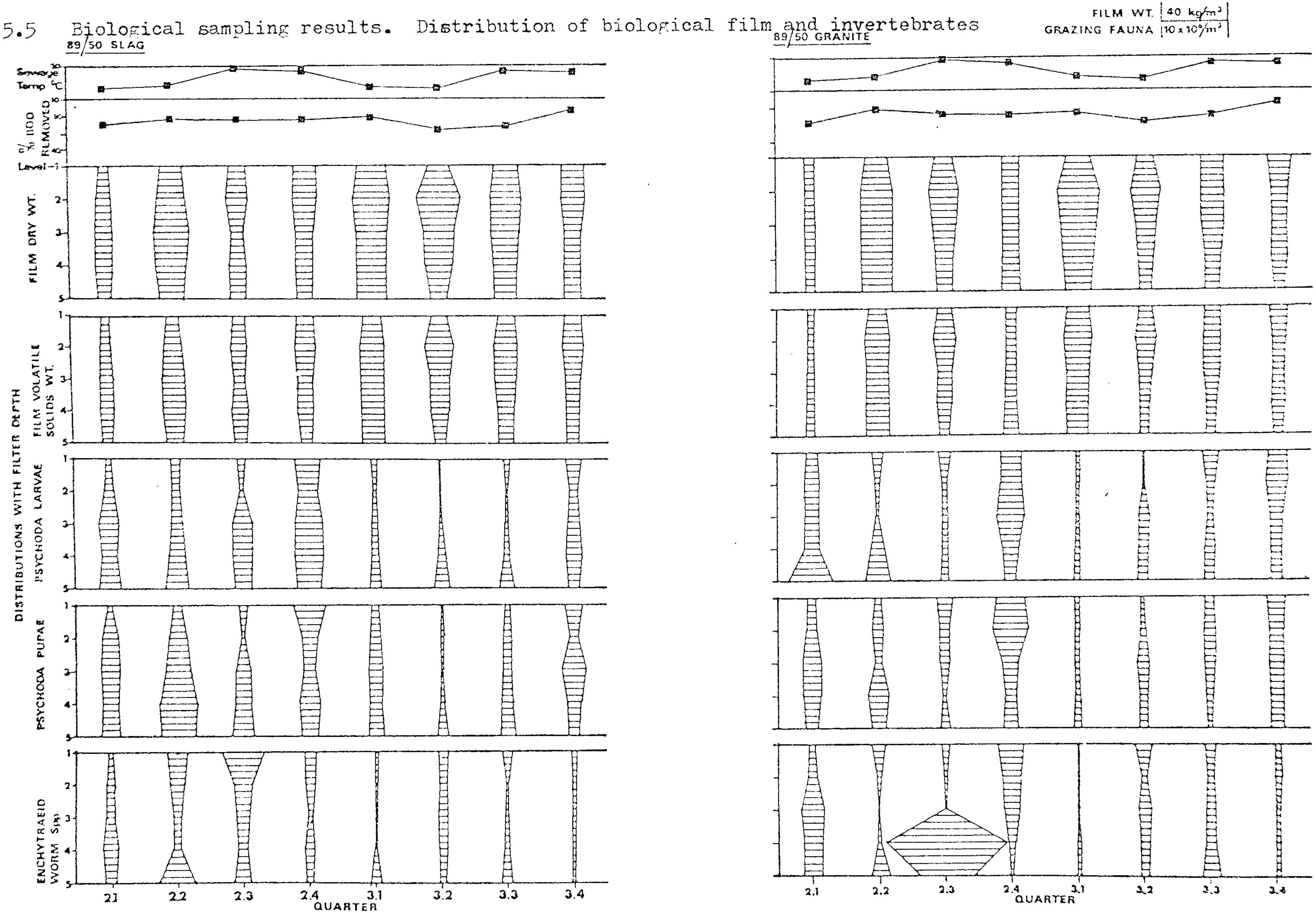


Fig. 5.5.6 Biological sampling results. Distribution of biological film and invertebrates with filter depth.

125/75 Slag and 125/75 Granite.

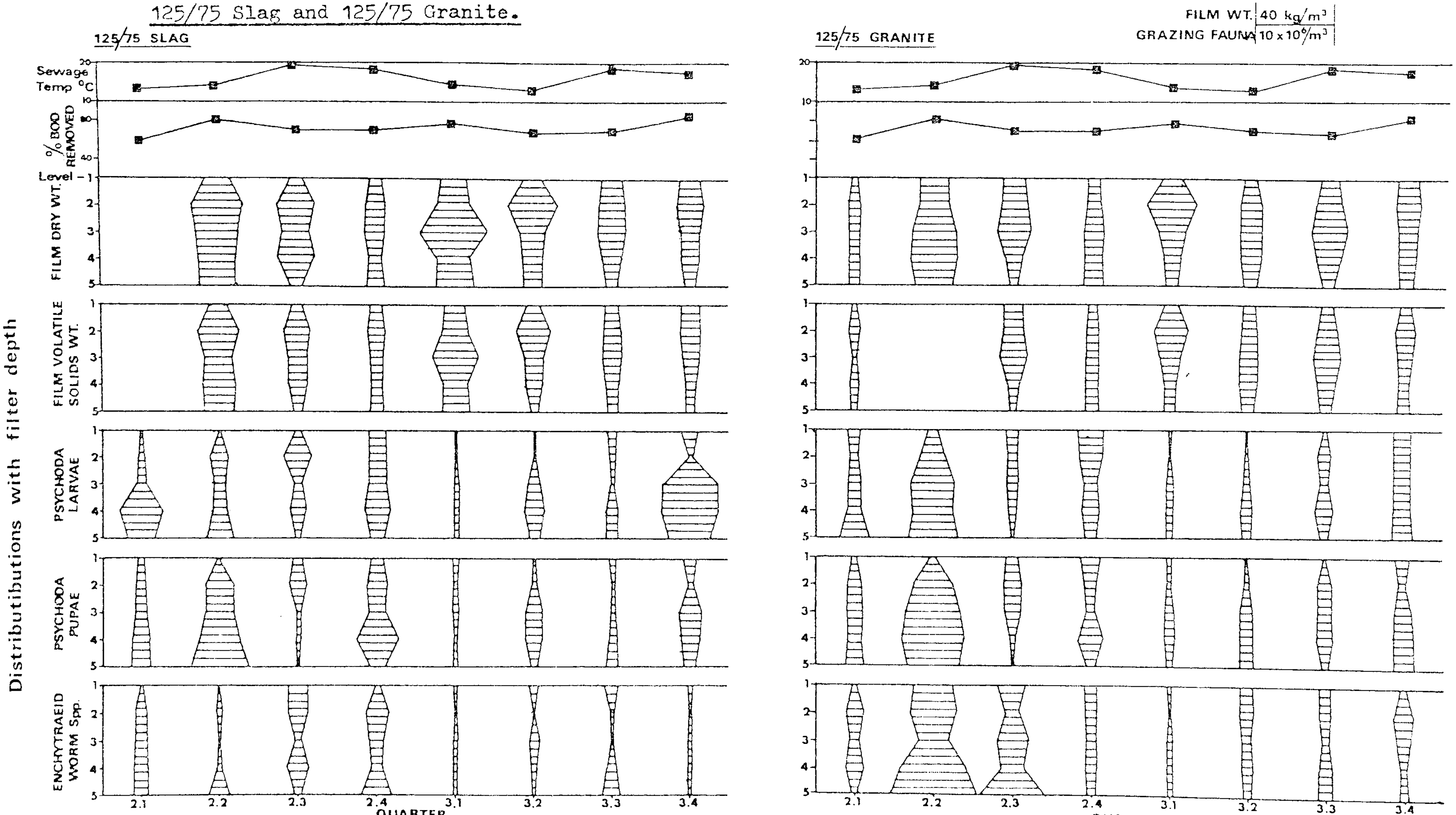


Fig. 5.5.7 Biological sampling results. Distribution of biological film and invertebrates with filter depth.

Biopac 90 and Biopac 50.

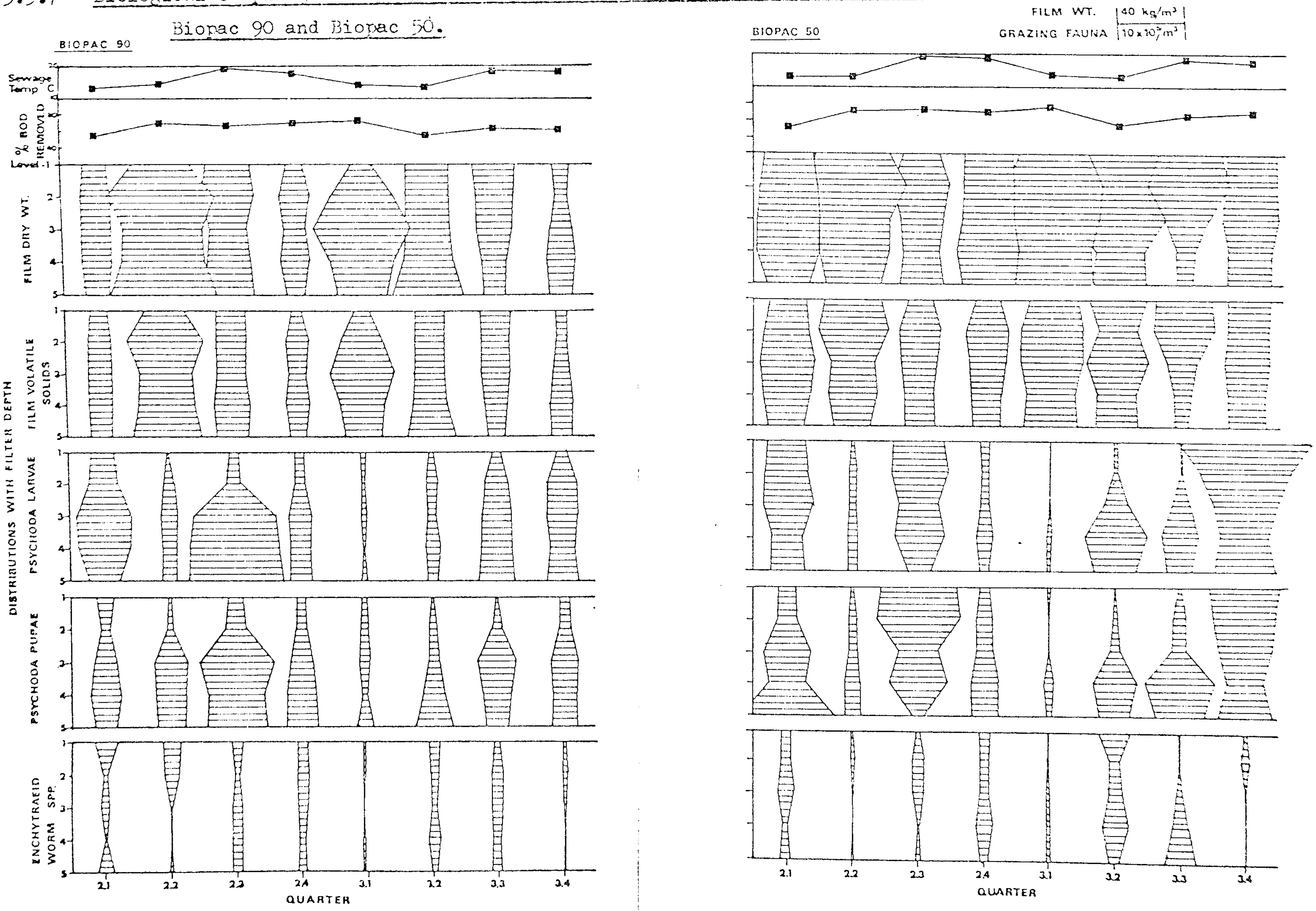
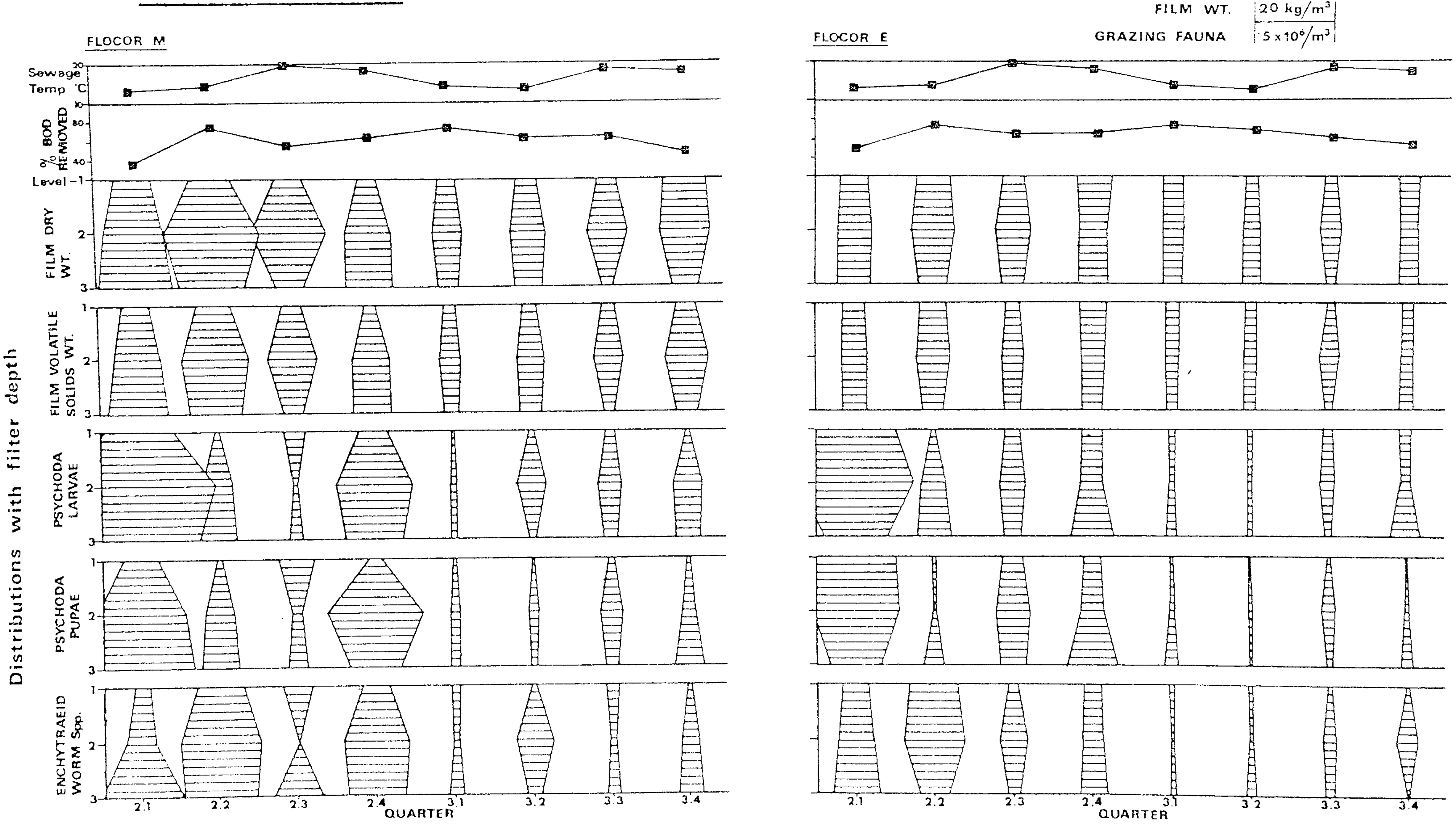


Fig. 5.5.8 Biological sampling results. Distribution of biological film and invertebrates with filter depth. Flocor M and Flocor E. Note change of scales used compared to Figs. 5.5.5 - 7.



Key to Figs 5.5.9 - 12

N - Nematoda

H - Holotrichia

P - Peritrichia

A - Amoebae

R - Rotifera

Sp - Spirotrichia

Su - Suctoria

Na - Naid worm spp.

M - Mite spp.

Scale - Numbers per sample (circle diameter) of ciliated protozoa and other micro-organisms (excluding flagellated protozoa).

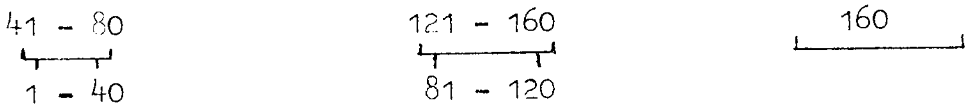


Fig. 5.5.9 Biological sampling results. Distribution and relative abundance of micro-organisms with filter depth. 89/50 Slag and 89/50 Granite.

Key given on page 166

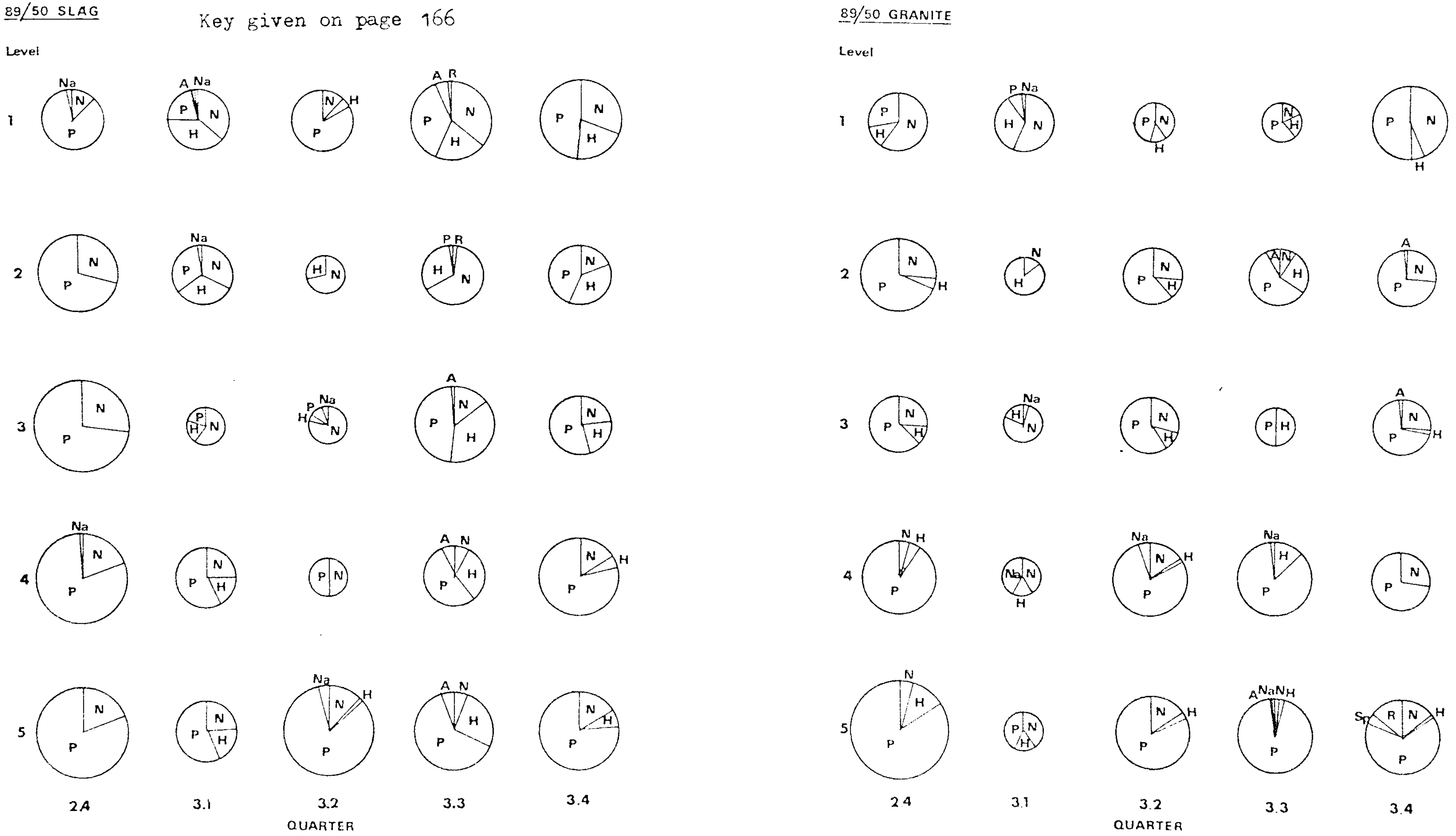


Fig. 5.5.10 Biological sampling results. Distribution and relative abundance of micro-organisms with filter depth. 125/75 Slag and 125/75 Granite.

Key given on page 166

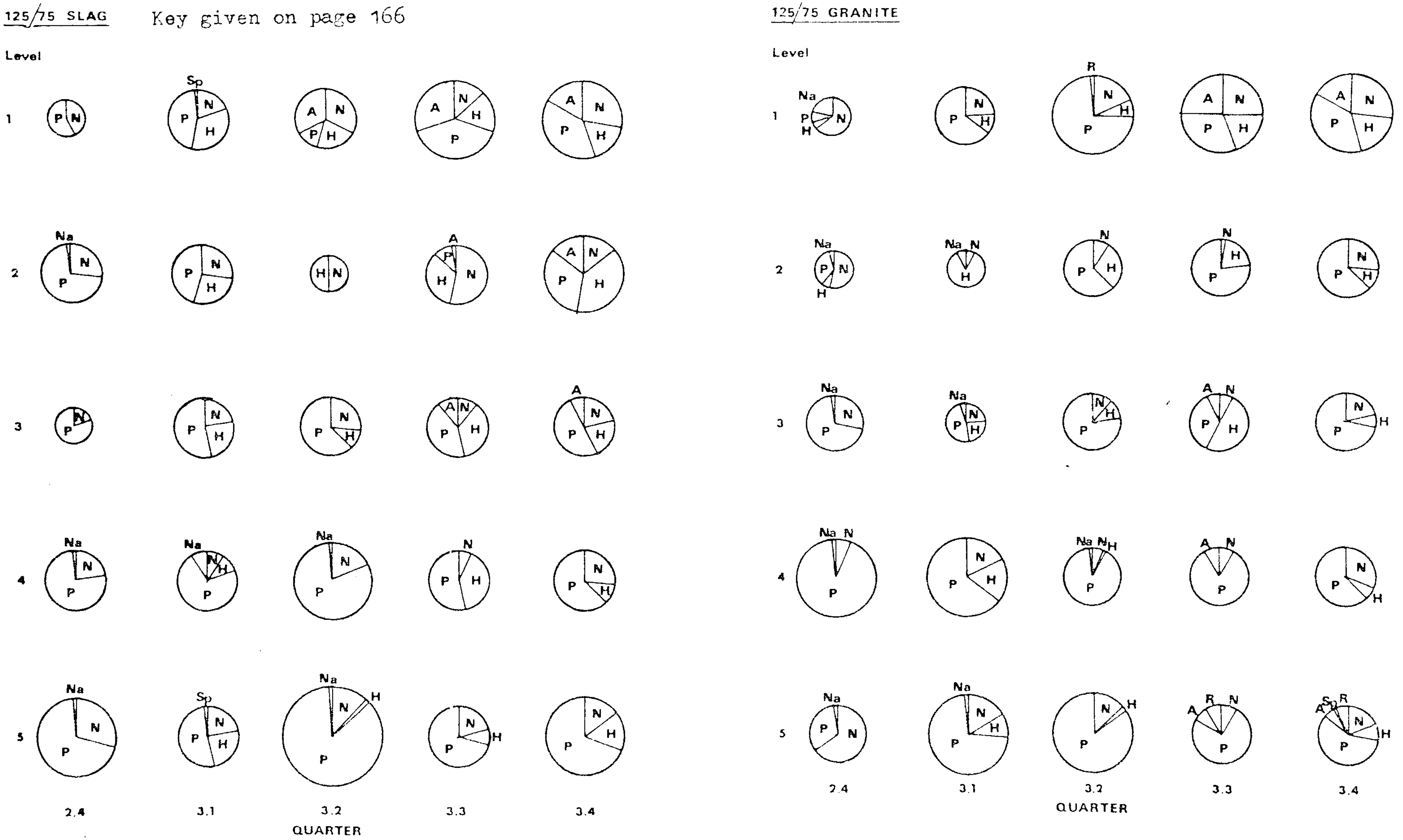


Fig 5.5.11 Biological sampling results. Distribution and relative abundance of micro-organisms with filter depth. Biopac 50 and Biopac 90.

Key given on page 166

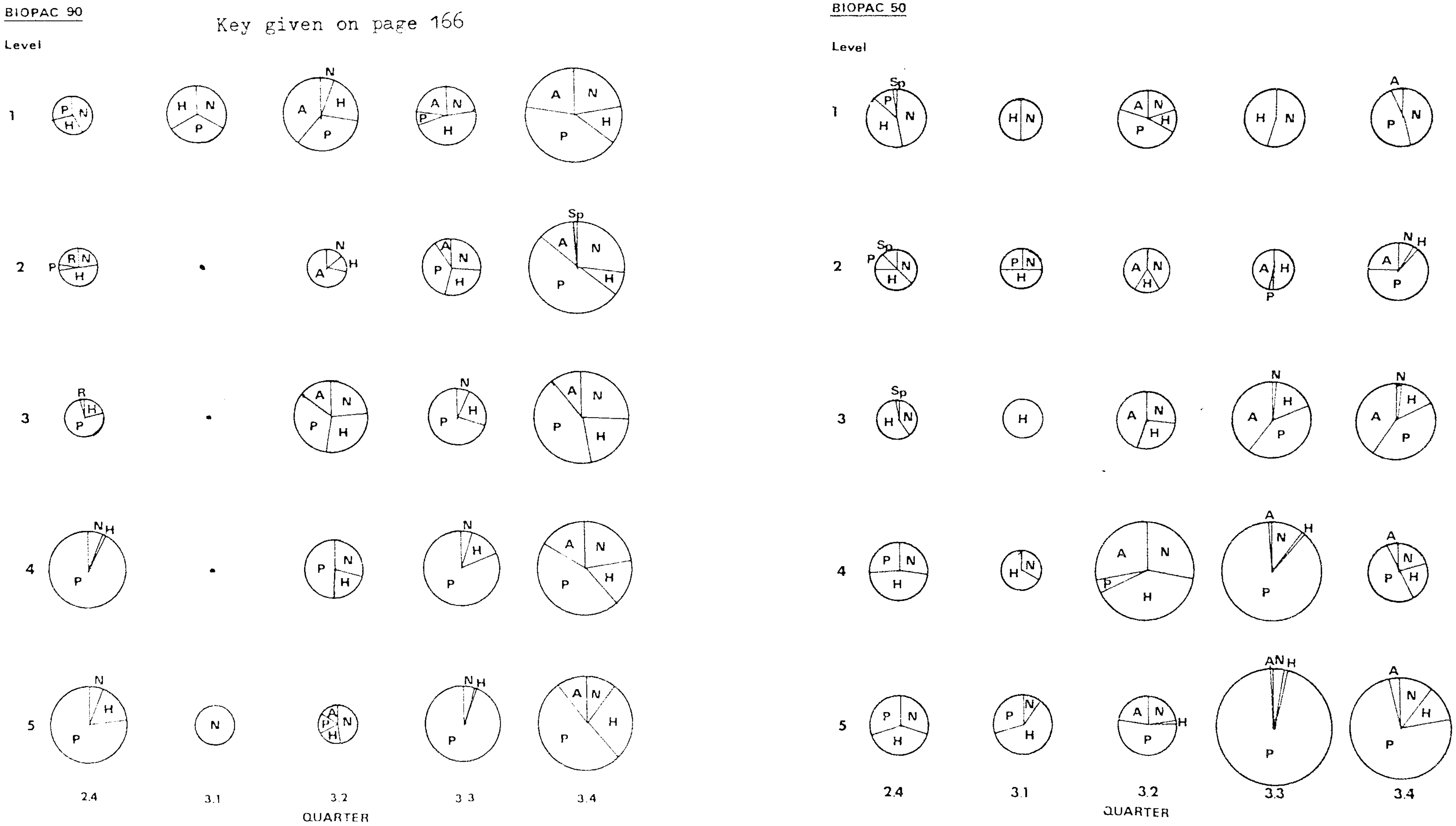
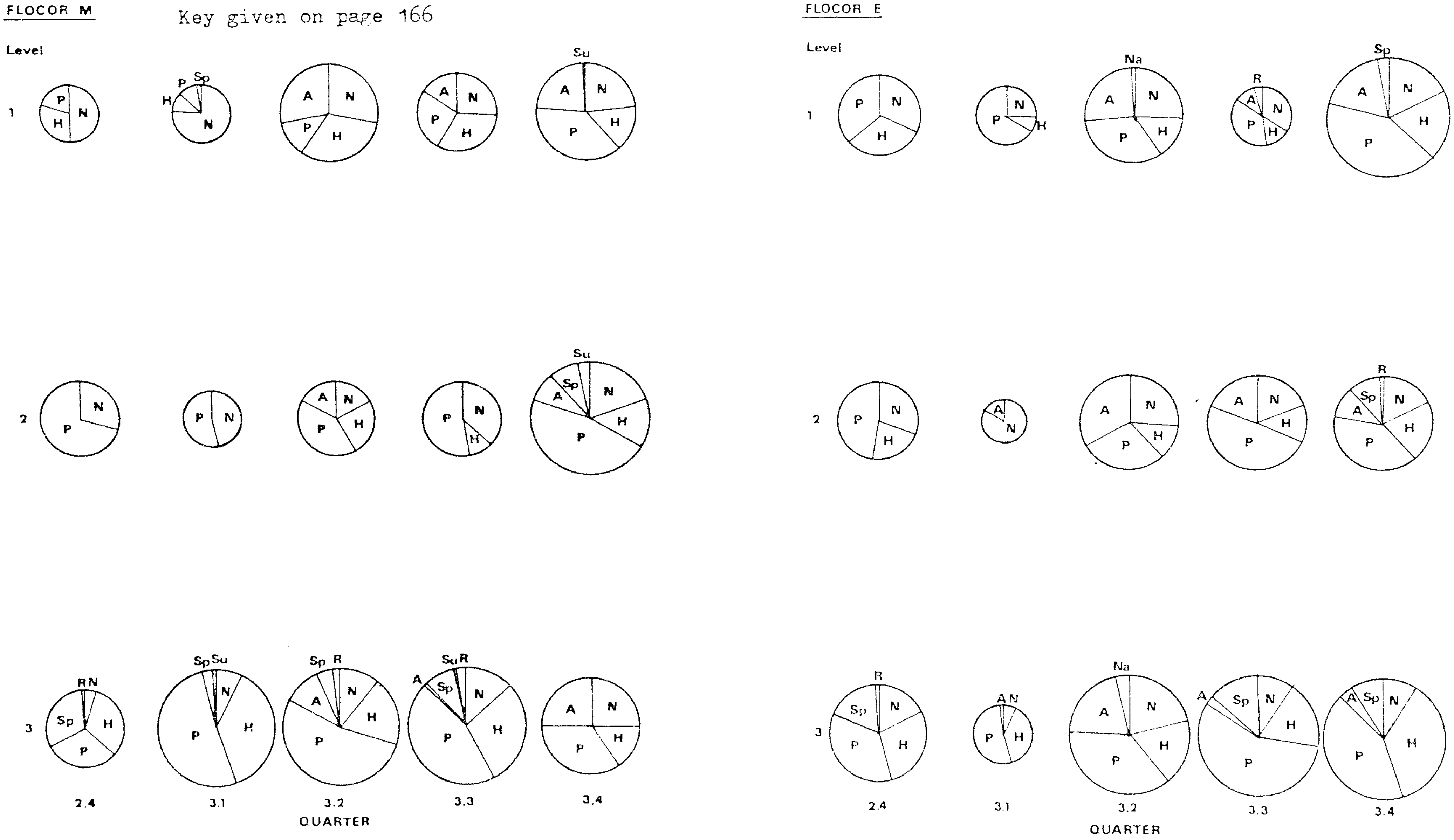


Fig. 5.5.12 Biological sampling results. Distribution and relative abundance of micro-organisms with filter depth. Flocor M and Flocor E.

Key given on page 166



5.6 The effect of increased hydraulic loading on filter efficiency

Attempts were made in late December - early January 1980 - 81 to increase the hydraulic loadings applied to the primary filters, so that short-term observations of the effects of such increases on filter performance could be made. Unfortunately it was found that the desired 25 percent increase in flow of sewage to the filters could not be achieved due to limitations in the capacity of the relevant pipework, and although observations of the BOD removal efficiency of two of the filter media were continued until May 1981, the flow rates applied were not markedly different from those applied during the rest of the study period (results presented in Appendices 5.1.1 and 2).

From an operational view point it is desirable to set the maximum loading conditions tolerable by each filter medium without consequent loss of removal efficiency. Table 5.6.1 presents the maximum loading conditions applied during the study, and from this Table it can be seen that the removal efficiency of none of the filters was badly affected by the maximum loadings applied. This illustrates that each of the filter media had the capacity to treat very high loadings for short periods of time. The long-term effects of such high loadings on filter ecology and performance were not assessed however, but as film levels were occasionally observed to reach very high levels in the random-fill media - particularly Biopac 50 - the nominal hydraulic loading conditions of 11.6 $m^3/m^3.d$ and 5.6 $m^3/m^3.d$ on the random-fill plastic and mineral medium filters respectively, using Hereford municipal sewage as feed, are believed to have approached the highest possible without risk of severe loss of efficiency due to ponding. The modular medium filters could withstand much higher loadings without the risk of ponding as they showed no propensity to accumulate heavy film, but such loadings would inevitably result in a fall in removal efficiency.

Table 5.6.1 Maximum loading conditions applied to the primary filters, September 1978 - April 1981

	BOD kg/m^3.d	COD kg/m^3.d	Flow m^3/m^3.d
Plastic Medium Filters			
Maximum Loading Applied	10.04 (11.58 Flocor M)	23.62 (26.24 Flocor M)	16.74 (18.60 Flocor M)
Date Applied	14.11.78	29.10.79	5.6.80
Filter Performance	% BOD Removal	% COD Removal	% BOD Removal
Biopac 50	64.4	88.3	62.4
Biopac 90	64.0	87.2	60.5
Flocor E	62.8	88.0	63.6
Flocor M	62.8	85.5	58.9
Mineral Medium Filters			
Maximum Loading Applied	5.27	14.22	9.23
Date Applied	14.11.78	22.10.79	6.3.80
Filter Performance	% BOD Removed	% COD Removed	% BOD Removed
89/50 Granite	67.0	82.1	68.0
125/75 Slag	68.3	87.4	73.1
89/50 Slag	67.1	89.0	64.7
125/75 Granite	66.8	87.8	72.2

5.7 Comparative filter media performance

In order to determine whether there were any statistical differences between the performance of different filter media a series of statistical analyses of the data was carried out. These analyses consisted of grouping the data into quarterly sets and analysing each Quarters data separately to determine whether any filter medium performed either better or worse at any particular time of the year. As the sewage strength changed seasonally, different Quarters were supplied with different sewage strengths, and it was hoped that this method of analysis might reveal more of the loading tolerance ranges of each medium than an overall analysis of the results from the two and a half year period. Two way analysis of variance followed,where appropriate,by Tuckeys Comparison of Means Test (Winer, 1971), was carried out on each Quarters data and the results are summarised in Tables 5.7.1 - 8. Tables 5.7.9 and 5.7.10 summarise the overall effluent quality figures obtained from the filters. In no instance has the performance of the mineral medium filters been compared with that of the plastic medium filters.

There were no obvious differences between the performance of the mineral media and the analysis of the quarterly data emphasise this fact (Tables 5.7.1 - 4). While the differences in effluent quality are statistically significant in many cases the actual range of values obtained in any Quarters data was not great. The performance of the small media was generally good, although during Quarters where film levels increased (Quarters 2.2, 3.1, 3.2 for 89/50 Slag and Quarters 2.2, 2.4, 3.1, 3.2 for 89/50 Granite) the condition of the effluents deteriorated in comparison with those of the large media.

The overall averages of performance data (Table 5.7.9) illustrate that the sludge production rates and settled and shaken sample suspended solids contents of the mineral media were all very similar. The lowest BOD was produced by 89/50 Slag, as was the lowest COD. 89/50 Granite produced the second lowest averages of these parameters and 125/75 Slag and 125/75 Granite the third and fourth respectively. This order corresponds roughly with that of the media SSA. In no respect can the differences in effluent quality be described as marked however, particularly in view of the fact that these are primary roughing filters.

The quality of the plastic media filter effluents fluctuated more widely with season than was found in the mineral media filters, and some of the plastic media proved to be more prone to seasonal changes in efficiency than others (Tables 5.7.5 - 8). The two modular media always supported low volumes of film and were therefore never subjected to impairment of efficiency caused by ponding. The random-fill media tended to support excessively heavy film levels as mentioned earlier (Section 5.5), and because of this filter efficiency deteriorated during Quarters 3.1 and 3.2. Biopac 50 tended to be more susceptible to such changes than Biopac 90, and it appears that Biopac 50 either produced the best or the worst quality effluents depending mainly on film accumulation levels. The Biopac 50 medium is therefore more suited to a situation where the sewage strength is not too high and the C:N ratio does not promote as heavy fungal growth as found at Hereford. In such a situation it could be expected to produce consistently good performance.

Tables 5.7.5 - 8 show that the performance of the Flocor M medium was consistently poor in comparison with the other media, and that the relative efficiency of this filter improved only through the deterioration of efficiency in the other media. From these analyses it would appear that the Flocor M medium was not suitable for use in treating Hereford municipal sewage. However this filter was loaded at an 11% higher rate throughout the study than were the other media tested and the effects of this increased loading on filter efficiency are difficult to assess. As the biological film levels of this medium were always low it would be most suited to a situation in which excessive film accumulation would normally be expected to cause severe ponding in random-fill media, for instance as a true roughing filter for the pre-treatment of wastes having extremely high C:N ratios.

The performance of the Biopac 90 and Flocor E was similar in many respects, although the Biopac was more susceptible to slightly impaired efficiency due to high film levels as mentioned earlier. When the data are analysed as in Tables 5.7.5 - 8, Biopac 90 appears to have performed slightly better than Flocor E, although the overall averages (Table 5.7.10) show that the differences were small. The 90 percentile figures for Biopac 90 are generally lower than for Flocor E, showing that very high values of each parameter are less likely in the random-fill medium. The differences in performance between these media were slight however and reflect the fact that they have the same SSA. Either of these two media would appear to be suitable for use with wastes of the type encountered at Hereford.

On averaging the data from Quarters 1.4 - 3.4 it was found that the BOD load removed was linearly related to BOD load applied (Figs 5.7.1 and 3), and the same relationship was valid in the case of COD loads (Figs 5.7.2 and 4). On pooling the quarterly averaged data from all the primary filters (Fig 5.7.5) the relationships were also found to be valid and the correlation coefficients high. The equation of the line for each filter medium represents the overall filter efficiency and could be used in the prediction of filter performance when using Hereford municipal sewage. The equation of the lines obtained by the pooling of all primary filter data could be similarly employed for high-rate filtration in general - provided always that hydraulic loading rates did not greatly exceed either 5.6 $m^3/m^3.d$ for mineral medium filters or 11.2 $m^3/m^3.d$ for plastic medium filters and that ponding could be avoided.

As the relationships between load applied and load removed were linear in each filter medium, it is assumed that the filters were not overloaded during the study and that the maximum organic load removal capacity of the filters (found by Bruce and Merkens (1970) when treating domestic sewage) was not reached. However, as mentioned in Section 5.6, the random-fill filters are believed to have been loaded at a level which approached the highest possible without risk of ponding.

Conclusions regarding the performance of the primary filter media are made in Chapter 9.

Table 5.7.1 Statistical analysis of seasonal changes in effluent quality. Mineral medium filter effluent BOD

Quarter	Ascending order of averaged effluent BOD concentrations (mg/l) with filter sector no. and statistically significant differences				
1.4	Filter No	3	1	2	4
	$\bar{x}$	190.3	194.8	202.0	217.8
2.1	Filter No	3^*	1	2^*	4
	$\bar{x}$	52.3	53.2	54.9	60.5
2.2	Filter No	4	2	1	3
	$\bar{x}$	65.5	67.1	70.7	72.6
2.3	Filter No	3	1	2	4
	$\bar{x}$	65.4	70.7	76.2	83.9
2.4	Filter No	3^*	4^+	1^{*+}	2
	$\bar{x}$	116.5	118.3	126.1	131.7
3.1	Filter No	4	2	3	1
	$\bar{x}$	68.3	73.5	78.0	79.9
3.2	Filter No	4	2	1	3
	$\bar{x}$	61.7	66.9	74.6	77.9
3.3	Filter No	3^*	1^+	4^*	2^+
	$\bar{x}$	64.5	69.3	81.4	83.8
3.4	Filter No	1	3	2	4
	$\bar{x}$	40.9	42.9	46.2	53.5

Where:- Pairs of filters joined by solid lines have non-significantly different quarterly averages

Pairs of filters with $^-$, *, or $^+$ - effluent quarterly averages differ @ 5% level of t

Non-connected pairs of filters in any particular Quarter - effluent quarterly averages differ @ 1% level of t

5.7.2 Statistical analysis of seasonal change in effluent quality. Mineral medium effluent settled solids

Quarter	Ascending order of averaged effluent settled solids concentrations (mg/l) with filter sectors no's and statistically significant differences				
1.4	Filter No	2	3	4	1
	$\bar{x}$	95	98	100	103
2.1	Filter No	4	3*	1	2*
	$\bar{x}$	53	54	56	58
2.2	Filter No	4	2	1	3
	$\bar{x}$	71	72	72	74
2.3	Filter No	1	2	3	4
	$\bar{x}$	47	49	49	53
2.4	Filter No	3	4	1	2
	$\bar{x}$	62	63	67	69
3.1	Filter No	4	1*	3*	2
	$\bar{x}$	56	57	58	59
3.2	Filter No	4	1	3	2
	$\bar{x}$	56	56	57	59
3.3	Filter No	1	4	3	2
	$\bar{x}$	50	54	54	56
3.4	Filter No	1	3	2	4
	$\bar{x}$	44	47	51	53

Where:- Pairs of filters joined by solid lines have non-significantly different quarterly averages

Pairs of filters with $^-$, *, or $^+$ - effluent quarterly averages differ @ 5% level of t

Non-connected pairs of filters in any particular Quarter - effluent quarterly averages differ @ 1% level of t

5.7.3 Statistical analysis of seasonal changes in effluent quality. Mineral medium filter effluent shaken solids

Quarter	Ascending order of averaged effluent shaken solids concentration (mg/l) with filter sector no's and statistically significant differences				
1.4	Filter No.	4	2	3	1
	$\bar{x}$	203	213	213	226
2.1	Filter No.	4	3	2	1
	$\bar{x}$	125	128	142	147
2.2	Filter No,	1	4	2*	3*
	$\bar{x}$	141	143	144	149
2.3	Filter No.	3	4	1	2
	$\bar{x}$	115	116	118	127
2.4	Filter No.	4*	3*	1	2
	$\bar{x}$	112	120	141	153
3.1	Filter No.	3	4*	2*	1
	$\bar{x}$	131	136	139	143
3.2	Filter No.	4	3	2	1
	$\bar{x}$	122	122	136	144
3.3	Filter No.	3	1	4	2
	$\bar{x}$	113	114	114	123
3.4	Filter No.	4	3	1	2
	$\bar{x}$	106	115	125	132

Where:- Pairs of filters joined by solid lines have non-significantly different quarterly averages

Pairs of filters with $^{-}$, *, or $^{+}$ - effluent quarterly averages differ @ 5% level of t

Non-connected pairs of filters in any particular Quarter - effluent quarterly averages differ @ 1% level of t

5.7.4 Statistical analysis of seasonal changes in effluent quality.

Mineral Medium filter effluent COD

Quarter	Ascending order of averaged effluent COD concentrations (mg/l) with filter no's and statistically significant differences				
1.4	Filter No.	3^{+*}	4^{*}	2^{+}	1
	$\bar{x}$	308	322	323	330
2.1	Filter No.	1	2	3	4
	$\bar{x}$	153	154	154	158
2.2	Filter No.	4	2	1	3
	$\bar{x}$	171	173	177	185
2.3	Filter No.	3	1	2	4
	$\bar{x}$	170	186	188	202
2.4	Filter No.	3	4	1	2
	$\bar{x}$	223	239	245	246
3.1	Filter No.	4	2^{+*}	3^{*}	1^{+}
	$\bar{x}$	172	175	180	181
3.2	Filter No.	4	2	1	3
	$\bar{x}$	162	171	183	187
3.3	Filter No.	1^{*}	3^{+-}	2^{+-}	4^{-}
	$\bar{x}$	183	186	203	205
3.4	Filter No.	1^{*}	3^{+}	4^{*}	2^{+}
	$\bar{x}$	168	174	185	189

Where:- Pairs of filters joined by solid lines have non-significantly different quarterly averages

Pairs of filters with $^{-}$, *, or $^{+}$ - effluent quarterly averages differ @ 5% level of t

Non-connected pairs of filters in any particular Quarter - effluent quarterly averages differ @ 1% level of t

Table 5.7.5 Statistical analysis of seasonal changes in effleuent quality. Plastic medium filter effluent BOD

Quarter	Ascending order of averaged effluent BOD concentrations (mg/l) with filter no's and statistically significant differences				
1.4	Filter No	9	10	11	15
	$\bar{x}$	241.0	244.0	252.0	258.8
2.1	Filter No	10	11	15	9
	$\bar{x}$	84.9	86.0	99.6	109.3
2.2	Filter No	9	11	15	10
	$\bar{x}$	72.8	78.2	80.7	105.8
2.3	Filter No	9	10	11	15
	$\bar{x}$	70.0	88.3	105.1	125.0
2.4	Filter No	9	10	11	15
	$\bar{x}$	139.0	144.6	164.6	174.1
3.1	Filter No	11	15	9	10
	$\bar{x}$	69,0	80.0	90.0	93.6
3.2	Filter No	11	15	10	9
	$\bar{x}$	63.3	75.4	91.3	92.7
3.3	Filter No	9	11	10	15
	$\bar{x}$	74.9	85.0	90.0	90.1
3.4	Filter No	9	10	11	15
	$\bar{x}$	87.1	113.3	152,1	161.6

Where:- Pairs of filters joined by solid lines have non-significantly different quarterly averages

Pairs of filters with $^-$, *, or $^+$ - effluent quarterly averages differ @ 5% level of t

Non-connected pairs of filters in any particular Quarter - effluent quarterly averages differ @ 1% level of t

Table 5.7. 6 Statistical analysis of seasonal changes in effluent quality
Plastic medium filter effluent settled solids

Quarter	Ascending order of averaged effluent settled solids (mg/l) with filter no's and statistically significant differences				
1.4	Filter No	9	10	11	15
	$\bar{x}$	95	103	107	111
2.1	Filter No	9	10	11^{*}	15^{*}
	$\bar{x}$	56	57	65	69
2.2	Filter No	9	10	11^{*}	15^{*}
	$\bar{x}$	74	75	76	79
2.3	Filter No	9^{*}	10^{*}	11	15
	$\bar{x}$	48	51	61	71
2.4	Filter No	10	9	11	15
	$\bar{x}$	68	69	86	95
3.1	Filter No	9	10	11	15
	$\bar{x}$	58	59	63	66
3.2	Filter No	10	9	15	11
	$\bar{x}$	53	55	62	66
3.3	Filter No	9	11	10	15
	$\bar{x}$	57	61	65	67
3.4	Filter No	9	10^{*+}	11^{*}	15^{+}
	$\bar{x}$	55	74	88	90

Where:- Pairs of filters joined by solid lines have non-significantly different quarterly averages

Pairs of filters with $^{-}$, *, or $^{+}$ -effluent quarterly averages differ @ 5% level of t

Non-connected pairs of filters in any particular Quarter - effluen quarterly averages differ @ 1% level of t

Table 5.7.7 Statistical analysis of seasonal changes in effluent quality
Plastic medium effluent shaken solids

Quarter	Ascending order of averaged effluent shaken solids (mg/l) with filter no's and satistically significant differences				
1.4	Filter No	10	9	11	15
	$\bar{x}$	251	262	$\underline{273}$	$\underline{273}$
2.1	Filter No	10	9	11	15
	$\bar{x}$	123	140	156	171
2.2	Filter No	10	11	15	9
	$\bar{x}$	$\underline{163}$	$\underline{165}$	$\underline{175}$	$\underline{176}$
2.3	Filter No	10	9	11	15
	$\bar{x}$	$\underline{120}$	$\underline{121}$	132	163
2.4	Filter No	10	9	11	15
	$\bar{x}$	138	146	180	212
3.1	Filter No	9	10	11	15
	$\bar{x}$	137	144	156	176
3.2	Filter No	10	9	11	15
	$\bar{x}$	126	143	152	168
3.3	Filter No	9^*	11	10	15^*
	$\bar{x}$	$\underline{133}$	$\underline{\underline{157}}$	$\underline{159}$	$\underline{174}$
3.4	Filter No	9^*	10^*	11	15
	$\bar{x}$	113	$\underline{152}$	$\underline{179}$	$\underline{185}$

Where:- Pairs of filters joined by solid lines have non-significantly different quarterly averages

Pairs of filters with $^-$, *, or $^+$ - effluent quarterly averages differ @ 5% level of t

Non-connected pairs of filters in any particular Quarter - effluent quarterly averages differ @ 1% level of t

Table 5.7.8 Statistical analysis of seasonal changes in effluent quality. Plastic medium filter effluent COD

Quarter	Ascending order of averaged effluent COD (mg/l) with filter no's and statistically significant differences				
1.4	Filter No	9	10	11	15
	$\bar{x}$	342	351	359	376
2.1	Filter No	10	11	15	9
	$\bar{x}$	179	180	189	191
2.2	Filter No	9	11	15	10
	$\bar{x}$	184	184	186	215
2.3	Filter No	9	10	11	15
	$\bar{x}$	170	195	215	237
2.4	Filter No	9	10	11	15
	$\bar{x}$	240	244	267	295
3.1	Filter No	11	9	15	10
	$\bar{x}$	165	175	178	180
3.2	Filter No	11	15	9	10
	$\bar{x}$	171	180	191	191
3.3	Filter No	10	9	11	15
	$\bar{x}$	205	208	221	232
3.4	Filter No	9	10	11	15
	$\bar{x}$	248	294	318	329

Where:- Pairs of filters joined by solid lines nave non-significantly different quarterly averages

Pairs of filters with $^-$, *, or $^+$ - effluent quarterly averages differ @ 5% level of t

Non-connected pairs of filters in any particular Quarter - effluent quarterly averages differ @ 1% level of t

Table 5.7.9 Summary of the comparative physico-chemical performance of the mineral medium filters, September 1978 - 80.

		Physico-chemical parameter						
		BOD (mg/l)	% BOD Removed	COD (mg/l)	% COD Removed	Settled SS (mg/l)	Shaken SS (mg/l)	Sludge Production Rate (g/g BOD removed)
Sewage	90%	535.7		890		172	269	
Filter medium								
89/50 Granite	90%	184.7	--	320	--	98	219	--
	$\bar{x}$	93.1	73.7	208	76.6	64	147	0.34
125/75 Slag	90%	189.9	--	313	--	100	195	--
	$\bar{x}$	96.2	72.8	210	76.4	65	148	0.35
89/50 Slag	90%	192.4	--	293	--	97	197	--
	$\bar{x}$	91.9	74.0	204	77.1	64	142	0.32
125/75 Granite	90%	206.6	--	371	--	96	194	--
	$\bar{x}$	99.5	71.9	212	76.2	64	134	0.30

Where :- 90% represents the ninety percentile value
and $\bar{x}$ represents the over-all average value

Table 5.7.10 <u>Summary of the comparative physico-chemical performance of the plastic medium filters, September 1978 - 80.</u>

		Physico-chemical parameter						
		BOD (mg/l)	% BOD Removed	COD (mg/l)	% COD Removed	Settled SS (mg/l)	Shaken SS (mg/l)	Sludge Production Rate (g/g BOD removed)
Sewage	90%	535.7		890		172	269	
Filter medium								
Biopac 50	90%	229.6	--	339	--	100	209	--
	$\bar{x}$	114.3	67.7	221	75.2	66	159	0.43
Biopac 90	90%	217.4	--	339	--	101	221	--
	$\bar{x}$	120.3	66.0	229	74.3	68	157	0.42
Flocor E	90%	244.9	--	345	--	107	239	--
	$\bar{x}$	119.4	66.2	231	74.0	74	175	0.45
Flocor M	90%	246.6	--	374	--	115	251	--
	$\bar{x}$	130.0	63.2	224	72.6	78	190	0.54

Where :- 90% represents the ninety percentile value

and $\bar{x}$ represents the over-all average value

Fig. 5.7.1 BOD load applied vs. BOD load removed. Quarterly averaged data, Quarters 1.4 - 3.4. Plastic medium filters.

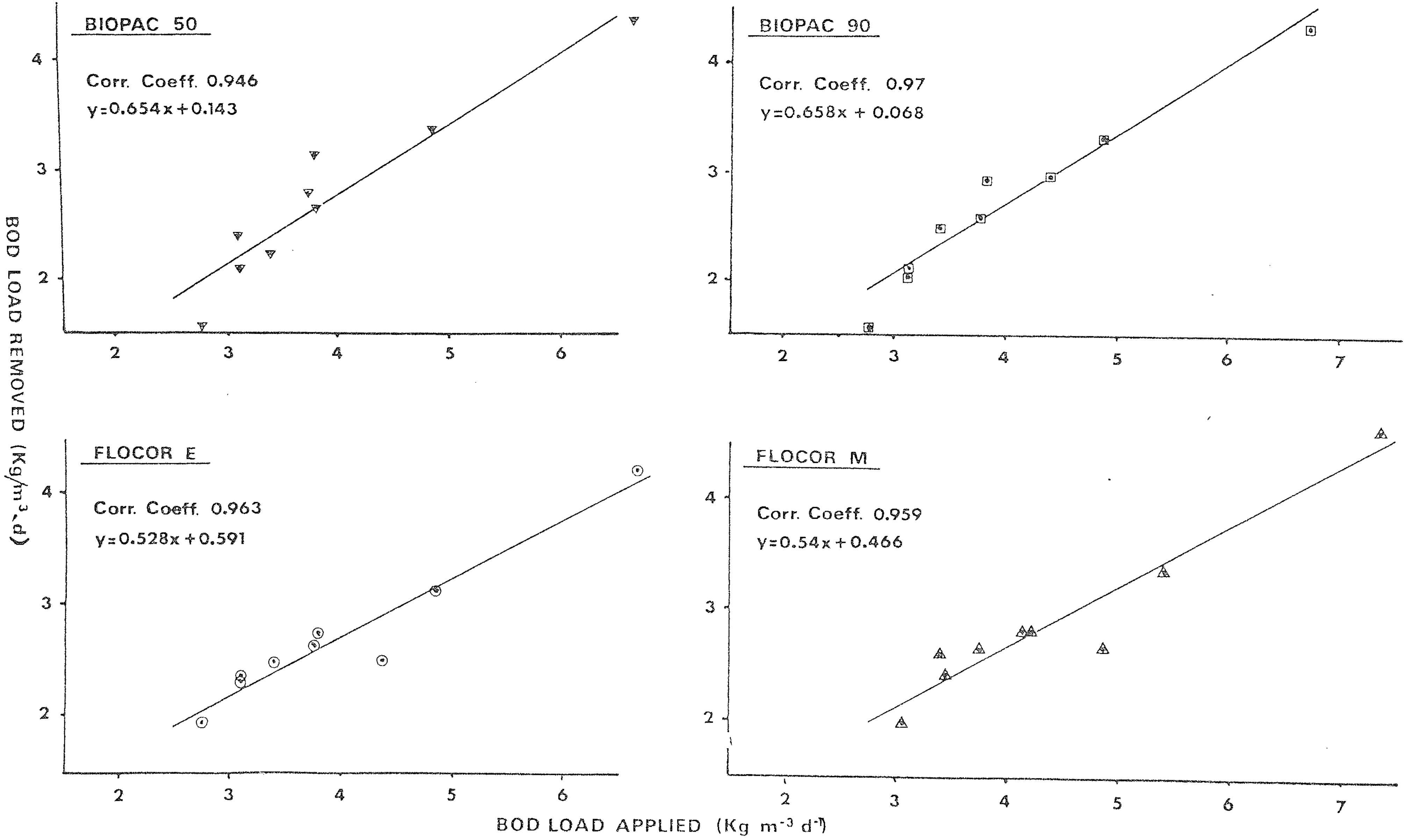


Fig. 5.7.2 COD load applied vs. COD load removed. Quarterly averaged data, Quarters 1.4 - 3.4. Plastic medium filters.

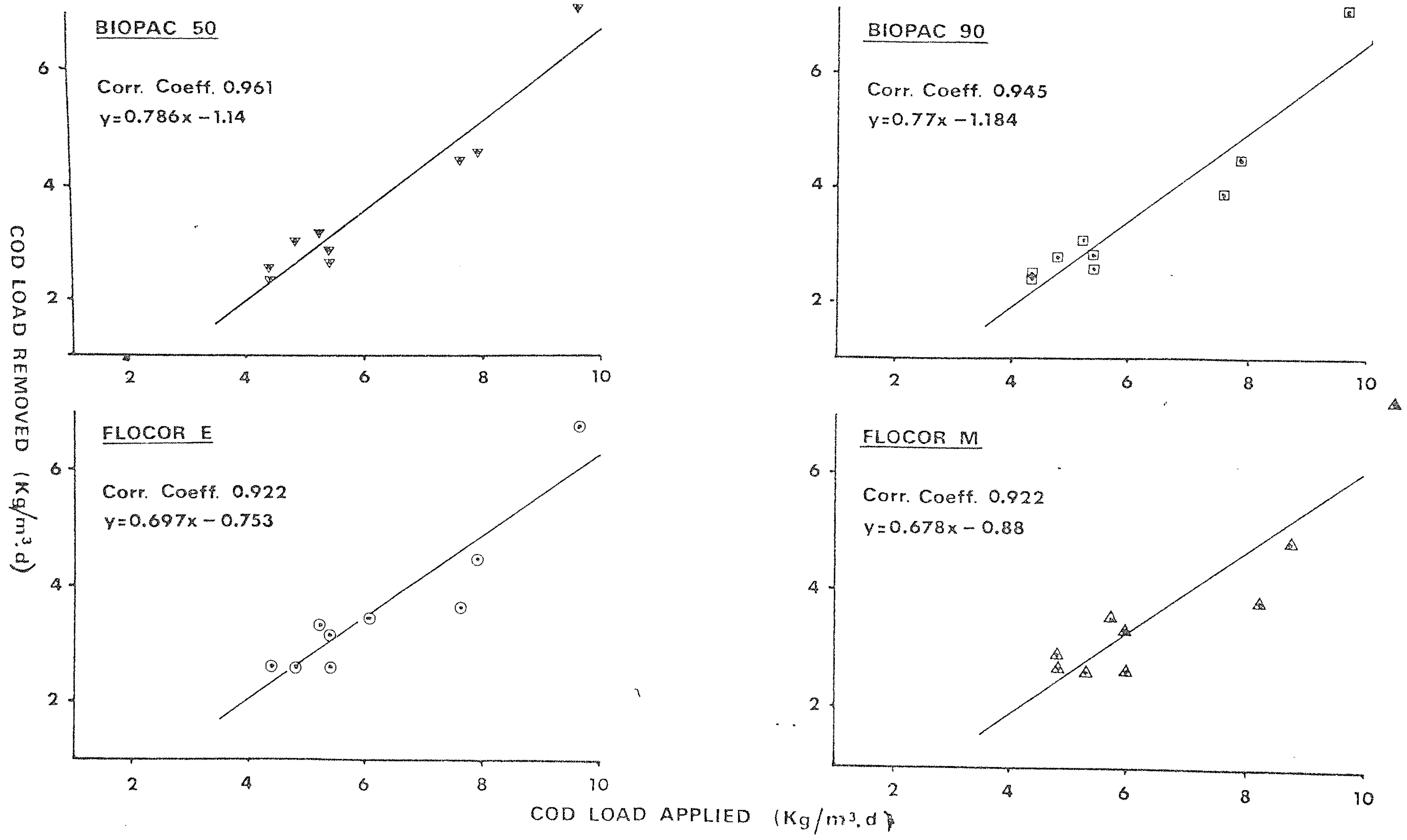


Fig. 5.7.3 BOD load applied vs. BOD load removed. Quarterly averaged data, Quarters 1.4 - 3.4. Mineral medium filters.

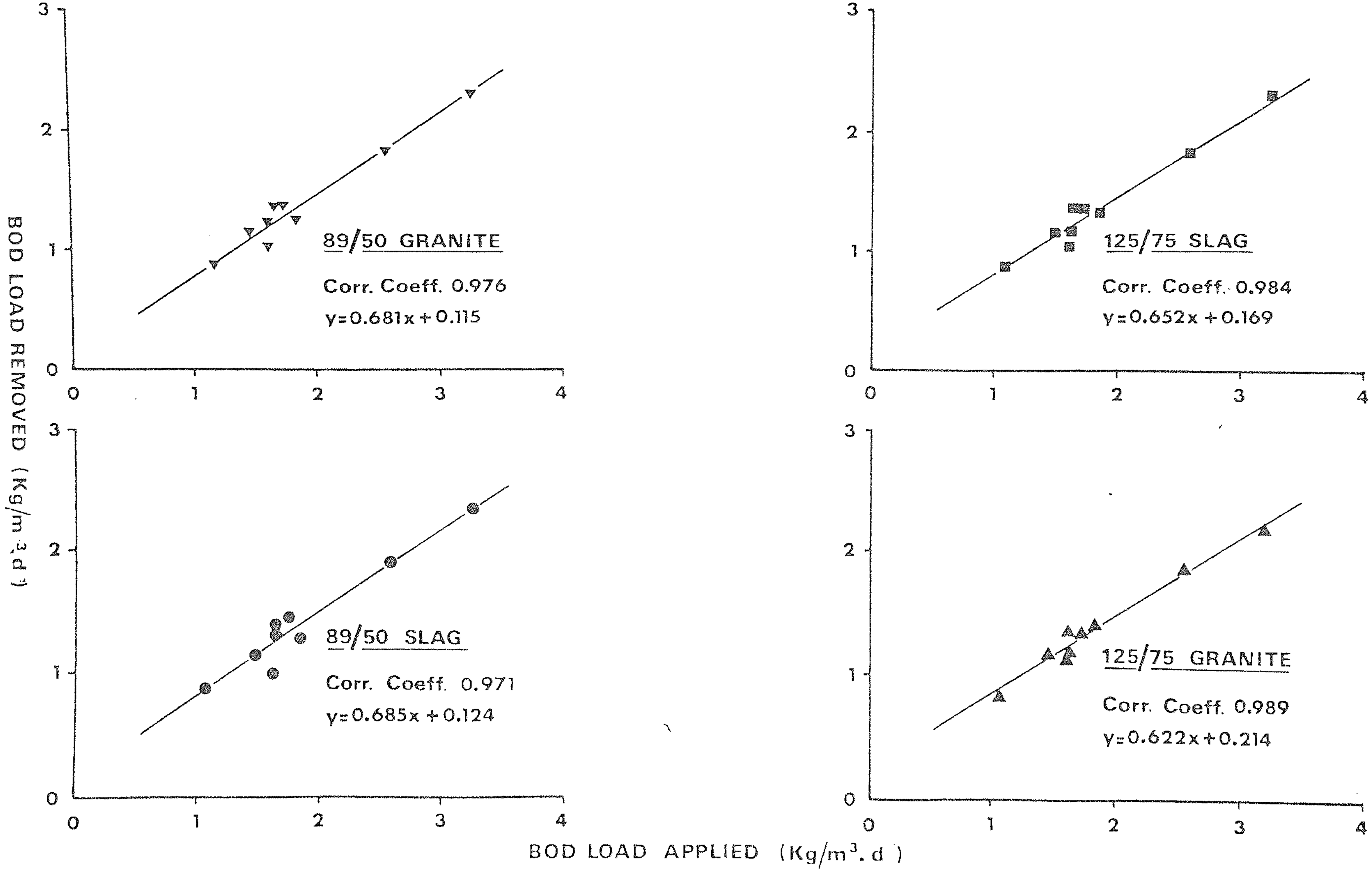


Fig. 5.7.4 COD load applied vs. COD load removed. Quarterly averaged data, Quarters 1.4 - 3.4. Mineral medium filters.

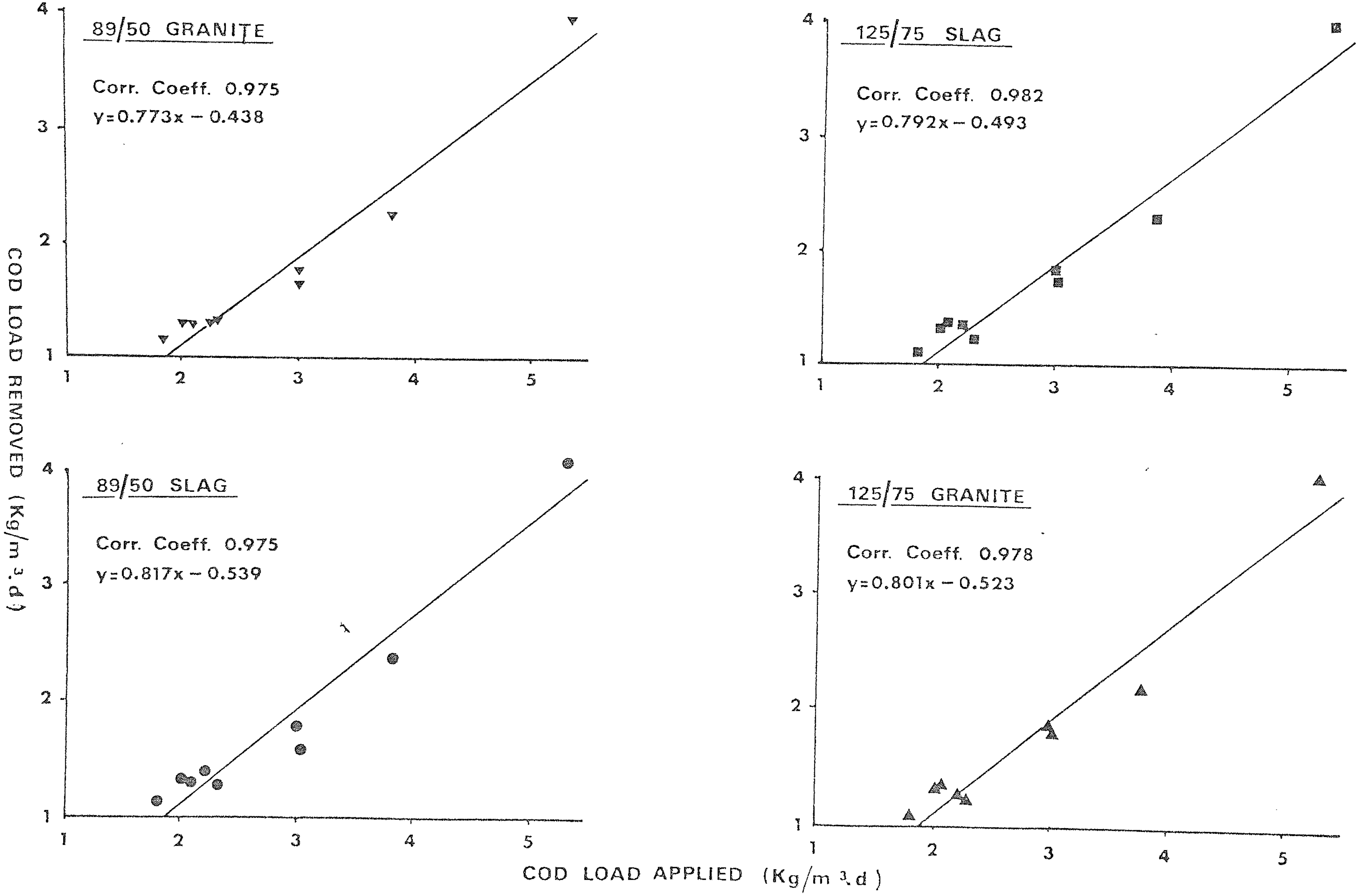
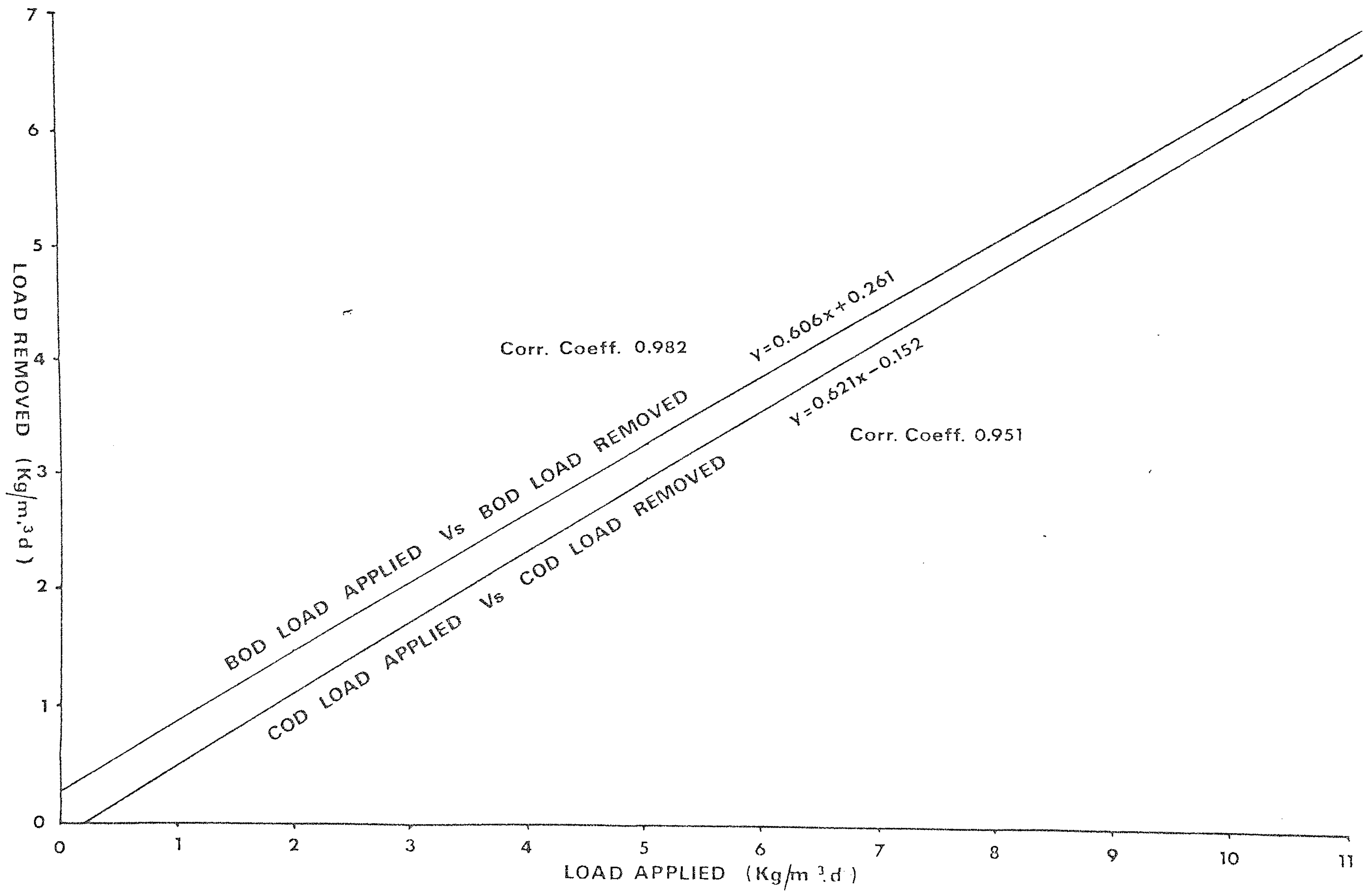


Fig. 5.7.5 Load applied vs. load removed. Quarterly averaged data, Quarters 1.4 - 3.4. Filters 1 - 16.



6 Secondary filter performances

6.1 Commissioning

The secondary filters were commissioned on 29th May 1979 and were operated until May 1981. Unfortunately several difficulties were experienced with the operation of the electrical drive motors of the distributor arms and normal operation was not achieved until August 1979. Further operational problems were experienced during late February and March 1980 when the filters were shut down for a period of four weeks. No samples were analysed during April and May after the filters had been restarted and therefore the immediate effect of this prolonged shutdown on filter performance was not evaluated. Almost continuous operation was achieved between April 1980 and May 1981. Appendix 4.3.1 lists secondary filter operational shutdowns.

6.2 Secondary filter feed

The liquor used to feed the secondary filters originated from the common sump receiving the mixed primary filter effluents. From this sump the mixed effluents were pumped to a 2 m^3 capacity settlement tank before distribution to the filters via reciprocating distributor arms (Fig 4.1.2a, b).

The variations in feed composition are recorded in Figs 6.3.1 - 3 and temperature in Fig 6.3.6. Appendix 6.3.7 gives sewage NH_3-N and oxidised -N content. Fig 6.3.1 shows that while sewage BOD increased during October and November 1979 and November 1980 to March 1981, the seasonal fluctuations were not as great as those experienced by the primary filters. Peaks in COD occurred in September and October 1979 and appeared to be rising again in September 1980 before COD analyses were stopped. No such fluctuations in sewage suspended solids content occurred, emphasising the fact that no seasonal offloading of film occurred in the primary filters.

Despite the fact that no attempts were made to insulate the 15 m length of uPVC piping which carried the mixed primary filter effluents to the secondary filter settlement tank (which stood 2 m above ground and was completely unprotected from adverse weather conditions) there was an average fall in temperature of only 1.7 centigrade degrees between the primary and secondary (settled) sewages.

6.3 Secondary filter results and discussion

Both secondary filters were operated at a nominal flow rate of 4.0 $m^3/m^3.d$ throughout the study period, and no changes in operation were made during this time. Figs 6.3.1 - 6 illustrate the monthly averaged physicochemical composition of secondary filter feed and effluents, Fig 6.3.7 the BOD and COD percent removal figures, and Figs 6.3.8 - 10 the frequency distributions of sewage and effluent sample BOD, COD and SS concentrations. Table 6.3.1 shows the monthly averaged loading conditions applied, while Table 6.3.2 summarises the overall performance of the filters during the two year period. Basic operating data are presented in Appendices 6.3.1 - 7.

It can be seen from Figs 6.3.1 - 7 that both filter media produced good quality effluents, and performance in relation to percent BOD and COD removal stabilised very rapidly after commissioning. The smaller of the two media (Flocor RS) produced better quality effluents from the beginning of the study, with only effluent shaken solids and sludge production rate (Figs 6.3.4 - 5) being of similar magnitude in the two filters.

Table 6.3.1 shows that the hydraulic loading applied to the Flocor R2S filter was slightly higher overall than that applied to the Flocor RS filter. This was due to problems encountered with accurately levelling the reciprocating distributor mechanisms supplying sewage to the filters. The BOD and COD loads applied to the Flocor R2S filter were therefore correspondingly higher, although t-tests showed that none of these differences were statistically significant. BOD and COD loadings to both of the secondary filters generally increased during the period September - December each year when the primary filter loadings were also high, although the seasonal variations in secondary filter feed strength were in no way as pronounced as in the primary filters sewage (Figs 6.3.1 and 2). Fig 6.3.1 shows that effluent BOD concentrations were higher during late autumn and winter than at other times of the year, as might be expected from consideration of both the fall in temperature and increase in sewage strength experienced at this time of year. Flocor R2S appears to have been more susceptible to changes in efficiency during these periods than was Flocor RS. A further peak in effluent BOD occurred in July 1980 although only one sample was analysed during this month and this may have been unrepresentative of filter performance at the time.

Monthly averaged effluent BOD concentration exceeded 20 mg/l on only two occasions in the Flocor RS filter (October 1979 and April 1981). The October 1979 peak was caused by the peak feed BOD concentration of 300 mg/l observed during this month, while the peak in April 1981 was caused by a single effluent sample with a BOD of 63.8 mg/l - although the accuracy of the BOD determination in this sample must be questioned as the samples taken one week before and after had BOD's of only 13.3 and 10.8 mg/l respectively. Fig 6.3.8 and Table 6.3.2 show that the 90 percentile value for BOD in Flocor RS was 24.6 mg/l, and in fact 79.8% of all samples had a BOD concentration of less than 20 mg/l. The Flocor R2S filter did not perform as well as Flocor RS and only eight monthly averaged BOD concentrations fell below 20 mg/l, the 90 percentile value for BOD was 40.5 mg/l and 63.6% of all samples had a BOD concentration of less than 20 mg/l.

The relationship between BOD load applied and load removed by the secondary filters was found to be linear (Fig 6.3.11), as found in the primary filter media. (Fig 6.3.12 shows that the relationship between COD load applied and load removed was also linear). Reducing the BOD load would therefore result in a measurable fall in effluent BOD concentration. This reduction in load - assuming feed strength to remain the same - could be achieved either by increasing the degree of interstage settlement of the primary filter effluents, by reducing the hydraulic loading or by a combination of these measures. The Flocor RS medium would probably have produced Royal Commission standard effluent with respect to BOD concentrations if fine adjustments of this type had been made to the mode of filter operation. Greater changes would have been necessary to produce Royal Commission standard effluents from the Flocor R2S medium.

Effluent COD concentrations rarely fell below 70 mg/l (Fig 6.3.2), and this may represent the concentration of non-oxidisable or very slowly oxidisable chemicals in Hereford sewage. Peaks in feed COD were occasionally high and these peaks caused corresponding increases in effluent concentrations. The 90 percentile values for effluent COD (Fig 6.3.9 and Table 6.3.2) were 136 and 124 mg/l for Flocor R2S and Flocor RS respectively, and reflect the difficulty encountered in removing the residual COD from Hereford sewage.

The effluent settled solids concentrations (Fig 6.3.3) show that the monthly average of the Flocor RS effluent exceeded 30 mg/l on only one occasion (September 1979), when feed strength was high. Several individual samples with solids contents greater than 30 mg/l were found however and the overall 90 percentile value was 30 mg/l (exact value 30.2 mg/l, Fig 6.3.10, Table 6.3.2). Flocor R2S monthly averaged effluent settled solids exceeded 30 mg/l on five occasions, the 90 percentile value was 40 mg/l with 73.0% of all samples having settled solids content of less than 30 mg/l.

The effluent shaken sample suspended solids data (Fig 6.3.4) show that the filters produced roughly equal quantities of settleable solids. Both effluent concentrations increased in months in which sludge production rate also peaked - August 1979 and 1980, February 1980 (Fig 6.3.5), which possibly illustrates some seasonal offloading of film by the filters. Both filters had similar sludge production rates (expressed as g sludge produced/g BOD removed) and these were higher than those of the primary filter media.

The higher rates of sludge production by the secondary filters could be due to a combination of the fact that the filters never reached full biological maturity (see Section 6.4), that the settlement of the feed before application to the filters was not sufficiently long, and that the filter media had a very open structure which allowed the rapid discharge of solids. Appendix 6.3.4 shows that after a further thirty minutes quiescent settlement period the suspended solids content of the secondary filter feed fell by an average of 50%. As the biological film was not fully mature during the study complete oxidation of these settleable solids would probably not have been possible, and the non-oxidised solids could either pass straight through the open structured filter media without being affected by the film or simply be flocculated by the film before discharge. Either of these routes would result in greater quantities of settleable solids reaching the humus sludge tanks than would normally be found and therefore artificially raise the sludge production rate figures of the filters. The high sludge production rate of these secondary filters is therefore not believed to be due to the production of unduly high quantities of humus by the biological film of the filters in oxidising the applied organic material, but to the large proportion of settleable solids in the sewage.

Fig 6.3.6 shows that at no time during the study was more than 40% of the sewage NH_3-N removed by the filters, and for much of the time less than 10% was removed. Bruce et al. (1975) considered that the lack of nitrification in the secondary filters of a two stage filtration plant at Stevenage was due to a fall in temperature between the primary and secondary filters. This fall averaged only 1.7 centigrade degrees at Hereford and is not considered to be the cause, although on three occasions the monthly averaged effluent temperature fell to just above 10°C, which would have been sufficiently low as to cause some inhibition had nitrification ever been occurring in these filters. The reasons that nitrification was not achieved are probably three-fold.

1. The feed BOD was too high (see Chapter 8).
2. The secondary filters never became fully mature due to occasional operational difficulties (Results obtained during March and April 1981 suggest that nitrification may have been possible to a certain extent during the following summer had operation of the filters continued).
3. The filters were never operated as nitrifying filters and care was not therefore taken to ensure that conditions were suitable for nitrification to occur.

Table 6.3.1 Monthly averaged loading conditions applied to the secondary filters.

	Flocor RS			Flocor R2S		
	Flow rate (m^3/m^3.d)	BOD load (kg/m^3.d)	COD load (kg/m^3.d)	Flow rate (m^3/m^3.d)	BOD load (kg/m^3.d)	COD load (kg/m^3.d)
J 79	4.55	0.54	1.29	5.37	0.63	1.53
A	4.73	0.45	1.03	4.90	0.45	1.05
S	4.68	0.72	1.42	4.95	0.76	1.49
O	4.36	0.94	1.72	4.03	0.82	1.53
N	3.82	0.74	1.33	4.18	0.80	1.46
D	4.10	0.66	1.24	3.72	0.59	1.12
J 80	4.04	0.46	0.98	3.74	0.43	0.91
F	3.44	0.31	0.72	3.35	0.29	0.70
M	-	-	-	-	-	-
A	-	-	-	-	-	-
M	4.05	-	-	4.42	-	-
J	3.55	0.42	0.99	3.84	0.45	1.06
J	4.25	0.46	0.94	4.25	0.46	0.94
A	3.46	0.34	1.00	4.13	0.37	1.13
S	3.95	0.50	1.25	3.80	0.48	1.19
O	3.48	0.40	-	4.50	0.52	-
N	4.12	0.73	-	4.61	0.82	-
D	4.35	0.84	-	4.35	0.84	-
J 81	4.39	0.77	-	4.32	0.76	-
F	-	-	-	-	-	-
M	3.53	0.64	-	3.87	0.70	-
A	4.99	0.47	-	4.92	0.46	-
Average	4.10	0.58	1.16	4.28	0.59	1.18

Table 6.3.2 Summary of the comparative physico-chemical performance of the secondary filter media. July 1979 - April 1981

		Physico-chemical parameter						
		BOD (mg/l)	% BOD load removed	COD (mg/l)	% COD load removed	Settled SS (mg/l)	Shaken SS (mg/l)	Sludge production rate (g/g BOD removed)
Secondary filter feed	90%	209.0		358		115	225	
Flocor RS	90%	24.6	--	124	--	30	140	--
	$\bar{x}$	14.5	89.6	90	67.8	21	100	0.75
Flocor R2S	90%	40.5	--	136	--	40	144	--
	$\bar{x}$	21.2	84.9	92	64.8	26	109	0.82

Where :- 90% represents the 90 percentile concentration

and $\bar{x}$ represents the over-all average value.

Fig. 6.3.1

Monthly averaged BOD data. Secondary filters.

Vertical lines are ranges of sewage BOD

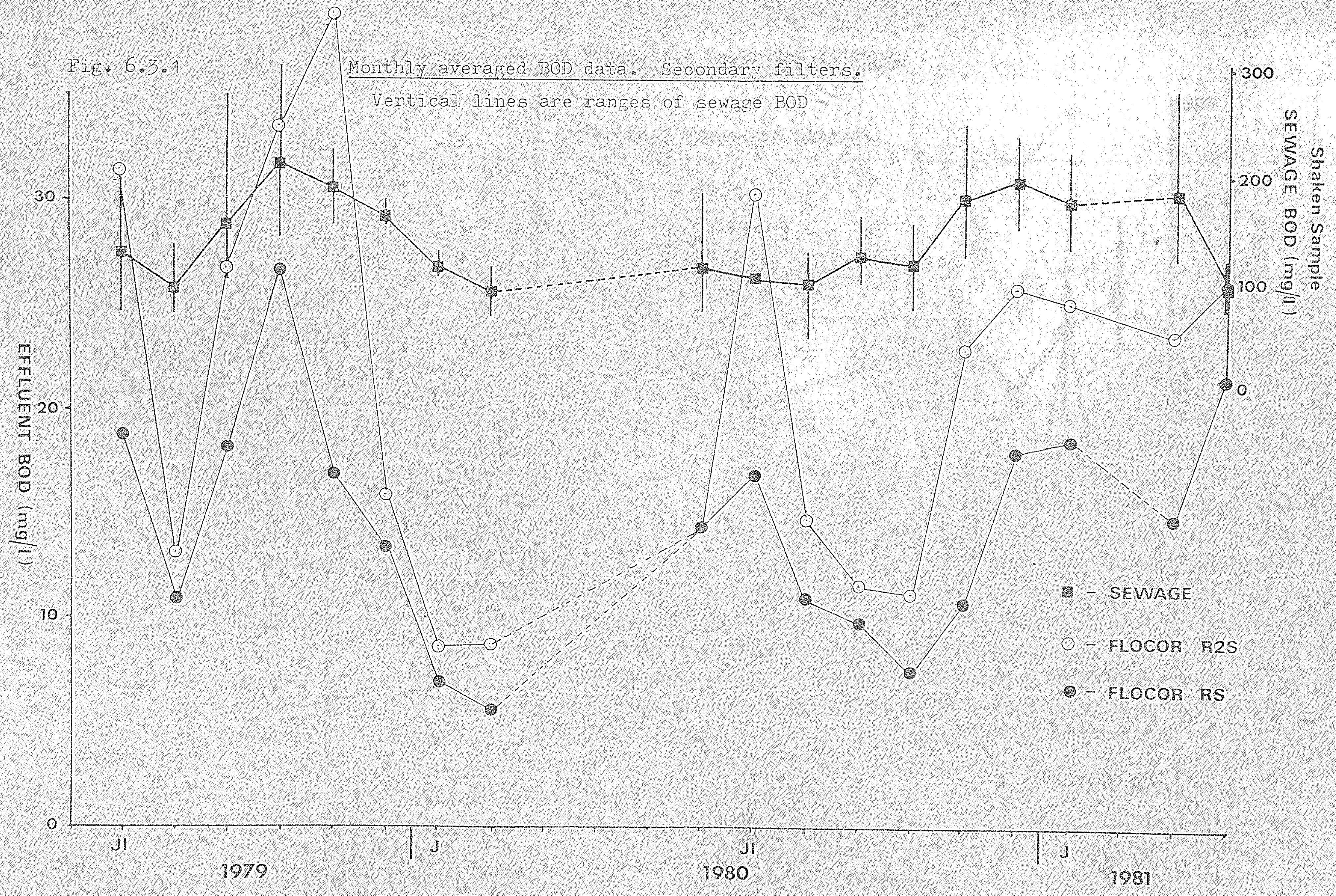
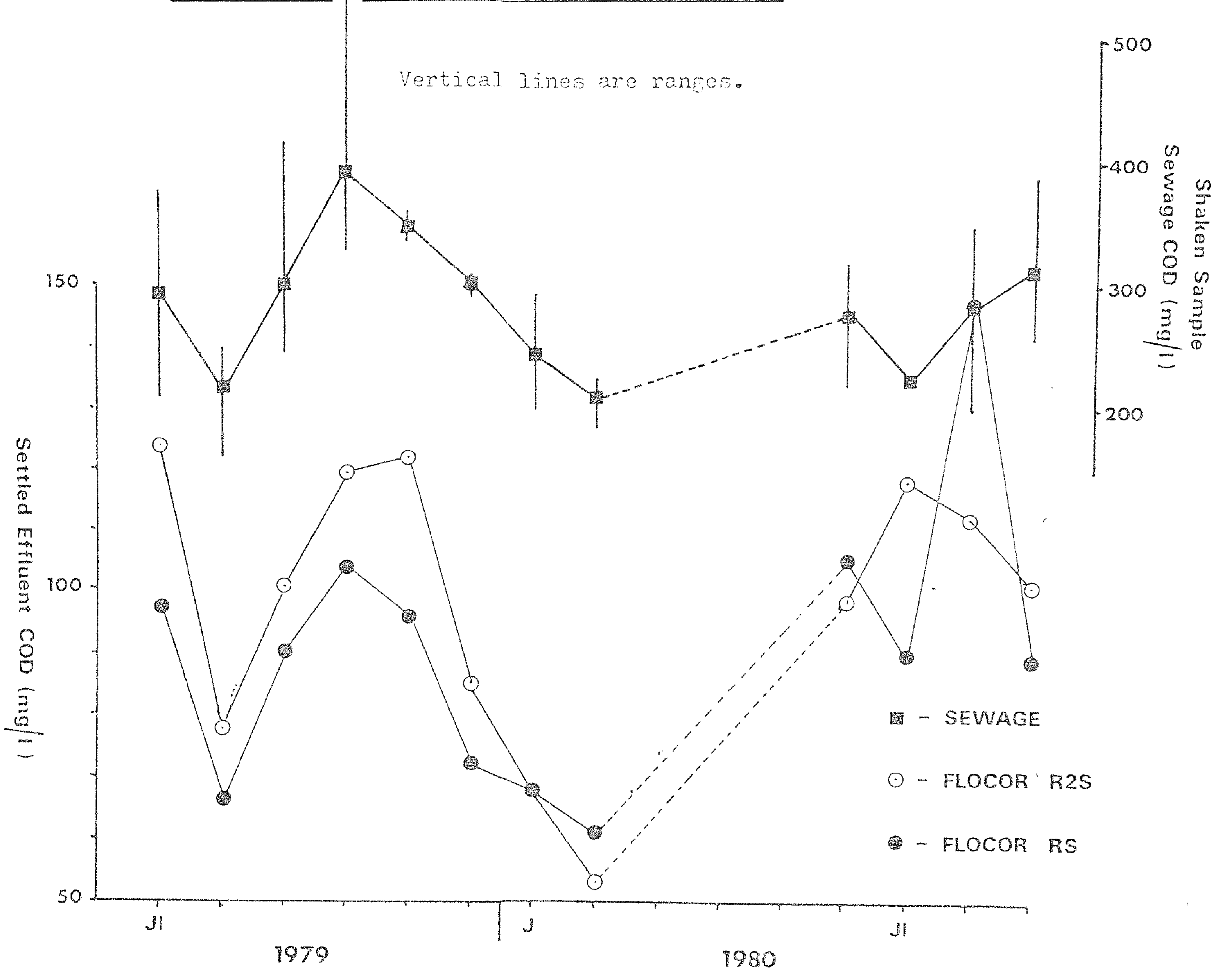


Fig. 6.3.2 Monthly averaged COD data. Secondary filters.



Vertical lines are ranges.

Fig. 6.3.3 Monthly averaged suspended solids data. Secondary filters.

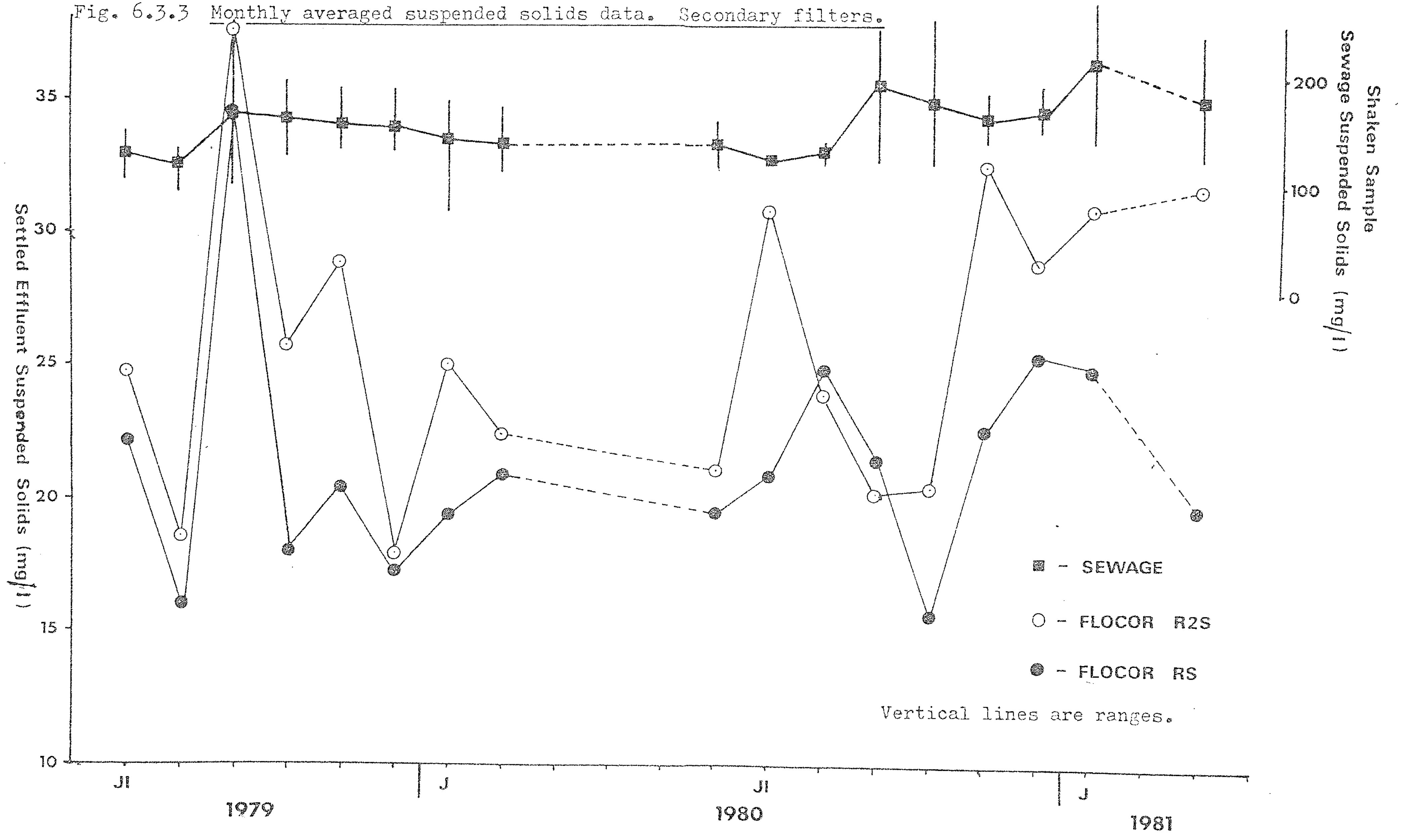


Fig. 6.3.4 Monthly averaged suspended solids (Shaken sample) data. Secondary filters.

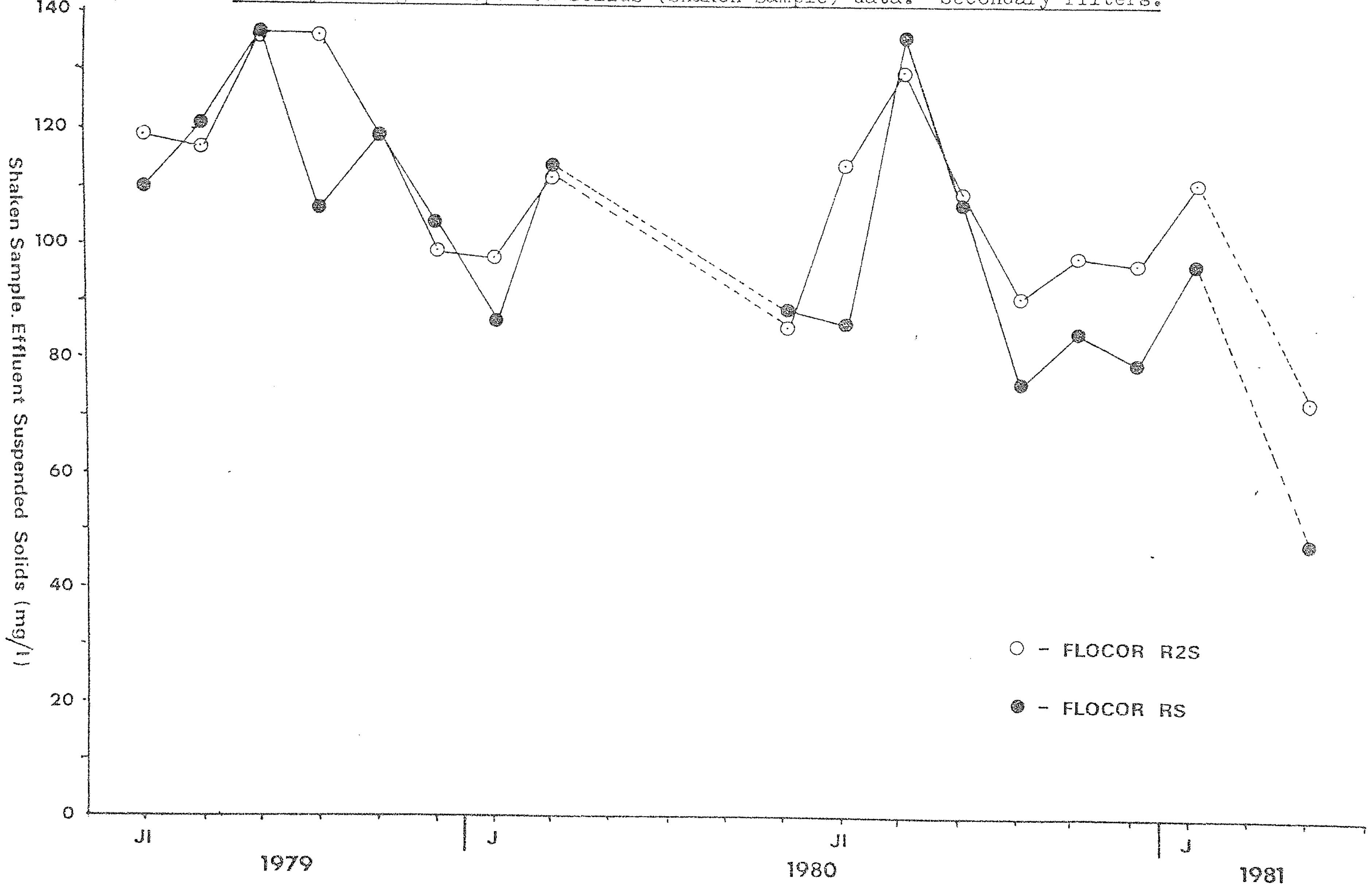


Fig. 6.3.5 Monthly averaged sludge production rate data. Secondary filters.

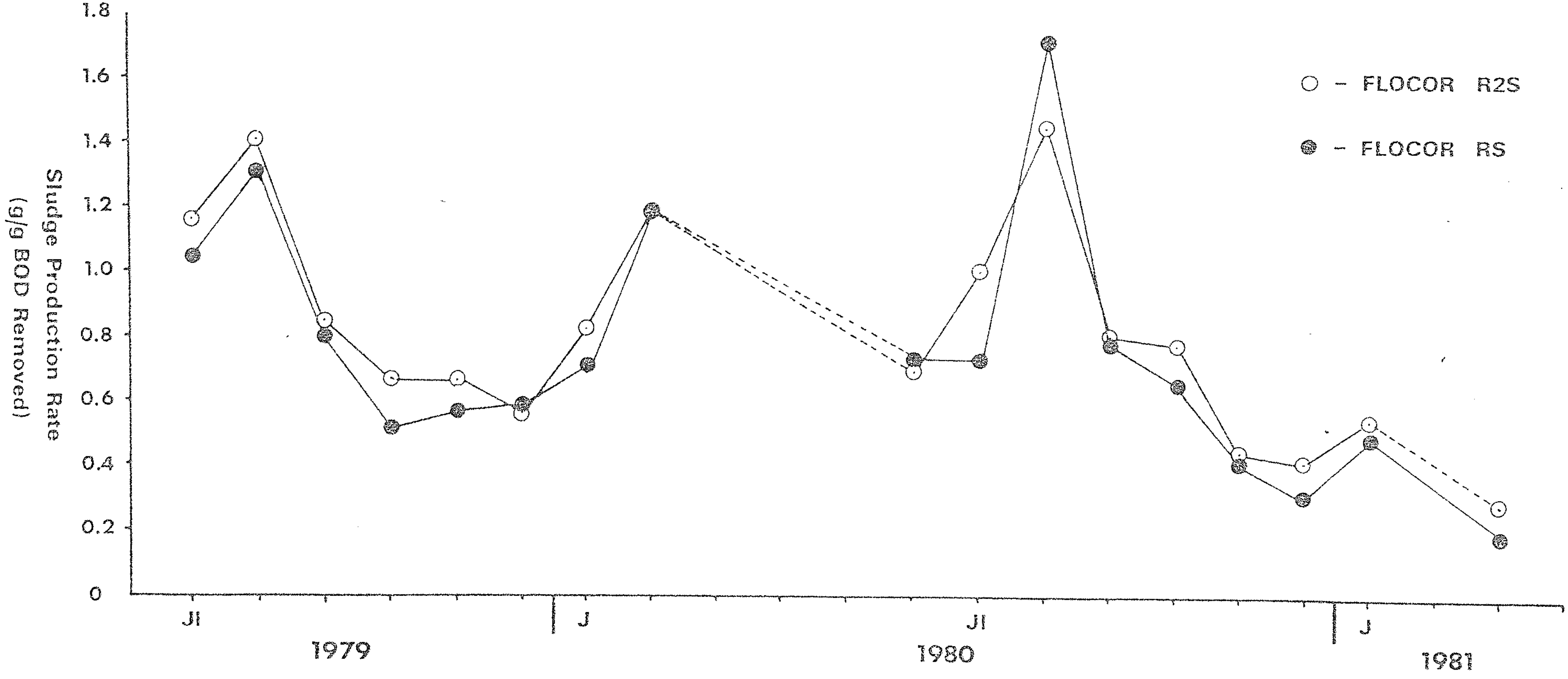


Fig. 6.3.6 Monthly averaged temperature and % NH_3-N removal data. Secondary filters.

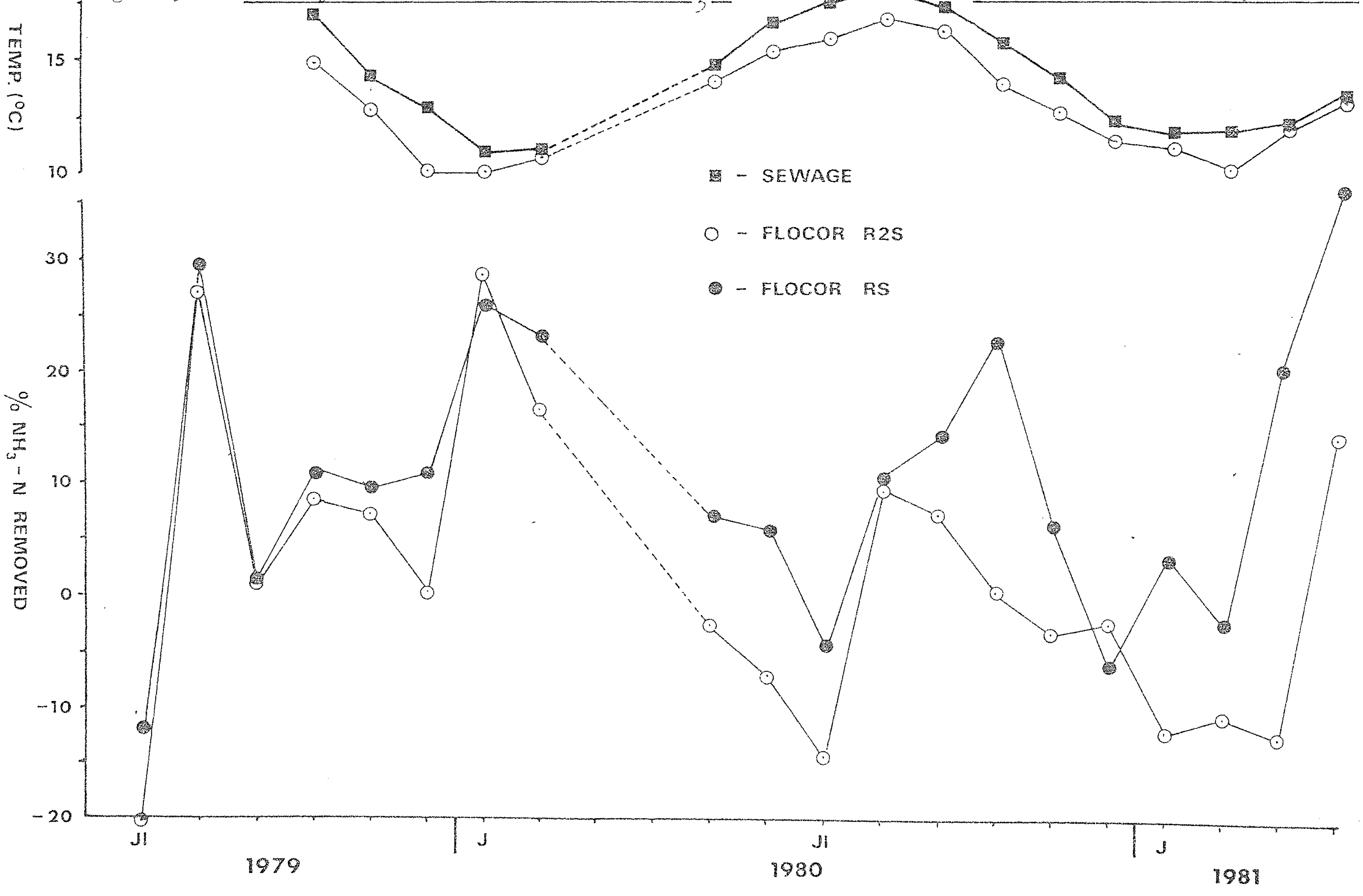


Fig. 6.3.7 Monthly averaged % removal data. Secondary filters.

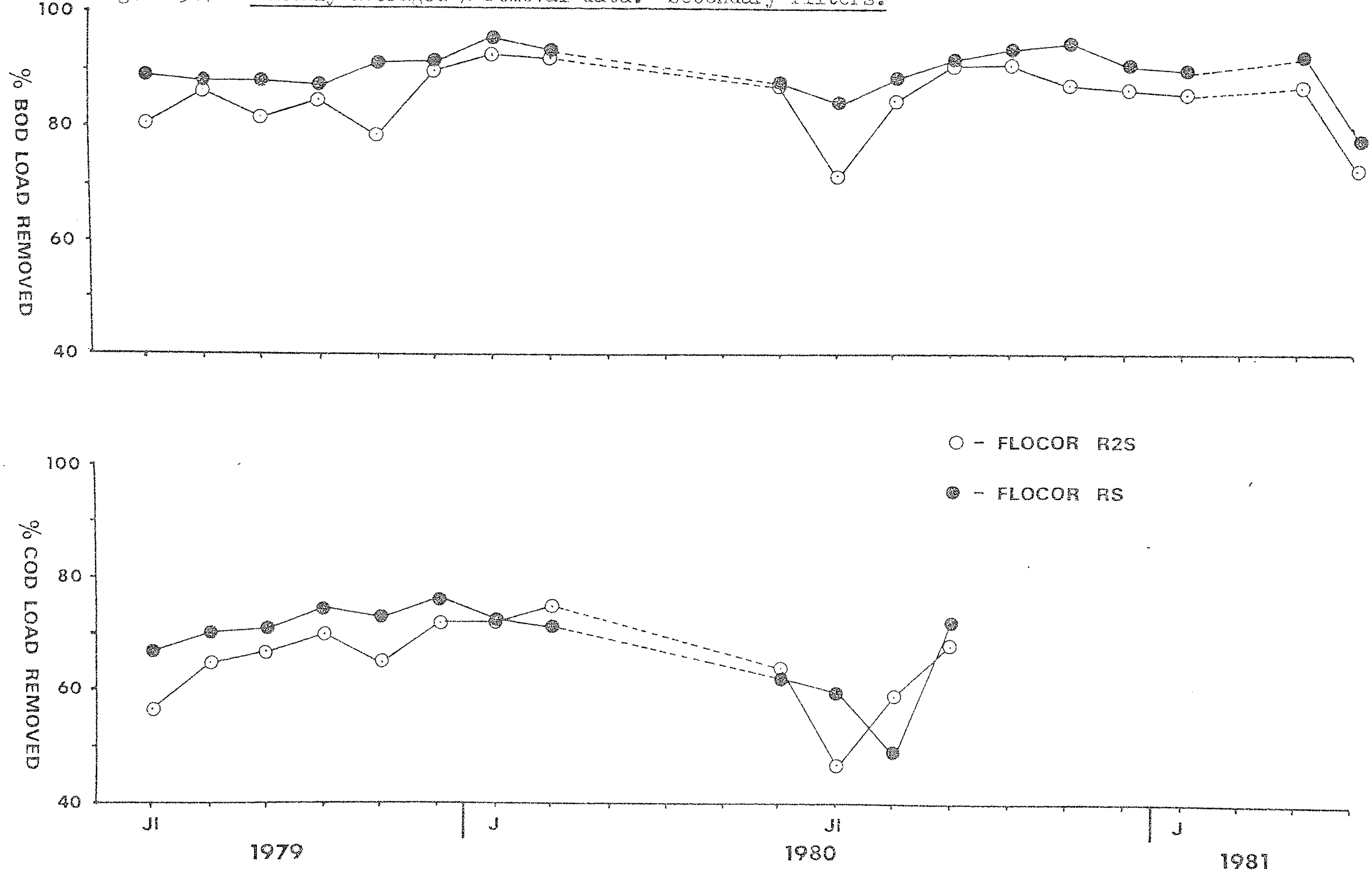


Fig. 6.3.8 Distributions of secondary filter BOD concentrations, July 1979 - May 1981.

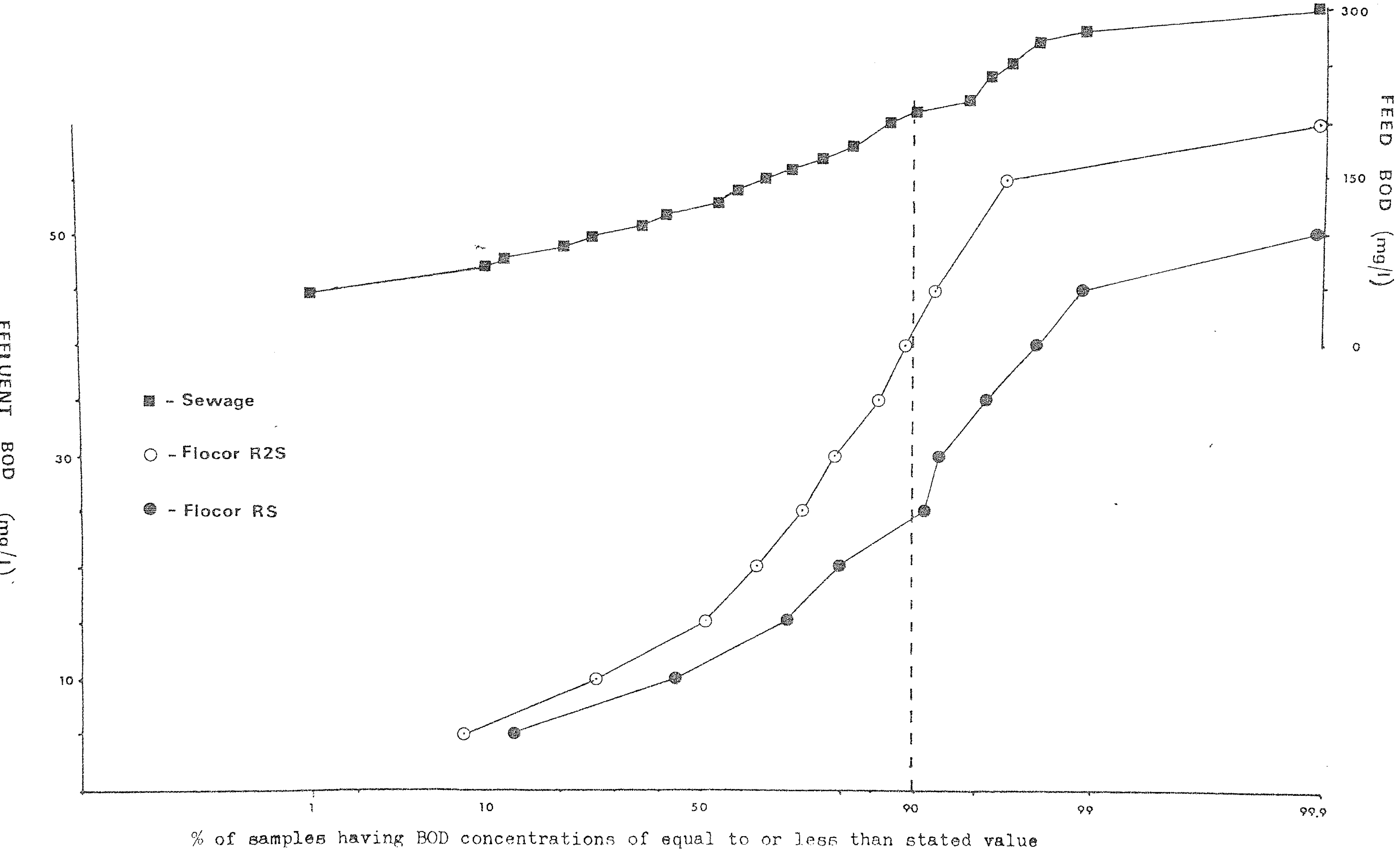


Fig. 6.3.9 Distributions of secondary filter COD concentrations, July 1979 - Sept. 1980.

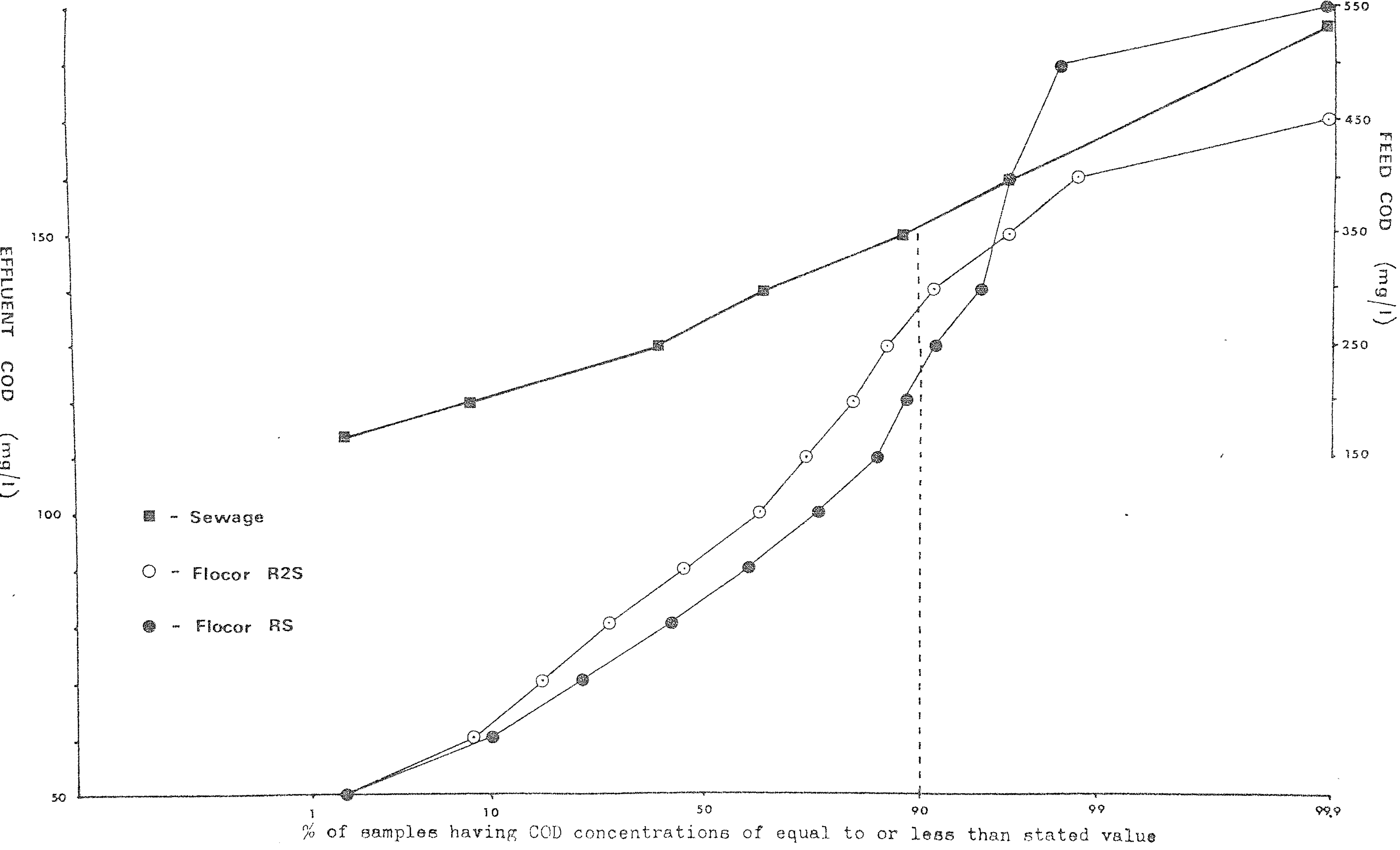


Fig. 6.3.10 Distributions of secondary filter suspended solids concentrations, July 1979 - May 1981.

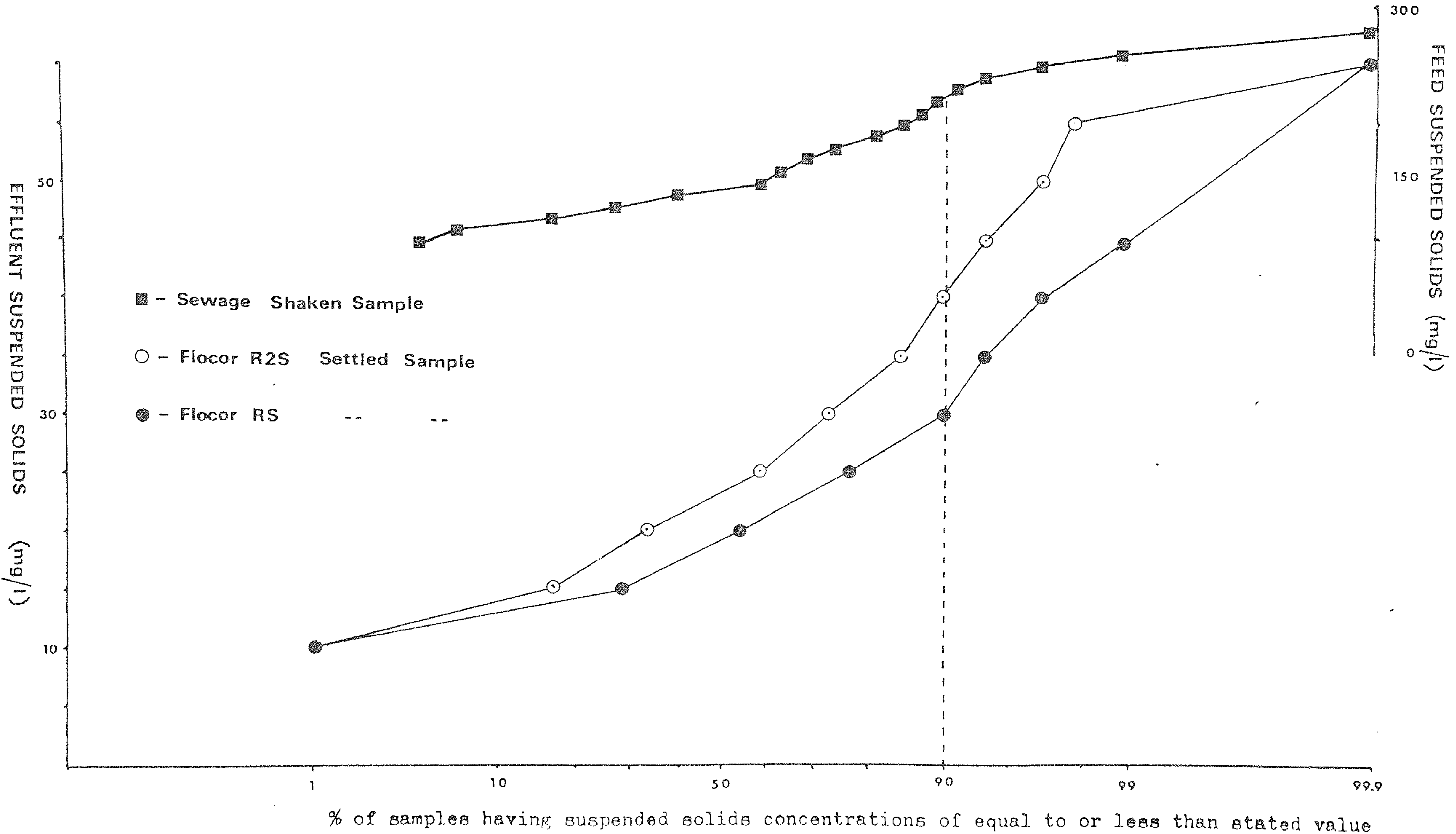
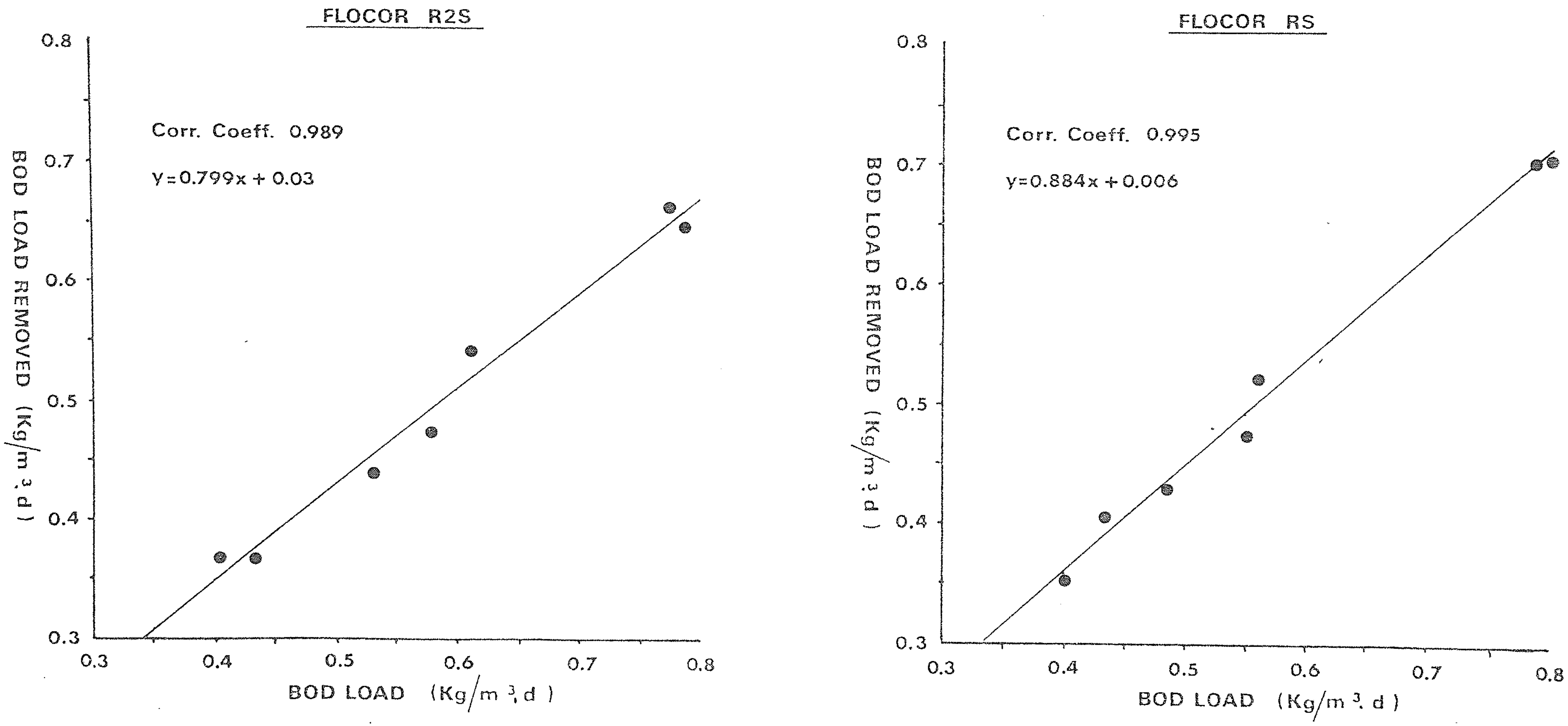
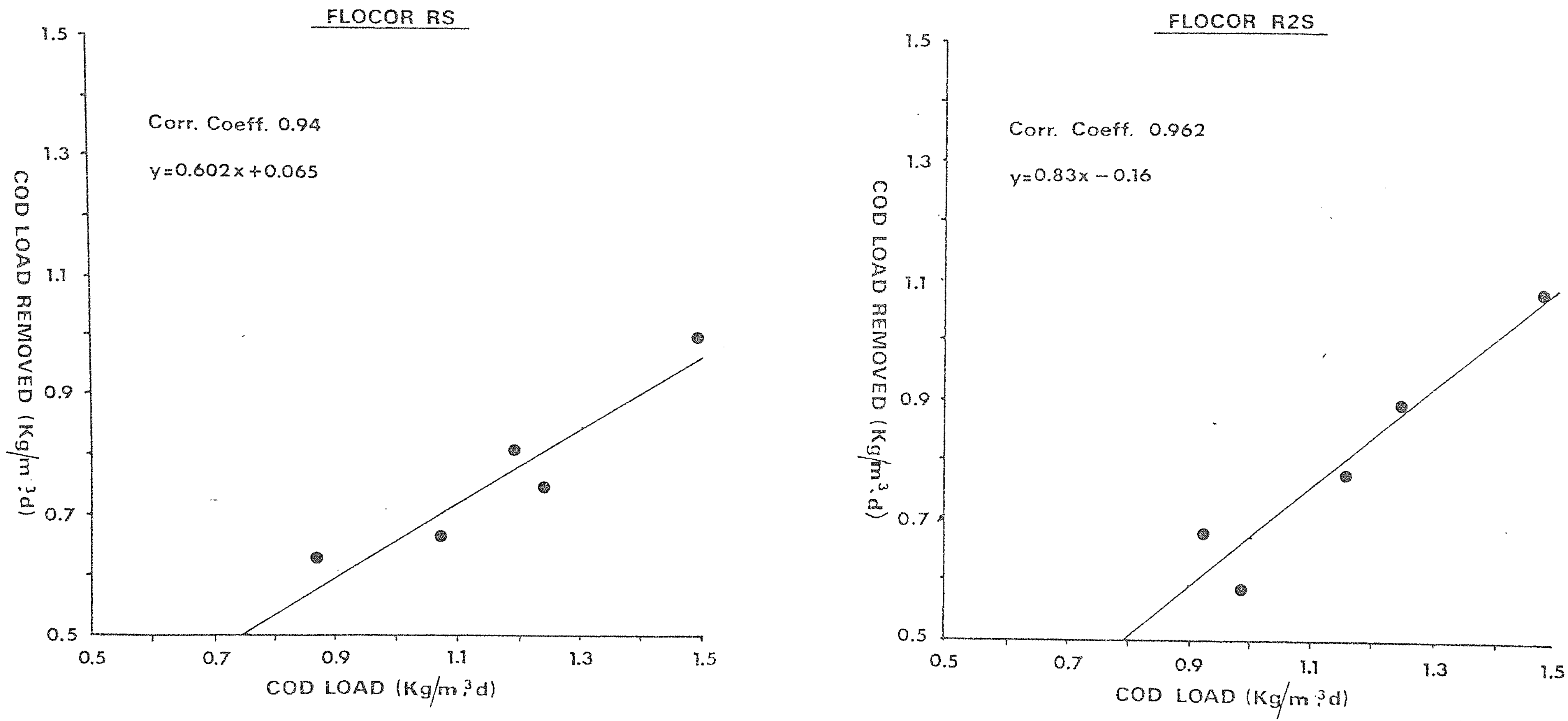


Fig. 6.3.11 BOD load vs BOD load removed. Quarterly averaged data. Secondary filters.


FLOCOR R2S

FLOCOR RS

Fig. 6.3.12 COD load vs COD load removed. Quarterly averaged data. Secondary filters.



6.4 Ecology and biology of the secondary filters

6.4.1 Film accumulation measurements

The same methods of film level assessment were used as in the primary filters (Section 4.6) and the results are presented in Figs 6.4.1 - 3 and Appendices 6.4.1 - 6.

While the film on the primary filter media was dominated by fungi, the film of the secondary filters was dominated by bacteria. Fungi were present during the winter of 1979 - 80 but failed to become established, no attempts were made to identify the species present. Figs 6.4.1 - 3 show that in the absence of high organic loadings, and consequently in the absence of fungi, the film levels in the secondary filters remained very low throughout the study.

Peaks in film accumulation were recorded in January 1980 (Quarter 3.1, Figs 6.4.2 and 3). These peaks were the result of a gradual accumulation of film during the Autumn of 1979, which corresponded to a gradual increase in organic loading and decrease in temperature during this time. Filter maturation may have also contributed to the film level increases (see later). The peak film level recorded in the Flocor RS filter was higher than that in the Flocor R2S filter, and the Flocor RS filter always supported slightly heavier film levels than the Flocor R2S because of the smaller size of the Flocor RS medium.

Following the peak film levels recorded in January 1980 the filters are believed to have sloughed some of their film, as the effluent solids and sludge production rate figures increased during February (Section 6.2). Unfortunately neutron moisture meter readings were not taken during the period February - April 1980 and the extent of the sloughing is difficult to assess. Long term changes in film level are also difficult to quantify due to the relatively short period of study following the commissioning of the filters.

The biological sampling and neutron moisture meter readings of July 1979 were carried out approximately six weeks after the filters had been commissioned, and Figs 6.4.2 and 3 show that appreciable quantities of biological film had already accumulated. Fig 6.4.1 shows that the percent saturation of voids in both filters increased gradually during the following six months, although it is not possible to dissociate the contribution that filter maturation made to these increases from the combined effects of the increasing organic loading and decreasing temperatures observed over these months.

6.4.2 The occurrence, abundance and distribution of invertebrate species and micro-organisms of the film

6.4.2.1 Invertebrate populations

The species diversity found in both of the secondary filters was higher than in the primary filters. While Psychoda alternata and enchytraeid worm spp. again dominated the invertebrate fauna, several other species appeared at various times during the study (Figs 6.4.2 and 3, Appendices 6.4.1 - 5). Chironomid sp. larvae were present in quite high numbers during the first six months of the filters operation, but disappeared during the winter and reappeared only in low numbers during the following summer. Species X - an unidentified Dipteran - generally increased in abundance as the filters matured, a pattern which was mirrored by the Naid worm sp. population in the Flocor RS filter. Although fly nuisance has been caused in the vicinity of some sewage works by Sylvicola fenestralis (Hawkes, 1965), the larvae were only found once, in low numbers in the Flocor RS filter. Hypogastrura viatica was found in high numbers at the base of the Flocor RS filter in Quarter 3.3 (Appendix 6.4.5), and this may have indicated a continuation of the process of biological maturation in this filter.

Unfortunately the biological surveillance of the secondary filters lasted for one year only, and from these data it is difficult to determine whether the filters had reached full biological maturity - i.e. whether the populations of the film had stabilised. During May 1981 however, immediately before the pilot plant was closed down, a visual inspection of the biological shaft contents revealed an increased species diversity, which would suggest that the filters had not fully matured at the end of the biological surveillance work (July 1980), and may not in fact have been fully mature at the end of the entire study. This prolonged maturation period did not affect the BOD removal capacity of the filters, which had stabilised very rapidly after commissioning, but it may have affected both sludge production rates (Section 6.2) and humus sludge conditionability (Section 7.3.3) as well as the nitrifying capacity of the filters (Section 6.3).

P. alternata and enchytraeid worm numbers tended to be high at the same time as film levels, with a particularly close association being apparent in the Flocor R2S filter (Fig 6.4.2). This would suggest that the invertebrate grazing populations could have had a far greater influence on the rate of accumulation of film than was found in the primary filters. This emphasises the difference between the growth of fungal film under heavy organic loading conditions as in the primary filters, and that of bacterial film under moderate organic loadings as in the secondary filters, with the rate of accumulation of the fungal film tending to be so great as to result in the film levels exerting control over invertebrate numbers, while the lower rate of accumulation of the bacterial film enables invertebrate numbers to increase to a point where film control is possible.

Although the invertebrates are believed to have exercised some control over the rate of film accumulation in the secondary filters by their grazing activity, it is difficult to assess whether this control affected filter performance in any way. Figs 6.4.2 and 3 show that the percent BOD removed by both media was very high throughout the period of biological surveillance, with the highest removal figures obtained by the Flocor R2S filter being during a winter period when film levels were also at their peak (Quarter 3.1). Therefore the highest film accumulation observed in this filter did not adversely affect filter efficiency, and there is no evidence to suggest that performance improved during subsequent months when film levels were low. In view of this fact, and of the results obtained from the primary filters, it is believed that the invertebrate grazing population can have no significant affect on filter performance if the organic loading is such that high film levels are not encouraged. It could only significantly affect the performance of filters operated under very high organic loadings which promote heavy film accumulation during the winter months if sufficiently high numbers were present during the summer months to reduce the film standing crop to a level where the subsequent winter accumulation may be prevented from reaching a level sufficient to cause ponding.

6.4.2.2 Protozoan and other micro-organism populations

Microscopical examination of film samples was carried out in the same manner as for the primary filters, and Figs 6.4.4 and 5 illustrate the composition and relative abundance of the micro-organism population of the film with filter depth, while Table 5.5.2 lists the species found. The relative abundance of the flagellate population was not assessed, although flagellate spp. were present in the majority of samples examined.

Figs 6.4.4 and 5 show that the size and diversity of the micro-organism populations were high throughout the study, and while the general inverse relationship observed between protozoan numbers and film volume in the primary filters was not apparent in the secondary filters, diversity tended to increase slightly when film levels were lowest. The adverse affect of increased film levels on protozoan numbers was not observed in these filters because the film levels were never excessive and the film itself therefore never became anaerobic.

Species diversity was high in the filters throughout the study, with large numbers of representatives of the Holotrichia, Peritrichia and Spirotrichia in particular. No species was found to dominate the micro-organism population, although nematode worm spp., Opercularia microdiscum and flagellate spp. were again almost universally present. Representatives of Opercularia and Vorticella were particularly common, although the protozoan zonation previously reported by Barker (1946) was not observed. High numbers of the spirotrich Aspidisca costata were occasionally recorded, while representatives of the Suctoria were found to be more common in the secondary filters than in the primary filters, where they were restricted to the Flocor M and Flocor E media (Table 5.5.2).

In consideration of the primary and secondary filter data it would therefore appear that high film levels restrict the protozoan numbers present, presumably because of oxygen starvation, while very low film levels lead to both an increase in species diversity and in numbers present.

Conclusions regarding the performance of the secondary filters are drawn in Chapter 9.

Fig. 6.4.1 Monthly neutron moisture meter data. Secondary filters.

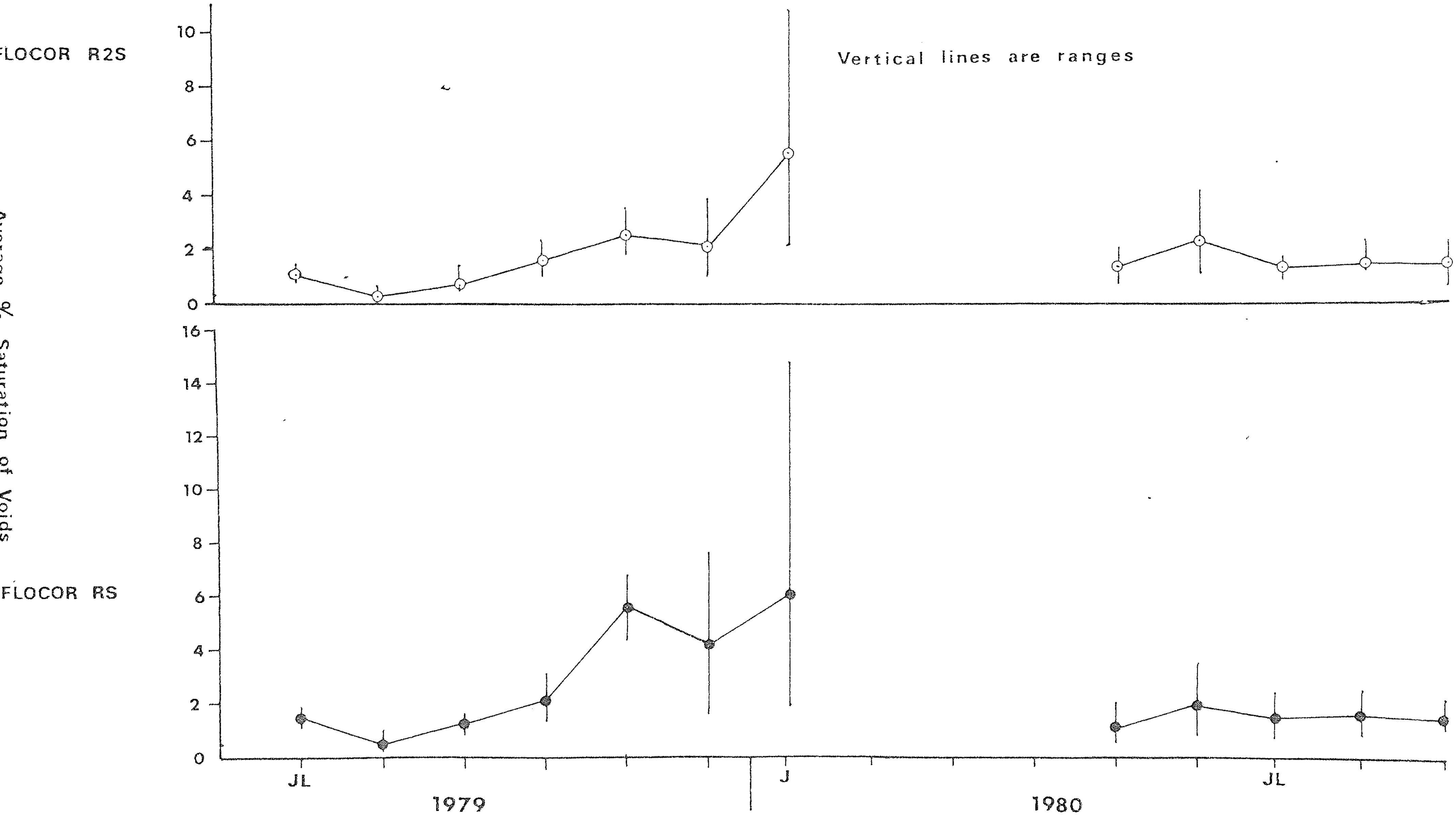


Fig. 6.4.2 Biological sampling data. Flocor R2S filter.

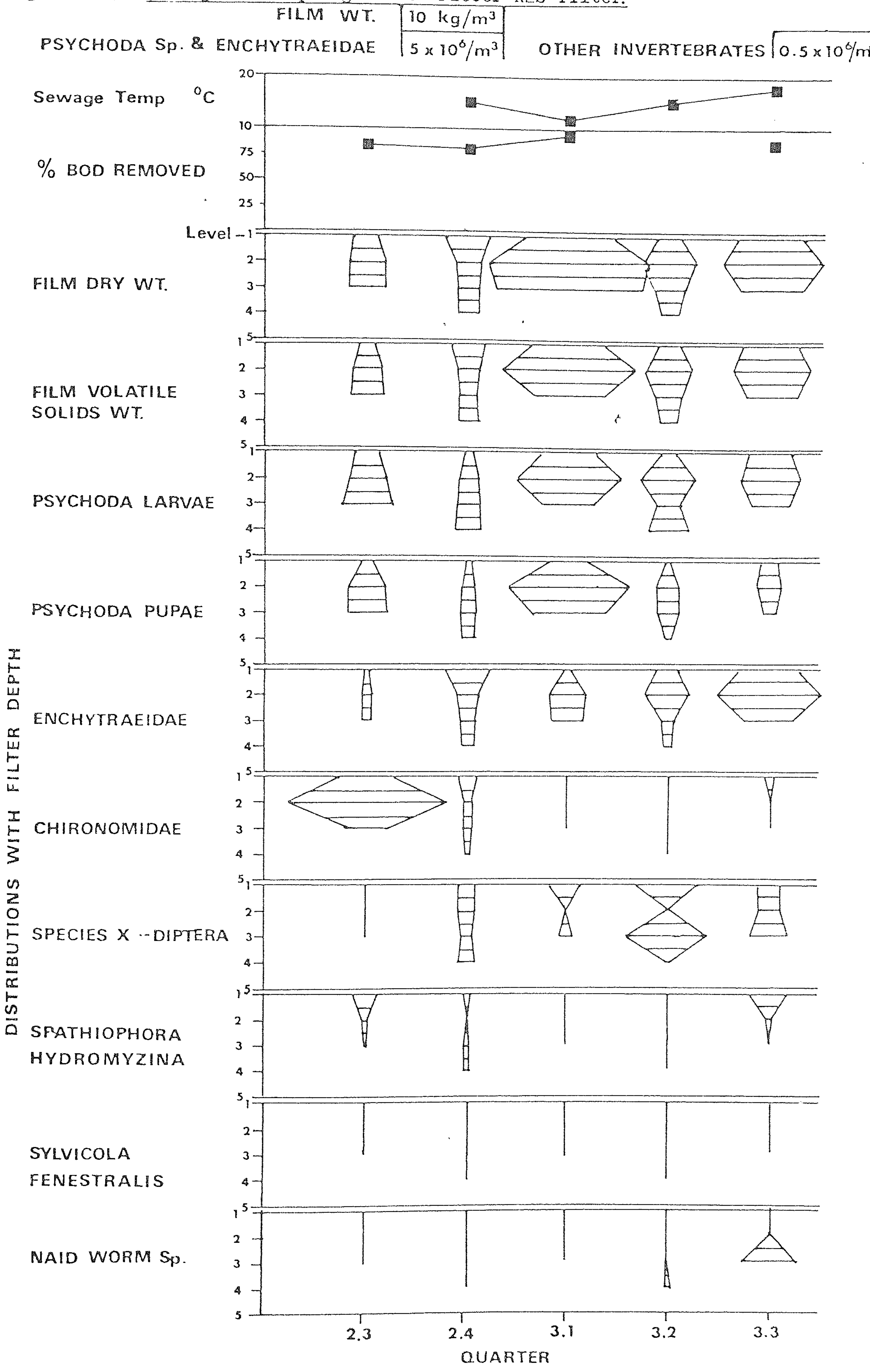
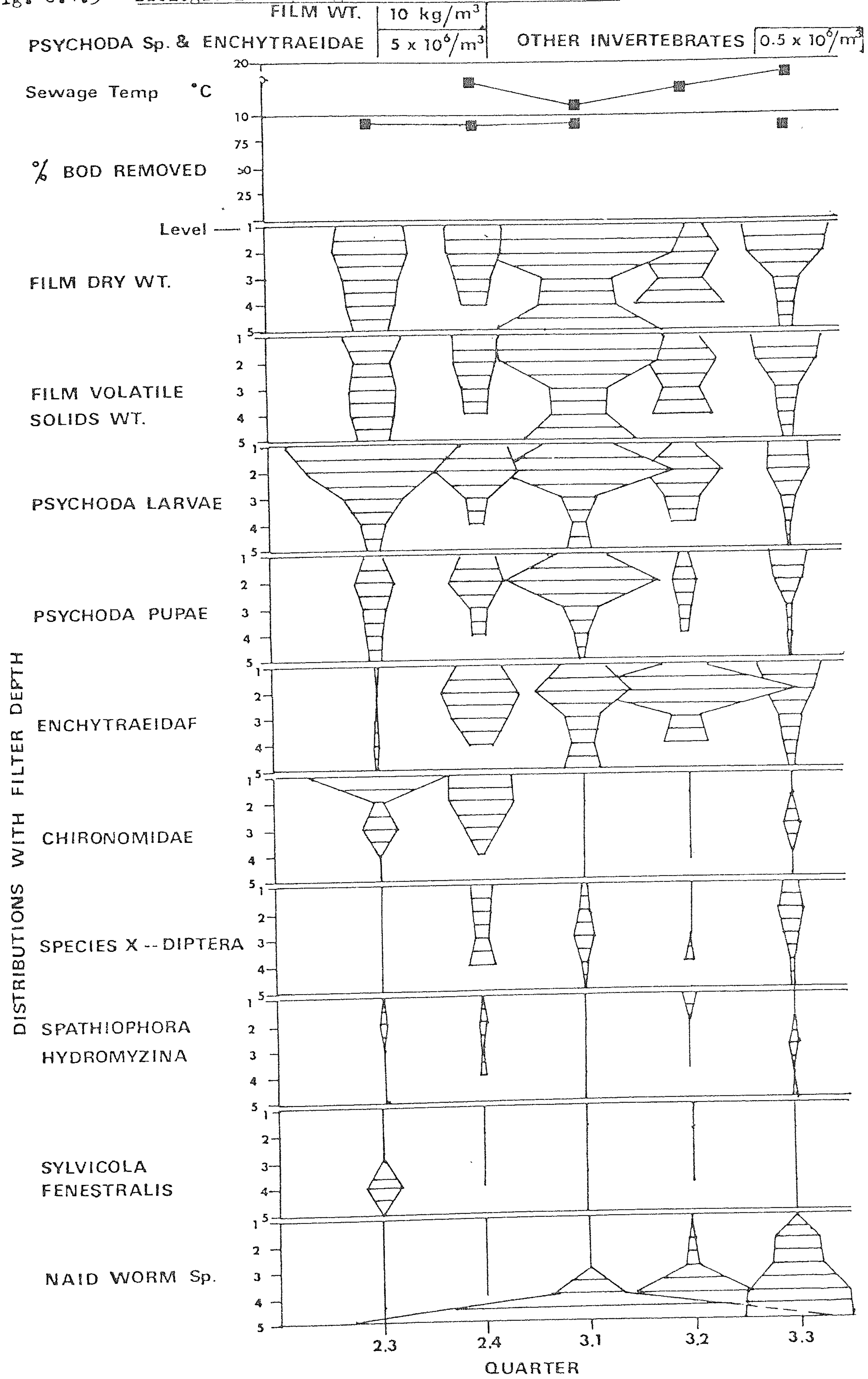


Fig. 6.4.3 Biological sampling data. Flocor RS filter.



Key to Figs 6.4.4 and 5

N - Nematoda

H - Holotrichia

P - Peritrichia

A - Amoebae

R - Rotifera

Sp - Spirotrichia

Su - Suctoria

Na - Naid worm spp.

M - Mite spp.

Scale - Numbers per sample (circle diameter) of ciliated protozoa and other micro-organisms (excluding flagellated protozoa).

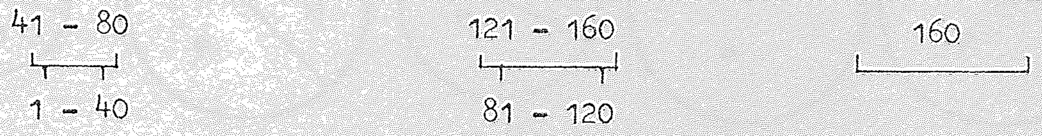


Fig. 6.4.4 Biological sampling data. Distribution and relative abundance of micro-organisms with filter depth. Flocor R2S

Key given on page 220

FLOCOR R2S

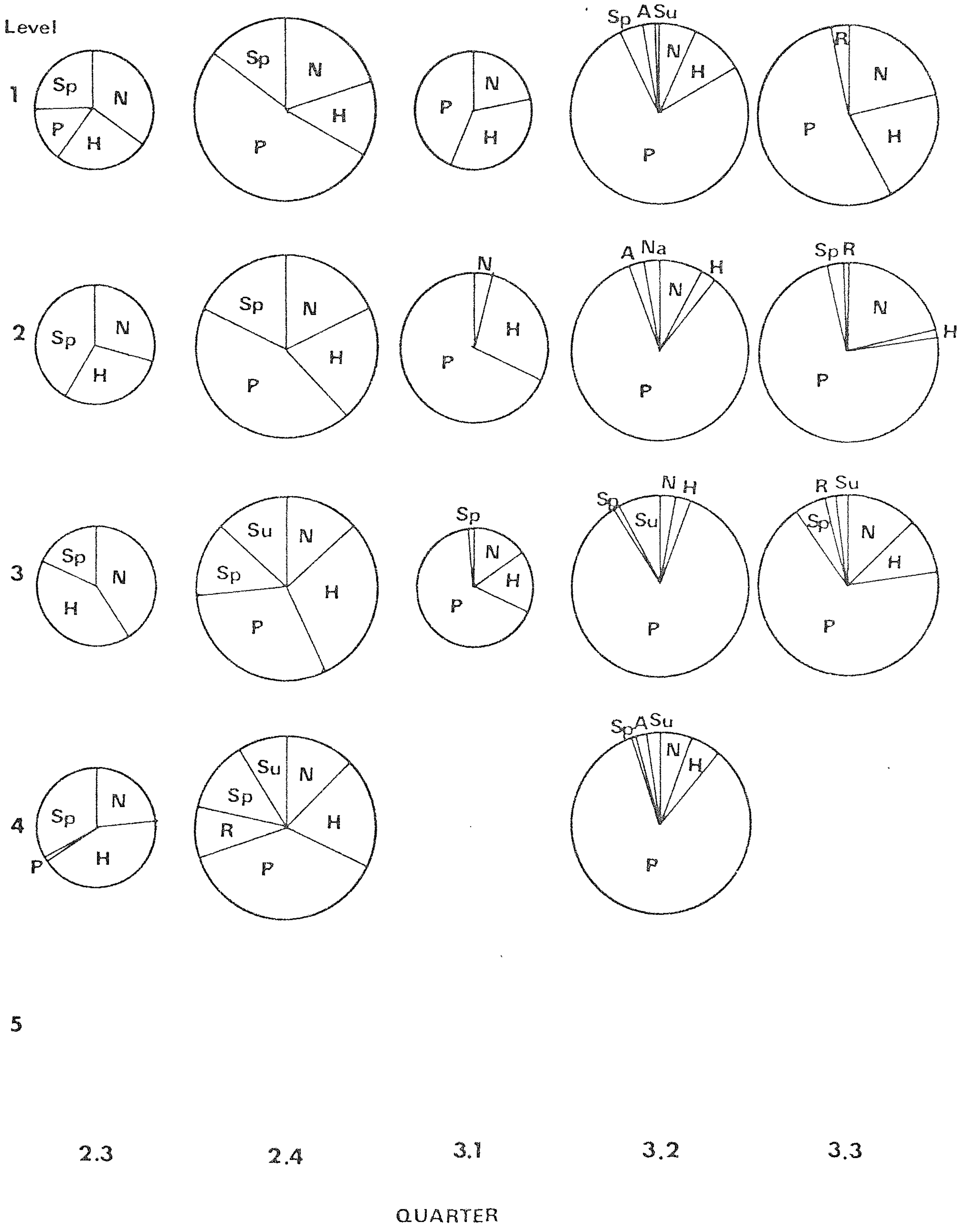
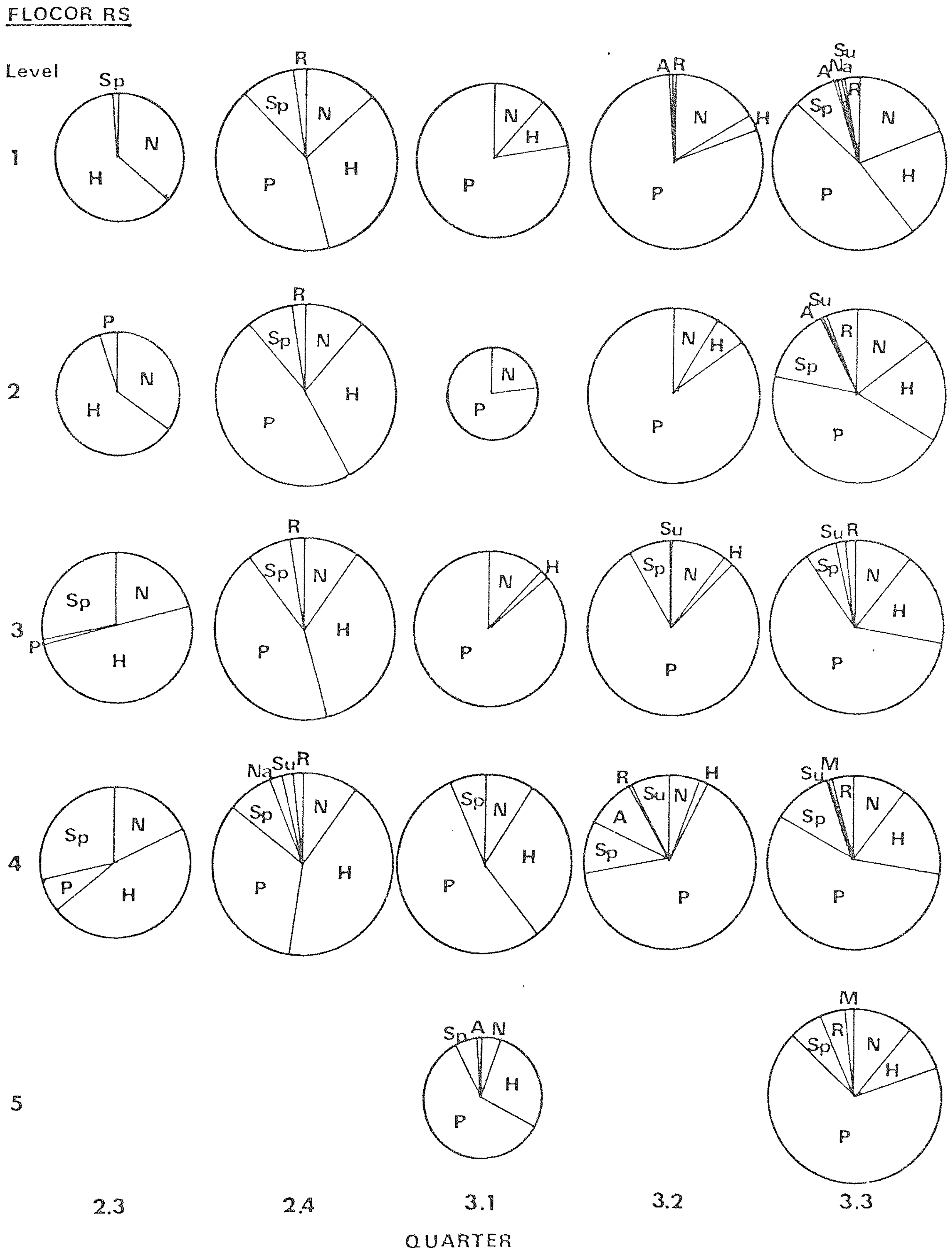


Fig. 6.4.5 Biological sampling data. Distribution and relative abundance of micro-organisms with filter depth. Flocor RS

Key given on page 220



7. Humus Sludge Characterisation

7.1 Introduction

The dewatering of humus sludges produced during the biological filtration of sewage often constitutes the most capital intensive stage of the purification process. The conditioning of the sludges produced by different filter media is therefore of considerable importance in the design and operation of sewage works.

In the past several authors have concluded that the humus sludge produced by high rate biological filters is more difficult to dewater than that produced by low rate filters (Bruce and Merkens, 1973, Bruce et al., 1975, Banks et al., 1976), while other workers have concluded that high rate filter sludges are no more difficult to dewater than low rate sludges (Hemming, 1968, Askew, 1969, Joslin et al., 1971). The difference of opinion may be partly due to the fact that high rate biological filters have often been used in areas where the sewage is difficult to treat by conventional filtration and is therefore liable to produce a 'difficult' sludge regardless of the biological filtration method used, and partly due to the difficulty in accurately comparing the dewaterability of different sludges.

Tests designed to characterise the humus sludges produced by the two stage pilot plant were therefore carried out in an attempt to identify any differences in sludge condition and conditionability which could be attributed to filter medium, hydraulic loading or season. Separate humus sludges were collected from the effluent channels of each filter medium on a monthly basis for a period of 12 months as described earlier (Section 4.5). The tests were performed in order to answer five questions.

i) Are there any differences in the dewaterability of the humus sludges produced by the different filter media of the pilot plant?

ii) Does the condition and conditionability of the humus sludges produced by the different media of the pilot plant vary with season?

iii) Which chemical conditioning agent provides the most cost efficient means of conditioning the humus sludges produced by the pilot plant filter media?

iv) Is there any difference between the dewaterability of the high rate biological filter sludges of the pilot plant and the low rate humus sludges of Hereford STW?

v) Is there any correlation between humus sludge dewaterability and biological conditions prevalent in any of the filters studied?

7.2 Results

The results of these studies are summarised in Appendices 7.2.1 - 11 and Figs 7.3.1 - 5. The appendices include results from both the traditional method of analysing sludge conditioning test data (calculation of the cost of a dose of aluminium chlorohydrate required to reduce $\bar{r}$ to 4.0×10^{12} m/kg) and from the Cost/dose index data analysis (calculated as outlined in Section 4.5). The weight of chemical - as received from the manufacturer - used in each conditioning test has been quoted, as has the cost of each dose. Chemical costs used in these calculations are presented in Appendix 7.2.12.

Assessment of seasonal changes in sludge condition and conditionability were made using aluminium chlorohydrate as chemical conditioner, as were assessments of the differences between the conditionability of different sludges. The results of these comparative studies show that aluminium chlorohydrate was not a particularly suitable conditioner for any sludge tested, and its use was continued only because of the ease of preparing and handling solutions.

Conditioning tests involving the use of Zetag 51 and 88 were carried out at the same time as tests involving the use of aluminium chlorohydrate. The efficiency of each polyelectrolyte solution can therefore be compared directly with that of chlorohydrate for each sludge (Appendices 7.2.1 - 11).

The initial solids content of the sludges was found to vary considerably, although all primary filter sludges thickened satisfactorily after 2 - 4 hours settlement in a WRC laboratory settlement apparatus. The thickened sludge solids contents are given in Appendices 7.2.1 - 11. The two secondary filter sludges, together with the low rate humus sludge, did not thicken to a solids content of greater than approximately 3% dm unless settled for around twenty hours. The secondary filter sludges were always thickened after collection, but thickening of the low rate humus sludges was abandoned after the first months sample had been conditioned (July 1980).

Unfortunately it was noted that the pilot plant sludges became slightly elutriated on laboratory thickening. The increase in suspended solids content of the supernatant after thickening was normally small and of the same magnitude in all sludges. Occasional analyses of supernatant suspended solids content after thickening are presented in Table 7.2.1. Analyses were only made during months when the elutriation appeared on visual inspection to be particularly marked.

Table 7.2.1 Suspended solids content of supernatant liquid after sludge thickening

Monthly Sludge Collection	Supernatant tested	Supernatant percent solids content (% dm)	Settled filter effluent suspended solids content (% dm)
Jan 1980	89/50 Granite	0.0961	0.0062
	125/75 Slag	0.0562	0.0068
	89/50 Slag	0.0364	0.0042

Swanwick et al. (1961) found that artificially induced elutriation of humus sludge resulted in both a reduction in $\bar{r}$ and in the coagulant demand of the sludge in conditioning tests. The amount of chemical required to condition the pilot plant sludges if they had been produced by a full scale works in which no elutriation occurred during thickening would therefore be higher than reported in Appendices 7.2.1 - 10. The increase in chemical dose which would be required is difficult to quantify from the pilot scale data available. Although fine solids were lost to the supernatant during thickening, no solids were lost during sludge collection. The supernatant from the collection vessels invariably contained lower quantities of suspended solids than were found in the filter effluents, due to the longer settlement period afforded by the collection vessels than the thirty minutes quiescent settlement given to effluent samples prior to suspended solids determinations.

The appearance and texture of the primary and secondary filter sludges differed markedly. The primary filter sludges tended to be largely made up of pieces of fungal material which were occasionally encrusted with grazing macro-invertebrates, while the secondary filter sludges were generally black, runny and homogenous - being made up of very finely divided solids as found in the low rate filter humus sludge. The volatile solids contents of all the sludges varied from month to month, and usually constituted between 60 and 80% of the total sludge dry weight.

Appendices 7.2.1 - 7.2.4 show that the initial specific resistance to filtration of the mineral media sludges was very low during July and September 1980. The distributor jets supplying the mineral medium filter during these months became regularly blocked with very heavy gross solids resulting in only intermittent wetting of the filters, and it is believed that this poor running caused the observed reduction in the initial specific resistance of the sludges. The initial specific resistance of the Biopac 50 and Biopac 90 sludges was also very low during September - this being due to the fact that these sludges were collected shortly after the distributor jets feeding the plastic medium filters had been restarted, having been out of commission for one month due to mechanical difficulties. The two primary filter Flocor media sludges were collected a week later when the filters appear to have been re-established as their specific resistance to filtration are reasonably high as usual.

7.3 Discussion

7.3.1 Thickened sludge condition

The specific resistance to filtration ($\bar{r}$) of the thickened sludges from the pilot plant were normally within the range 20 - 250 x 10^{12} m/kg, although periods of poor operation of the sewage distribution mechanisms resulted in greatly reduced specific resistances as mentioned earlier (Section 7.2).

As illustrated in Figs 7.3.1 - 5 the initial $\bar{r}$ of the mineral media sludges were all very similar, and while the initial $\bar{r}$ of the two Biopac media were slightly higher there is no clear evidence of differences between sludges before conditioning which were due to the filter medium - the increase in $\bar{r}$ of the Biopac media over the mineral media was probably due to the different loading conditions applied to the former. Fig 7.3.4 shows that the initial $\bar{r}$ of sludges from the Flocor M and E media tended to be higher and considerably less stable than those of the other primary filters. As both modular media filters produced sludges which were in worse condition than those produced by random-fill media of the pilot plant, it can only be assumed that the nature of the medium affects the sludge produced to a certain extent.

The two secondary filter media (Fig 7.3.5) had very marked and separate peaks in initial $\bar{r}$ during March and April, but otherwise both produced very similar sludges. With the exception of the peaks in initial $\bar{r}$, the secondary filter sludges do not appear to be markedly different from primary filter sludges, although they were in better condition than those of the two modular media.

The initial stability to shear index in all sludges was very similar, with a normal range of 1.01 - 1.93. This indicates that the average increase in $\bar{r}$ after 100 sec shear did not normally exceed 93% of $\bar{r}$

after 10 sec shear. Sludges collected from the 89/50 Granite filter in September 1980, (Fig 7.3.1, initial stability of 2.82) and from the Flocor RS filter in December 1979 (Fig 7.3.5, initial stability of 2.41) were considerably less stable to the influence of shear than the other pilot plant sludges. The low rate filter humus sludge had an initial stability to shear index range of 1.18 - 1.25, showing that this sludge was no different in this respect from the pilot plant sludges. The sludge stability to shear before conditioning is therefore not influenced by either filter medium or hydraulic loading.

7.3.2 Comparison of sludge conditionability using aluminium chlorohydrate as conditioner

As mentioned earlier (Section 7.2) aluminium chlorohydrate did not prove to be a successful conditioner of the sludges tested, and only occasionally did the minium $\bar{r}$ achieved fall below 1.0 x 10^{12} m/kg. This chemical was used in long-term conditioning tests however, and the results of these tests are best summarised in terms of the cost of reducing $\bar{r}$ to 4.0 x 10^{12} m/kg (the coagulant demand) and the minimum Cost/dose index of sludge conditionability (Appendices 7.2.1 - 11).

Comparing the data provided by the traditional method of analysis (the aluminium chlorohydrate coagulant demand) with the Cost/dose index data (Appendices 7.2.1 - 11) it can be seen that while the Cost/dose index invariably produces a tangible figure, the traditional method fails to quantify the difficulty experienced in dewatering some sludges. This is evident in the Flocor M sludge produced in November 1979 (Appendix 7.2.8) and the Flocor E sludge produced in January and February 1980 (Appendix 7.2.7). In addition the traditional data analysis technique does not provide any information with respect to the ease of conditioning a sludge to $\bar{r}$ of around 1.0 x 10^{12} m/kg, which is usually required for satisfactory mechanical dewatering, while the minimum achievable

$\bar{r}$ through conditioning forms an integral part of the Cost/dose index. Experience with the costs per dose of the chemical conditioners used in these tests has shown that a Cost/dose index of less than 20 cannot be reached unless the minimum achievable $\bar{r}$ through conditioning approaches unity, and the act of conditioning dose not appreciably weaken the sludges resistance to shear. The Cost/dose index has also been formulated so that it provides a simple and direct method for comparing the effectiveness of different conditioning agents in conditioning sludges of different origins.

While the index has been used as an aid in the assessment of sludge conditionability in this research, it is not suggested that it should be used as a universally acceptable means of treating sludge conditioning test data, although a similar index may be of considerable value.

Data collected during the period September 1979 - 1980 show that the sludges conditionability, as measured by both the Cost/dose index (Figs 7.3.1 - 5) and the coagulant demand (Appendices 7.2.1 - 11), remained reasonably stable throughout the year, with the exception of the Flocor M and E sludges. These two sludges exhibited a far greater range of conditionability, with Flocor E in particular proving to be very difficult to dewater on occasions. Fig 7.3.6 shows the averaged coagulant demand and Cost/dose index for each sludge over the twelve month period. Both of these data analysis techniques show that the sludges from the two modular media were more difficult to dewater than the other (random-fill) primary filter media sludges. The difference between the dewaterability of these two sludges and the others tested is amplified when sludge stability and minimum achievable $\bar{r}$ are taken into consideration, as in the Cost/dose index. The two modular medium sludges exhibited the least stability to shear of all the sludges tested (when using aluminium chlorohydrate as conditioner), and this may be an important factor when deciding whether to use modular or random-fill media for high rate filters.

Using the coagulant demand data the secondary filters were slightly more difficult to dewater than the random-fill primary filter sludges, although the differences are of the magnitude which might reasonably be expected in a two stage system. In the case of the Flocor RS sludge this difference is not apparent when sludge stability is taken into consideration, as in the Cost/dose index. There appears to be little difference between the mineral medium sludges, and none which could be directly attributed to either medium size or type. The difference between the conditionability of the Biopac 50 and 90 sludges is small in both sets of data, but it is interesting to note that Biopac 50 produced the most easily dewatered sludge when the Cost/dose index is used as the means of comparing sludge conditionability.

Comparing the two data analysis techniques, which are summarised in Fig 7.3.6, it can be seen that while both produce almost identical conclusions with respect to which sludges were more difficult to dewater than the others, important dewatering problems which might arise in a full scale works are emphasised by using the Cost/dose index. Therefore, although the coagulant demand data suggest that the Flocor E sludge was only slightly more difficult to condition than the Flocor M sludge, the Cost/dose index shows that this difference was greater when the full effect of chemical conditioning on sludge characteristics was included in the calculation. Comparison of sludges which are not markedly weakened by conditioning, and which can all be conditioned to a similar $\bar{r}$ using the same chemical, is not generally affected by including the stability to shear index. Comparison of sludges conditioned with polyelectrolytes which weaken floc strength (outlined in Section 7.3.5) are greatly influenced by the inclusion of the stability index, and comparison of the effectiveness of different conditioners is improved by the use of the index.

There were several peaks in initial $\bar{r}$ throughout the twelve month period of study (Figs.7.3.1 - 5, Table 7.3.1). The peaks which occurred in November and February were common to several of the pilot plant sludges. Although these peaks did not generally affect the conditionability of the sludges concerned, the peaks found in the 125/75 Granite, Flocor M and Flocor E sludges collected during February did affect their conditionability as measured by the Cost/dose index. The conditionability of the 89/50 Granite sludge was similarly affected when the coagulant demand data were used. Table 7.3.1 lists the peaks in $\bar{r}$ in the primary filter sludges, together with the dates on which the sludges affected were collected and the feed and effluent shaken solids content from the routine sampling day which was closest to the sludge collection date. From this Table it can be seen that in almost all instances where peaks in initial $\bar{r}$ were found there was a corresponding peak in effluent suspended solids, indicating that the filters in question were offloading film to some degree. This offloading of film must therefore alter the nature of the sludge and hence produce a higher initial $\bar{r}$, which can occasionally affect conditionability. In conventional (low rate) biological filters this would not be expected as the seasonal offloading of film usually produces humus solids which originated from healthy, aerobic areas of the filter. This would not normally alter the nature of the sludge itself, merely increase its volume. The phenomenon is observed in high rate filters however as the shedding of filter film does not follow a temporal pattern and is probably brought about by different means to those causing low rate filters to offload film.

The offloading of film in low rate filters follows a distinct seasonal pattern, with large volumes of film being sloughed in the spring, largely because of greatly increased grazing activity by macro-invertebrates (Hawkes, 1965). However Reidmuller (quoted by Hawkes, 1965) believed that in high rate filters the hydraulic scouring of the film by sewage as it passed through the filter was probably more important in causing film sloughing than the grazing fauna. This is considered to be the principal cause of the shedding of film observed in the high rate filters at Hereford, but the sloughed film probably originated from anaerobic zones within each filter where biological film levels were high and no longer securely attached to the filter medium. This film is then sloughed by hydraulic scour and the humus sludge produced during the occasional periods of film offloading observed in high rate filters is therefore of different composition to that which is normally obtained, and may have higher initial $\bar{r}$. If the film has been sufficiently decomposed within the filter before sloughing, conditioning would produce a well floculated and relatively easily dewatered sludge. If the film is sloughed before the constituent fungal mycelia etc. have begun to decompose, conditioning would become more difficult. This appears to have occurred in the filters cited during February 1980.

The observed differences in the conditionability of different sludges from the pilot plant (Fig 7.3.6) cannot normally be explained in terms of the initial $\bar{r}$ of the thickened sludges. These differences would be of great economic importance in the design and operation of any sewage works containing high rate filters, and would influence any decision regarding the medium to be used in such filters. An understanding of the reason for the differences in sludge conditionability observed would therefore be of value in deciding which filter medium should be used.

7.3.3 The influence of biological loading applied to high rate filters on humus sludge conditionability

Fig 7.3.7 shows the relationship between the biological loading (or Food:Micro-organisms (F:M) ratio, expressed as g BOD applied/g Biomass/day) and sludge conditionability in the high rate primary filters. The biological loading averages have been calculated from the biological sampling data and BOD loading conditions from the twelve month period during which sludge conditioning tests were carried out.

Fig 7.3.7 shows that, if organic loading (expressed as g BOD applied/m^3 filter medium/day) conditions are equal in all filter media, the filter medium which supports the greatest biomass will produce the most easily dewatered sludge. This could explain why some high rate filters produce humus sludge which is difficult to dewater. Of the references cited at the begining of this chapter, none include detailed quantification of biological film accumulation in the filters studied, although generalisations are made as to film levels. Bruce and Merkens (1973) report that the humus sludges produced by six different high rate filters were difficult to dewater, and that biological film levels - as estimated by neutron moisture meter readings - were very low. Similar findings were reported by Bruce et al. (1975) when investigating two stage filtration with a high rate primary filter. Banks et al. (1976) report that experimental high rate filters at Ipswich produced sludges which were difficult to dewater and no ponding difficulties were encountered. In these cases the film levels were all low, and the corresponding biological loading or F:M ratio was high. Hemming (1968) and Askew (1969) discussing the performance of high rate plastic medium filters treating industrial wastes in which film levels were presumably high, report good sludge dewatering characteristics. Joslin et al. (1971) also report high rate filters with good sludge dewatering characteristics, and imply that, as the use of one of their filters treating municipal wastes had to be discontinued due to ponding difficulties, biological film levels were high. The literature therefore supports the evidence, presented in Fig 7.3.7, that increasing the F:M ratio applied to high rate filters results in the production of humus sludge which is difficult to dewater.

The relationship between F:M ratio and sludge filterability has also been demonstrated in the activated sludge process (Boon and Burgess, 1972). In activated sludge, increasing the F:M ratio results in increased likelihood that the rate of adsorbtion of organic matter on to the surface of the floc will exceed the rate of its subsequent oxidation by the constituents of the floc. This causes a reduction in both the surplus sludges filterability and settleability, mainly because the floc is maintained in an actively growing phase resulting in the sludge flocculating less readily. If the F:M ratio is reduced, the flocs tend to decline into an endogenous respiration phase which results in a better flocculated, more readily dewatered sludge. The F:M ratio in activated sludge is also known as the sludge age, the older the floc the more stable it is and the more easily dewatered the surplus activated sludge. The biological film of a percolating filter performs the same function as the floc in activated sludge, and if the F:M ratio is maintained at a high level the same process must occur. Therefore to obtain a readily dewatered humus sludge from a high rate filter the biological film must undergo endogenous respiration at some point within the filter, and the greater the volume of endogenously respiring film the better will be the dewaterability of the sludge produced due to the improved bioflocculation of solids. It is therefore desirable to operate high rate filters with as much film as possible in relation to the organic loading, provided that ponding can be avoided.

Factors concerned with the nature of biological filter media which affect the level of biomass supported by each filter are therefore important in determining both the type of medium employed and the dewaterability of the humus sludge produced. When treating equal volumes of the same waste under the same environmental conditions the standing crop of biomass in a filter will depend largely on the rate of discharge of sloughed film. This rate of discharge can be affected by both medium configuration and SSA, and dissociation of the relative affects of these factors on biological film levels in high rate filters is therefore of importance in the choice of filter medium.

Of the plastic filter media used at Hereford, Biopac 90 and Flocor E have the same SSA but different geometrical configurations. When operated under identical loading conditions Biopac 90 supported a much higher crop of biomass than Flocor E (Fig 5.5.4) and produced a more readily dewatered humus sludge (Fig 7.3.6). It would therefore appear that medium configuration is of considerable importance in determining the volume of film present and consequently the dewaterability of the sludge produced. This is due to the fact that the open, ordered structure of the Flocor medium allowed the rapid discharge of humus, while the random-fill nature of the Biopac medium prevented such rapid discharge and allowed film to accumulate to high levels. Similar differences in film levels supported and sludge dewaterability can be seen between the Biopac 50 and Flocor M media (Figs 5.5.4 and 7.3.6), and as the total available SSA was the same in these two filters medium configuration can again be seen to be important in determining both film levels and sludge dewaterability. (In making this comparison between the Biopac 50 and Flocor M filters it should be noted that the organic loading applied to the Flocor M filter was 11 percent higher than that applied to the Biopac 50 filter). The difference in biological film levels between Biopac 50 and Biopac 90 were small by comparison (Fig 5.5.4) and can be attributed to the affect of the difference in SSA on film accumulation as these media have identical configurations. In fact

Biopac 50 produced the most conditionable of all the pilot plant sludges (Fig 7.3.6) because the small void spaces and random-fill nature of this medium resulted in greater film accumulation than in any other filter, producing the lowest overall F:M ratio. Not withstanding the higher organic and hydraulic loadings applied to the Flocor M filter, and the slight differences in geometry, the differences between biological film levels supported by the Flocor M and Flocor E filters (Fig 5.5.4) and the differences in sludge dewaterability in these filters (Fig 7.3.6) are mainly due to the difference in the SSA's of the media. These differences can be seen to be less pronounced than those observed between media of different configuration (eg Biopac 90 and Flocor E, Biopac 50 and Flocor M) and it would appear that medium configuration is of greater importance than SSA in determining the level of biological film and therefore the dewaterability of the humus sludge produced by plastic filter media.

The ideal high rate plastic filter medium with respect to obtaining an easily dewatered humus sludge would therefore be random-fill, having small void spaces which would encourage both rapid film accumulation and retention of sloughed film, provided that ponding could be avoided. Conversely, modular plastic media which do not encourage heavy film accumulation would be expected to produce less readily dewatered humus sludge when treating the same wastes as such a random-fill medium.

The 125/75 Granite filter produced a humus sludge which was more difficult to dewater than the other mineral media sludges (Fig 7.3.6). This is because the 125/75 Granite medium supported the lowest biomass of the mineral media due to its relatively smooth surfaces, large void spaces and low SSA. This prevents the development of a thick film because the sewage can flow relatively quickly through the filter, preventing any accumulation of sloughed solids. While the 125/75 Slag medium is of the same size grading, the rough surface texture of each piece of medium allows a greater build-up of film and the consequentially lower F:M ratio (Fig 7.3.7) results in a slightly more readily dewaterable sludge than that produced by the 125/75 Granite filter. Differences between the conditionability of the 89/50 Granite and Slag media sludges can be similarly explained. The SSA of mineral media, the surface texture and the size of the void spaces between pieces of media therefore all affect the level of biomass supported by the filter and consequently the F:M ratio and the dewaterability of the sludge produced.

The ideal high rate mineral filter medium with respect to obtaining an easily dewatered sludge would therefore be of small grading with a rough surface texture. Regardless of the choice of either plastic or mineral filter media it would also be advantageous to use high rate filters to treat wastes which promote heavy film accumulation, particularly if the C:N ratio is high enough to result in a biological film largely dominated by fungus, as at Hereford.

Data from the conditioning of the secondary filter humus sludges does not fit the relationship between biological loading and sludge conditionability. There are several reasons for this:-

i The secondary filters had not reached full maturity and film levels were very low.

ii With low film levels and the very open structure of the media, the opportunity for any of the biological processes involved in determining sludge conditionability in high rate primary filters to have a significant influence on sludge characteristics are limited

iii Interstage settlement between the primary and secondary stages of the pilot plant was poor, with a further quiescent settlement period of thirty minutes in the laboratory reducing the solids content of the secondary filter feed by an average of 50%. Some of these settleable solids could pass straight through the filters because of the open structure of the media and the low film levels and settle in the humus sludge. This would not only increase sludge production rates in the secondary filters but also influence the dewaterability of the sludge itself.

7.3.4 Investigation of seasonal influence on sludge conditionability, using aluminium chlorohydrate as conditioner

The fact that no seasonal pattern in the offloading of film by the high rate filters was observed indicates that there are not likely to be any seasonal changes in sludge conditionability due to film sloughing, rather any changes will be of a more random nature.

As the most important factor determining sludge dewaterability appears to be the biological loading applied to the filter, seasonal changes in conditionability could only be expected if the F:M ratio changed with season. Such seasonal changes in F:M ratio do not occur at Hereford because the seasonal increase in organic loading corresponds with the colder temperatures of late autumn and winter when film levels are expected to increase. The increased organic loading at this time increases further the rate of film accumulation and therefore the F:M ratio remains relatively unchanged from the summer months when both organic loading and biological film levels are proportionally lower.

As there were also no detectable seasonal changes in either sludge stability to shear or conditionability as measured by the Cost/dose index (Figs 7.3.1-5), there appear to be no changes in sludge condition or conditionability which can be directly attributed to seasonal influence. While it is accepted that a one year study period is not sufficient time to investigate the possibility of the existance of cyclical change caused by seasonal influences in any system, the results obtained do not provide any indication that such cyclical changes are in operation.

7.3.5 Conditioning tests to investigate the effectiveness of polyelectrolyte conditioners

Tests involving the use of Zetag 51 in 1% solution appear to have been quite successful in conditioning several of the sludges, when assessment is made using the coagulant demand figures (Appendices 7.2.1 - 10). These figures show that in all sludges, except 89/50 Slag collected in February, the costs to reduce $\bar{r}$ to 4.0×10^{12} m/kg are reasonably low, suggesting that this conditioner can be used to effectively dewater the sludges. When assessment of conditioner effectiveness is made using the Cost/dose index however it can be seen that in all of the primary filter sludges Zetag 51 weakens floc strength, and the instability induced by this chemical makes it unsuitable for use with the primary filter sludges. The conditioning tests with the secondary filter sludges were more successful however, with floc strength not greatly affected by the conditioner and minimum $\bar{r}$ achieved being generally below 1.0×10^{12} m/kg. The low rate filter sludge was not tested with this conditioner, although the Eign Road sewage works uses this polyelectrolyte to successfully condition mixed sludges.

Conditioning tests involving the use of Zetag 88 in 0.4% solution proved to be successful in each sludge, with sludge stability to shear being improved on conditioning in several instances (Appendices 7.2.1 - 11). The single occasion on which the Flocor E sludge was conditioned with this chemical resulted in an increase in stability on conditioning and this is reflected in the Cost/dose index. The minimum $\bar{r}$ achieved by conditioning with Zetag 88 did not exceed 1.0×10^{12} m/kg in any of the sludges tested, including the low rate humus sludge.

Comparing Zetag 51 with Zetag 88 as conditioning agents for the secondary sludges it can be seen from the Cost/dose index that Zetag 51 appears to be slightly better. It should be pointed out that the minimum $\bar{r}$ achieved during March 1980 in the Flocor RS sludge with Zetag 51 as conditioner was just above 1.0 x 10^{12} m/kg, and the slightly higher costs incurred through using Zetag 88 may therefore be justified to ensure that the sludge is always thoroughly conditioned.

Zetag 88 is therefore an efficient conditioning agent for use with all of the sludges tested, and the high cost of the chemical as recieved from the manufacturer is offset by the low weight of chemical required per tonne of sludge dry solids and the increased activity of the conditioner.

7.3.6 Comparison of the condition and conditionability of high and low rate filter humus sludges

The results of the characterisation of the humus sludges produced by the low rate filter are presented in Appendix 7.2.11 and these results are summarised and superimposed on the axes of Figs 7.3.1 - 5 for comparative purposes.

The initial $\bar{r}$ of the low rate humus sludge tended to be slightly higher than in the high rate sludges, although the low rate sludge was only collected over a three month period and it is not known whether this sludge is susceptible to seasonal change. The stability to shear before conditioning was no different to that found in the other sludges.

The aluminium chlorohydrate coagulant demand figures, averaged in Fig 7.3.6, show that the low rate humus sludge required a greater cost dose to reduce $\bar{r}$ to 4.0 x 10^{12} m/kg than any of the primary filter random-fill media, and the Cost/dose index broadly reflects this fact. As the pilot plant sludges were known to be elutriated to some degree, while the low rate sludges were assumed to have lost no fines while settling in the final effluent settlement tanks of the Rotherwas STW, the coagulant demand required to condition the high rate sludges may be slightly higher in a full scale works. Despite this observation there is no evidence to suggest that the low rate humus sludge is any easier to condition than the high rate random-fill media. The modular media high rate sludges may be more difficult to dewater than the low rate sludge.

Table 7.3.1 Peaks in primary filter media humus sludge initial specific resistance to filtration ($\bar{r}$).

Filter Medium	Monthly sludge collection	Date on which sludge collected	Peak $\bar{r}$ recorded	Shaken sample suspended solids		Film off-loading
				Sewage	Effluent	
			(10^{12} m/kg)	(mg/l)	(mg/l)	
89/50 Granite	Nov	19.11.79	125.7	277	164	
	Feb	26.02.80	208.9	140	150	✓
125/75 Slag	Feb	27.02.80	134.3	167	150	
89/50 Slag	Nov	22.11.79	141.5	277	164	
	Feb	7.03.80	119.3	182	110	
125/75 Granite	Sep	19.09.79	139.4	209	140	
	Nov	23.11.79	112.4	277	120	
	Feb	11.03.80	130.1	177	140	
	Aug	20.08.80	146.7	-	-	
Biopac 50	Feb	26.02.80	153.9	140	114	
Biopac 90	Feb	27.02.80	158.0	167	185	✓
	May	30.05.80	141.5	-	-	
Flocor E	Sep	20.09.79	209.6	209	174	
	Nov	22.11.79	179.2	277	177	
	Feb	7.03.80	177.0	170	179	✓
	Mar	2.04.80	235.3	-	-	
	May	31.05.80	273.3	172	157	
Flocor M	Sep	18.09.79	126.8	209	189	
	Nov	23.11.79	323.2	277	214	
	Feb	11.03.80	126.7	177	151	
	Apr	1.05.80	133.1	-	-	
	May	3.06.80	240.6	172	154	
	Jun	27.06.80	140.2	243	281	✓

Sewage and effluent suspended solids contents determined on or near to sludge collection dates.

Sludge specific resistance to filtration determined at 500 g/cm^2 filtration pressure and sludge temperature of 20°C.

Fig. 7.3.1 Summary of sludge condition and conditionability data, using aluminium chlorohydrate as conditioner. 89/50 Granite and 89/50 Slag.

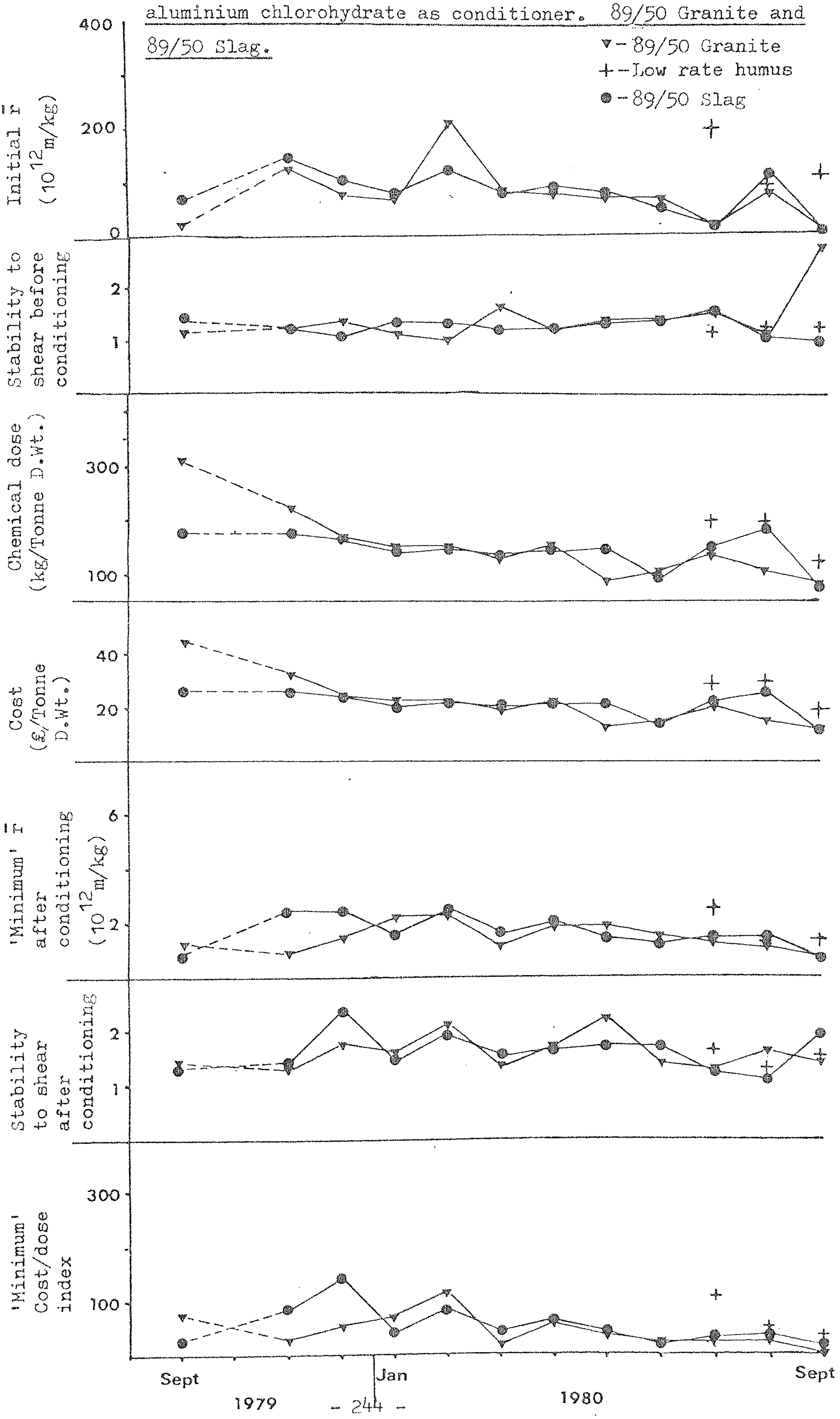


Fig. 7.3.2 Summary of sludge condition and conditionability data, using aluminium chlorohydrate as conditioner. 125/75 Granite and 125/75 Slag.

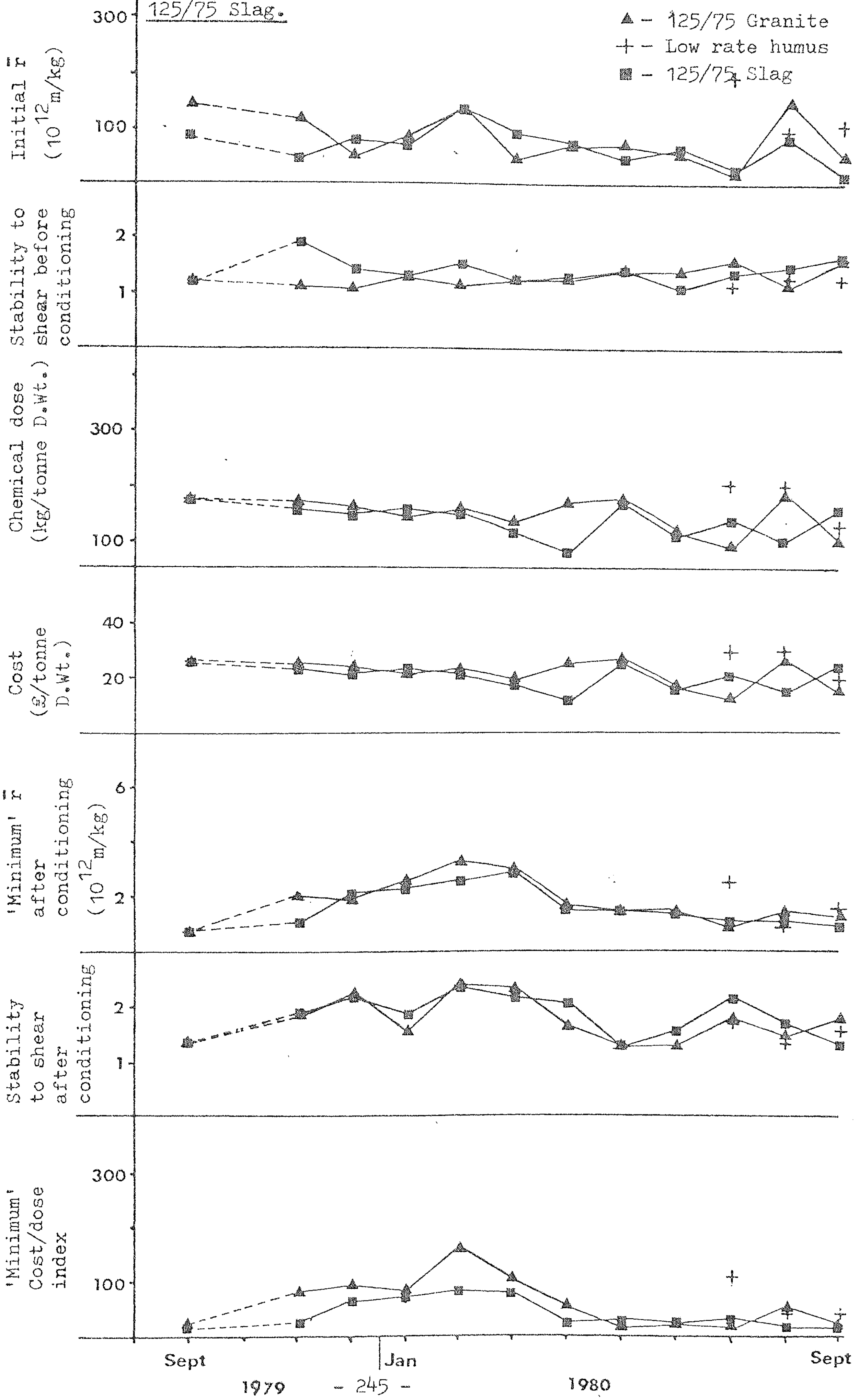


Fig. 7.3.3 Summary of sludge condition and conditionability data, using aluminium chlorohydrate as conditioner. Biopac 50 and Biopac 90.

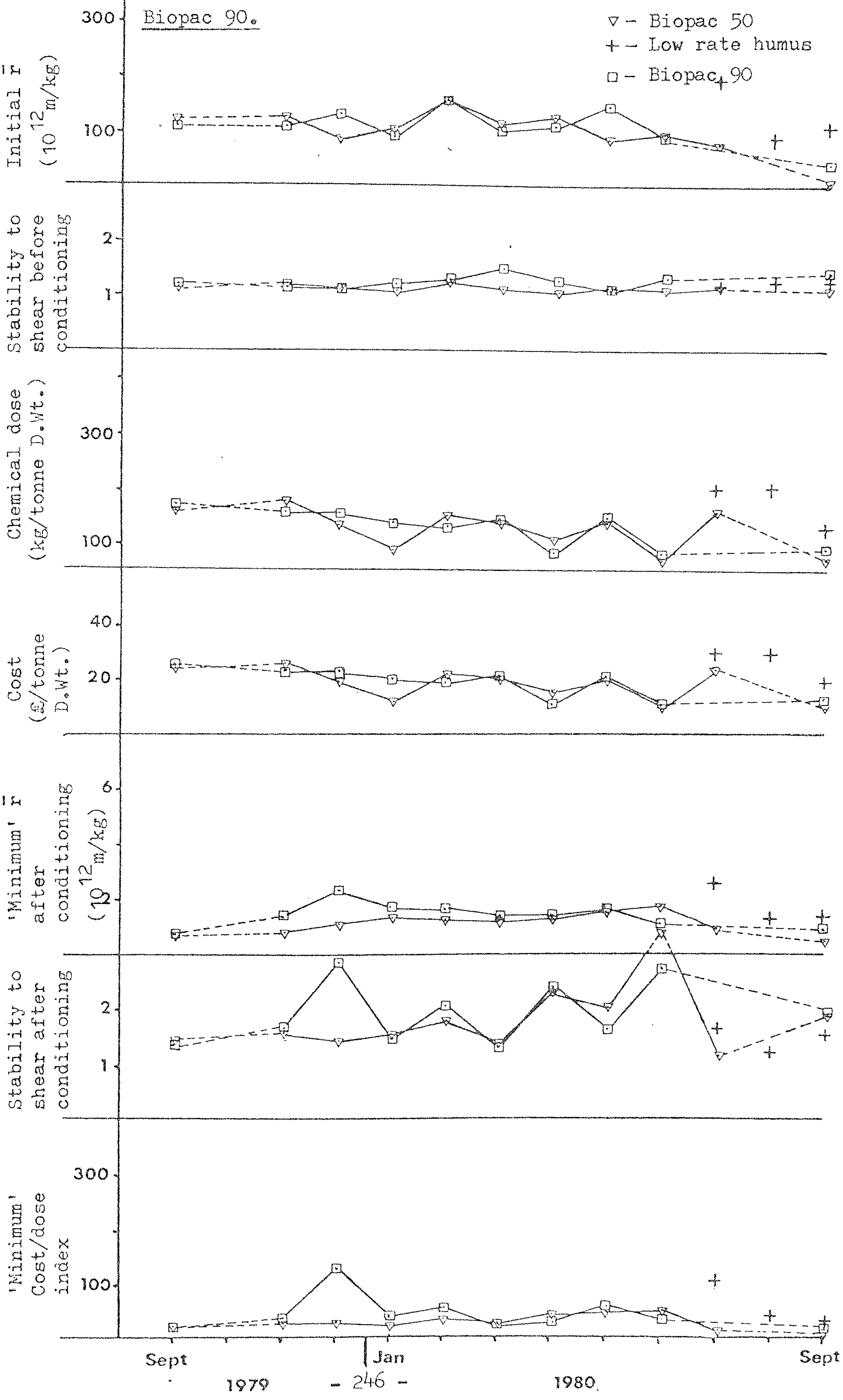


Fig. 7.3.4 Summary of sludge condition and conditionability data, using aluminium chlorohydrate as conditioner. Flocor M and Flocor E.

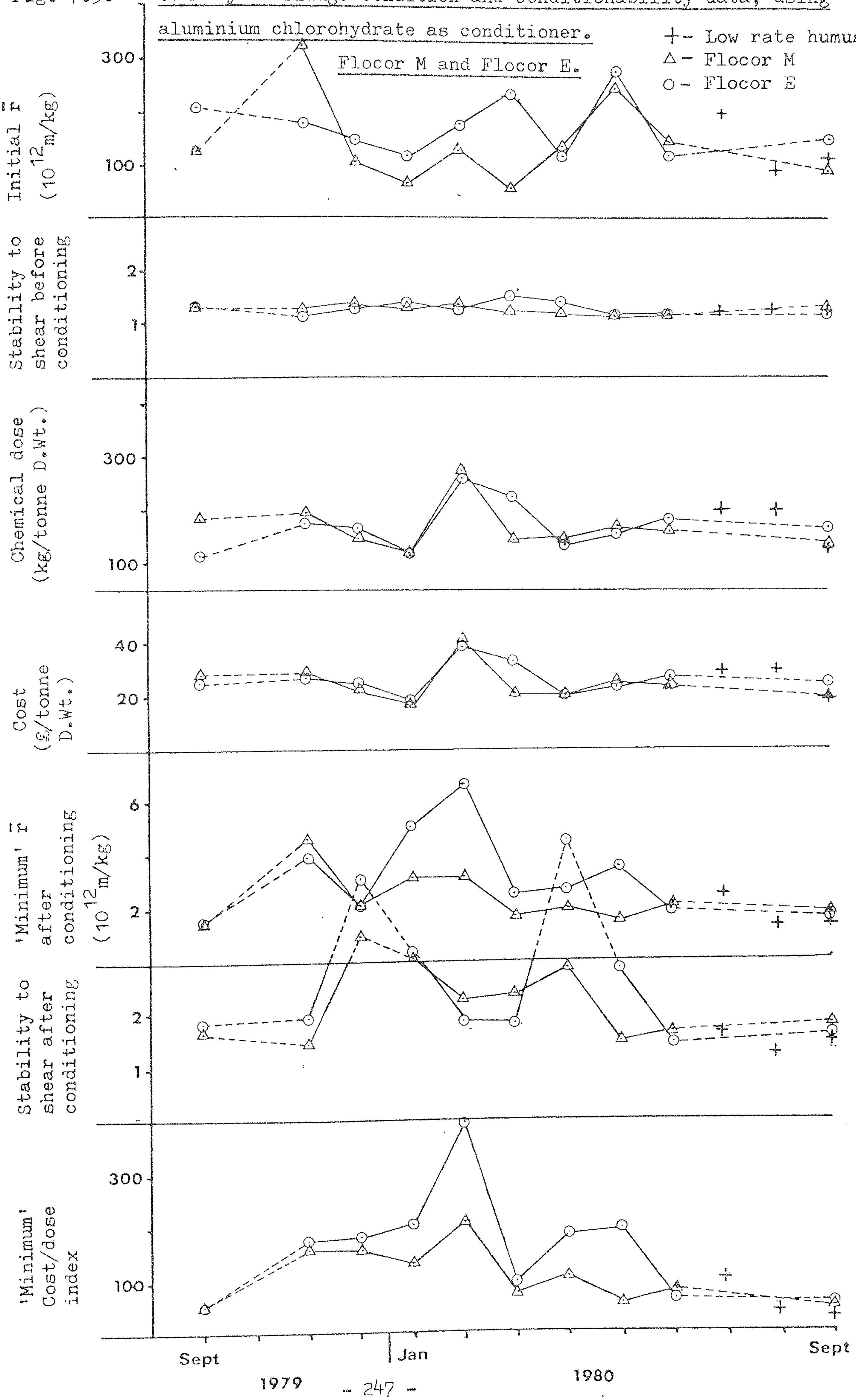


Fig. 7.3.5 Summary of sludge condition and conditionability data, using aluminium chlorohydrate as conditioner. Flocor R2S and Flocor RS.

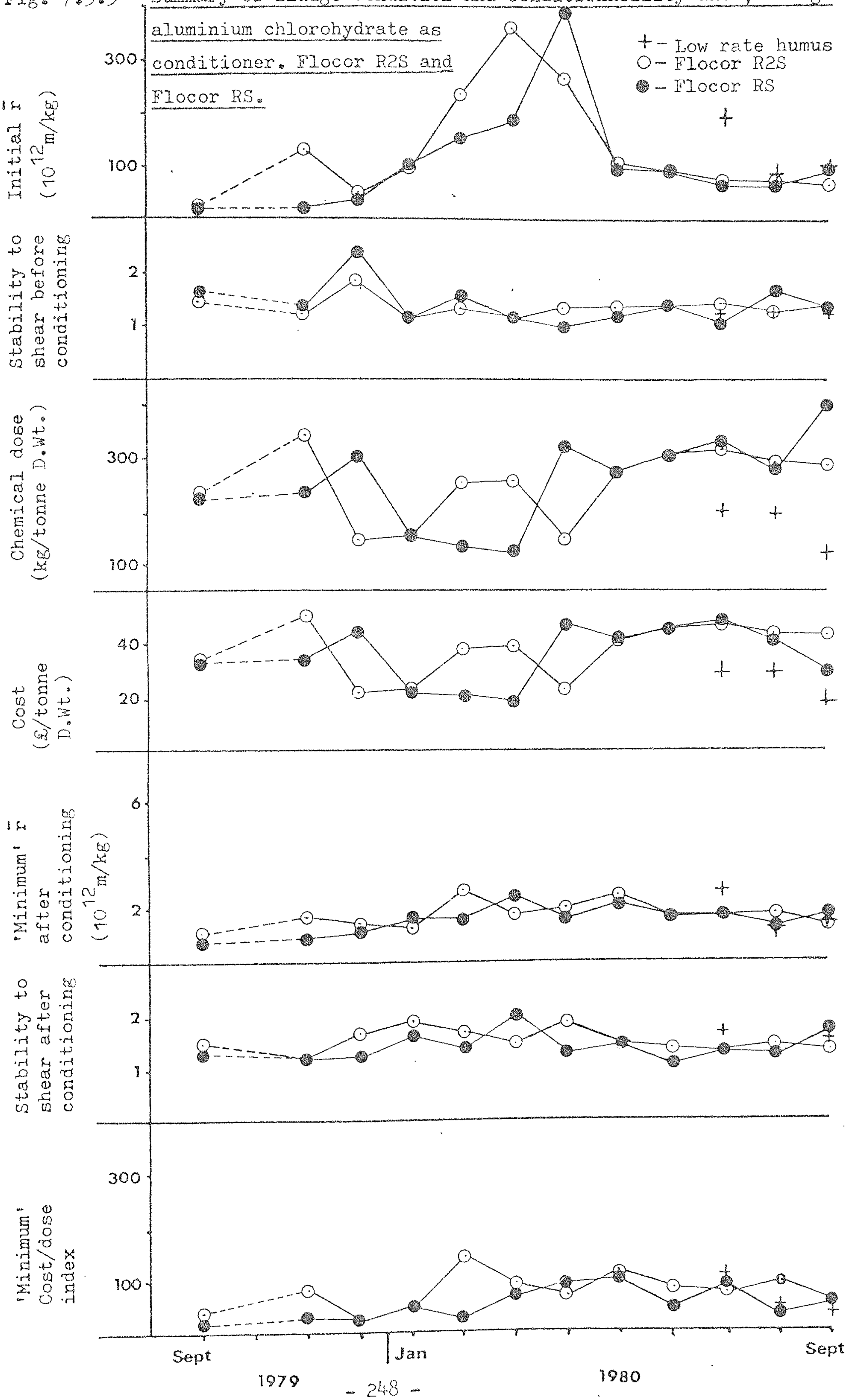


Fig. 7.3.6 Overall averaged cost to reduce $\bar{r}$ to 4.0×10^{12} m/kg and Cost/dose index of sludge conditionability for each sludge tested, using aluminium chlorohydrate as conditioner.

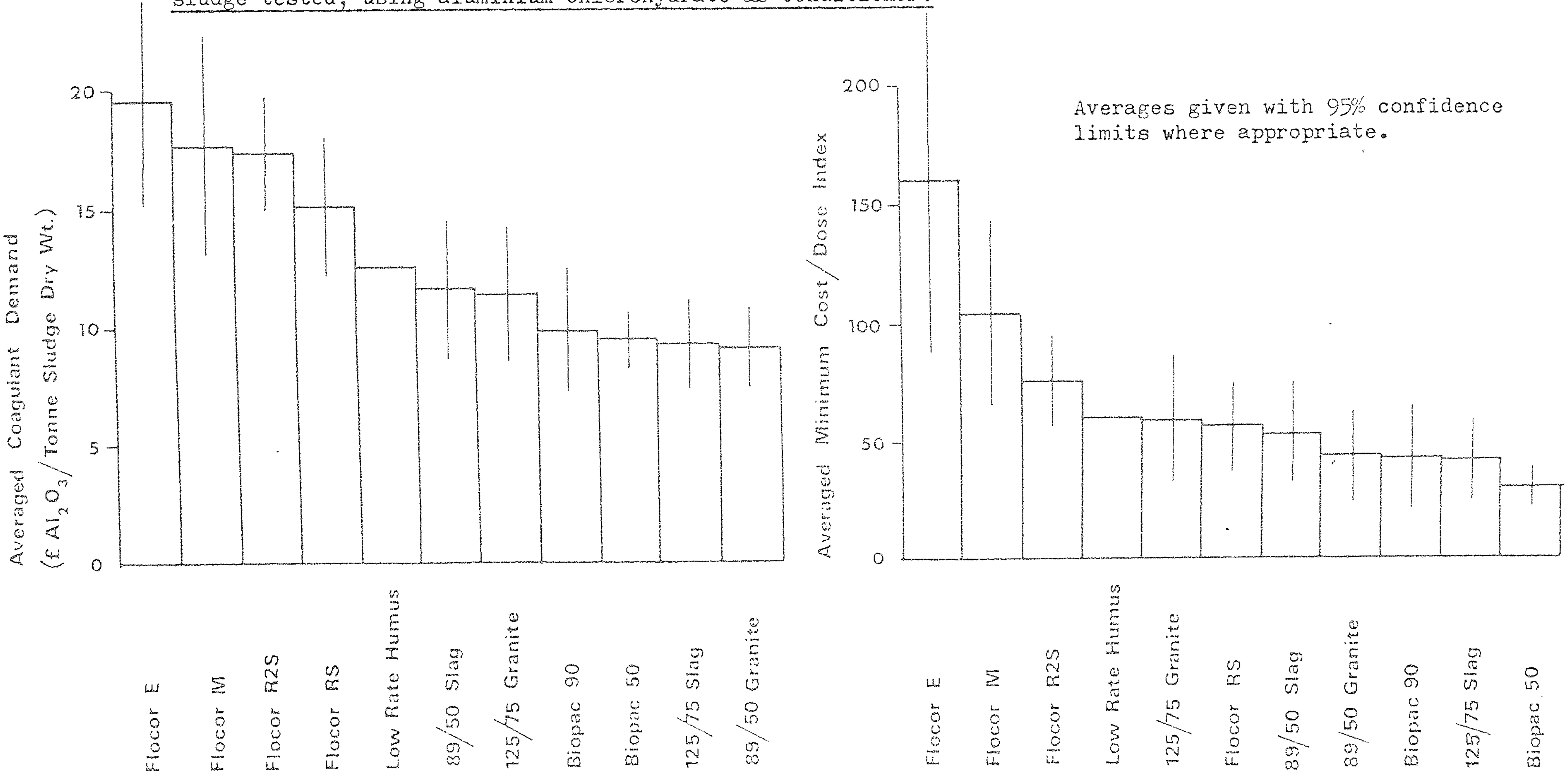
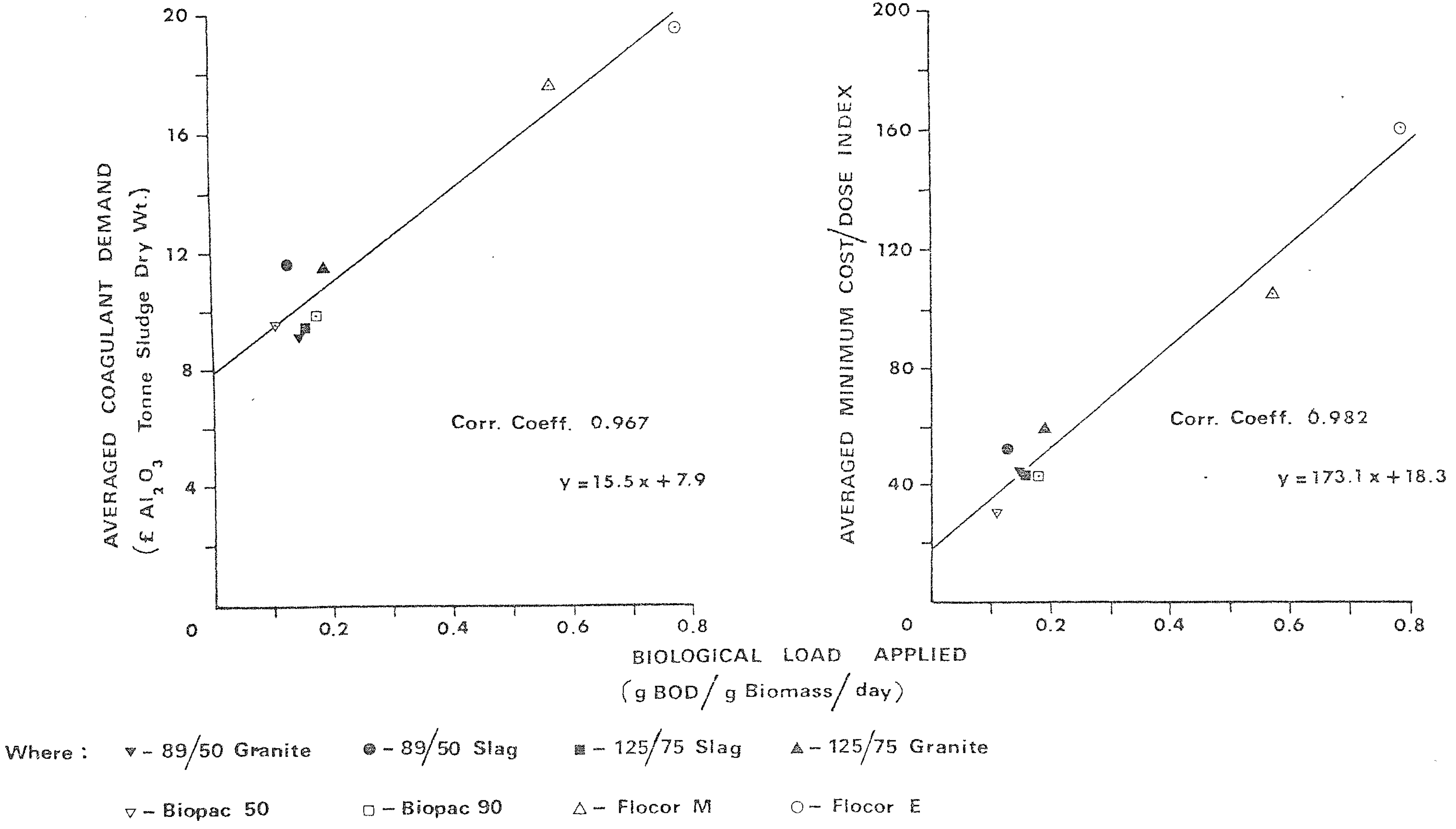

Averages given with 95% confidence limits where appropriate.

Fig. 7.3.7 Relationship between biological load applied and humus sludge conditionability, using aluminium chlorohydrate as conditioner.



7.4 Conclusions

1. Sludge conditionability in high rate filters is linearly related to the biological loading applied (expressed as g BOD/g Biomass/day) and they would therefore produce the most readily dewatered sludges when treating wastes having high C:N ratios which encourage the development of high biological film levels (providing ponding could be avoided).

2. The humus sludges produced by the modular Flocor media were more difficult to dewater than those produced by random-fill media, and this is because the lower film levels found in the modular media resulted in a high biological loading. Medium configuration appeared to be of greater importance in determining biomass levels and therefore biological loading than was medium SSA in the plastic filter media.

3. Small differences observed between the conditionability of mineral medium humus sludges can be attributed to the influence of medium SSA, configuration and surface texture on the accumulation of biological film and therefore on biological loading.

4. The ideal high rate plastic filter medium with respect to obtaining an easily dewatered humus sludge would be random-fill, having small void spaces and allowing the accumulation of high biological film levels.

5. The ideal high rate mineral filter medium with respect to obtaining an easily dewatered humus sludge would be of small grading and having a rough surface texture.

6. A Cost/dose index is proposed for use in the comparison of sludge conditionability and conditioner effectiveness. This index includes quantification of the cost of conditioning, the minimum achievable specific resistance to filtration through conditioning

and the change in sludge stability to shear induced by the act of conditioning.

7. Use of the Cost/dose index shows that the Biopac 50 medium produced the most readily dewaterable sludge, and this is confirmed using aluminium chlorohydrate coagulant demand data.

8. Secondary filter sludges were not discernably different from the random-fill primary filter sludges. Sludge conditionability could not be related to biological loading data in the secondary filters because they were biologically immature and the sludges may have been affected by poor interstage settlement of the secondary filter sewage.

9. There were no detectable seasonal changes in sludge condition or conditionability, although there were changes in sludge condition which could be attributed to periods of sloughing of filter film.

10. Zetag 51 in 1% solution was reasonably successful in conditioning the humus sludges of the pilot plant, although use of the Cost/dose index indicated that this chemical was not suitable for use with the primary filter sludges because of its detrimental effect on floc strength. Weights of chemical (as received from the manufacturer) used varied with sludge solids content between 33.6 and 47.0 kg/tonne dry solids.

11. Zetag 88 in 0.4% solution successfully conditioned all humus sludges from the pilot plant and from Hereford STW to a specific resistance to filtration of less than 1.0×10^{12} m/kg, with no marked loss of sludge stability. Weights of chemical used (as received from the manufacturer) varied with sludge solids content between 4.5 and 24.5 kg/tonne dry sludge solids.

12. Aluminium chlorohydrate did not condition either the humus sludge of the pilot plant or of the Hereford STW well, in consideration

of both the high costs involved and poor results obtained.

13. The humus sludges produced by the random-fill high rate filter media of the pilot plant were no more difficult to dewater than the low rate filter sludge produced at Hereford STW, when treating the same sewage.

8 Nitrification of sewage effluents in relation to loading conditions

8.1 Introduction

The relationship between nitrification and loading conditions in biological filters has not been fully described in the past, and observation of the effects of different loading conditions on the degree of nitrification achieved may be of value in optimising conditions required in filters for full nitrification.

Biological filters containing small mineral media operated at sufficiently low loading rates, in the absence of inhibitors and at sufficiently high temperatures usually produce well nitrified effluents. Under higher loading conditions however the degree of nitrification achieved can become extremely variable and unsatisfactory. An understanding of the relationship between nitrification and loading conditions might be of value in determining the reasons for the variability observed and the conditions required for satisfactory nitrification. This would be of particular interest in cases where existing filters are overloaded or where either single or two stage high rate filtration is considered as a possibility for providing substantial carbonaceous removal to be followed by a separate nitrifying filter, as it would help to determine the degree of treatment required before application to the nitrifying filter and the hydraulic loading which could be best used to produce well nitrified effluents.

Experiments were therefore carried out at Hereford in which lab-scale nitrifying filters were operated at different organic and hydraulic loadings, and the degree of nitrification achieved under these different loading conditions was observed. These experiments were initially designed in an attempt to answer three questions.

1 Is the effluent from the second stage of the two stage filtration

plant nitrifiable?

2 Is there any quantifiable relationship between any of the loading factors and the degree of nitrification achieved which could be of use in predicting the extent of nitrification in biological filters?

3 Which loading factors are most likely to affect nitrification in biological filters, at which levels do these factors exert the greatest influence on the degree of nitrification achieved, and can these factors be used to explain variations in nitrification efficiency observed?

The experimental methods used are described fully in Section 4.4 and the experimental programme in Table 4.4.2.

As the purpose of the experiments was to study the effects of different loading conditions on nitrification it was decided that as many of the other factors affecting the process as possible should be controlled. Temperature was therefore controlled at 20°C, as it is known that nitrification is not inhibited at this temperature (Downing et al., 1964). Nitrification may be slightly inhibited by bright light (Painter, 1970) and the development of algal growths can cause ponding in small filters, as well as causing a reduction in the concentration of NH_3-N reaching the filters themselves through algal synthesis in supply tubes, so the experiments were carried out in a darkened room and the filters wrapped in black polythene to exclude light during maintenance periods. Each filter was filled with media of identical size, shape and volume (0.75 1 x 6 mm glass beads) having a very high SSA, so that the performance of filters operated under different regimes could be directly compared and the SSA of the medium would not be a limiting factor in filter performance

It was felt that the use of sewage rather than synthetic wastes would provide data more applicable to full scale filter operation as the filters would then be subject to normal sewage composition fluctuations.

However it was necessary to prevent the development of invertebrate populations in the filters as it was believed that differential population development may produce variations in performance between filters operated under otherwise identical conditions. In order to study the effects of increasing organic loading on nitrification, sewages of different BOD strengths but otherwise essentially the same were required. These were drawn from different points on the pilot plant as shown in Table 4.4.1. It is felt that as far as possible these wastes are identical in terms of treatability with the only difference between them assumed to be the level of BOD.

8.2 Results

The first test, to investigate whether the secondary filter effluent could be nitrified, was carried out over a period of nine weeks and consisted of applying sieved secondary filter effluent (Flocor R2S) at a nominal flow rate of 2 $m^3/m^3.d$ to 15 filters which had been seeded earlier with nitrifying bacteria populations using final effluent from the Eign sewage works.

BOD analyses were not carried out during this experimental period, but NH_3-N, NO_2-N, total oxidised -N and flow rate analyses were performed and the data are presented in Appendix 8.2.1. Second order running means were calculated from these data for feed and effluent NH_3-N concentrations and percent removal of NH_3-N. These means are plotted in Figs 8.2.1 and 8.2.2. Fig 8.2.2 shows a rapid increase in percent NH_3-N removed by the filters over the first six sample days (two and a half weeks) after which the percent removal reached a plateau and remained stable at between 80 and 90% for the rest of the experiment. Fig 8.2.1 shows that the running average effluent NH_3-N concentration obtained following the acclimation period did not exceed 3.5 mg/l, despite wide fluctuations in feed NH_3-N concentration.

From this study it is concluded that the secondary filter effluent was readily nitrified at low flow rates and under a suitable temperature regime. It is assumed that as the Flocor R2S filter effluent was of consistently lower quality than the Flocor RS effluent, the latter would be at least as readily nitrified.

Following this first test the filters were randomly assigned to groups of three and were kept in these groups for the remaining experiments. Each of these filters was labelled alphabetically, i.e. A1, A2, A3, B1, B2, B3 etc with the wastes used to supply them denoted by single letters, W, X, Y, Z and V etc.

The second experiment, as shown in Tables 4.4.1 and 2, involved the use of four sewages of different BOD concentrations, one applied to each filter group, with the secondary filter effluent being applied to both filter groups E and A. The flow rate was maintained at nominally 2 m^3/m^3.d. A long period (eight weeks) of acclimation to the increased BOD concentrations was allowed, and as soon as satisfactorily stable performance had been maintained for a reasonable period of time in all filter groups the experiment proper was commenced. Data from the acclimation and experimental periods are presented in Appendix 8.2.2. From these data it can be seen that performance was stable after the fifth week of the acclimation period, and the filters are assumed to have been fully mature after this time. BOD analyses are presented in Appendix 8.2.2 for both the acclimation and experimental periods, although allyl thiourea (ATU) suppression of nitrification during the BOD test was not used until the start of the experimental period itself. Fig 8.2.3 presents the averaged data from the experimental period.

This experiment gave no real indication of any relationship between loading conditions and nitrification, simply because the filters were underloaded and produced good quality effluents regardless of the BOD concentration with which they were fed. The loading conditions applied to the filters were therefore changed in the third experiment by doubling the hydraulic load from 2 - 4 m^3/m^3.d, while the origin (and therefore the BOD concentration) of the wastes applied remained the same as in Experiment 2 (Table 4.4.2). Filter group A was chosen to monitor the nitrifiability of the secondary filter effluent and long-term changes in filter maturity, and the flow rate to this group was reduced to nominally 1.4 m^3/m^3.d for the remainder of the study.

After a three week acclimation period the filters were considered to have reached steady state performance and the third experiment was commenced. Data from the acclimation and experimental periods are presented in Appendix 8.2.3. Fig 8.2.4 presents the averaged data from the experimental period. The results of this experiment show that although the increase in hydraulic loading caused a general increase in both effluent BOD and NH_3-N concentrations there was again no apparent relationship between feed BOD and effluent NH_3-N concentrations.

The fourth experiment involved increasing the BOD concentrations applied to the filters from nominally 100, 70, 40 and 20 mg/l to nominally 180, 150, 120 and 90 mg/l (supplied to filter groups B, C, D and E respectively Table 4.4.1), whilst maintaining the hydraulic loading at 4 m^3/m^3.d. The increased BOD concentrations required in the feeds were obtained by mixing varying proportions of the primary settled sewage (T1) and secondary filter feed (T2) (Table 4.4.1), after rough estimations of the strength of these two wastes relative to each other had been made by running ten minute permanganate value (PV) tests each day (method used as given by Mackereth (1963), with ten minutes boiling of samples in a water bath as opposed to the 30 minutes recommended) before changing the feed liquors. Although it was found that the ten minute PV data did not correlate with BOD concentrations, from the estimations of the relative strengths of T1 and T2 four mixtures could be made which provided liquors of suitably varied BOD concentrations. These mixtures were then applied to the filter groups as described in Table 4.4.2. The proportions of each waste used in preparing the feed mixtures are presented in Appendix 8.2.4, together with data from the acclimation and experimental periods. From Appendix 8.2.4 it can be seen that on three occasions effluent from filter 9 of the pilot plant was used. This was necessary because of a fall in the strength of T2, and it is assumed that the only difference between the primary filter effluent and T2 was the BOD concentration. The experiment was therefore not detrimentally affected by the use of this waste. To ensure that the concentration of NH_3-N available in the feed did not limit the extent of the nitrification achieved, the concentration was increased in each feed by approximately 20 mg N/l by the addition of ammonium sulphate solution each day as the feeds were changed.

Appendix 8.2.4 shows that, although only a short acclimation period was allowed, all filter groups had reached stable performance levels by the start of the experiment proper. Fig 8.2.5 presents the averaged data from this experiment, which show that the effluent BOD produced by the filters fell with decreasing feed BOD and that the concentration of NH_3-N removed increased with decreasing feed BOD. However it is not clear from the raw data whether it was the high feed BODs or the correspondingly high effluent BODs which contributed most to the poor nitrification performance of the filters compared with earlier experimen

The final experiment was carried out, at a flow rate of 6 $m^3/m^3.d$, in two parts, the first half was carried out at the same time as Experiment 3, and the second half at the same time as Experiment 4. This was necessary because of the lack of time available to run a completely separate experiment. For this fifth experiment six further filters were required. These were seeded and acclimatised to secondary filter effluents in the same way as the original 15 filters, although the seeding period was reduced to two weeks and the acclimation to secondary filter effluents to three weeks. Two weeks of this acclimation period were over a vacation period and the filters were run on stale secondary filter effluent during this time. The acclimation of the filters may have suffered because of the use of this stale waste.

The first half of the experiment involved the supply of feeds Y and Z (Table 4.4.1) to the two groups of three filters which were randomly formed at the end of the acclimation period. Appendix 8.2.5 shows that the filters had not reached a satisfactorily stable performance level at the start of the experimental period. However this part of the experiment was run simultaneously with Experiment 3 and as most of the filter groups in Experiment 3 were producing reasonably stable performances, it was decided to consider the experiment started after three and a half weeks acclimation. Only filter group E improved markedly following the commencement of the experiment, as group D reached a stable performance level with regard to percent NH_3-N removed within a further two sample days.

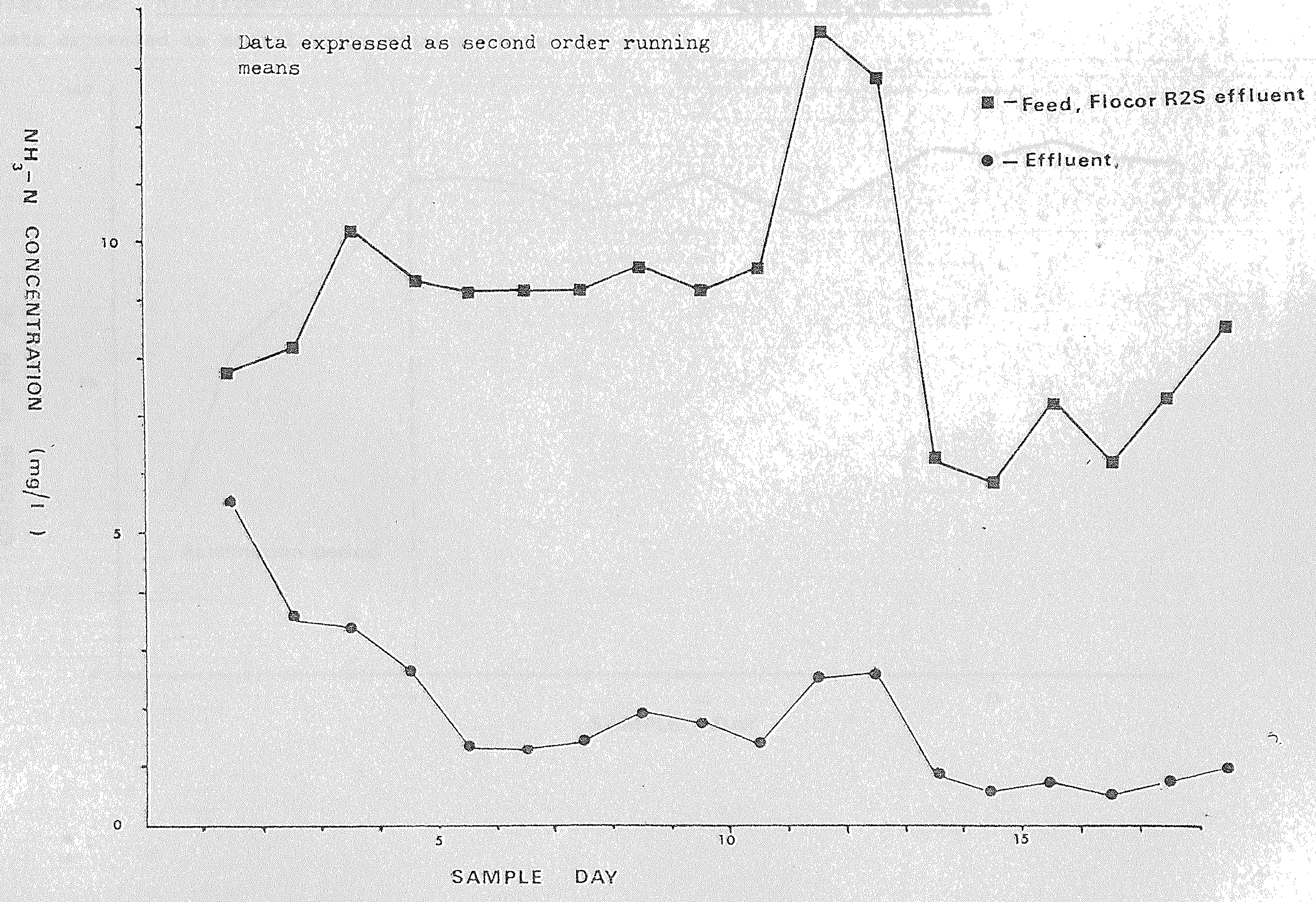
Immediately following the first half of the experiment the sewage feeds were changed to feeds W and X (Table 4.4.1) and a period of four and a half weeks acclimation allowed. The filters appeared to have reached steady state performance levels at the start of the experimental period (Appendix 8.2.5) although both filter groups showed a subsequent increas in NH_3-N removal efficiency. Filter groups B, C and D are considered to have reached maturity at the commencement of the experiment and any changes in filter efficiency were therefore probably due to changes in operating conditions. Filter group E was possibly not mature at the beginning of the experiment.

Data from Experiment 5 are presented as averages in Fig 8.2.6. The Feed BOD concentration data show that while the BOD of feeds Y and Z in the first half of the experiment were reasonably close, at 50.7 and 17.1 mg/l, to the nominal concentrations of 40 and 20 mg/l which were expected, the sewage strength had fallen by the start of the second half of the experiment so that the strength of feeds X and W averaged only 61.6 and 69.8 instead of the 70 and 100 mg/l expected. The fact that filter group E may not have been fully mature at the start of the first half of the experiment, and that the sewage during the second half was of low strength bring the significance of these data into question.

The long-term performance of filter group A in treating the secondary filter effluent is shown in Fig 8.2.7. Second order running means are used to show effluent NH_3-N concentration and percent NH_3-N removed over an eight month period of continuous operation. After the thirteenth sample day there was a fall in the efficiency (in terms of percent NH_3-N removed) and thereafter performance varied between 60 and 90% removal of ammonia until extra NH_3-N was added to the feed before application to the filter (Sample day 41). The filters quickly recovered from the effects of this extra addition however and percent removal returned to a high level. The running average effluent NH_3-N concentration never exceeded 5 mg/l when the filters were supplied with secondary filter effluent alone and this is taken as further proof of the nitrifiability of secondary filter effluent. The fact that there was no apparent long term improvement or deterioration in filter performance indicates that these filters were fully mature when the second experiment commenced. The other filters used in Experiments 2, 3 and 4 are therefore also assumed to have reached full maturity at the beginning of the second experiment, while the maturity of the filters used in Experiment 5 has already been discussed.

The individual experiments did not provide any direct evidence of any relationship between organic loading conditions and the degree of nitrification achieved, and the true nature of the relationship only became apparent when the data were averaged and considered collectively.

Fig 8.2.1 Nitrification of secondary filter effluent. NH_3-N concentrations.



Data expressed as second order running means

Fig. 8.2.2 Nitrification of secondary filter effluent. Percent NH_3-N removed.

Data expressed as second order running means

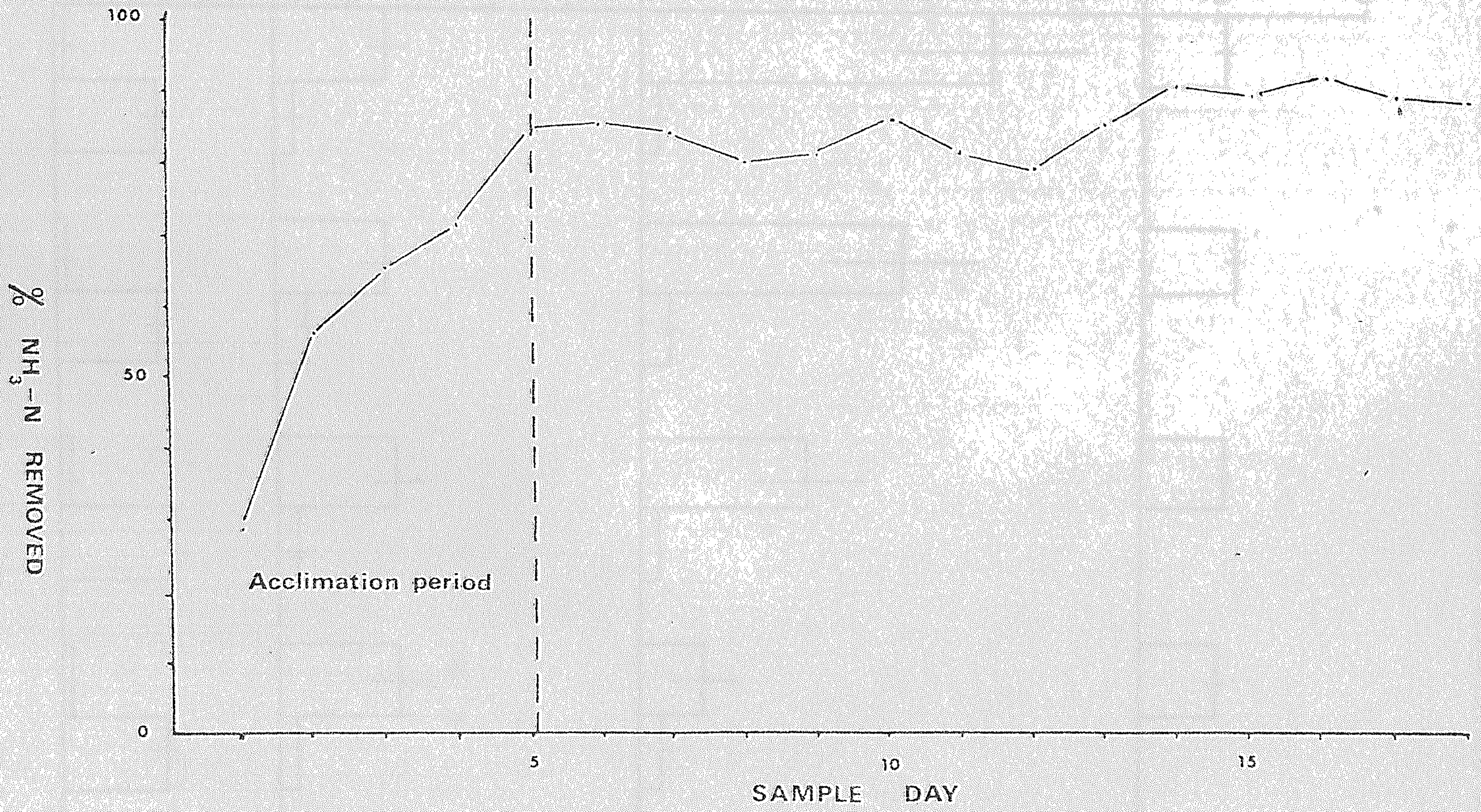


Fig. 8.2.3 Histograms of averaged data. Second nitrification experiment - nominal flow rate 2.0 $m^3/m^3.d$

Vertical lines are 95 % confidence limits

Average temperature 18.19 ± 0.34 °C

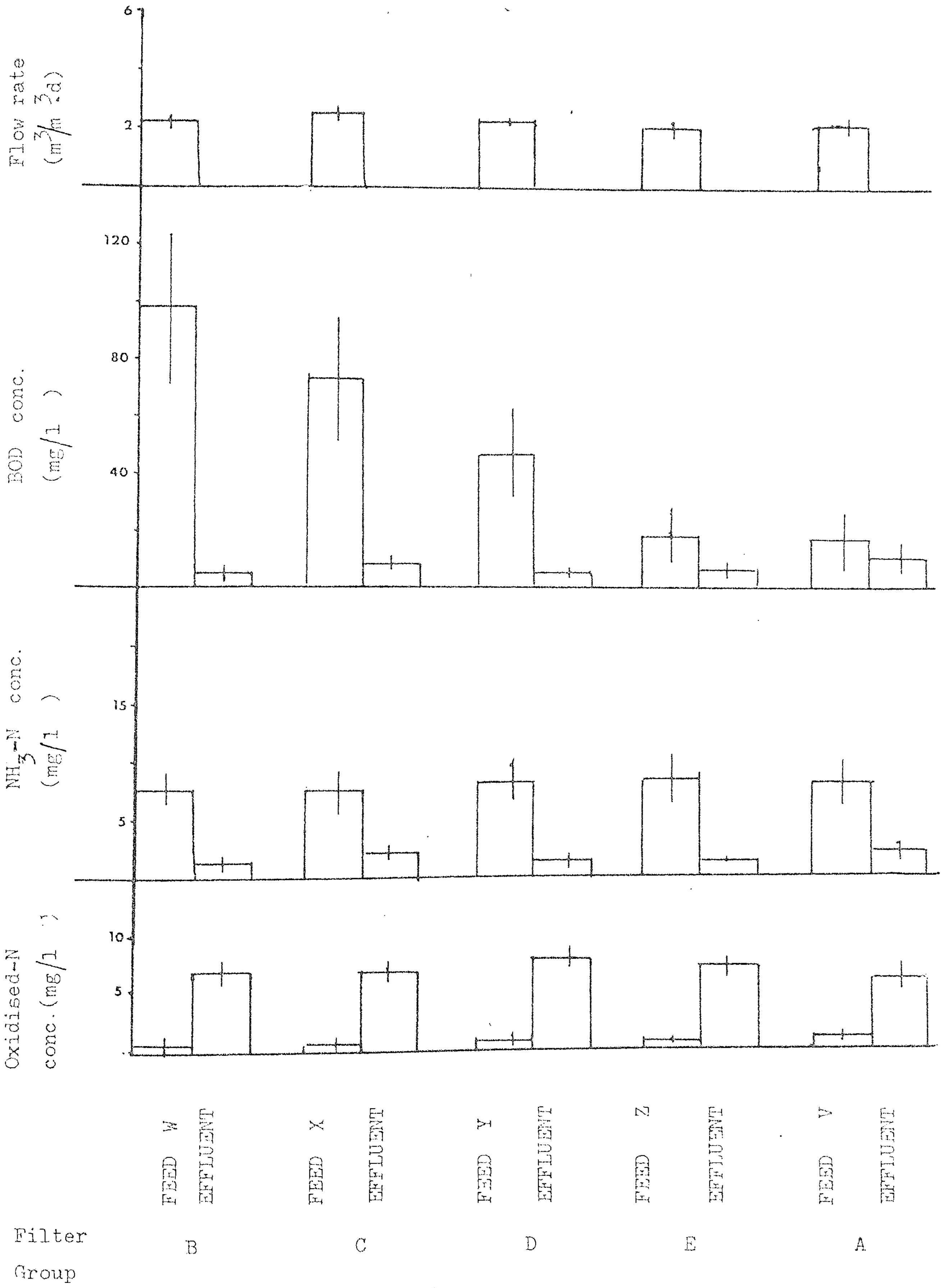


Fig. 8.2.4 Histograms of averaged data. Third nitrification experiment - nominal flow rate 4.0 $m^3/m^3.d$.

Vertical lines are 95 % confidence limits of means

Average temperature 19.83 ± 0.17 °C

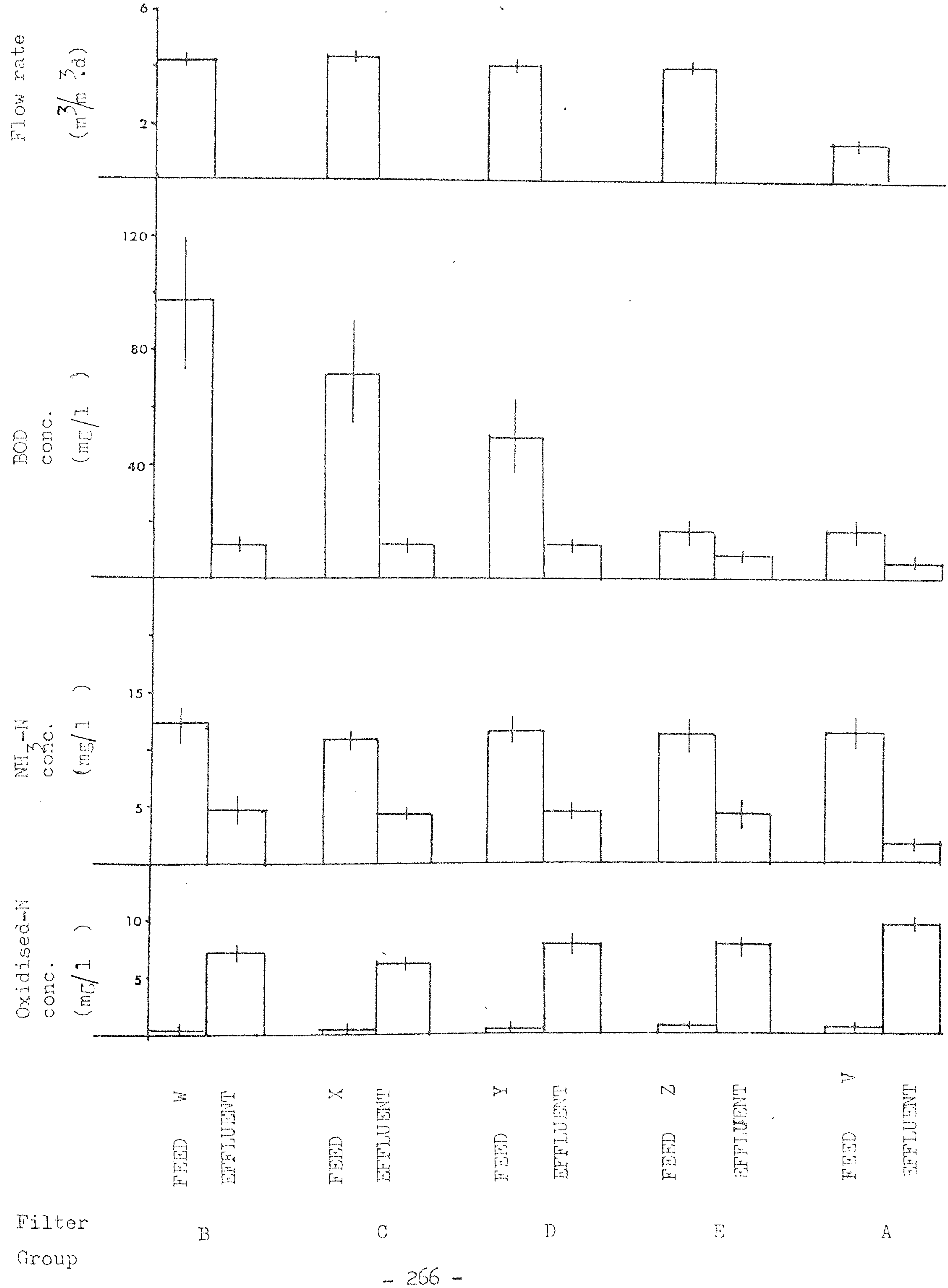


Fig. 8.2.5 Histograms of averaged data. Fourth nitrification experiment - nominal flow rate 4.0 m^3/m^3d.

Vertical lines are 95 % confidence limits of means

Average temperature 19.91 ± 0.12 °C

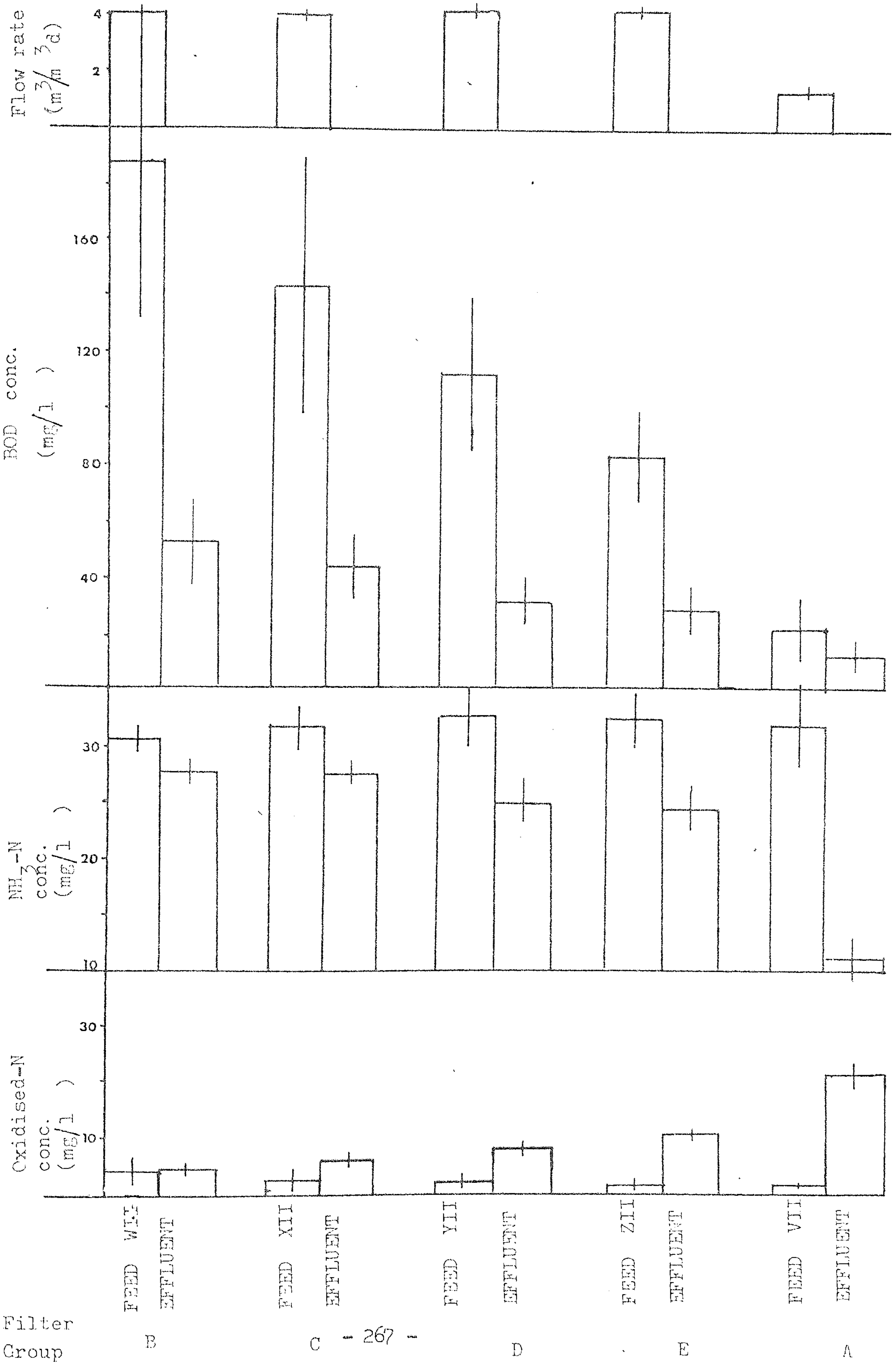


Fig. 8.2.6 Histograms of averaged data. Fifth nitrification experiment - nominal flow rate 6.0 m³/m³d.

Vertical lines are 95 % confidence limits of means

Average temperature 19.91 ± 0.12 °C

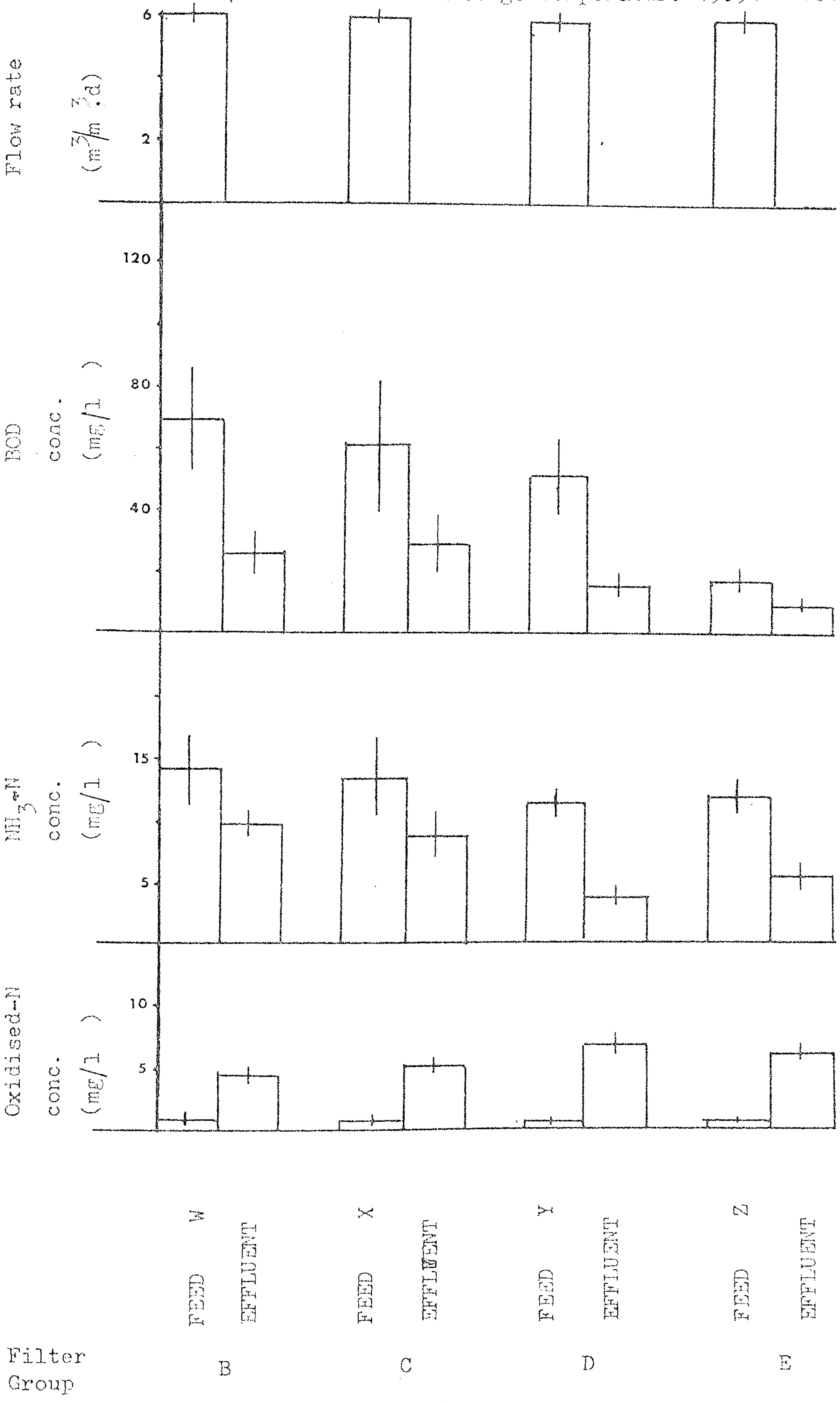
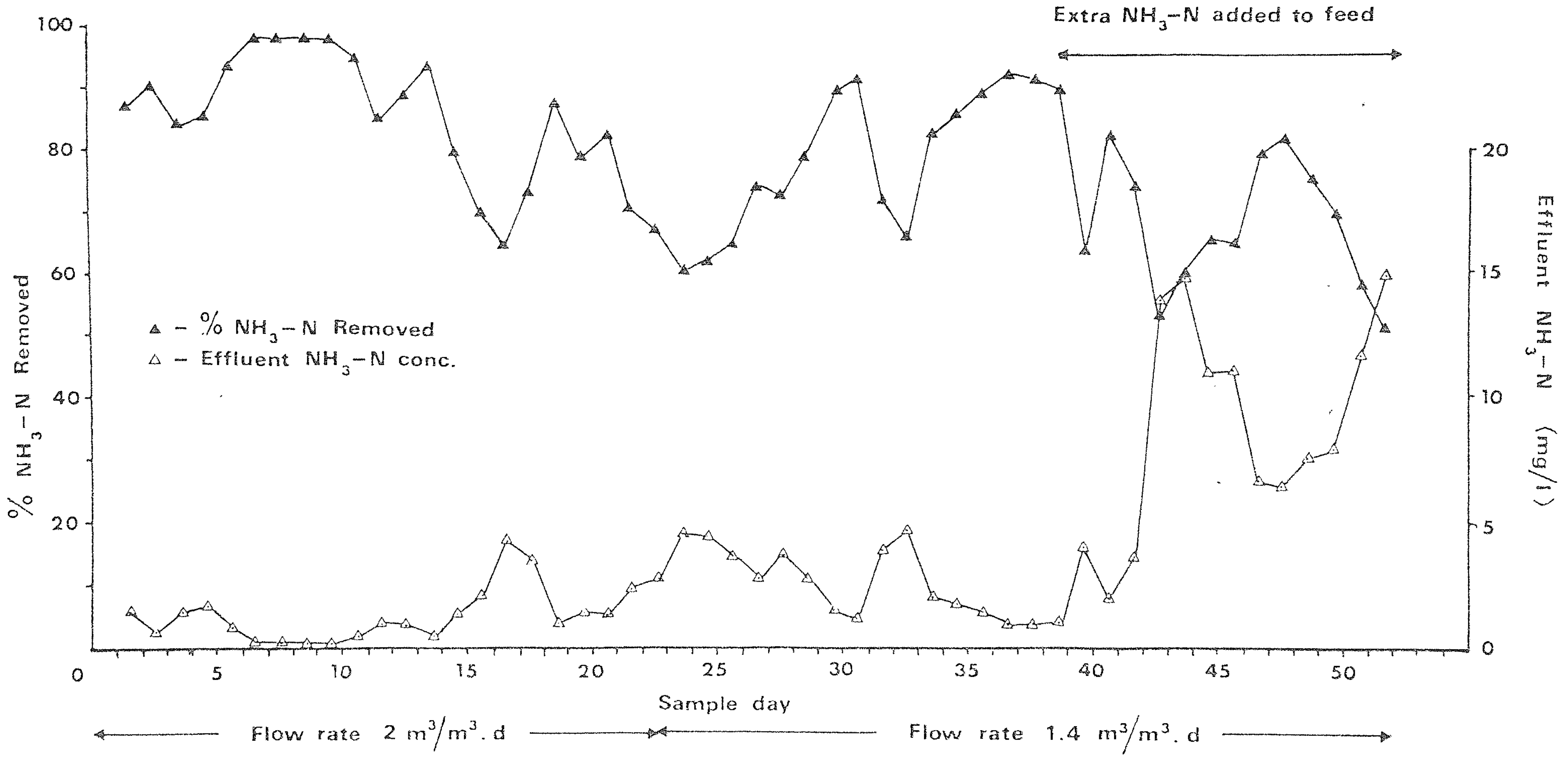


Fig. 8.2.7 Observation of the nitrifiability of secondary filter effluent and long-term study of changes in the performance of laboratory scale nitrifying towers, 1.9.80 - 7.5.81.

Data expressed as second order running means



8.3 Discussion

Due to the fact that feed NH_3-N concentrations varied between experiments, and for the purpose of comparison, the degree of nitrification achieved by the filters has been expressed as the percent NH_3-N removed. Oxidised -N production was not used to estimate nitrification.

The raw data from the nitrification experiments do not appear to provide direct evidence of any relationship between increased organic loading and nitrification, with the exception that increased feed BOD concentration and/or flow rate results in generally increased effluent NH_3-N concentration, and possibly that a decrease in feed BOD increases the NH_3-N removed.

Fig 8.3.1 shows the curves of BOD load applied vs percent NH_3-N removed during each experiment. There is no relationship between these two parameters which is applicable over the complete range of loads used during the experiments, and the effect of increasing BOD load within each experiment is variable. The results of Experiment 5 seem to show that these filters were possibly hydraulically overloaded in that their performance was very erratic. The immaturity of some of these filters may also have adversely affected the results obtained from this experiment.

The lack of any overall relationship between BOD load applied and percent nitrification is probably due to the fact that BOD load can be increased by either increasing feed BOD concentration or hydraulic loading or both, and that the effects of increasing flow rate are not the same as the effects of increasing feed BOD concentration. Fig 8.3.2 shows the influence of increasing feed BOD at two different flow rates on the degree of nitrification achieved. The curves are obtained from the data from Experiment 2 and 3, between which the only differences in loading conditions applied to each filter group which could significantly affect percent nitrification obtained were the increased flow rates. From the two curves it can be seen that increasing feed BOD concentration whilst maintaining constant flow rate has very little effect on the degree of nitrification, while the effect of increasing flow rate by a constant amount at any feed BOD is more pronounced but again relatively stable over a wide range of BOD concentrations. If both flow rate and feed BOD concentration are increased simultaneously the effect of these changes is the same as the effect of an increase in flow rate alone. A unit increase in BOD load caused solely by increasing feed BOD concentration therefore does not have as great an effect on the degree of nitrification achieved as the same increase caused either solely by increasing flow rate or by a combination of increased flow and feed BOD, and it is because of this that a direct relationship between BOD loading and nitrification does not exist.

There is therefore no overall relationship between organic loading conditions and nitrification, although Fig 8.3.3, showing the relationship between average effluent BOD concentration and percent NH_3-N removed during the whole experimental period, indicates that the organic content of the effluent can be correlated with percent NH_3-N removed. The exponential decay curve, fitted by eye, describes the data well with the exception of the Experiment 5 data - again possibly because of non-stable conditions within these filters. The fact that the majority of the data fits this curve demonstrates that there is a quantifiable correlation between effluent BOD quality and the degree of nitrification achieved which is independent of other loading conditions applied.

The curve can be split into three sections, corresponding to approximately 0 - 10%, 10 - 40% and 40 - 100% NH_3-N removal. Removal of NH_3-N of greater than 40% is considered to be due primarily to nitrification, 10 - 40% removal could be due to both nitrification and heterotrophic assimilation, while reduction of less than 10% could be due almost entirely to heterotrophic assimilation. Nitrification does not proceed to a level of greater than 40% NH_3-N removal unless effluent BOD falls below 17.5 mg/l. Within the effluent BOD range of 0 - 17.5 mg/l the degree of nitrification achieved is highly sensitive to changes in effluent BOD, any increase in effluent BOD resulting in a disproportionate decrease in percent NH_3-N removed. This sensitivity within the stated effluent BOD range can be attributed to the greater proportion of the filter depth supporting large heterotrophic bacterial populations actively involved in carbonaceous oxidation as effluent BOD increases. The greater this proportion of filter depth the smaller the proportion available for nitrification to proceed without the rate suppressing influence exerted by the heterotrophs in competitively taking up available D.O. When effluent BOD is increased to around 17.5 mg/l, the depth of the filter available for nitrification to proceed unhindered by heterotrophic activity is reduced, and the degree of nitrification achieved is markedly lowered. Increasing effluent BOD from 17.5 mg/l causes a less sensitive response because nitrification rate is suppressed at any effluent BOD within this range due to heterotrophic activity, with higher BODs simply causing slightly increased suppression. Effluent BOD concentrations of greater than 40 mg/l result in the D.O. concentration within the filter available to nitrifying bacteria never reaching a level at which a significant degree of nitrification can occur, and the curve therefore assymptotes to a level which probably corresponds to the amount of heterotrophic assimilation taking place.

Plotting Fig 8.3.3 on Log - normal axes produces the linear relationship shown in Fig 8.3.4. The regression of this line is

$$\text{Percent } NH_3\text{-N Removed} = -70.076 (\text{Log}_{10} \text{ Effluent BOD}) + 131.579 \quad \text{------}(1)$$

and this regression accounts for 93% of the variation observed in percent NH_3-N removal data. If the data from the fifth experiment are not included in the regression because of the unstable conditions within some of the filters during this experiment, the equation becomes

$$\text{Percent } NH_3\text{-N Removed} = -73.805\,(\text{Log}_{10} \text{ Effluent BOD}) + 134.27 \quad \text{------(2)}$$

and this regression accounts for 99% of the variation observed in the percent NH_3-N Removal data.

The data from all the experiments fit the regression of Equ. 1 very well, although the fit is improved slightly if the 6 m^3/m^3.d data are not included, as in Equ. 2. This indicates that filters operating at higher hydraulic loadings may produce effluents which do not fit the linear relationship. Equ. 1 describes the data from all the experiments well however and could be used with reasonable confidence in predicting the nitrification performance if the effluent BOD could also be predicted.

Fig 8.3.5 shows the relationship between BOD load applied and BOD load removed during all experiments. The regression of these lines and the correlation coefficients are:

	Corr. coeff.
Exp. 2, BOD Load Removed = 0.983(BOD Load) - 8.57 ------(3)	0.9990
Exp. 3, " " " = 0.976(BOD Load) - 34.93 ------(4)	0.9995
Exp. 4, " " " = 0.751(BOD Load) - 21.91 ------(5)	0.9984
Exp. 5, " " " = 0.656(BOD Load) - 16.20 ------(6)	0.9843

At the different hydraulic and organic loading rates used during each experiment the slope of this relationship differed, although the correlation coefficients are always high. From these equations the effluent BOD expected from a filter operated at a known flow rate and sewage BOD can be calculated with reasonable accuracy. This figure can then be used in Equ. 2 to estimate the expected degree of nitrification.

These equations may be of value in both the prediction and optimisation of filter performance, although several assumptions are made in the experiments which may not be valid when considering the operation of full scale biological filters. The experiments assume that neither filter medium nor temperature limit filter performance, that filter condition is good and ponding absent, and that the absence of invertebrate populations does not adversely affect performance. Williams and Taylor (1967) report that filters operated without mixed invertebrate populations do not perform as efficiently as those with mixed invertebrate populations, and therefore the filters used in these experiments may have produced better quality effluents had invertebrates been present. The assumption that filter medium and temperature do not limit nitrification are valid in these experiments, but pilot-scale investigations would be required to ascertain whether the relationship between effluent BOD and percent NH_3-N removal would exist under non-controlled conditions with a filter medium of a more conventional type. The relationship between BOD load and BOD load removed has already been shown to apply in pilot-scale operation (Section 5.7). The correlation coefficients of Equ. 1 - 6 are all very high, and the strength of these relationships suggests that they would hold over a wide range of operating conditions and that conventional filters operated under closely controlled loading conditions would, in all probability, produce similar results provided nitrification was not inhibited by low temperatures or inhibitory substances in the sewage.

Fig. 8.3.1 BOD load applied vs. percent NH_3-N removed. Nitrification experiments.

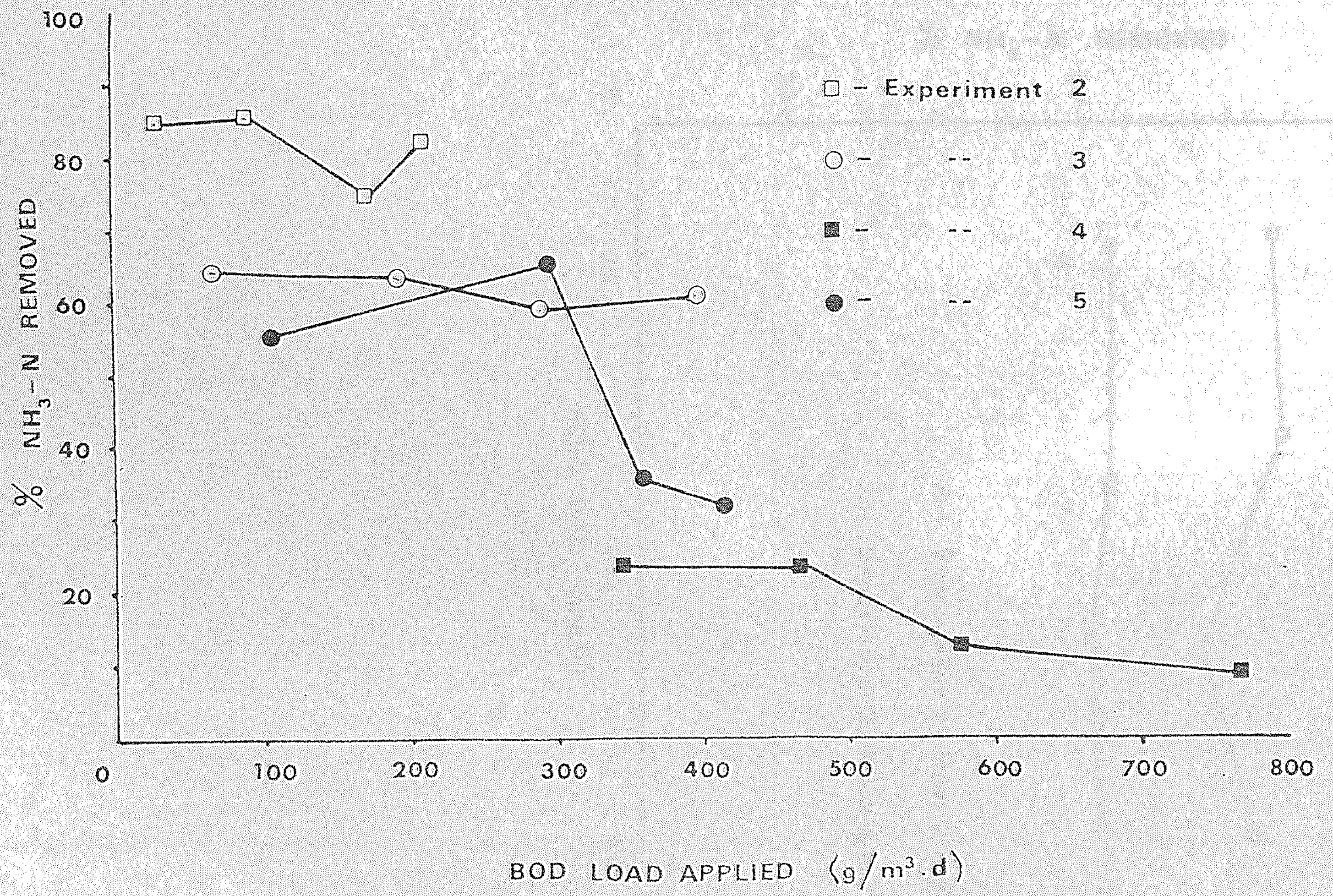


Fig. 8.3.2 Feed BOD concentration vs. percent NH_3-N removed at two different flow rates. Nitrification experiments 2 and 3.

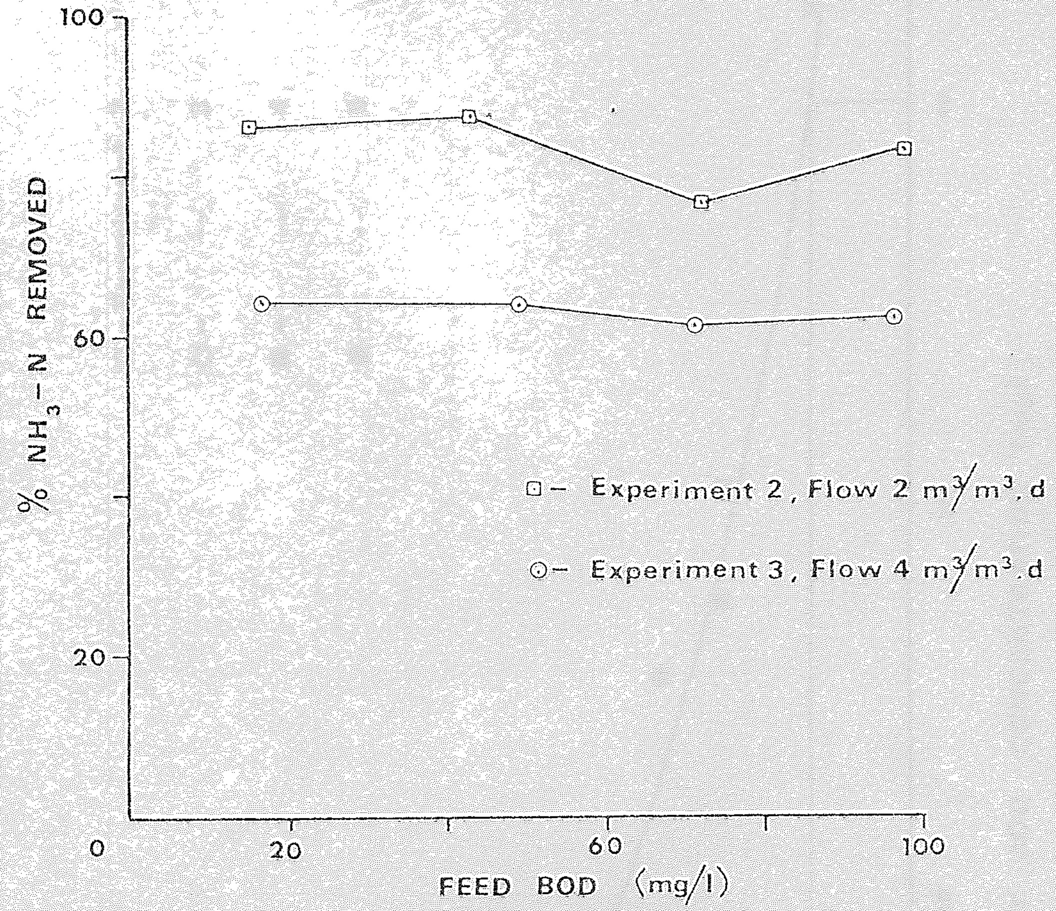
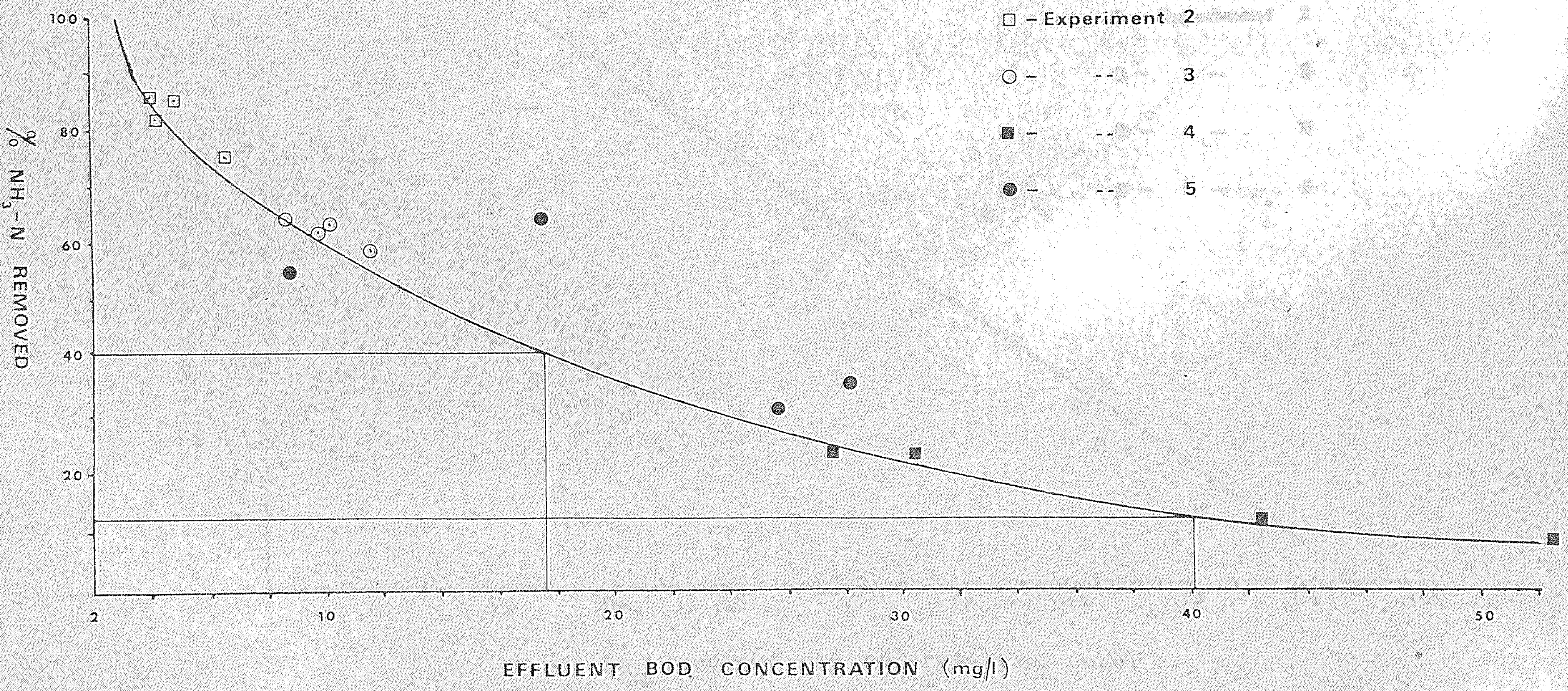


Fig 8.3.3 Effluent BOD concentrations vs. percent NH_3-N removed. Nitrification experiments.



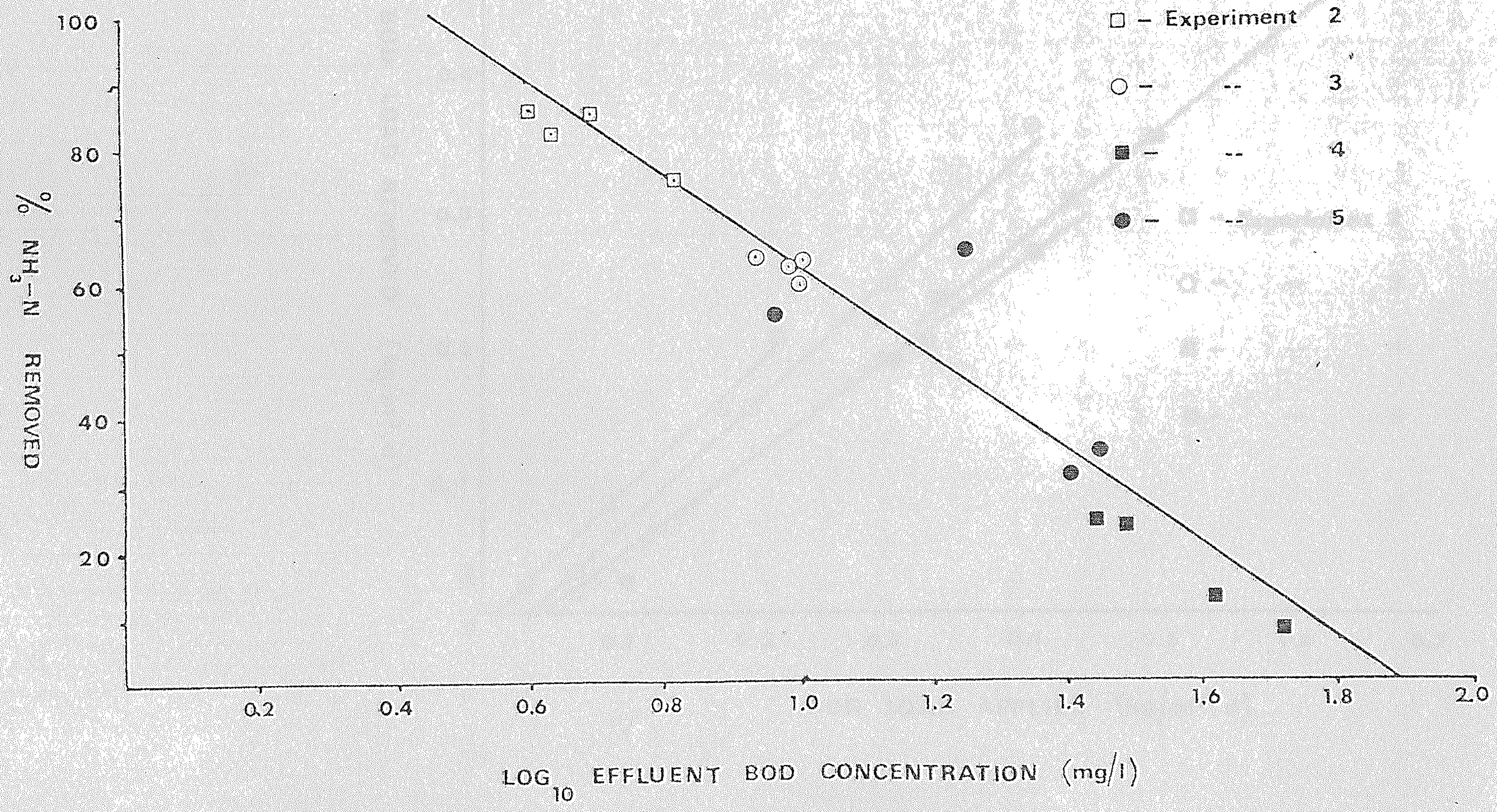
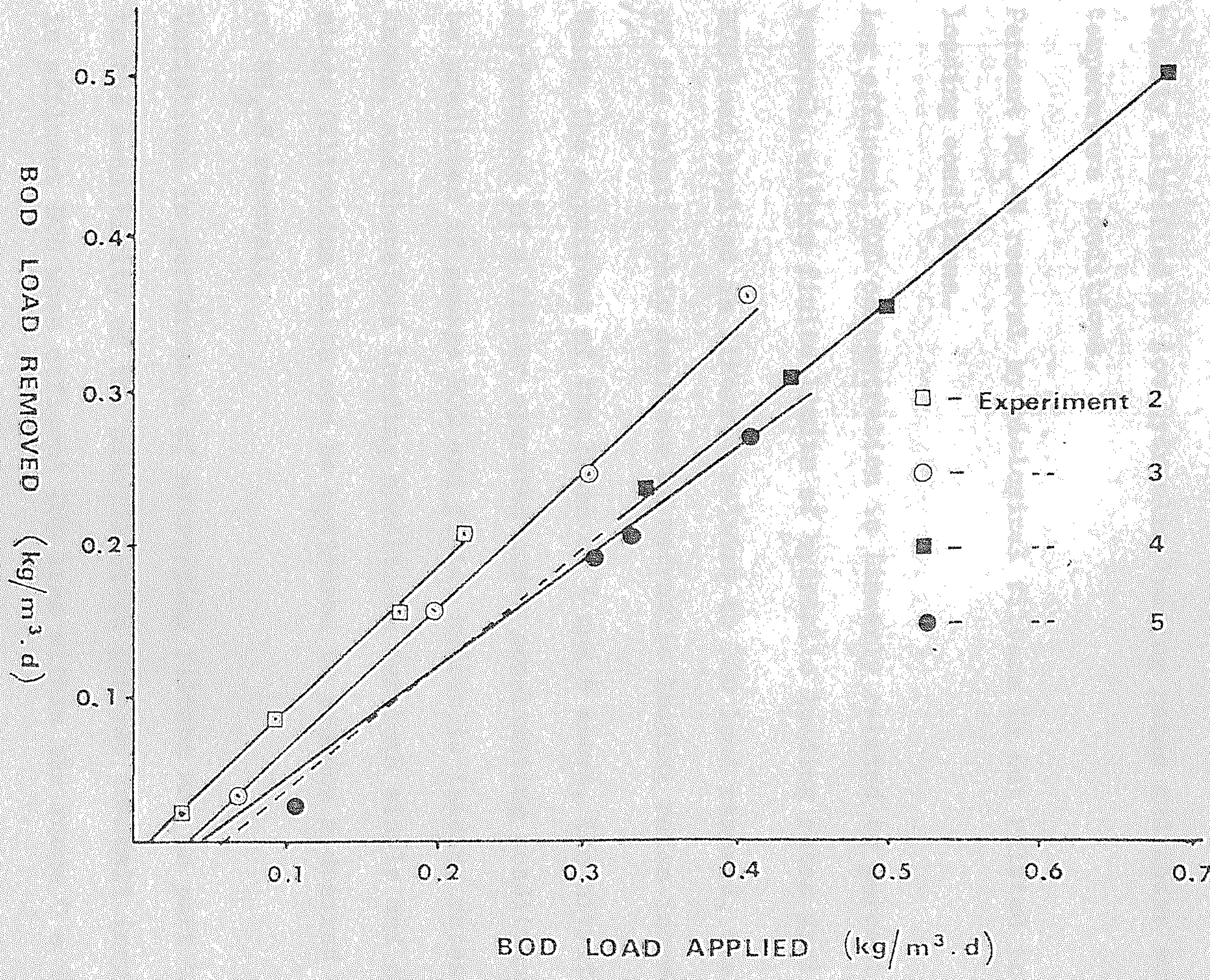


Fig. 8.3.4 Log_{10} effluent BOD concentration vs. percent NH_3-N removed. Nitrification experiments.

Fig. 8.3.5 BOD load applied vs. BOD load removed. Nitrification experiments.



8.4 Conclusions

1 The effluent from the Flocor R2S medium of the secondary filter is readily nitrified at low hydraulic loading rates and under suitable temperature conditions.

2 Percent NH_3-N removal by biological filters is not related to BOD loading conditions.

3 Log effluent BOD concentration is linearly related to percent NH_3-N removal, within finite limits of hydraulic loading rates applied.

4 BOD load applied is linearly related to BOD load removed, the slope of the relationship declines as hydraulic loading rates increase.

5 Using the equations of the lines of 3 and 4 above, the nitrification performance of a filter operated under non-limiting conditions can be predicted if sewage BOD and filter hydraulic loading rates are known, and therefore loading conditions for both single and multi-stage filtration units can be optimised to produce a desired degree of NH_3-N removal.

6 Variations in performance of nitrifying filters may in part be due to the sensitivity of the nitrification process to small increases in effluent BOD when effluent BOD lies within the range 0 - 17.5 mg/l.

9 Synthesis and conclusions

The physico-chemical data obtained during two and a half years operation of high rate primary filters and two years operation of secondary filters run at intermediate hydraulic loadings show that such a two stage filtration plant could be used to successfully treat the seasonally strong municipal sewage at Hereford. It is believed that this system, with small adjustments to the loading conditions applied to either the primary or secondary filtration stage, could produce Royal Commission standard effluents.

Of the four mineral media studied no real differences in performance capability were found. At a nominal hydraulic loading of 5.6 $m^3/m^3.d$, with sewage having a 90 percentile BOD concentration of 536 mg/l, the filters removed an average of 73% of the BOD applied. The media with the greatest SSA generally performed very slightly better than those with the lowest, although the smaller media tended to develop heavier biological film levels during periods of high organic loading and low temperature. At no stage in the investigation did ponding develop, nor did filter efficiency ever deteriorate badly through the excessive accumulation of film in any of the mineral medium filters.

Detailed study of the biology and ecology of the mineral medium filters revealed that Psychoda alternata and enchytraeid worm spp. dominated the invertebrate fauna of the film, while the film itself was dominated by fungi. The level and condition of the film was found to largely control the size of the invertebrate and protozoan populations, particularly during the winter months when organic loadings were high and temperatures low. Only during the summer months, when film levels tended to be low due to the reduced organic loading and increased rate of microbial lysis of fungal mycelia, could invertebrate numbers increase to a level where they could contribute to the control of film accumulation by grazing. The role of grazing in film control is considered to have been minor however.

Statistical analysis of the physico-chemical data provided by the study of the plastic medium primary filters showed that while there were real differences between the performances of the different media, particularly at different times of the year, the overall average percent BOD load removed figures attained by each individual medium varied over the narrow range of 63% (Flocor M) to 68% (Biopac 50). Although Biopac 50 produced the best overall performance this medium was prone to deterioration in effluent quality due to the seasonally high accumulation of film. This film occasionally developed to a point where ponding almost occurred - a problem which was not usually encountered with the other pilot plant media.

The fauna and flora of the plastic medium filters were similar to those described in the mineral filters, although the extent to which heavy film levels suppressed the invertebrate population was greater in the two Biopac media than in any of the mineral media. The modular Flocor media were found to support very low volumes of biological film because of their open, ordered structures which allow sloughed film to be flushed rapidly from the filter. As film levels were low in the Flocor filters, film conditions never became anaerobic and consequently these media supported the most diverse protozoan population of the primary filters. In all of the pilot plant media the most frequently occurring protozoan species were Opercularia microdiscum and flagellate spp., while nematode spp. were also very common. The role of the grazing invertebrate populations in controlling film accumulation is again believed to have been minor, although the lower rates of film accumulation and the absence of film anaerobicity in the Flocor M and E filters may have enabled a slightly greater degree of influence to be exerted by the invertebrate grazers.

The ease with which sloughed film was washed from the modular Flocor filters probably accounts for the fact that the humus sludge production rates (expressed as g humus produced/g BOD removed) of these media were higher than those of the other primary filter media. Although the sludge production rates of all of the primary filter media were found to be higher than those reported for low rate filters, no seasonal off-loading of the film was observed, nor were any seasonal variations in sludge condition or conditionability detected. All of the humus sludge produced by the media of the pilot plant (including the secondary filters) and the low rate filter humus from Hereford STW could be satisfactorily dewatered after chemical conditioning with between 4.5 and 24.5 kg Zetag 88 per tonne dry sludge solids. No differences were found between the dewaterability of the random-fill high rate filter sludges of the pilot plant and the low rate filter sludge produced at Hereford STW when treating the same sewage. The humus sludges produced by the modular media were more difficult to dewater than any of the other sludges tested however. This is because sludge conditionability has been shown to be linearly related to the biological loading applied to the filter (expressed as g BOD/g Biomass/day), and as the Flocor media supported low volumes of biological film the biological loading applied to these filters was always high and consequently sludge conditionability was poor. Differences observed between the conditionability of the sludges produced by the other media of the primary filters have been ascribed to the affect that differences in medium configuration, SSA and surface texture have on the degree of film accumulation and consequently on biological loading. Hence the small random-fill Biopac 50 medium encouraged a high degree of film retention, and as a result the biological loading to this filter was the lowest applied to any of the primary filters and the sludge produced was the most easily dewatered.

The relationship between biological loading and sludge conditionability may be used to explain why some high rate filters have in the past been reported as producing sludges with poor dewatering characteristics. It also suggests that where possible high rate filter media should be used which will promote the greatest accumulation of biological film possible (i.e. small random-fill media with small void spaces) while avoiding any risk of ponding, and that high rate filters may not be suitable if the waste to be treated does not encourage film growth (e.g. sewage of purely domestic origin) - if the humus sludge produced is to be dewatered prior to disposal.

Of the plastic medium primary filters, Biopac 50 produced both the highest quality effluents and the most easily dewatered sludge. This medium almost ponded on several occasions however, and although it has been shown that under certain limited conditions a reduction in periodicity of dosing could reduce film levels in this filter, it is felt that the risk of total ponding would be too great to justify its use to treat Hereford municipal sewage. The Flocor M medium did not perform as well as the others studied and is also not considered suitable for use at Hereford, although it is difficult to assess the effect that the 11% lower volume of this filter and the consequently higher organic loadings applied had on effluent quality. The Flocor E and Biopac 90 filters produced effluents of very similar quality, although occasionally the heavy film levels supported by Biopac 90 caused a slight loss of efficiency. Flocor E consistently produced greater quantities of humus sludge than Biopac 90 however and this sludge was also considerably more difficult to dewater. In view of this fact Biopac 90 is considered to be most suitable of the plastic media studied for use in treating Hereford sewage, provided that the seasonal peaks in sewage strength continue to decline in the future. If seasonal peaks in sewage strength were to return to the levels recorded in 1978-9, Flocor E would become the most suitable medium as Biopac 90 could pond if consistently loaded at very high rates. While none of the media suffered any marked loss of efficiency due to overloading during this study it is believed that the maximum loading applied approached the highest each medium could withstand without loss of efficiency.

In view of the fact that none of the mineral media studied performed any better than the others, the 125/75 Granite is considered to be the most suitable medium for the high rate filtration of sewage at Hereford, as this filter exhibited the least propensity for heavy film accumulation of those investigated.

The differences in efficiency between the two secondary filter media during the two year study were marked and consistent, with the Flocor RS medium producing better quality effluents than the Flocor R2S. Ninety percent of the Flocor RS effluent samples satisfied a 25 mg/l BOD and 30 mg/l SS standard, and had continuous operation been possible the effluent could well have reached the 20:30 Royal Commission standard. Ninety percent of the Flocor R2S effluent samples satisfied a 40:40 standard and it is unlikely that Royal Commission effluents could have been produced by this medium at the hydraulic and organic loading rates employed. Filter efficiency was never affected by high film levels in either medium, and although the grazing fauna was basically similar to that observed in the primary filters greater diversity was found in the secondary filter media. The biological film of these filters was dominated by bacteria, and although fungi were occasionally present they never became fully established. Invertebrate grazing is believed to have exerted a greater degree of control over film levels than observed in the primary filter, although in no instance did invertebrate grazing affect filter performance.

Full maturity may not have been attained by the secondary filters during this study, and while it is possible that some nitrification could have developed on maturity it is highly unlikely that full nitrification could be achieved with either medium under the operating conditions imposed. If high rate two stage filtration were to be used at Hereford, a tertiary nitrification stage would be required to satisfy any NH_3-N standards imposed, although as the Hereford sewage has very low NH_3-N concentrations this tertiary treatment stage would only be necessary if strict standards were introduced. Biological film may have been seasonally offloaded by the secondary filter media during August and February of each year, although this offloading was not marked. Sludge production rates were high in both of the secondary filters, and this may be attributable to the fact that the interstage settlement of primary filter effluents was inadequate and that the filters were not biologically mature. These factors may also explain why the relationship between biological loading and sludge dewaterability did not apply to the secondary filter sludges.

Flocor RS would obviously be the medium most suited to the secondary filtration of sewage at Hereford, and - with some fine adjustments to operating conditions - this medium would probably produce Royal Commission standard effluents if used in a full-scale two stage filtration system. Flocor R2S would probably be more suited to the treatment of weak municipal sewage than the secondary filtration of strong sewage, or alternatively in a situation where a more liberal standard than Royal Commission was required. In neither of the two media is ponding likely to be experienced if they are operated at a nominal flow rate of 4.0 m^3/m^3.d and if sewage strength did not exceed a 90 percentile BOD concentration of 210 mg/l.

The overall performance of the two stage filtration pilot plant illustrates that sewage having a 90 percentile BOD value of 536 mg/l and SS value of 269 mg/l can be treated to a standard of 25 mg/l BOD and 30 mg/l SS by primary treatment with either Biopac 90 at a nominal flow rate of

11.2 m^3/m^3.d (removing 66% of the BOD load) or 125/75 Granite at a nominal flow rate of 5.6 m^3/m^3.d (removing 72% of the BOD load), followed by brief interstage settlement and secondary treatment with Flocor RS at a nominal flow rate of 4.0 m^3/m^3.d. As the relationship between BOD load applied and BOD load removed was found to be linear in all filter media, the loading conditions required to produce effluent of any given BOD concentration could be calculated if the sewage BOD were known.

The effluent produced by the Flocor RS filter could be readily nitrified at low hydraulic loading rates and under suitable temperature conditions. If tertiary biological filtration were to be employed to produce final effluents which satisfied an NH_3-N standard the degree of nitrification achieved by these filters would be linearly related to Log_{10} of the effluent BOD concentration. Using this relationship, and the linear relationships between BOD load applied and BOD load removed, the loading conditions required during each stage of treatment to satisfy a final effluent NH_3-N standard could be optimised.

9.1 Conclusions

1. Two stage high rate filtration could be used to produce effluents of Royal Commission standard when treating seasonally strong municipal sewage.

2. Mineral medium primary filters operated at a nominal hydraulic loading of 5.6 $m^3/m^3.d$ successfully removed an average of 73% of the BOD load applied when the 90 percentile BOD concentration of the sewage was 536 mg/l.

3. Plastic medium primary filters operated at a nominal hydraulic loading of 11.2 $m^3/m^3.d$ successfully removed an average of 66% of the BOD load applied.

4. The 125/75 Granite was considered to be the most suitable primary filter mineral medium as it showed the least propensity for heavy film accumualtion of those studied.

5. Although Biopac 50 produced the best overall effluent quality and the most easily dewatered humus sludge of the primary filter plastic media studied, the risk of ponding in this medium is considered too great to justify its use in the high rate filtration of wastes with high C:N ratios.

6. The Biopac 90 was considered to be the most suitable plastic filter medium provided that seasonal peaks in sewage strength were not excessively high.

7. The Flocor E was considered to be the most suitable plastic filter medium if seasonal peaks in sewage strength became excessively high.

8. The invertebrate grazing population of the primary filters was restricted to *Psychoda alternata* and enchytraeid worm spp. during most of the study. The role of these invertebrates in controlling the level of fungal film which accumulated in the filters is

considered to have been minor.

9. Reducing the periodicity of dosing from two to three minutes caused a reduction in biological film levels in the Biopac 50 medium, data relating to the effects of the change in the other primary filter media were inconclusive.

10. Sludge dewaterability was shown to be linearly related to biological loading (expressed as g BOD applied /g Biomass/day) and this relationship may explain why some high rate filters have been reported as producing sludge which is difficult to dewater.

11. The humus sludge produced by the random-fill high rate filter media were no more difficult to dewater than those produced by low rate filtration of the same sewage, while modular plastic media produced sludges which were more difficult to dewater.

12. The Flocor RS was considered to be the most suitable secondary filter medium, producing effluents of a 25 mg/l BOD and 30 mg/l SS standard when the 90 percentile BOD concentration of the sewage was 210 mg/l.

13. While the invertebrate grazing population was basically the same as in the primary filters there was greater species diversity in the secondary filters. Grazing by invertebrates may have exerted a significant influence in the control of film levels in these filters.

14. All media tested produced greater quantities of sludge than normally expected of low rate filters. Very high sludge production rates in the secondary media may have been partly due to poor interstage settlement and the biological immaturity of the filters.

15. The BOD removal and nitrification performance of a biological filter could be predicted if the sewage BOD and proposed hydraulic loading rates were known, and this could be used in the optimisation of the

operating conditions used in a sewage treatment works.

Appendix 4.3.1 Dates, duration and reasons for pilot plant shutdowns lasting one day or longer.

Date	Duration (days) of shutdown	Filters affected	Reason
10.09.78	1	Primary	Broken pipe on primary sedimention tank (PST)
21.09.78	3	Primary	Maintenance to PST
16.11.78	1	Primary mineral	Maintenance to effluent drain sumps on pilot plant
12.01.79	5	Primary	Failure of Mono pump on PST supplying sewage to pilot plant
02.04.79	3	Primary	Re-siting of supply Mono pump
11.04.79	6	Primary	Re-siting of supply Mono pump
20.05.79	5	Primary	Overhaul of distributor motor on primary plastic media filter and changing both primary filter distributor drive gear ratios
03.06.79	1	All	PST failure
07.06.79	60	Secondary	Secondary filter distributor drive functioning only intermittently
29.11.79	1	Secondary	Not known
05.01.80	2	All	PST shut down due to excessive grit accumulations following heavy rain
18.01.80	3	All	Power failure
25.02.80	20	Secondary	Distributor motor and moter cut-out switch failure
18.03.80	7	All	Sewage supply lost due to fractured supply pipe
14.05.80	22	Secondary	Intermittent electrical fault on distributor drive motor
30.05.80	1	All	Power failure
30.07.80	20	Primary plastic	Distributor drive motor failure
30.07.80	1	All	Gross solids blocking primary filter distributor jets intermittently
05.08.80	1	Secondary	Intermittent electrical fault on distributor drive motor
15.09.80	4	All	Gross solids blocking primary filter distributor jets intermittently
23.02.81	1	All	Failure of supply Mono pump
24.02.81	2	Primary plastic	Failure of distributor drive motor
15.03.81	9	Primary plastic	Failure of distributor drive motor

Appendix 4.3.3a Data from nitrogen sample preservation investigation.

Ammoniacal - Nitrogen data.

Sample origin	Days stored	Preservation technique Acid	Min. Acid	Chloroform	Mercury	Alkali	Frozen	Fridge	Room Temp.
T1 - Primary feed	0	5.3	5.5	5.1	4.4	5.2	5.1	4.7	4.7
	1	5.5	5.4	5.3	4.3	5.0	5.2	4.4	4.6
	6	5.5	5.6	5.2	4.5	4.8	4.3	4.7	7.4
	9	5.6	5.6	5.5	4.5	5.0	4.5	6.8	6.3
	16	5.7	5.6	5.3	4.5	4.9	3.6	7.5	0.4
	23	5.6	5.6	5.5	4.7	4.8	4.4	7.5	0.2
	30	5.6	5.6	5.4	4.4	3.6	4.7	8.1	0.1
	60	5.9	6.0	5.6	5.1	3.4	5.2	0.1	0.2
T2 - Secondary feed	0	5.6	5.6	5.1	4.8	5.1	5.1	4.9	4.8
	1	5.5	5.5	5.3	4.9	5.2	5.2	5.1	5.3
	6	5.6	5.8	5.3	4.8	5.2	5.1	5.6	7.1
	9	5.7	5.9	5.8	4.9	5.3	5.2	6.6	5.7
	16	5.6	5.8	5.4	4.7	4.5	4.9	7.3	0.1
	23	5.8	5.8	5.5	4.8	4.4	4.7	7.6	0.1
	30	5.6	5.8	5.2	4.7	3.7	4.7	7.6	0.1
	60	5.6	5.8	5.6	4.8	4.8	4.5	0.1	0.1
17 - Flocor R2S effluent	0	5.7	5.8	5.5	5.1	5.5	5.6	5.3	5.2
	1	5.8	5.8	5.4	5.3	5.3	5.5	5.3	5.3
	6	5.9	6.0	5.4	5.1	5.4	5.3	5.3	2.3
	9	5.9	6.0	5.6	5.2	5.5	5.5	5.7	0.2
	16	6.0	6.0	5.5	5.0	4.7	5.6	6.0	0.1
	23	6.0	6.1	5.6	5.0	5.0	5.3	5.8	0.1
	30	5.9	6.0	5.6	4.9	4.6	5.3	4.6	0.1
	60	5.9	6.0	5.6	5.1	4.5	5.2	0.1	0.1

All data expressed as mg N/l

Appendix 4.3.3b Data from nitrogen sample preservation investigation.

Nitrate - Nitrogen data.

		Preservation technique							
Sample origin	Days stored	Acid	Min. Acid	Chloroform	Mercury	Alkali	Frozen	Fridge	Room Temp.
T1 - Primary feed	0	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00
	1	0.05	0.00	0.15	0.05	0.05	0.00	0.00	0.00
	6	0.00	0.00	0.20	0.00	0.05	0.05	0.00	0.10
	9	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00
	16	0.00	0.05	0.10	0.00	0.00	0.00	0.05	-
	23	0.00	0.00	0.05	0.05	0.05	0.00	0.00	8.20
	30	0.00	0.00	0.10	0.10	0.00	0.00	0.05	8.90
	60	0.05	0.00	0.05	0.05	0.10	0.00	0.90	9.50
T2 - Secondary feed	0	0.35	0.30	0.30	0.20	0.20	0.20	0.25	0.20
	1	0.35	0.35	0.40	0.30	0.30	0.25	0.25	0.20
	6	0.30	0.30	0.50	0.30	0.30	0.30	0.10	0.10
	9	0.30	0.25	0.45	0.25	0.25	0.25	0.30	1.05
	16	0.30	0.35	0.40	0.25	0.30	0.25	0.75	7.90
	23	0.38	0.33	0.35	0.33	0.35	0.28	0.25	8.30
	30	0.35	0.35	0.40	0.35	0.35	0.30	1.15	8.20
	60	0.35	0.40	0.45	0.35	0.30	0.30	9.50	8.60
17 - Flocor R2S effluent	0	1.05	1.00	1.10	0.95	0.95	0.95	1.05	1.00
	1	1.10	1.15	1.25	1.10	1.10	1.05	1.20	1.20
	6	1.10	1.20	1.40	1.25	1.10	1.15	1.45	2.70
	9	1.10	1.05	1.30	1.05	1.05	1.05	1.45	7.85
	16	1.10	1.10	1.10	1.10	1.05	1.05	1.65	8.60
	23	1.13	1.20	1.10	1.08	1.08	1.05	2.30	7.90
	30	1.15	1.15	1.15	1.00	1.15	1.15	3.70	8.70
	60	1.20	1.20	1.20	1.10	1.10	1.10	8.60	9.50

All data expressed as mg N/l.

Appendix 4.3.3c Data from nitrogen sample preservation investigation.

Nitrite - Nitrogen data.

Sample origin	Days stored	Preservation technique							
		Acid	Min. Acid	Chloroform	Mercury	Alkali	Frozen	Fridge	Room Temp.
T1 - Primary feed	0	0.000	0.000	0.005	0.005	0.005	0.005	0.005	0.005
	1	0.000	0.000	0.000	0.005	0.005	0.000	0.005	0.000
	6	0.000	0.000	0.000	0.005	0.005	0.005	0.005	0.015
	9	0.000	0.000	0.025	0.000	0.005	0.000	0.005	1.670
	16	0.000	0.000	0.010	0.000	0.005	0.005	0.004	>4.000
	23	0.000	0.000	0.005	0.005	0.010	0.005	0.010	0.020
	30	0.000	0.000	0.003	0.005	0.005	0.000	0.010	0.025
	60	0.000	0.000	0.025	0.005	0.005	0.000	0.005	0.005
T2 - Secondary feed	0	0.115	0.170	0.240	0.240	0.235	0.260	0.230	0.235
	1	0.100	0.140	0.210	0.220	0.215	0.215	0.235	0.125
	6	0.070	0.080	0.200	0.220	0.220	0.210	0.105	0.230
	9	0.050	0.090	0.200	0.210	0.210	0.205	0.165	0.835
	16	0.035	0.070	0.200	0.220	0.210	0.205	0.015	0.020
	23	0.025	0.045	0.195	0.220	0.215	0.200	0.005	0.020
	30	0.018	0.035	0.198	0.223	0.218	0.200	0.010	0.025
	60	0.000	0.005	0.195	0.220	0.220	0.190	0.005	0.005
17 - Flocor R2S effluent	0	0.140	0.185	0.245	0.240	0.235	0.260	0.230	0.265
	1	0.120	0.140	0.220	0.230	0.220	0.215	0.215	0.330
	6	0.080	0.105	0.220	0.220	0.200	0.220	0.160	1.070
	9	0.045	0.095	0.220	0.220	0.220	0.205	0.045	0.015
	16	0.030	0.065	0.215	0.215	0.215	0.205	0.005	0.015
	23	0.020	0.050	0.210	0.220	0.220	0.205	0.015	0.005
	30	0.018	0.038	0.218	0.228	0.220	0.210	0.025	0.000
	60	0.005	0.010	0.205	0.220	0.230	0.190	0.005	0.000

All data expressed as mg N/l.

Appendix 5.1.1 Monthly averaged flow rate data ($m^3/m^3.d$). Primary filters.

		1978							1979							
Month	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
Mineral media	5.73	4.80	4.18	4.18	4.60	5.69	3.68	4.54	4.81		6.27	3.86	4.30	6.63	5.57	6.87
Plastic media	9.59	10.20	9.06	9.46	11.09	10.92	10.60	8.59	9.83		10.27	10.54	8.69	11.08	11.71	12.18
Flocor M	10.66	11.33	10.07	10.51	12.33	12.12	11.78	9.54	10.91		11.40	11.72	9.66	12.31	13.01	13.54

					1980									1981		
Month	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A
Mineral media	5.70	7.83	7.64			4.94	6.21	8.13	4.10	5.78	4.62	5.56	5.36		5.71	
Plastic media	10.55	12.23	13.42			12.54	14.59	14.06	13.09	11.08	9.83	12.61	12.47		12.55	11.70
Flocor M	11.72	13.59	14.91			13.95	16.21	15.62	14.17	12.31	10.92	14.01	13.86		13.94	13.00

Appendix 5.1.2a BOD data from routine sampling of primary filter sewage and effluents. Quarter 1.4. Sept. - Nov. 1978.

		BOD (mg/1)										
Date		4/9	12/9	9/10	12/10	19/10	23/10	26/10	2/11	6/11	9/11	14/11
Shaken sewage		515.0	545.0	445.0	712.5	582.0	987.0	672.0	722.0	800.0	740.0	865.0
Settled sewage		251.0	347.0	403.5	542.5	487.0	950.0	542.0	557.0	587.0	590.0	687.0
Filter No :-	1	91.0	125.0	126.0	307.5	199.0	204.0	212.0	217.0	153.0	211.0	287.0
	2	103.0	139.0	139.0	322.0	201.0	208.0	220.0	209.0	174.0	225.0	278.0
	3	84.0	130.0	144.5	308.0	192.0	192.0	201.0	203.0	156.0	231.0	281.0
	4	119.5	180.0	143.0	340.0	193.0	238.0	232.0	227.0	207.0	235.0	292.0
	5	95.5	131.5	135.0	314.5	203.0	203.0	209.0	213.0	153.0	212.0	283.0
	6	105.0	137.0	135.0	319.5	207.0	209.0	223.0	212.0	176.0	231.0	271.0
	7	83.0	127.5	150.5	307.0	193.0	191.0	200.0	207.0	151.0	230.0	288.0
	8	117.0	176.0	139.0	342.0	200.0	234.0	230.0	225.0	208.0	234.0	282.0
	9	114.0	208.5	132.5	328.0	269.0	260.0	267.0	277.0	226.0	253.0	310.0
	10	118.0	206.0	161.5	334.0	236.0	267.0	268.0	289.0	212.0	257.0	312.0
	11	118.5	221.5	174.5	350.0	246.0	266.0	274.0	300.0	221.0	271.0	323.0
	12	122.5	217.5	177.5	354.0	249.0	267.0	274.0	-	223.0	273.0	321.0
	13	119.5	207.0	129.0	330.0	271.0	258.0	272.0	289.0	227.0	249.0	306.0
	14	124.0	207.5	158.5	333.0	234.0	268.0	270.0	291.0	207.0	263.0	311.0
	15	127.0	225.0	178.5	390.0	302.0	284.0	283.0	214.0	253.0	275.0	320.0
	16	129.0	219.0	179.0	385.0	302.0	281.0	281.0	-	254.0	275.0	324.0

Appendix 5.1.2b BOD data from routine sampling of primary filter sewage and effluents. Quarter 2.1.

Dec. 1978 - Feb. 1979.

	BOD (mg/l)									
Date	12/12	14/12	8/1	22/1	25/1	1/2	5/2	12/2	15/2	19/2
Shaken sewage	183.0	177.0	382.5	302.5	340.0	325.0	380.0	380.0	355.0	315.0
Settled sewage	-	-	335.0	200.0	285.0	242.5	250.0	240.0	265.0	230.0
Filter No :- 1	83.0	47.0	80.0	39.0	42.5	56.5	62.5	46.0	42.5	34.5
2	89.0	56.0	93.5	38.0	48.5	61.0	55.5	38.5	44.0	35.5
3	79.0	32.0	96.0	30.5	37.0	52.0	53.0	47.0	51.5	41.5
4	82.0	58.0	106.0	67.0	52.5	46.5	67.0	45.0	45.5	38.5
5	85.0	49.0	84.0	36.5	35.5	56.0	58.5	45.5	41.0	40.0
6	90.0	52.0	87.0	32.5	44.5	56.0	58.0	40.0	41.0	37.0
7	80.0	35.0	91.5	34.5	47.0	50.5	53.0	43.0	49.0	42.0
8	82.0	59.0	110.5	63.5	57.0	44.0	60.5	44.5	42.5	38.5
9	122.0	61.0	208.5	100.0	121.5	82.5	97.0	100.5	118.5	82.0
10	113.0	52.0	136.0	69.0	81.5	66.5	92.5	77.0	107.5	59.5
11	122.0	66.0	140.5	63.5	79.0	56.5	108.5	75.5	104.0	46.0
12	122.0	68.0	139.5	62.5	77.0	55.5	108.5	75.5	102.5	47.5
13	121.0	57.0	210.0	97.0	121.0	82.0	100.5	104.5	119.0	80.5
14	115.0	46.0	134.5	63.5	81.0	63.0	94.0	75.0	111.0	61.0
15	139.0	102.0	157.0	74.5	107.0	61.5	100.5	79.5	107.5	64.5
16	141.0	101.0	158.5	76.0	112.5	62.5	97.5	78.5	107.5	63.0

Appendix 5.1.2c <u>BOD data from routine sampling of primary filter sewage and effluents. Quarter 2.2.</u>

<u>Mar. - May 1979.</u>

	BOD (mg/l)										
Date	12/3	15/3	9/4	19/4	23/4	26/4	30/4	10/5	15/5	17/5	22/5
Shaken sewage	275.0	470.0	260.0	305.0	332.5	397.5	412.5	330.0	190.0	270.0	370.0
Settled sewage	217.5	422.5	237.5	275.0	207.5	345.0	297.5	210.0	147.5	210.0	245.0
Filter No :- 1	55.0	105.5	50.0	67.0	38.5	96.0	94.0	87.0	41.5	58.0	86.0
2	42.5	93.5	54.0	73.0	38.0	95.5	83.5	79.5	45.0	45.5	91.5
3	56.5	114.0	51.5	66.0	39.5	84.0	83.0	89.0	57.0	71.5	84.0
4	37.5	101.5	44.0	67.0	41.5	88.0	83.5	94.5	27.5	51.0	84.0
5	50.0	101.0	51.0	69.5	39.5	99.0	92.0	86.0	36.0	54.0	90.5
6	41.5	95.5	52.0	75.5	37.0	93.0	83.5	79.0	42.0	43.0	91.5
7	48.5	114.0	50.5	67.5	40.5	95.0	85.5	90.5	56.0	67.0	86.0
8	37.0	99.0	42.5	69.5	38.0	89.0	85.5	90.0	31.0	54.0	84.5
9	57.5	148.5	44.5	66.5	39.5	99.0	78.5	74.5	43.5	67.5	79.5
10	57.0	156.5	51.5	115.0	89.5	145.5	92.0	139.0	95.0	100.0	123.5
11	53.0	136.5	44.0	106.0	57.0	94.0	79.0	97.5	46.5	64.5	86.0
12	50.5	135.0	44.5	106.5	55.5	92.0	78.5	96.5	46.5	62.5	88.5
13	55.0	152.0	48.5	70.0	38.5	101.5	78.5	70.0	40.5	69.5	79.5
14	56.5	157.0	52.5	111.0	91.5	146.0	92.0	140.5	95.0	97.5	122.5
15	54.0	145.5	57.0	93.5	50.5	95.5	76.5	86.5	66.0	69.0	90.0
16	53.5	143.0	57.0	94.0	49.0	94.0	78.5	88.5	66.0	70.0	88.0

Appendix 5.1.2d <u>BOD data from routine sampling of primary filter sewage and effluents. Quarter 2.3.</u>

<u>Jun. - Aug. 1979.</u>

	BOD (mg/l)												
Date	12/7	17/7	19/7	23/7	27/7	30/7	2/8	6/8	9/8	13/8	16/8	23/8	30/8
Shaken sewage	245.0	331.0	328.0	233.0	270.0	500.0	305.0	320.0	377.0	350.0	545.0	420.0	525.0
Settled sewage	237.0	302.0	302.0	193.0	227.0	322.0	250.0	275.0	340.0	237.0	492.0	300.0	442.0
Filter No :- 1	95.5	146.0	98.0	53.0	51.0	55.5	51.5	34.0	58.0	38.5	90.0	26.0	119.0
2	108.5	183.0	94.0	64.5	54.5	51.5	52.5	46.5	48.5	46.5	100.0	28.5	121.0
3	85.5	156.0	91.5	42.5	38.0	47.0	30.0	38.5	39.0	39.0	94.5	20.5	120.0
4	125.5	189.0	104.0	60.0	82.0	70.0	56.0	57.5	62.5	36.5	87.5	42.5	144.0
5	103.0	158.0	91.0	50.0	54.0	53.0	50.0	37.0	56.5	38.0	90.0	27.0	114.5
6	109.0	154.5	107.0	58.5	55.5	53.0	47.0	49.0	55.5	41.5	100.5	30.0	120.0
7	88.5	153.5	91.5	38.5	42.5	46.0	35.5	31.5	54.0	38.5	101.5	24.0	113.5
8	115.5	175.0	82.5	64.5	75.0	72.0	57.0	60.0	57.0	36.5	91.0	37.0	141.0
9	101.0	153.5	102.5	22.5	61.0	54.5	43.0	49.5	44.5	34.5	98.0	45.5	88.5
10	125.5	163.5	144.0	46.5	84.5	67.0	51.5	50.0	47.0	34.5	109.0	94.5	118.5
11	115.5	136.0	146.0	104.0	94.5	75.5	67.0	52.5	85.5	47.0	141.5	137.0	139.5
12	114.5	183.5	147.5	101.5	95.5	78.5	67.0	54.0	84.0	47.0	138.5	138.0	141.0
13	99.5	140.5	96.5	30.0	64.0	53.0	45.5	45.5	47.0	38.0	98.5	45.0	119.0
14	117.0	151.0	160.0	57.5	78.0	71.5	54.0	55.5	49.5	40.0	111.5	96.0	119.0
15	139.5	189.0	189.5	115.5	115.0	102.0	84.5	101.5	114.5	52.0	146.5	131.5	148.5
16	143.5	178.0	190.0	115.5	115.5	103.0	86.5	101.5	113.0	51.5	144.5	133.0	146.0

Appendix 5.1.2e BOD data from routine sampling of primary filter sewage and effluents. Quarter 2.4.

Sep. - Nov. 1979.

	BOD (mg /1)											
Date	3/9	6/9	20/9	24/9	27/9	15/10	22/10	25/10	29/10	5/11	12/11	15/11
Shaken sewage	412.0	467.0	382.0	260.0	527.0	540.0	500.0	537.5	520.0	407.5	597.5	407.5
Settled sewage	290.0	370.0	272.0	195.0	492.0	467.5	407.5	420.0	387.5	372.5	445.0	357.5
Filter No :- 1	32.5	78.0	104.0	59.0	230.0	117.0	205.5	129.0	145.5	78.5	155.5	181.0
2	50.5	104.5	104.5	59.5	236.0	109.5	241.5	145.5	134.0	95.5	182.0	165.5
3	46.0	93.0	75.5	46.5	215.5	85.0	204.0	124.5	125.5	98.5	161.5	177.5
4	59.0	119.5	100.0	59.0	218.5	117.0	221.5	147.5	125.5	92.5	155.5	168.5
5	33.5	80.5	103.0	55.0	229.5	121.0	210.0	131.5	144.0	73.5	153.0	171.0
6	47.0	119.0	102.0	58.0	236.0	109.5	135.5	144.0	135.5	98.5	182.0	165.5
7	46.5	79.0	69.5	48.0	220.0	86.0	200.0	122.0	126.5	97.0	157.5	186.5
8	58.5	107.0	103.0	61.5	221.5	113.5	222.5	150.0	131.0	91.0	162.0	165.5
9	78.5	105.0	22.5	46.5	227.0	105.5	232.5	125.5	152.5	127.0	228.0	203.0
10	79.5	121.5	112.5	56.5	234.5	110.0	207.0	133.0	167.0	105.5	218.0	181.0
11	108.0	132.0	139.5	64.0	254.0	122.5	252.5	184.5	157.0	130.0	235.0	191.0
12	111.0	134.0	141.0	64.5	253.0	124.0	252.0	186.5	157.0	131.5	233.5	191.5
13	75.5	141.0	21.5	43.5	222.5	105.5	230.0	125.5	157.0	130.0	225.0	204.5
14	77.5	142.5	106.5	59.0	235.0	110.0	211.0	132.5	164.0	108.5	218.0	180.5
15	111.0	156.0	135.5	82.0	240.0	147.0	268.0	188.5	186.0	154.5	241.0	198.0
16	110.0	116.0	138.5	82.0	241.5	146.5	-	186.5	187.0	156.0	239.0	199.5

Appendix 5.1.2f <u>BOD data from routine sampling of primary filter sewage and effluents. Quarter 3.1.</u>

<u>Dec. 1979 - Feb. 1980.</u>

	BOD (mg/l)													
Date	3/12	6/12	12/12	3/1	22/1	24/1	28/1	4/2	11/2	15/2	18/2	21/2	25/2	28/2
Shaken sewage	382.5	325.0	340.0	452.5	350.0	230.0	247.5	270.0	260.0	237.5	187.5	200.0	142.5	172.5
Settled sewage	227.5	267.5	280.0	270.0	277.5	200.0	182.5	192.5	132.5	187.5	140.0	157.5	95.0	150.0
Filter No :- 1	108.0	122.5	144.5	124.5	90.0	44.5	50.0	44.0	67.0	80.0	58.0	74.0	42.5	67.5
2	109.5	126.0	134.0	127.0	83.0	46.5	41.0	37.5	53.0	67.0	45.0	60.0	38.5	63.0
3	111.0	138.0	135.0	104.0	77.0	51.5	38.5	32.0	64.0	95.5	55.5	79.0	44.0	61.5
4	96.5	104.0	129.0	121.0	82.0	30.0	49.0	39.5	58.5	64.5	35.5	55.5	19.5	56.0
5	101.0	124.0	143.0	130.0	93.5	44.0	46.5	44.0	61.5	86.0	61.0	78.5	39.5	68.0
6	114.0	122.5	137.0	124.0	79.0	39.5	41.5	40.0	59.0	66.0	42.5	62.5	35.0	63.0
7	115.0	138.5	134.0	107.0	74.5	49.0	36.5	31.5	73.0	100.0	55.5	76.5	42.0	61.5
8	97.0	100.0	130.0	124.0	73.5	30.0	45.5	37.5	56.0	61.5	33.5	60.0	19.5	53.0
9	124.0	151.5	174.5	119.5	93.5	49.0	60.0	41.0	78.0	100.5	65.0	88.5	41.0	80.0
10	112.5	154.5	157.5	152.5	87.5	88.0	51.0	54.0	93.0	85.0	68.5	90.0	48.5	83.0
11	105.5	110.0	137.5	115.5	97.0	60.0	46.5	41.5	37.0	66.0	33.5	47.0	19.5	50.0
12	102.5	110.0	138.5	116.5	98.0	57.5	47.5	41.5	38.0	65.5	34.0	47.0	18.5	50.0
13	129.5	154.0	174.0	114.0	84.5	48.5	60.5	43.0	83.5	98.0	68.0	88.5	39.5	77.5
14	112.5	152.5	168.0	148.5	91.5	56.5	56.5	50.0	83.0	84.0	66.5	83.5	48.5	83.0
15	108.5	148.0	138.5	129.5	97.0	62.5	55.5	44.0	46.0	72.0	48.5	65.5	40.5	69.0
16	107.0	149.0	137.0	126.0	97.0	62.5	53.5	42.0	48.5	70.5	49.5	64.0	40.0	68.0

Appendix 5.1.2g BOD data from routine sampling of primary filter sewage and effluents. Quarter 3.2.

Mar. - May 1980.

	BOD (mg/l)			
Date	6/3	10/3	13/3	17/3
Shaken sewage	235.0	225.0	195.0	170.0
Settled sewage	185.0	192.5	150.0	120.0
Filter NO :- 1	75.0	77.5	98.0	48.5
2	62.0	78.5	85.5	40.0
3	83.0	87.0	92.0	47.5
4	65.5	67.5	81.5	32.5
5	75.5	74.0	97.5	51.0
6	64.5	80.0	86.0	38.5
7	83.0	90.0	90.5	50.0
8	65.0	67.5	81.5	32.5
9	84.5	108.5	99.0	79.0
10	84.5	106.0	99.0	77.5
11	67.0	64.5	76.0	47.0
12	67.0	64.5	76.0	44.0
13	84.5	106.0	98.5	81.5
14	85.5	106.5	98.5	73.0
15	84.0	84.0	83.0	56.5
16	82.5	75.0	84.5	54.0

Appendix 5.1.2h <u>BOD data from routine sampling of primary filter sewage and effluents. Quarter 3.3.</u>

<u>Jun. - Aug. 1980.</u>

	BOD (mg/l)												
Date	2/6	5/6	9/6	12/6	16/6	19/6	23/6	26/6	30/6	3/7	5/8	7/8	28/8
Shaken sewage	232.0	402.5	262.5	395.0	210.0	292.5	545.0	220.0	275.0	285.0	227.0	295.0	170.0
Settled sewage	227.5	317.5	202.5	330.0	170.0	272.5	500.0	207.5	260.0	265.0	201.5	235.0	130.0
Filter No :- 1	58.0		52.0		31.0		105.5		67.5		70.0		
2	59.5		58.5		33.0		122.5		76.5		84.0		
3	72.5		54.5		25.0		54.0		59.0		58.5		
4	81.0		57.0		37.5		66.0		62.0		105.5		
5		89.0		74.0		74.0		61.0		80.5		68.5	
6		103.5		104.0		109.0		89.5		90.5		75.5	
7		84.5		61.0		81.0		56.5		97.0		71.0	
8		113.5		96.5		101.0		84.0		97.0		75.5	
9	96.0		78.5		48.0		89.5		82.0				25.5
10	92.0		101.5		51.0		88.0		93.0				40.0
11	100.5		80.5		41.0		61.0		93.5				44.0
12		146.5		105.5		105.5		87.5		110.5			44.0
13		151.5		74.0		71.0		59.5		99.0			24.0
14		159.0		108.5		113.0		88.5		103.0			42.5
15	109.0		100.5		49.5		86.5		112.0				54.0
16		165.5		88.5		110.0		96.5		109.0			52.5

Appendix 5.1.2i BOD data from routine sampling of primary filter sewage and effluents. Quarter 3.4.

Sep. - Nov. 1980. (Continued overleaf)

	BOD (mg/1)							
Date	1/9	4/9	8/9	15/9	18/9	22/9	25/9	2/10
Shaken sewage	350.0	285.0	250.0	282.5	482.5	165.0	300.0	332.5
Settled sewage	295.0	257.5	227.5	200.0	442.5	137.5	272.5	300.0
Filter No :- 1	53.0		42.5	49.5		19.0		
2	58.0		50.5	45.5		27.0		
3	62.5		37.5	50.5		19.0		
4	64.0		59.5	54.0		37.0		
5	55.5		44.5	46.5		17.0		
6	63.5		52.5	45.5		27.0		
7	63.0		39.0	51.5		19.5		
8	65.0		58.5	54.0		36.0		
9		85.0			132.5		58.0	71.5
10		97.0			163.0		96.5	96.5
11		134.5			194.0		117.5	161.5
12		136.0			194.0		118.5	160.5
13		87.5			132.5		58.0	72.0
14		100.0			162.0		97.5	93.5
15		141.5			210.0		135.5	161.0
16		140.0			210.0		135.5	159.5

Appendix 5.1.2i(Cont.) BOD data. Quarter 3.4. Sep. - Nov. 1980.

	BOD (mg/l)					
Date	7/10	9/10	14/10	30/10	6/11	10/11
Shaken sewage	277.5	277.5	260.0	200.0	347.5	210.0
Settled sewage	227.5	262.5	245.0	195.0	245.0	200.0
Filter No :- 1	29.5	65.5	57.5			80.0
9	40.0	92.5	58.0			139.0

Date	13/11	17/11	20/11	24/11	27/11
Shaken sewage	235.0	167.5	357.5	252.5	382.5
Settled sewage	185.0	135.0	270.0	230.0	290.0
Filter No :- 1	148.0	86.0	126.0	76.0	155.5
9	192.5	111.5	200.0	123.5	264.5

Appendix 5.1.2j BOD data from routine sampling of primary filter sewage and effluents. Quarter 4.1. Dec. 1980 - Feb. 1981.

	BOD (mg/l)				
Date	1/12	4/12	6/1	8/1	13/1
Shaken sewage	220.0	345.0	330.0	350.0	327.5
Settled sewage	140.0	317.5	300.0	320.0	305.0
Filter NO :- 1	126.5	177.5			
9	180.5	267.5		161.5	

Date	15/1	20/1	22/1	27/1	29/1
Shaken sewage	225.0	265.0	237.5	375.0	255.0
Settled sewage	167.5	212.5	147.5	325.0	150.0

Appendix 5.1.2k BOD data from routine sampling of primary filter sewage and effluents. Quarter 4.2. Mar. - May 1981.

	BOD (mg/l)					
Date	3/3	7/3	10/3	19/3	7/4	14/4
Shaken sewage	387.5	395.0	365.0	220.0	134.0	204.0
Settled sewage	-	-	-	-	-	172.0
Filter No 1	129.0	186.5	80.5			
9	182.5	225.0	122.5	109.5	107.0	101.0

Date	15/4	21/4	28/4	29/4	5/5	7/5
Shaken sewage	195.0	209.0	184.5	377.5	195.0	217.5
Settled sewage	143.5	-	-	-	-	-
Filter No :- 9	102.0	135.0	78.5	122.5	86.0	85.0

Appendix 5.1.3a COD data from routine sampling of primary filter sewage and effluents. Quarter 1.4.

Sep. - Nov. 1978.

	COD (mg/l)											
Date	4/9	12/9	18/9	9/10	12/10	19/10	23/10	26/10	2/11	6/11	9/11	14/11
Shaken sewage	422	-	-	860	-	890	850	1010	1200	1060	910	1050
Settled sewage	388	448	506	580	606	580	610	870	860	710	750	770
Filter No :- 1	234	276	272	264	550	320	354	326	376	318	328	408
2	236	290	224	280	448	312	352	310	364	344	348	390
3	222	282	110	294	442	292	326	284	356	332	350	394
4	254	318	262	286	460	322	390	334	382	370	354	400
5	230	268	260	268	434	322	360	320	372	316	322	412
6	232	280	222	274	436	316	386	284	360	334	344	394
7	220	270	218	284	428	284	316	280	350	326	352	384
8	246	316	252	276	466	316	384	326	378	372	360	406
9	230	312	270	262	450	360	376	340	417	356	364	384
10	260	334	300	296	446	352	370	344	422	340	368	406
11	238	324	266	342	460	340	348	380	432	348	400	422
12	232	328	264	336	464	342	354	374	-	352	406	428
13	226	302	262	250	448	354	366	350	408	362	370	380
14	254	324	284	292	436	356	374	332	424	332	374	412
15	230	312	278	344	486	370	378	378	436	384	420	510
16	232	318	272	340	480	364	372	376	-	380	424	506

Appendix 5.1.3b COD data from routine sampling of primary filter sewage and effluents. Quarter 2.1. Dec. 1978 - Feb. 1979.

	COD (mg/l)											
Date	12/12	14/12	18/12	8/1	22/1	25/1	29/1	1/2	5/2	12/2	15/2	19/2
Shaken sewage	382	386	434	428	388	408	428	390	382	436	458	422
Settled sewage	332	322	316	390	370	376	406	372	356	382	-	-
Filter No :- 1	182	122	218	222	170	138	140	132	174	132	128	106
2	176	134	204	220	166	142	152	124	184	142	132	104
3	198	112	196	218	156	140	148	134	178	130	138	100
4	168	130	210	220	210	146	154	122	186	130	116	96
5	172	120	210	212	160	130	146	126	168	136	126	100
6	182	126	192	208	162	134	144	126	178	138	120	104
7	196	106	190	210	152	184	142	128	170	132	132	98
8	174	124	208	224	214	188	146	118	182	124	112	100
9	188	118	212	310	198	198	168	150	244	196	180	146
10	185	122	224	260	172	162	146	148	228	168	182	156
11	174	128	236	246	214	154	152	142	250	194	160	120
12	172	132	234	250	208	156	150	138	246	188	160	124
13	178	114	202	316	200	202	162	154	242	192	176	142
14	186	120	210	268	178	156	154	156	234	158	172	152
15	180	166	218	258	218	172	166	140	244	182	192	130
16	176	162	224	262	220	166	172	144	240	186	186	128

Appendix 5.1.3c COD data from routine sampling of primary filter sewage and effluents. Quarter 2.2. Mar. - May 1979.

	COD (mg/1)										
Date	12/3	15/3	9/4	19/4	23/4	26/4	30/4	10/5	15/5	17/5	22/5
Shaken sewage	426	548	414	522	508	492	424	492	372	398	484
Settled sewage	-	-	350	400	386	346	366	338	294	330	406
Filter No :- 1	194	172	118	162	156	224	216	206	158	170	206
2	168	186	112	186	148	218	198	200	150	150	202
3	192	212	110	178	166	216	200	210	168	172	212
4	150	180	102	194	154	212	186	218	148	142	194
5	172	174	122	158	150	228	210	200	152	162	192
6	162	180	116	182	154	208	192	194	154	146	198
7	198	206	116	182	168	208	202	206	164	168	210
8	156	176	108	192	150	204	182	216	152	140	198
9	208	258	104	174	154	232	174	194	152	174	208
10	208	266	122	206	194	264	216	262	170	206	250
11	184	208	114	214	160	228	196	214	148	164	194
12	178	212	110	218	166	222	198	220	146	166	198
13	214	260	110	172	150	226	176	190	148	170	200
14	212	270	124	200	184	268	222	266	172	200	244
15	186	224	132	202	154	224	190	214	160	166	202
16	182	226	128	198	148	228	192	210	164	160	196

Appendix 5.1.3d <u>COD data from routine sampling of primary filter sewage and effluents. Quarter 2.3.</u>

Jun. - Aug. 1979.

	COD (mg/1)													
Date	12/7	17/7	19/7	23/7	27/7	30/7	2/8	6/8	9/8	13/8	16/8	20/8	23/8	30/8
Shaken sewage	450	514	534	496	400	412	392	482	382	394	470	498	496	510
Settled sewage	428	496	486	414	358	376	346	420	348	336	390	430	374	416
Filter No :- 1	298	308	224	204	162	154	180	182	142	118	162	146	124	226
2	260	322	256	206	168	144	166	204	138	150	184	144	134	202
3	-	-	224	186	150	136	144	170	124	116	160	150	100	184
4	-	-	234	190	214	186	198	228	142	128	160	192	138	222
5	-	-	220	198	160	146	168	178	144	120	158	150	188	212
6	-	-	230	176	152	150	168	200	142	142	182	140	130	194
7	226	304	226	158	146	140	156	170	134	112	184	152	104	178
8	248	312	214	194	212	192	260	246	140	134	168	194	132	224
9	202	238	214	162	188	140	150	184	130	100	150	194	156	172
10	224	296	302	204	204	172	166	194	132	124	192	204	166	176
11	222	268	310	260	210	180	188	200	182	148	238	210	216	192
12	-	-	304	242	190	186	188	200	178	148	238	212	220	190
13	-	-	208	168	170	138	154	190	126	108	156	188	150	182
14	-	-	284	190	194	178	164	194	136	118	198	206	160	174
15	-	-	344	252	202	222	222	266	190	154	248	250	192	220
16	298	330	362	282	206	216	220	268	192	158	250	256	190	216

Appendix 5.1.3e COD data from routine sampling of primary filter sewage and effluents. Quarter 2.4.
Sep. - Nov. 1979.

	COD (mg/l)												
Date	3/9	6/9	20/9	24/9	27/9	15/10	22/10	25/10	29/10	5/11	12/11	15/11	19/11
Shaken sewage	486	558	436	438	1060	1380	1970	492	2000	640	850	620	750
Settled sewage	422	392	370	372	492	750	1900	468	1880	414	710	428	570
Filter No :- 1	142	184	226	180	324	224	348	226	364	208	272	284	246
2	140	206	222	170	320	234	384	254	256	238	288	284	230
3	130	198	158	162	378	202	320	206	222	240	268	280	210
4	166	214	202	166	308	230	342	234	246	222	272	278	220
5	138	178	216	182	314	218	342	220	354	202	266	282	240
6	134	200	214	174	312	228	384	248	248	236	284	280	224
7	136	194	154	162	282	196	318	200	216	210	262	276	206
8	174	216	210	172	306	232	338	238	244	216	270	274	216
9	172	200	192	158	292	210	334	196	234	244	352	304	240
10	186	210	198	176	304	208	346	230	257	230	314	290	226
11	210	232	240	202	332	234	396	284	240	252	338	302	218
12	204	228	236	206	328	236	400	286	242	250	334	306	218
13	166	202	188	156	288	206	330	200	236	246	346	310	244
14	182	214	190	180	302	204	352	228	254	236	312	288	222
15	210	246	224	214	316	312	500	306	292	278	370	322	244
16	208	242	220	212	318	316	502	310	288	274	374	326	246

Appendix 5.1.3f COD data from routine sampling of primary filter sewage and effluents. Quarter 3.1. Dec. 1979 - Feb. 1980.

	COD (mg/l)														
Date	3/12	6/12	12/12	3/1	22/1	24/1	28/1	31/1	4/2	11/2	15/2	18/2	21/2	25/2	28/2
Shaken sewage	494	402	452	1090	444	342	402	408	404	438	368	386	386	368	374
Settled sewage	360	340	374	424	394	318	346	322	290	380	334	328	324	322	304
Filter No :- 1	226	218	254	252	186	132	170	158	126	166	166	166	212	164	168
2	236	230	236	230	180	144	162	156	136	170	158	142	148	142	164
3	246	250	228	196	176	176	146	140	140	182	192	170	154	128	178
4	222	216	262	230	178	140	180	166	152	148	154	134	136	122	146
5	218	222	248	242	176	128	172	152	124	160	170	160	156	168	166
6	250	234	234	236	174	138	156	150	142	166	152	138	134	144	160
7	288	244	222	200	174	164	144	142	134	174	190	164	152	132	170
8	220	210	266	232	172	134	174	172	148	150	160	130	132	126	148
9	228	276	240	206	178	128	154	142	190	156	156	148	144	144	172
10	210	234	270	238	170	152	184	154	160	164	148	154	148	152	188
11	218	220	238	234	194	156	154	176	126	122	135	122	116	112	148
12	222	218	234	232	200	156	156	174	128	120	134	120	116	116	152
13	234	274	236	210	172	122	152	140	182	152	152	144	138	138	166
14	206	230	266	232	168	148	178	158	154	162	146	146	150	156	184
15	224	256	246	244	202	160	162	164	162	157	150	132	132	132	158
16	226	260	244	240	206	156	166	160	156	160	146	128	134	130	154

Appendix 5.1.3g COD data from routine sampling of primary filter sewage and effluents. Quarter 3.2. Mar. - May 1980.

	COD (mg/l)			
Date	6/3	10/3	13/3	17/3
Shaken sewage	362	434	394	406
Settled sewage	304	412	364	360
Filter No :- 1	158	188	212	170
2	134	178	206	168
3	168	194	218	170
4	144	166	186	156
5	164	190	218	166
6	130	186	202	164
7	172	190	214	172
8	148	168	180	150
9	152	210	200	198
10	162	210	200	198
11	150	180	186	164
12	148	186	192	160
13	158	206	204	196
14	166	210	206	178
15	154	236	192	150
16	150	220	192	156

Appendix 5.1.3h <u>COD data from routine sampling of primary filter sewage and effluents. Quarter 3.3. Jun. - Aug. 1980.</u>

	COD (mg/l)												
Date	2/6	5/6	9/6	12/6	16/6	19/6	23/6	26/6	30/6	3/7	5/8	7/8	28/8
Shaken sewage	402	422	422	436	410	432	416	434	448	428	408	414	370
Settled sewage	358	378	366	382	338	404	362	380	414	382	360	342	324
Filter No :- 1	180		174		148		164		198		176		
2	186		200		146		178		216		238		
3	168		190		142		168		164		214		
4	172		204		142		200		196		260		
5		196		190		198		170		202		196	
6		210		202		252		196		212		204	
7		212		172		220		168		224		194	
8		274		188		218		190		220		198	
9	238		222		168		210		214				202
10	196		228		170		212		238				192
11	234		246		154		182		212				210
12		226		206		228		288		250			212
13		290		178		196		154		214			210
14		326		212		266		198		196			184
15	260		244		166		200		258				204
16		374		190		240		224		212			206

Appendix 5.1.3i COD data from routine sampling of primary filter sewage and effluents. Quarter 3.4.

Sep. - Nov. 1980.

	COD (mg/1)						
Date	1/9	4/9	8/9	15/9	18/9	22/9	25/9
Shaken sewage	458	426	452	428	770	408	610
Settled sewage	388	392	386	398	710	366	570
Filter No :- 1	180		172	182		144	
2	204		188	184		182	
3	190		174	196		138	
4	180		196	204		154	
5	170		168	186		144	
6	200		190	182		178	
7	188		172	192		140	
8	184		198	206		156	
9		236			288		222
10		258			342		280
11		286			368		298
12		292			370		296
13		226			292		226
14		252			346		284
15		310			380		300
16		306			380		300

Appendix 5.1.4a Settled sample suspended solids data from routine sampling of primary filter sewage and effluents.
Quarter 1.4. Sep. - Nov. 1978.

Settled Sample Suspended Solids (mg/l)												
Date	4/9	12/9	18/9	9/10	12/10	19/10	23/10	26/10	2/11	6/11	9/11	14/11
Sewage	109	65	234	213	190	147	159	185	221	138	159	122
Filter No :- 1	79	57	137	87	119	96	114	204	134	86	93	93
2	66	24	128	92	129	86	98	114	127	92	101	91
3	70	43	113	90	116	94	102	108	130	79	93	87
4	71	52	130	88	148	82	111	134	124	93	96	100
5	69	55	129	83	114	93	122	113	131	76	86	92
6	68	33	122	98	126	82	111	103	127	85	100	90
7	62	48	108	98	117	89	89	198	122	82	108	97
8	67	59	125	90	123	73	97	114	134	95	92	111
9	49	31	131	78	108	87	81	110	135	89	103	111
10	64	84	148	88	103	89	106	113	144	82	99	112
11	59	34	139	124	122	96	102	119	139	84	109	112
12	66	45	146	118	115	97	104	116	133	86	114	115
13	53	33	137	81	140	90	89	118	123	287	96	111
14	62	85	133	102	102	88	109	115	137	97	104	104
15	59	87	131	108	126	106	115	138	147	96	114	107
16	59	93	131	115	115	104	116	138	142	98	117	103

Appendix 5.1.4b <u>Settled sample suspended solids data from routine sampling of primary filter sewage and effluents.</u>

Quarter 2.1. Dec. 1978 - Feb. 1979.

	Settled sample Suspended Solids (mg/l)											
Date	12/12	14/12	18/12	8/1	22/1	25/1	29/1	1/2	5/2	12/2	15/2	19/2
Shaken sewage	201	187	188	210	145	165	196	270	258	194	145	132
Settled sewage	129	118	101	71	88	98	109	124	111	109	98	78
Filter No :- 1	86	74	80	40	45	23	65	73	43	52	50	59
2	90	83	67	37	49	32	66	61	49	59	56	68
3	105	69	78	32	41	29	71	59	45	59	38	56
4	88	70	61	38	52	25	70	49	45	47	39	62
5	76	75	69	36	46	24	69	62	45	58	37	59
6	87	83	70	34	39	29	67	60	51	54	42	68
7	95	55	61	35	42	28	65	53	42	47	34	56
8	87	64	66	31	37	32	53	43	43	51	38	71
9	86	57	53	33	49	48	60	65	38	59	44	64
10	76	67	51	43	41	37	66	68	41	64	41	74
11	91	88	57	38	44	45	67	76	62	80	58	77
12	88	91	68	46	42	41	62	74	60	86	38	83
13	81	56	56	28	51	49	79	76	44	61	44	63
14	88	65	57	36	39	37	67	64	41	69	53	73
15	87	74	58	42	52	62	86	87	58	89	56	87
16	81	84	61	40	62	57	82	87	54	88	52	78

Appendix 5.1.4c Settled sample suspended solids data from routine sampling of primary filter sewage and effluents.

Quarter 2.2. Mar. - May 1979.

	Settled sample Suspended Solids (mg/l)										
Date	12/3	15/3	9/4	19/4	23/4	26/4	30/4	10/5	15/5	17/5	22/5
Shaken sewage	258	213	168	168	216	178	269	242	207	212	258
Settled sewage	158	117	97	85	102	112	151	117	140	125	162
Filter No :- 1	74	51	31	59	64	86	129	57	68	68	119
2	55	48	43	72	65	81	115	71	73	69	116
3	75	53	34	53	75	81	114	70	91	81	117
4	57	48	34	67	65	77	116	72	81	72	113
5	69	50	31	62	65	88	111	62	69	65	116
6	64	41	42	65	59	83	110	67	73	67	101
7	70	45	30	52	68	77	108	57	91	69	118
8	48	49	30	65	67	75	116	75	68	73	100
9	74	53	43	55	66	67	114	58	99	77	102
10	70	56	45	69	70	74	112	70	98	70	102
11	68	74	38	66	75	73	107	64	94	73	95
12	72	78	40	71	71	73	114	74	92	71	87
13	71	55	41	52	65	69	118	58	106	76	100
14	57	63	46	64	74	67	112	65	94	69	102
15	75	77	47	49	72	57	117	81	103	88	102
16	73	77	52	47	68	61	114	78	105	83	107

Appendix 5.1.4d <u>Settled sample suspended solids data from routine sampling of primary filter sewage and effluents.</u>

<u>Quarter 2.3.</u> <u>Jul. - Aug. 1979.</u>

	Settled sample Suspended Solids (mg/l)													
Date	12/7	17/7	19/7	23/7	27/7	30/7	2/8	6/8	9/8	13/8	16/8	20/8	23/8	30/8
Shaken sewage	247	176	213	173	139	148	154	176	135	162	234	267	226	235
Settled sewage	98	132	145	120	89	90	120	104	102	107	152	149	109	141
Filter No :- 1	63	64	56	56	42	40	55	42	26	35	54	38	36	58
2	50	79	58	67	31	35	52	45	37	47	58	44	26	48
3	-	-	53	65	32	29	54	44	42	43	48	47	49	56
4	-	-	69	57	51	41	69	55	26	42	32	69	45	66
5	-	-	78	61	45	20	60	48	28	39	63	38	38	57
6	-	-	68	67	36	31	51	47	38	49	56	40	28	42
7	58	63	59	61	30	28	62	50	29	37	52	50	56	48
8	65	75	66	54	24	43	64	49	31	44	37	72	46	59
9	36	90	71	79	30	35	59	36	21	39	41	51	44	49
10	55	79	79	45	42	27	59	40	29	40	56	49	60	54
11	60	62	97	74	46	46	68	41	44	46	74	64	62	63
12	-	-	97	76	46	42	67	44	47	44	79	63	75	63
13	-	-	66	64	28	29	54	42	22	32	43	63	46	47
14	-	-	85	48	36	31	64	43	36	36	56	51	44	53
15	-	-	103	78	63	50	82	64	52	49	73	74	73	52
16	75	85	116	76	59	61	81	67	48	46	84	75	71	62

Appendix 5.1.4e <u>Settled sample suspended solids data from routine sampling of primary filter sewage and effluents.</u>

<u>Quarter 2.4.</u> <u>Sep. - Nov. 1979.</u>

	Settled sample Suspended solids (mg/l)												
Date	3/9	6/9	20/9	24/9	27/9	15/10	22/10	25/10	29/10	5/11	12/11	15/11	19/11
Shaken sewage	158	259	209	254	322	199	275	194	235	227	277	205	277
Settled sewage	67	161	155	186	187	133	204	130	149	128	159	112	170
Filter No :- 1	27	60	94	84	107	63	73	40	77	50	58	71	67
2	16	66	91	70	102	54	100	43	89	56	74	67	59
3	26	67	53	75	103	54	69	30	62	61	65	78	65
4	19	64	82	67	99	58	72	37	65	41	67	66	67
5	26	57	100	83	105	64	78	37	75	48	63	69	68
6	17	69	92	65	102	51	98	48	87	54	74	76	63
7	25	64	54	78	102	53	67	35	62	71	53	83	67
8	19	67	86	76	97	57	77	44	68	51	62	67	64
9	24	83	67	94	89	55	84	28	66	68	89	78	71
10	32	83	73	103	101	42	77	40	73	60	71	75	64
11	37	93	79	109	125	55	98	76	88	83	104	79	83
12	40	91	81	108	126	59	101	75	94	78	107	79	81
13	22	80	64	95	95	44	82	35	69	66	90	74	69
14	33	82	66	97	100	51	74	41	68	57	72	71	62
15	52	89	93	118	123	75	130	76	102	89	111	85	83
16	49	90	100	119	125	75	132	75	100	87	113	87	83

Appendix 5.1.4f Settled sample suspended solids data from routine sampling of primary filter sewage and effluents.

Quarter 3.1. Dec. 1979 - Feb. 1980.

	Settled sample Suspended Solids (mg/1)														
Date	3/12	6/12	12/12	3/1	22/1	24/1	28/1	31/1	4/2	11/2	15/2	18/2	21/2	25/2	28/2
Shaken sewage	251	199	221	369	178	155	155	104	191	175	191	153	155	140	167
Settled sewage	125	128	128	164	105	112	95	60	94	102	149	106	120	98	109
Filter No :- 1	72	57	73	95	65	48	62	43	45	49	48	50	46	51	49
2	77	59	69	103	63	51	68	38	52	63	39	41	48	55	60
3	78	63	52	79	52	50	62	42	50	59	45	50	51	59	44
4	76	63	69	88	67	40	70	43	58	51	48	44	56	47	65
5	73	58	69	96	62	51	59	43	41	48	48	49	41	52	53
6	84	64	71	90	59	49	61	39	50	60	37	40	52	56	54
7	67	57	50	74	55	53	68	44	47	58	48	49	52	64	43
8	77	64	66	83	66	44	71	44	53	57	49	45	59	40	65
9	71	70	72	63	65	56	60	63	52	49	49	53	45	50	48
10	67	61	67	90	61	66	58	44	51	56	47	49	48	53	69
11	87	65	79	83	63	63	59	61	59	51	44	55	59	44	64
12	85	62	75	84	63	65	64	66	61	47	45	53	60	51	65
13	74	64	76	58	65	52	58	68	52	52	51	42	54	53	46
14	66	59	64	93	65	65	57	54	40	54	46	46	47	51	65
15	78	70	71	93	68	75	63	54	46	60	66	61	54	61	55
16	97	72	71	91	72	72	61	56	47	62	67	57	53	58	56

Appendix 5.1.4g Settled sample suspended solids data from routine sampling of primary filter sewage and effluents.

Quarter 3.2. Mar. - May 1980.

	Settled sample Suspended Solids (mg/l)			
Date	6/3	10/3	13/3	17/3
Shaken sewage	182	177	144	178
Settled sewage	88	119	107	123
Filter No :- 1	29	63	63	69
2	41	70	51	65
3	38	73	52	67
4	38	68	52	61
5	31	65	62	67
6	43	75	54	65
7	40	73	50	60
8	36	81	55	57
9	30	66	47	80
10	36	68	50	60
11	38	81	53	94
12	37	77	52	96
13	27	62	50	77
14	35	62	49	63
15	37	72	52	84
16	38	70	54	87

Appendix 5.1.4h Settled sample suspended solids data from routine sampling of primary filter sewage and effluents.

Quarter 3.3. Jun. - Aug. 1980.

	Settled sample Suspended Solids (mg/l)												
Date	2/6	5/6	9/6	12/6	16/6	19/6	23/6	26/6	30/6	3/7	5/8	7/8	28/8
Shaken sewage	172	192	174	186	206	238	218	191	243	208	145	169	107
Settled sewage	132	117	119	113	117	122	121	132	136	107	112	102	89
Filter No :- 1	45		41		45		51		58		67		
2	55		49		50		49		71		66		
3	53		50		46		58		48		67		
4	49		53		45		67		52		48		
5		31		66		64		48		49		30	
6		43		55		74		64		58		33	
7		46		44		64		44		82		42	
8		54		50		77		65		52		31	
9	58		70		57		61		59				49
10	66		62		71		77		79				57
11	75		74		57		50		77				33
12		63		83		82		45		57			32
13		61		49		59		44		58			57
14		71		48		74		65		43			61
15	76		82		70		76		91				41
16		82		53		72		65		52			38

Appendix 5.1.4i Settled sample suspended solids data from routine sampling of primary filter sewage and effluents.

Quarter 3.4. Sep. - Nov. 1980. (Continued overleaf)

	Settled sample Suspended Solids (mg/l)							
Date	1/9	4/9	8/9	15/9	18/9	22/9	25/9	2/10
Shaken sewage	191	198	161	197	191	154	279	214
Settled sewage	108	120	122	135	135	114	152	135
Filter No :- 1	46		42	47		42		
2	58		55	51		46		
3	50		40	54		34		
4	56		48	48		59		
5	45		38	49		41		
6	58		42	49		46		
7	51		50	53		42		
8	55		48	49		57		
9		52			57		48	55
10		86			65		89	59
11		79			89		87	98
12		83			87		85	99
13		61			55		53	55
14		83			65		87	57
15		77			83		99	103
16		79			85		95	99

Appendix 5.1.4i (Cont.) Settled sample suspended solids data. Quarter 3.4. Sep. - Nov. 1980.

	Settled sample Suspended Solids (mg/l)											
Date	7/10	9/10	14/10	16/10	30/10	6/11	10/11	13/11	17/11	20/11	24/11	27/11
Shaken sewage	215	216	160	179	196	237	219	255	244	263	272	262
Settled sewage	138	163	112	140	114	103	139	196	191	200	167	200
Filter No :- 1	51	81	46	27	-	-	68	106	78	95	59	69
9	43	62	38	21	-	-	78	100	69	107	76	101

Appendix 5.1.4j Settled sample suspended solids data from routine sampling of primary filter sewage and effluents. Quarter 4.1. Dec. 1980 - Feb. 1981.

	Settled sample Suspended Solids (mg/l)									
Date	1/12	4/12	6/1	8/1	13/1	15/1	20/1	22/1	27/1	29/1
Shaken sewage	199	237	182	229	163	162	178	146	199	186
Settled sewage	139	161	122	159	123	102	152	118	123	55
Filter No :- 1	90	97								
9	93	129								

Appendix 5.1.4k Settled sample suspended solids data from routine sampling of primary filter sewage and effluents. Quarter 4.2. Mar. - May 1981.

	Settled sample Suspended Solids (mg/l)			
Date	3/3	7/3	10/3	19/3
Shaken sewage	223	242	167	156
Settled sewage	146	151	128	106
Filter No :- 1	96	102	70	-
9	122	117	106	82

Appendix 5.1.5a **Shaken sample suspended solids data from routine sampling of primary filter sewage and effluents.**

Quarter 1.4. Sep. - Nov. 1978.

	Shaken Sample Suspended Solids (mg/l)											
Date	4/9	12/9	18/9	9/10	12/10	19/10	23/10	26/10	2/11	6/11	9/11	14/11
Sewage	223	204	473	336	331	223	289	298	639	318	361	313
Filter No :- 1	198	214	396	207	222	228	254	235	274	167	166	194
2	141	149	281	207	217	168	168	221	284	313	235	198
3	173	211	220	287	257	207	160	203	295	178	233	168
4	167	222	235	184	291	127	184	251	279	229	121	184
5	189	172	393	208	228	219	251	220	277	154	163	189
6	153	155	286	198	212	162	164	221	297	282	190	204
7	162	196	203	275	238	196	154	215	290	168	250	179
8	151	209	237	176	287	142	174	231	254	224	117	193
9	124	188	318	159	271	198	308	273	483	351	231	245
10	275	159	392	211	209	163	334	263	378	226	177	203
11	306	221	432	246	237	203	233	240	414	255	260	229
12	314	217	440	244	238	209	232	242	411	253	253	227
13	129	181	328	155	290	199	303	279	500	345	222	216
14	274	222	370	200	197	170	350	267	366	244	173	190
15	196	227	444	222	250	206	246	272	400	336	246	210
16	206	228	466	217	255	204	254	280	412	338	240	203

Appendix 5.1.5b Shaken sample suspended solids data from routine sampling of primary filter sewage and effluents.

Quarter 2.1. Dec. 1978 - Feb. 1979.

	Shaken sample Suspended Solids (mg/l)											
Date	12/12	14/12	18/12	8/1	22/1	25/1	29/1	1/2	5/2	12/2	15/2	19/2
Shaken sewage	201	187	188	210	145	165	196	270	258	194	145	132
Settled sewage	129	118	101	71	88	98	109	124	111	109	98	78
Filter No :- 1	173	166	220	188	127	65	197	169	129	116	87	119
2	168	192	201	114	152	93	163	143	115	148	92	132
3	207	122	204	119	107	93	152	134	116	127	79	104
4	159	131	200	122	137	86	124	106	96	107	97	137
5	176	172	209	177	126	96	201	158	124	124	90	117
6	174	188	189	118	152	90	157	143	116	141	88	134
7	203	107	188	112	118	85	146	131	118	124	85	98
8	166	130	206	119	155	83	120	108	99	101	83	139
9	181	112	121	134	155	133	193	118	158	138	115	123
10	110	135	127	117	153	102	138	108	138	107	102	152
11	176	138	154	163	123	119	166	176	202	161	136	161
12	185	137	153	161	113	115	164	132	102	157	142	164
13	183	117	114	149	145	136	187	114	163	138	106	129
14	102	133	123	106	149	96	138	103	131	110	103	173
15	148	175	156	196	157	156	201	161	198	179	127	192
16	146	178	163	194	159	154	199	151	205	175	131	193

Appendix 5.1.5c Shaken sample suspended solids data from routine sampling of primary filter sewage and effluents.

Quarter 2.2. Mar. - May 1979.

	Shaken sample Suspended Solids (mg/l)										
Date	12/3	15/3	9/4	19/4	23/4	26/4	30/4	10/5	15/5	17/5	22/5
Shaken sewage	258	213	168	168	216	178	269	242	207	212	258
Settled sewage	158	117	97	85	102	112	151	117	140	125	162
Filter No :- 1	116	145	88	132	172	149	237	105	127	128	179
2	104	125	137	157	161	159	219	116	124	112	174
3	176	123	94	150	187	123	226	105	122	131	221
4	114	128	141	170	172	140	195	147	134	112	156
5	111	124	83	136	167	147	228	105	125	131	171
6	106	121	130	154	159	156	217	116	126	112	172
7	171	123	95	143	183	116	218	100	141	129	210
8	105	124	131	167	166	138	181	142	131	103	145
9	145	154	157	183	200	193	226	118	155	186	198
10	124	152	145	184	199	152	184	145	141	153	220
11	207	161	93	165	167	201	228	117	140	177	193
12	200	147	93	158	161	198	220	112	137	174	186
13	151	158	147	180	203	184	229	124	207	179	193
14	142	147	139	181	195	144	177	146	144	139	222
15	170	178	124	149	184	168	200	187	184	164	214
16	164	182	114	148	183	166	202	191	189	168	218

Appendix 5.1.5d Shaken sample suspended solids data from routine sampling of primary filter sewage and effluents.

Quarter 2.3. Jul. - Aug 1979.

	Shaken sample Suspended Solids (mg/l)													
Date	12/7	17/7	19/7	23/7	27/7	30/7	2/8	6/8	9/8	13/8	16/8	20/8	23/8	30/8
Shaken sewage	247	176	213	173	139	148	154	176	135	162	234	267	226	235
Settled sewage	98	132	145	120	89	90	120	104	102	107	152	149	109	141
Filter No :- 1	116	136	149	122	109	92	141	117	118	89	126	99	107	156
2	113	156	145	152	92	85	96	148	146	103	176	99	141	137
3	-	-	126	126	90	96	95	111	115	105	140	124	158	122
4	-	-	113	87	120	128	114	123	77	81	118	190	175	111
5	-	-	133	114	117	87	135	115	120	92	125	96	98	138
6	-	-	129	137	97	85	89	147	170	105	162	96	151	127
7	117	101	125	107	95	83	105	117	118	98	149	117	151	109
8	122	107	122	86	86	113	101	119	80	80	87	187	179	119
9	127	126	118	93	93	103	135	126	76	113	121	175	126	134
10	138	144	154	93	117	98	107	117	111	85	113	125	127	122
11	109	96	129	152	97	121	118	117	135	99	179	164	187	137
12	-	-	131	141	94	122	121	127	147	97	185	162	188	140
13	-	-	111	87	91	106	157	109	178	99	101	172	121	129
14	-	-	151	95	108	91	97	119	117	175	118	132	121	107
15	-	-	211	161	120	166	138	198	126	97	144	156	203	157
16	185	225	186	158	117	162	145	204	127	98	149	158	197	152

Appendix 5.1.5e Shaken sample suspended solids data from routine sampling of primary filter sewage and effluents.

Quarter 2.4. Sep. - Nov. 1979.

	Shaken sample Suspended Solids (mg/l)												
Date	3/9	6/9	20/9	24/9	27/9	15/10	22/10	25/10	29/10	5/11	12/11	15/11	19/11
Shaken sewage	158	259	209	254	322	199	275	194	235	227	277	205	277
Settled sewage	67	161	155	186	187	133	204	130	149	128	159	112	170
Filter No :- 1	92	96	219	212	223	123	137	98	182	107	101	99	164
2	93	150	175	168	213	104	233	122	187	114	146	115	135
3	105	142	176	110	163	85	100	71	116	142	98	131	164
4	87	107	140	128	139	102	128	91	119	89	101	97	120
5	83	98	206	193	229	121	136	94	180	105	103	100	161
6	94	144	169	163	267	108	236	123	186	114	144	118	161
7	93	139	100	117	143	84	105	70	113	151	101	141	158
8	86	109	134	137	137	101	124	91	120	91	104	99	127
9	115	135	132	170	203	153	155	96	145	168	145	147	133
10	86	144	150	167	228	101	146	95	172	117	102	152	127
11	144	141	174	237	235	111	175	145	193	229	219	160	177
12	147	140	169	240	240	113	177	147	196	217	221	158	175
13	108	131	132	167	204	153	153	96	147	164	148	144	136
14	91	146	147	170	229	103	157	97	176	113	104	153	126
15	147	178	189	256	235	160	259	209	232	218	262	200	209
16	150	176	194	259	233	160	256	204	238	221	256	198	214

Appendix 5.1.5f Shaken sample suspended solids data from routine sampling of primary filter sewage and effluents.

Quarter 3.1. Dec. 1979 - Feb 1980.

	Shaken sample Suspended Solids (mg/1)														
Date	3/12	6/12	12/12	3/1	22/1	24/1	28/1	31/1	4/2	11/2	15/2	18/2	21/2	25/2	28/2
Shaken sewage	251	199	221	369	178	155	155	104	191	175	191	153	155	140	167
Settled sewage	125	128	128	164	105	112	95	60	94	102	149	106	120	98	109
Filter No :- 1	116	156	157	230	189	121	145	100	141	122	175	124	123	150	124
2	165	114	131	200	188	126	156	89	124	148	164	103	113	132	130
3	187	118	113	148	188	157	151	82	140	118	162	104	99	126	96
4	144	109	144	192	166	90	175	89	154	135	191	102	135	92	118
5	127	154	152	236	185	118	138	104	139	117	167	106	122	142	116
6	164	117	128	203	198	124	157	81	126	155	163	108	116	128	121
7	154	123	212	151	191	159	148	75	131	116	166	98	100	119	98
8	147	109	144	195	150	96	172	87	156	134	191	93	144	90	123
9	158	135	157	165	157	140	110	92	152	135	176	128	108	114	123
10	133	118	169	251	145	168	139	92	135	126	120	118	139	130	185
11	266	113	172	215	179	171	141	104	149	128	178	104	103	108	165
12	261	113	170	218	182	165	140	105	148	127	183	100	102	108	160
13	163	135	146	165	156	148	111	103	148	137	178	124	102	113	124
14	145	112	166	241	151	170	137	95	129	125	126	114	141	120	188
15	230	190	170	244	178	206	151	85	142	242	253	139	123	147	131
16	234	193	170	248	178	211	155	87	139	240	258	138	126	145	129

Appendix 5.1.5g Shaken sample suspended solids data from routine sampling of primary filter sewage and effluents.

Quarter 3.2. Dec. 1979 - Feb. 1980.

	Shaken sample Suspended solids (mg/l)			
Date	6/3	10/3	13/3	17/3
Shaken sewage	182	177	144	178
Settled sewage	88	119	107	123
Filter No :- 1	119	179	155	123
2	135	153	107	152
3	110	142	107	129
4	122	140	108	108
5	115	191	156	117
6	132	149	109	148
7	112	137	107	133
8	121	151	112	110
9	127	154	107	189
10	112	132	115	140
11	121	170	107	205
12	123	179	108	204
13	124	143	108	190
14	114	134	116	146
15	177	147	163	184
16	176	151	161	181

Appendix 5.1.5h Shaken sample suspended solids data from routine sampling of primary filter sewage and effluents.

Quarter 3.3. Jun. - Aug. 1980.

	Shaken sample Suspended solids (mg/l)												
Date	2/6	5/6	9/6	12/6	16/6	19/6	23/6	26/6	30/6	3/7	5/8	7/8	28/8
Shaken sewage	172	192	174	186	206	238	218	191	243	208	145	169	107
Settled sewage	132	117	119	113	117	122	121	132	136	107	112	102	89
Filter No :- 1	92		102		95		105		134		94		
2	140		96		104		102		162		131		
3	103		107		96		117		105		99		
4	95		99		91		130		108		103		
5		98		197		111		131		114		95	
6		96		135		167		122		125		93	
7		113		99		102		98		196		117	
8		111		106		136		181		121		92	
9	114		141		105		139		135				178
10	113		179		184		163		180				191
11	157		186		120		128		194				128
12		202		212		171		109		147			124
13		130		135		109		104		126			174
14		192		125		132		127		129			198
15	154		243		165		164		281				129
16		216		144		159		151		151			129

Appendix 5.1.5i Shaken sample suspended solids data from routine sampling of primary filter sewage and effluents.

Quarter 3.4. Sep. - Nov. 1980. (Continued overleaf)

	Shaken sample Suspended Solids (mg/l)							
Date	1/9	4/9	8/9	15/9	18/9	22/9	25/9	2/10
Shaken sewage	191	198	161	197	191	154	279	214
Settled sewage	108	120	122	135	135	114	152	135
Filter No :- 1	113		101	121		157		
2	164		108	96		161		
3	151		104	99		105		
4	153		98	88		88		
5	112		98	123		155		
6	158		101	101		168		
7	153		103	100		102		
8	147		100	87		88		
9		100			108		127	105
10		191			135		177	118
11		159			166		191	194
12		161			171		184	204
13		108			112		127	104
14		177			128		174	115
15		134			176		219	215
16		133			171		215	220

Appendix 5.1.5i(Cont.) Shaken sample suspended solids data. Quarter 3.4. Sep. - Nov. 1980.

	Shaken sample Suspended solids (mg/l)											
Date	7/10	9/10	14/10	16/10	30/10	6/11	10/11	13/11	17/11	20/11	24/11	27/11
Shaken sewage	215	216	160	179	196	237	219	255	244	263	272	262
Settled sewage	138	163	112	140	114	103	129	196	191	200	167	200
Filter No :- 1	111	111	121	58	-	-	111	280	100	168	127	118
9	94	118	109	254	-	-	124	148	104	148	108	158

Appendix 5.1.5j Shaken sample suspended solids data from routine sampling of primary filter sewage and effluents. Quarter 4.1. Dec. 1980 - Feb. 1981.

	Shaken sample Suspended Solids (mg/l)									
Date	1/12	4/12	6/1	8/1	13/1	15/1	20/1	22/1	27/1	29/1
Shaken sewage	199	237	182	229	163	162	178	146	199	186
Settled sewage	139	161	122	159	123	102	152	118	123	55
Filter No :- 1	138	147								
9	146	204								

Appendix 5.1.5k Shaken sample suspended solids data from routine sampling of primary filter sewage and effluents. Quarter 4.2. Mar. - May 1981.

	Shaken sample Suspended Solids (mg/l)			
Date	3/3	7/3	10/3	19/3
Shaken sewage	223	242	167	156
Settled sewage	146	151	128	106
Filter No :- 1	158	142	100	
9	197	173	203	132

Appendix 5.1.6 Monthly averaged sludge production rate data. Primary filters. (Continued overleaf)

	1978				1979											
Month	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
Filter No :- 1	0.33	0.24	0.18	0.79	0.31	0.23	0.22	0.30	0.27		0.34	0.23	0.35	0.20	0.13	0.36
2	0.24	0.23	0.28	0.87	0.29	0.22	0.21	0.34	0.23		0.38	0.26	0.32	0.27	0.19	0.30
3	0.32	0.31	0.22	0.67	0.25	0.20	0.33	0.31	0;25		0.27	0.21	0.23	0.10	0.19	0.33
4	0.35	0.24	0.18	0.61	0.29	0.20	0.23	0.35	0.24		0.27	0.20	0.19	0.14	0.12	0.31
5	0.28	0.28	0.18	0.89	0.34	0.24	0.19	0.29	0.26		0.32	0.21	0.32	0.19	0.13	0.36
6	0.25	0.22	0.25	0.89	0.30	0.23	0.20	0.34	0.25		0.33	0.27	0.35	0.24	0.18	0.28
7	0.29	0.26	0.22	0.71	0.25	0.21	0.33	0.30	0.29		0.25	0.21	0.17	0.10	0.21	0.33
8	0.31	0.25	0.16	0.67	0.33	0.19	0.22	0.33	0.24		0.26	0.19	0.18	0.13	0.12	0.27
9	0.33	0.35	0.44	1.02	0.50	0.30	0.32	0.46	0.37		0.26	0.23	0.27	0.22	0.28	0.40
10	0.38	0.32	0.28	0.51	0.34	0.24	0.28	0.43	0.45		0.39	0.20	0.27	0.20	0.20	0.39
11	0.60	0.31	0.37	0.92	0.38	0.36	0.44	0.37	0.35		0.30	0.27	0.39	0.23	0.41	0.44
12	0.58	0.28	0.36	1.01	0.35	0.37	0.39	0.35	0.33		0.29	0.27	0.39	0.23	0.39	0.45
13	0.32	0.33	0.44	1.08	0.52	0.28	0.34	0.45	0.44		0.27	0.27	0.26	0.22	0.28	0.39
14	0.47	0.31	0.27	0.37	0.32	0.24	0.33	0.41	0.46		0.36	0.23	0.29	0.21	0.21	0.40
15	0.40	0.34	0.35	1.37	0.52	0.36	0.37	0.37	0.47		0.70	0.32	0.43	0.39	0.49	0.57
16	0.40	0.35	0.34	1.39	0.51	0.37	0.37	0.36	0.49		0.64	0.32	0.42	0.38	0.49	0.56

All data expressed as g sludge produced/g BOD removed.

Appendix 5.1.6 (Cont.) Monthly averaged sludge production rate data. Primary filters.

	1980												1981			
Month	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A
Filter No :- 1	0.43	0.64	0.69			0.27		0.17	0.40	0.25	0.59	0.41			0.18	
2	0.40	0.53	0.57			0.32		0.45	0.41							
3	0.43	0.49	0.50			0.25		0.19	0.33							
4	0.37	0.49	0.45			0.24		0.45	0.25							
5	0.42	0.59	0.69			0.34	0.32	0.29	0.40							
6	0.43	0.54	0.54			0.35	0.34	0.27	0.44							
7	0.42	0.47	0.53			0.22	0.61	0.33	0.31							
8	0.35	0.49	0.46			0.39	0.37	0.28	0.25							
9	0.35	0.64	0.81			0.33		0.89	0.25	0.27	0.57	1.15			0.39	
10	0.50	0.69	0.65			0.50		1.03	0.40	0.25						
11	0.47	0.50	0.60			0.48		0.75	0.46	0.56						
12	0.46	0.48	0.62			0.49	0.52	0.76	0.45	0.61						
13	0.37	0.62	0.80			0.29	0.37	0.80	0.24	0.19						
14	0.46	0.69	0.67			0.39	0.47	1.07	0.38	0.24						
15	0.54	0.72	0.83			0.72		0.73	0.49	0.65						
16	0.55	0.72	0.81			0.51	0.56	0.77	0.47	0.70						

All data expressed as g sludge produced/g BOD removed.

Appendix 5.1.7 Monthly averaged temperature data. Primary filter sewage and effluents. (Continued overleaf)

		1978									1979					
Month		S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
Sewage		19.5	19.3	17.8	14.9	12.3	11.8	13.0	14.0	14.9		19.1	19.6	19.3	18.7	16.6	15.3
Filter No :-	1	18.7	18.4	17.0	12.4	11.7	9.9	10.9	12.9	14.0		18.0	18.7	18.7	18.2	15.9	13.9
	2	18.5	18.4	17.0	11.4	12.5	10.3	11.6	11.7	14.7		18.7	19.4	18.1	17.4	15.8	16.2
	3	18.5	18.3	17.3	13.1	11.8	10.3	12.0	11.5	13.2		19.2	18.4	18.4	17.2	16.2	14.8
	4	18.7	18.5	16.5	15.8	10.7	9.0	11.5	11.6	13.6		17.9	18.4	18.1	17.9	15.5	13.7
	5	18.9	18.1	16.5	14.3	12.0	10.9	10.9	11.7	14.0		18.0	18.7	18.5	17.6	15.6	15.1
	6	18.8	18.4	16.7	15.1	12.5	10.6	11.6	13.0	14.7		17.7	18.7	18.4	18.2	15.8	12.5
	7	18.8	18.4	17.1	15.0	10.6	10.9	12.0	12.9	13.8		19.2	18.6	18.2	16.2	15.2	13.6
	8	18.7	18.4	16.6	14.4	10.7	11.4	11.5	11.6	13.6		17.9	18.8	18.4	17.9	16.0	14.4
	9	19.0	18.7	16.9	16.4	12.6	11.1	11.6	13.6	15.0		18.7	18.2	19.2	17.4	15.3	14.5
	10	18.8	18.7	16.7	15.7	11.8	11.0	12.0	12.7	15.5		18.8	18.6	18.4	18.9	17.2	12.4
	11	18.7	18.5	16.7	15.9	11.8	11.3	11.8	13.6	15.1		20.5	19.0	19.3	18.2	16.6	15.2
	12	19.0	18.9	17.6	16.7	11.8	11.3	11.8	13.6	15.1		20.5	19.0	19.0	18.2	16.6	15.2
	13	18.9	18.6	18.2	12.2	12.6	11.0	11.6	13.5	15.0		18.7	19.1	18.9	18.6	17.1	16.5
	14	19.1	18.2	17.3	11.3	11.8	10.6	12.0	12.7	15.5		18.8	19.7	18.7	18.2	17.2	15.2
	15	19.3	18.4	17.0	14.2	11.9	10.0	11.8	14.5	14.8		18.8	18.8	19.4	17.6	17.6	16.2
	16	19.0	18.5	16.5	15.8	11.0	8.9	11.8	13.6	14.9		18.8	19.2	18.6	18.6	15.7	16.2

All data expressed as °C.

Appendix 5.1.7 (Cont.) Monthly averaged temperature data. Primary filter sewage and effluents.

	1980												1981			
Month	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A
Sewage	13.2	13.1	13.0			17.6	19.2	19.1	19.2	17.5	16.3	14.8	14.4		13.3	14.9
Filter No :- 1	12.3	12.3	11.3			16.7		18.2	18.6	16.6	14.6	14.1	13.4		13.3	13.4
2	12.2	11.8	12.0			17.2		18.3	18.6							
3	12.5	12.3	12.2			16.7		18.5	18.6							
4	12.1	12.4	11.6			16.7		17.3	18.0							
5	12.3	12.5	12.1			16.4	17.7	18.8	18.5							
6	12.1	11.9	11.7			16.9	17.8	18.9	18.9							
7	11.8	11.8	11.8			17.2	17.7	18.1	18.8							
8	12.4	12.0	11.7			17.3	17.9	18.6	18.0							
9	12.4	12.1	11.7			16.5		18.0	18.4	16.6	15.2	14.3	13.1		12.4	13.4
10	12.2	11.0	12.2			16.9		18.2	18.4	14.5						
11	12.5	11.9	12.8			16.6		18.4	18.4	14.6						
12	12.5	11.9	11.8			17.0	17.7	18.8	17.6	15.5						
13	12.4	12.1	11.7			16.6	17.2	18.0	18.8	16.7						
14	12.4	11.0	12.2			17.5	17.5	17.3	18.3	16.6						
15	12.4	12.5	11.9			16.3		16.5	18.3	17.1						
16	12.4	12.5	11.1			16.4	17.7	16.5	17.7	16.3						

All data expressed as °C.

Appendix 5.1.8 Monthly averaged NH_3-N data. Primary filter sewage and effluents. (Continued overleaf)

		1979						1980								
Month		J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S
Sewage		5.4	5.6	6.5	9.5	11.3	11.8	10.0	11.2	9.6	8.8			11.2	12.8	12.8	13.8
Filter No :-	1	5.4		10.0	11.2	15.7	13.0	13.2	13.6	11.6	10.8			14.2		13.6	15.8
	2	6.2		10.3	12.0	15.3	14.2	16.0	15.6	12.0	11.2			13.9		13.2	15.6
	3	6.4		10.7	12.0	16.2	14.8	13.2	12.8	12.0	11.6			14.7		13.2	16.2
	4	5.6		8.5	10.7	14.7	12.8	12.4	13.2	12.0	11.2			13.3		13.6	15.1
	5	7.3		10.3	11.9	15.7	14.4	14.0	13.6	12.0	10.8			13.8	16.0	13.2	15.8
	6	6.1		9.6	12.0	15.2	14.2	12.8	12.4	12.0	11.6			13.7	15.2	13.2	15.5
	7	6.2		10.0	12.2	16.0	14.8	12.8	13.2	12.8	11.6			14.6	16.8	13.2	16.3
	8	5.7		9.4	11.6	14.2	13.2	12.8	13.6	12.0	11.2			13.1	14.8	12.8	15.2
	9	5.5	10.3	9.6	11.9	15.1	15.0	13.2	14.8	13.2	12.0			14.1		10.4	16.1
	10	6.3	7.7	9.5	12.5	15.2	15.2	12.8	15.6	13.2	11.6			13.9		11.8	15.8
	11	4.2	6.1	6.3	9.2	11.9	11.4	10.0	10.4	13.6	8.8			11.9		11.4	14.2
	12	4.2	6.2	6.3	9.5	12.0	11.2	10.0	10.4	13.6	9.2			12.2	12.8	11.2	13.9
	13	4.5	8.8	10.1	13.6	14.4	15.2	12.4	14.0	12.8	11.6			14.7	16.0	10.8	16.3
	14	5.0	7.2	8.7	12.7	14.6	14.4	12.4	14.0	13.2	11.6			12.9	15.6	12.0	15.4
	15	4.1	4.7	7.6	9.2	11.0	11.4	10.4	12.0	13.2	9.2			11.8		11.2	14.2
	16	4.3	4.7	6.1	8.6	11.3	11.0	10.0	11.6	13.6	9.2			10.6	12.8	11.2	14.3

All data expressed as mg N/l.

Appendix 5.1.8 (Cont.) Monthly averaged NH_3 - N data. Primary filter sewage and effluents.

		1980			1981		
Month	O	N	D	J	F	M	A
Sewage	14.6	11.6	11.1	13.6		9.9	13.2
Filter No :- 1	10.3	13.7	13.0			12.6	
9	12.1	14.0	13.7			12.2	16.3
10	16.8						
11	13.8						
12	13.8						
13	17.8						
14	16.4						
15	14.2						
16	14.6						

All data expressed as mg N/l.

Appendix 5.1.9 Monthly averaged total oxidised-N data. Primary filter sewage and effluents. (Continued overleaf)

	1979							1980								
Month	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S
Sewage	6.38	0.05	2.02	1.56	1.24	1.29	4.32	6.75	6.42	5.61			0.15	0.01	0.06	0.07
Filter No :- 1	0.37		0.39	0.57	0.13	0.07	0.25	1.30	0.36	1.20			0.17		0.06	0.12
2	0.43		0.20	0.22	0.13	0.18	0.70	0.19	0.81	0.82			0.07		0.06	0.08
3	0.15		0.32	0.13	0.10	0.07	0.10	3.85	0.36	0.39			0.09		0.06	0.06
4	0.31		0.33	0.48	0.13	0.15	0.60	1.91	0.82	0.82			0.07		0.06	0.07
5	0.05		0.20	0.23	0.09	0.15	0.25	0.35	0.31	1.22			0.15	0.01	0.06	0.13
6	0.46		0.36	0.12	0.19	0.15	0.20	2.55	1.26	0.92			0.22	0.02	0.06	0.05
7	0.13		0.33	0.07	0.14	0.07	0.45	2.75	0.36	0.30			0.12	0.01	0.06	0.08
8	0.15		0.17	0.45	0.18	0.43	0.55	0.85	0.66	0.92			0.12	0.01	0.05	0.06
9	0.39	0.10	0.23	0.42	0.17	0.13	0.30	0.20	0.31	0.30			0.05		0.38	0.03
10	0.06	0.05	0.15	0.43	0.14	0.13	0.35	1.00	0.11	0.41			0.07		0.06	0.04
11	2.49	0.10	0.45	0.55	0.29	0.35	1.20	5.01	1.08	2.29			0.10		0.05	0.33
12	1.89	0.10	0.76	0.57	0.27	0.41	1.20	4.86	1.43	2.33			0.29	0.01	0.05	0.38
13	0.16	0.15	0.16	0.18	0.12	0.15	0.40	1.10	0.31	0.41			0.11	0.02	0.06	0.07
14	0.36	0.05	0.22	0.18	0.11	0.18	0.35	2.25	0.11	0.41			0.05	0.01	0.05	0.07
15	1.12	0.05	0.41	0.98	0.37	0.55	1.65	3.41	2.18	3.02			0.10		0.05	0.33
16	2.27	0.10	0.89	1.27	0.45	0.48	1.70	3.60	2.47	2.73			0.39	0.00	0.10	0.51

All data expressed as mg N/l.

Appendix 5.1.9 (Cont.) Monthly averaged total oxidised-N data. Primary filter sewage and effluents.

		1980			1981		
Month	O	N	D	J	F	M	A
Sewage	0.75	2.88	0.73	2.80		5.60	4.42
Filter No :- 1	0.20	0.05	0.01			0.59	
9	0.07	0.06	0.06			0.90	0.98
10	0.01						
11	0.01						
12	0.01						
13	0.08						
14	0.01						
15	0.06						
16	0.07						

All data expressed as mg N/l.

Appendix 5.5.1 Biological sampling data. Primary filters. Quarter 2.1 (December 1978)

Filter medium	Level	Film dry wt (kg/m^3)	Film volatile solids (kg/m^3)	%dry wt as volatile solids	No. of invertebrates present (x 10^6/m^3)		
					Psychoda larvae	Psychoda pupae	Enchytraeid worm spp.
89/50 Slag	1	6.08	4.76	78.1	0.90	0.72	0.52
	2	8.32	6.40	77.0	1.52	2.26	1.20
	3	9.78	7.90	80.9	3.06	2.82	1.28
	4	9.72	8.02	82.5	2.32	2.56	2.12
	5	7.76	6.04	77.8	3.32	2.94	1.42
125/75 Slag	1	-	-	-	0.28	0.90	0.01
	2	-	-	-	0.86	1.12	1.54
	3	-	-	-	1.16	1.42	1.58
	4	-	-	-	5.50	2.16	1.84
	5	-	-	-	3.68	2.44	1.88
89/50 Granite	1	5.34	4.26	79.8	1.82	1.56	0.90
	2	5.12	4.08	79.7	2.24	1.50	1.34
	3	5.62	4.42	78.7	2.14	2.92	3.42
	4	6.32	4.56	72.2	2.42	2.90	2.96
	5	6.02	4.96	82.4	6.60	1.96	2.94
125/75 Granite	1	3.78	3.04	80.4	1.60	0.94	0.52
	2	6.34	5.02	79.2	1.20	1.94	2.36
	3	4.92	2.40	48.7	1.72	2.00	1.20
	4	5.22	4.16	79.7	1.86	1.78	2.22
	5	4.88	3.50	71.7	3.96	2.24	0.90
Biopac 50	1	31.06	23.42	75.4	5.50	2.70	1.08
	2	35.08	27.62	78.7	6.56	2.86	1.24
	3	37.16	32.60	87.7	7.48	7.14	2.30
	4	37.16	28.98	78.0	4.76	5.82	0.74
	5	26.48	20.24	76.4	5.28	14.16	1.40
Biopac 90	1	13.50	10.56	78.2	3.74	2.74	3.70
	2	18.90	14.78	78.2	4.42	1.28	0.86
	3	17.40	13.82	79.4	8.28	3.46	1.98
	4	18.86	14.88	78.9	7.88	4.96	0.28
	5	15.58	12.06	77.4	4.64	3.32	2.30
Flocor M	1	9.77	7.56	77.4	4.56	2.37	0.87
	2	15.13	11.70	77.3	9.47	5.70	1.92
	3	18.74	14.80	79.0	7.65	6.78	5.48
Flocor E	1	7.92	5.97	75.4	5.04	5.29	1.66
	2	8.45	6.23	73.7	7.45	5.66	2.24
	3	8.20	6.39	77.9	4.04	3.26	3.04

Appendix 5.5.2 Biological sampling data. Primary filters. Quarter 2.2 (March 1979)

Filter medium	Level	Film dry wt (kg/m^3)	Film volatile solids (kg/m^3)	% dry wt as volatile solids	No. of invertebrates present (x 10^6/m^3)		
					Psychoda larvae	Psychoda pupae	Enchytraeid worm spp.
89/50 Slag	1	12.06	7.84	65.0	1.42	1.32	3.12
	2	16.34	11.22	68.7	1.32	2.98	2.22
	3	20.40	13.46	66.0	1.96	3.96	1.08
	4	19.88	13.66	68.7	2.78	5.68	1.24
	5	15.24	11.24	73.8	3.68	5.06	5.06
125/75 Slag	1	12.12	8.92	73.6	0.32	0.16	0.20
	2	24.90	20.28	81.5	2.12	3.70	0.80
	3	21.58	15.64	72.5	1.54	3.78	0.28
	4	19.82	16.88	85.2	1.86	5.10	0.54
	5	18.92	15.92	84.1	3.28	7.14	2.80
89/50 Granite	1	12.12	10.32	85.2	1.42	0.98	2.24
	2	19.86	17.10	86.1	0.80	1.66	0.62
	3	19.20	12.34	64.3	0.58	1.06	0.06
	4	18.94	13.64	72.0	2.12	2.34	0.60
	5	17.82	13,52	75.8	3.88	2.24	2.94
125/75 Granite	1	14.18	-	-	1.12	0.92	4.96
	2	15.76	-	-	2.34	5.00	5.70
	3	21.62	-	-	5.48	7.00	3.62
	4	23.72	-	-	4.06	7.80	8.14
	5	19.20	-	-	6.20	6.76	10.92
Biopac 50	1	43.52	33.68	77.4	0.32	0.52	0.62
	2	62.20	41.40	66.6	0.90	1.20	0.74
	3	42.56	27.22	65.4	0.94	1.30	0.12
	4	41.64	28.78	69.1	1.36	2.44	0.00
	5	32.94	21.58	65.5	1.50	2.68	0.32
Biopac 90	1	32.56	23.58	72.4	0.38	0.52	2.70
	2	64.20	47.12	73.4	1.70	0.84	2.40
	3	48.40	31.86	65.8	2.74	5.06	0.28
	4	51.22	35.24	68.8	2.38	4.62	0.00
	5	64.20	40.76	63.5	2.28	4.08	0.50
Flocor M	1	11.40	8.58	75.3	0.34	0.44	3.07
	2	25.22	17.73	70.3	1.97	1.82	5.16
	3	17.38	13.79	79.4	2.29	2.43	4.67
Flocor E	1	8.38	6.40	76.4	0.23	0.21	3.12
	2	10.87	8.06	74.2	1.62	0.20	3.94
	3	7.34	5.77	78.6	2.13	1.38	1.91

Appendix 5.5.3 Biological sampling data. Primary filters. Quarter 2.3 (July 1979)

Filter medium	Level	Film dry wt (kg/m^3)	Film volatile solids (kg/m^3)	% dry wt as volatile solids	No. of invertebrates present (x 10^6/m^3)		
					Psychoda larvae	Psychoda pupae	Enchytraeid worm spp.
89/50 Slag	1	10.28	7.94	77.2	1.28	1.02	6.30
	2	12.32	9.50	77.1	0.52	0.36	2.92
	3	7.08	5.96	84.2	3.38	2.32	2.19
	4	11.48	9.40	81.9	3.00	2.58	1.31
	5	8.24	7.04	85.4	2.64	3.24	2.53
125/75 Slag	1	7.94	6.04	76.1	0.97	1.08	2.54
	2	19.04	12.62	66.3	3.50	2.22	2.66
	3	15.02	10.60	70.6	1.01	0.63	0.67
	4	18.06	10.62	58.9	1.98	0.55	2.90
	5	5.94	4.24	71.4	0.53	0.16	0.83
89/50 Granite	1	10.74	8.28	77.1	1.88	2.32	1.16
	2	17.94	14.58	81.3	0.89	1.53	0.74
	3	15.38	8.00	52.0	0.99	1.56	0.57
	4	11.16	8.64	77.4	0.99	0.69	18.15
	5	9.22	6.50	70.5	1.08	1.37	8.43
125/75 Granite	1	11.40	9.32	81.8	1.49	1.49	3.42
	2	12.78	10.26	80.3	1.29	2.04	1.82
	3	16.52	13.48	81.6	1.37	2.02	3.88
	4	8.44	6.82	80.8	1.16	0.78	2.98
	5	4.16	3.50	84.1	0.35	0.30	7.89
Biopac 50	1	21.62	15.66	72.5	7.87	11.81	0.35
	2	34.26	24.88	72.6	8.69	12.56	1.72
	3	22.84	21.30	82.1	5.99	6.00	1.46
	4	26.54	16.60	80.6	7.72	8.95	0.06
	5	29.20	19.74	76.6	3.23	1.94	0.79
Biopac 90	1	25.86	16.98	65.6	1.06	2.31	1.83
	2	30.88	19.00	61.5	2.24	3.10	0.86
	3	22.84	18.00	78.8	12.46	11.40	1.92
	4	26.54	21.22	80.0	13.78	8.64	1.84
	5	29.20	19.96	68.3	14.57	9.16	1.73
Flocor M	1	7.51	5.55	73.9	1.43	2.38	1.95
	2	18.77	12.41	66.1	0.29	0.64	0.00
	3	7.21	5.57	77.2	0.77	1.29	3.17
Flocor E	1	5.45	3.64	66.9	1.00	1.27	0.61
	2	8.74	5.74	65.6	1.58	2.10	1.77
	3	5.66	4.26	75.2	1.11	1.68	0.73

Appendix 5.5.4 Biological sampling data. Primary filters. Quarter 2.4 (October 1979)

Filter medium	Level	Film dry wt (kg/m^3)	Film volatile solids (kg/m^3)	% dry wt as volatile solids	No. of invertebrates present (x $10^6/m^3$)		
					Psychoda larvae	Psychoda pupae	Enchytraeid worm spp.
89/50 Slag	1	12.34	8.84	71.6	3.96	4.94	1.86
	2	13.98	12.14	86.8	2.88	2.56	1.56
	3	11.36	8.10	71.3	4.16	1.88	0.60
	4	10.56	8.84	83.7	4.36	3.16	1.22
	5	8.40	6.38	76.0	3.76	2.44	0.98
125/75 Slag	1	7.62	6.34	83.2	2.06	1.56	0.74
	2	9.68	8.40	86.8	2.10	2.64	2.98
	3	10.54	7.48	71.0	2.08	2.10	1.70
	4	7.18	5.54	77.2	3.16	5.22	1.42
	5	8.18	7.50	91.7	1.98	2.14	3.84
89/50 Granite	1	9.86	7.66	77.7	3.12	4.34	3.62
	2	9.62	6.42	66.7	3.12	5.10	2.92
	3	9.72	6.82	70.2	4.20	2.54	2.42
	4	9.74	7.66	78.6	2.40	1.86	1.18
	5	10.96	8.48	77.4	1.64	2.10	0.64
125/75 Granite	1	5.92	4.72	79.7	3.16	2.52	1.48
	2	7.18	6.30	87.7	3.12	1.42	1.44
	3	9.18	6.48	70.6	1.70	1.04	1.14
	4	8.40	6.48	77.1	2.04	3.10	1.30
	5	9.18	7.08	77.1	1.44	1.34	1.22
Biopac 50	1	28.72	14.88	51.8	1.22	1.76	1.84
	2	29.30	26.28	89.7	1.10	2.62	1.26
	3	29.98	22.78	76.0	1.30	2.32	1.38
	4	37.10	16.80	45.3	2.50	4.18	2.42
	5	31.98	16.30	51.0	1.40	4.22	1.66
Biopac 90	1	11.46	7.86	68.6	1.26	1.38	1.64
	2	19.06	14.14	74.2	1.42	1.42	1.92
	3	12.66	10.38	82.0	3.46	3.40	1.40
	4	17.48	13.90	79.5	3.02	4.24	1.22
	5	11.26	9.52	84.5	3.38	4.70	1.38
Flocor M	1	4.32	3.38	78.2	1.95	0.95	1.75
	2	11.49	9.34	81.3	4.92	6.03	4.19
	3	11.73	9.60	81.8	3.68	3.34	3.52
Flocor E	1	8.14	6.57	80.7	1.25	1.12	1.15
	2	6.54	6.01	91.9	1.39	1.47	1.34
	3	7.38	5.35	72.5	2.67	3.15	1.74

Appendix 5.5.5 Biological sampling data. Primary filters. Quarter 3.1 (January 1980)

Filter medium	Level	Film dry wt (kg/m^3)	Film volatile solids (kg/m^3)	% dry wt as volatile solids	No. of invertebrates present (x 10^6/m^3)		
					Psychoda larvae	Psychoda pupae	Enchytraeid worm spp.
89/50 Slag	1	16.40	11.92	72.7	0.71	1.02	0.40
	2	22.10	15.10	68.3	0.54	1.60	0.20
	3	18.28	12.80	70.0	0.97	2.08	0.24
	4	18.04	12.40	68.7	1.10	1.77	0.17
	5	17.98	12.60	70.1	1.63	2.05	1.72
125/75 Slag	1	13.30	9.76	73.4	0.33	0.80	0.42
	2	16.94	12.24	72.3	0.23	0.48	0.29
	3	33.98	23.38	68.8	0.42	1.00	0.44
	4	16.42	11.84	72.1	0.77	0.45	0.38
	5	19.76	13.72	69.4	0.84	0.90	0.38
89/50 Granite	1	17.74	12.80	72.2	0.41	0.82	0.15
	2	24.20	16.44	67.9	0.27	0.60	0.13
	3	20.52	14.30	69.7	0.48	0.71	0.19
	4	19.14	13.24	69.2	0.92	0.95	0.52
	5	17.70	12.48	70.5	0.94	1.13	0.49
125/75 Granite	1	10.30	7.56	73.4	0.30	0.67	0.60
	2	24.58	16.90	68.8	0.16	0.60	0.33
	3	14.54	10.60	72.9	0.94	1.24	0.84
	4	8.28	6.28	75.8	0.96	1.27	0.70
	5	6.58	4.98	75.7	0.71	0.89	0.81
Biopac 50	1	41.48	28.60	68.9	0.10	0.30	0.13
	2	56.76	37.26	65.6	0.00	0.00	0.04
	3	55.38	37.10	67.0	0.04	0.16	0.04
	4	44.58	29.66	66.5	0.55	1.09	0.66
	5	47.96	32.22	67.2	0.43	0.74	0.97
Biopac 90	1	12.16	8.74	71.9	0.87	0.82	0.21
	2	36.84	24.04	65.3	0.49	1.20	0.18
	3	58.20	38.90	66.8	0.86	1.42	0.00
	4	38.02	25.58	67.3	0.23	0.83	0.51
	5	29.98	21.12	70.4	0.76	2.89	0.35
Flocor M	1	4.28	3.22	75.2	0.16	0.20	0.67
	2	7.57	5.65	74.6	0.48	0.64	0.43
	3	4.88	3.70	75.8	0.46	0.56	0.93
Flocor E	1	5.19	3.70	71.3	0.41	0.16	0.40
	2	5.43	3.60	66.3	0.36	0.39	0.16
	3	4.36	3.24	74.3	0.65	0.81	0.26

Appendix 5.5.6 Biological sampling data. Primary filters, Quarter 3.2 (April 1980)

Filter medium	Level	Film dry wt (kg/m^3)	Film volatile solids (kg/m^3)	% dry wt as volatile solids	No. of invertebrates present (x $10^6/m^3$)		
					Psychoda larvae	Psychoda pupae	Enchytraeid worm spp.
89/50 Slag	1	12.10	8.76	72.4	0.40	0.26	1.48
	2	25.40	16.80	66.1	0.18	0.49	1.04
	3	17.46	11.66	66.8	0.25	0.48	1.18
	4	16.70	11.62	69.6	1.38	0.74	1.18
	5	9.98	7.52	75.4	2.31	1.59	0.88
125/75 Slag	1	9.40	7.16	76.2	0.18	0.25	1.22
	2	24.90	17.06	68.5	0.28	0.66	0.23
	3	12.46	9.22	74.0	1.76	2.05	1.39
	4	10.82	8.22	76.0	2.45	2.15	0.89
	5	4.82	3.80	78.8	1.29	0.89	0.79
89/50 Granite	1	10.78	8.00	74.2	0.37	0.39	2.75
	2	18.92	12.68	67.0	0.26	0.96	0.93
	3	11.96	8.22	68.7	1.77	1.92	1.99
	4	8.92	6.60	74.0	1.46	1.31	1.54
	5	7.44	5.28	71.0	1.58	1.18	1.45
125/75 Granite	1	7.64	5.70	74.6	0.12	0.20	1.59
	2	11.08	8.28	74.7	0.51	0.99	1.85
	3	10.84	8.52	78.6	0.88	1.58	1.09
	4	11.04	8.74	79.2	1.46	1.69	1.44
	5	7.34	5.84	79.6	1.25	1.88	1.22
Biopac 50	1	46.96	34.92	74.4	0.50	0.24	4.74
	2	32.64	23.54	72.1	0.54	0.41	1.40
	3	54.20	36.36	67.1	3.45	1.71	2.16
	4	29.68	23.96	80.7	9.35	6.66	3.94
	5	32.08	25.70	80.1	6.89	4.68	1.74
Biopac 90	1	25.26	18.30	72.4	0.64	0.33	1.60
	2	24.96	17.82	71.4	1.63	1.30	1.34
	3	26.46	19.00	71.8	1.32	1.93	0.90
	4	28.76	20.24	70.4	2.09	3.19	1.88
	5	41.70	28.56	68.5	1.42	5.51	0.88
Flocor M	1	5.61	3.76	67.0	0.24	0.05	0.35
	2	8.67	6.87	79.2	1.84	0.63	2.30
	3	7.27	5.57	76.6	0.42	0.43	0.90
Flocor E	1	3.52	2.78	79.0	0.31	0.10	0.26
	2	4.18	3.30	78.9	0.45	0.36	0.31
	3	4.24	3.06	72.2	0.28	0.28	0.52

Appendix 5.5.7 Biological sampling data. Primary filters. Quarter 3.3 (July 1980)

Filter medium	Level	Film dry wt (kg/m^3)	Film volatile solids (kg/m^3)	% dry wt as volatile solids	No. of invertebrates present (x $10^6/m^3$)		
					Psychoda larvae	Psychoda pupae	Enchytraeid worm spp.
89/50 Slag	1	13.44	10.44	77.7	1.17	0.81	1.54
	2	18.24	14.10	77.3	0.36	1.36	0.21
	3	16.80	12.78	76.1	0.55	1.28	0.50
	4	14.68	10.80	73.6	0.98	1.93	0.91
	5	13.34	9.46	70.9	2.27	2.21	1.67
125/75 Slag	1	10.44	7.12	68.2	1.17	0.70	1.83
	2	12.50	8.70	69.6	0.94	0.48	0.49
	3	15.34	10.08	65.7	0.56	0.76	0.43
	4	10.90	7.02	64.4	1.71	1.41	1.27
	5	6.62	4.32	65.3	1.46	1.16	2.09
89/50 Granite	1	12.54	9.50	75.8	2.32	1.49	1.76
	2	14.20	10.60	74.6	1.15	1.67	1.11
	3	14.30	10.58	74.0	0.83	1.76	1.47
	4	10.80	7.56	70.0	1.46	1.24	1.70
	5	8.94	6.08	68.0	1.43	0.94	2.78
125/75 Granite	1	8.58	6.78	79.0	0.48	0.37	1.52
	2	13.08	10.44	79.8	1.94	1.86	1.52
	3	18.06	14.08	78.0	1.03	1.62	0.95
	4	12.02	9.68	80.5	2.25	2.08	1.66
	5	7.42	5.88	79.2	1.02	0.74	1.77
Biopac 50	1	43.76	32.68	74.7	0.17	0.49	0.24
	2	51.30	37.06	72.7	0.08	1.94	0.16
	3	25.22	18.72	74.2	2.92	2.11	1.02
	4	11.76	10.60	90.1	5.51	10.57	2.54
	5	11.08	8.94	80.7	3.94	7.57	4.77
Biopac 90	1	24.74	18.10	73.2	1.07	0.42	0.93
	2	22.70	16.50	72.7	3.48	1.65	1.62
	3	22.34	17.56	78.6	4.31	5.84	1.76
	4	17.58	14.08	80.1	4.58	4.04	1.16
	5	14.26	11.34	79.2	5.38	3.39	1.22
Flocor M	1	4.52	3.69	81.6	0.53	0.47	0.86
	2	10.01	7.77	77.6	1.41	1.49	0.49
	3	3.13	2.62	83.7	0.83	0.82	0.89
Flocor E	1	2.80	2.32	82.9	0.69	2.46	0.33
	2	5.67	4.50	79.4	0.97	0.87	0.72
	3	2.40	1.81	75.4	0.46	0.32	0.52

Appendix 5.5.8 Biological sampling data. Primary filters. Quarter 3.4 (October 1980)

Filter medium	Level	Film dry wt (kg/m^3)	Film volatile solids (kg/m^3)	% dry wt as volatile solids	No. of invertebrates present (x $10^6/m^3$)		
					Psychoda larvae	Psychoda pupae	Enchytraeid worm spp.
89/50 Slag	1	12.68	10.54	83.2	2.29	2.57	0.84
	2	14.94	12.18	81.5	1.03	1.19	0.59
	3	10.60	8.84	83.5	1.94	3.40	0.53
	4	9.76	8.00	82.0	2.45.	2.05	0.54
	5	10.00	7.90	79.1	1.72	1.78	0.40
125/75 Slag	1	11.54	9.66	83.6	2.06	1.58	0.78
	2	13.66	10.62	77.7	0.99	0.88	0.38
	3	10.10	8.40	83.2	7.14	3.01	0.52
	4	8.90	7.26	81.5	7.40	2.51	0.53
	5	5.46	4.38	80.3	5.44	1.65	0.55
89/50 Granite	1	13.32	10.32	77.5	2.99	2.68	0.91
	2	10.64	9.14	86.0	3.24	2.33	1.10
	3	8.78	7.38	84.0	1.94	2.28	0.74
	4	10.00	8.24	82.3	1.90	2.09	0.78
	5	5.90	4.70	79.6	1.63	2.18	0.75
125/75 Granite	1	11.04	6.90	62.6	2.35	1.90	0.99
	2	12.12	10.00	82.6	2.39	0.95	2.51
	3	9.52	7.86	82.6	2.33	2.17	1.76
	4	8.56	6.78	79.1	2.03	2.58	0.76
	5	7.76	6.10	78.5	2.45	2.76	1.04
Biopac 50	1	29.32	25.42	86.7	19.96	10.67	0.87
	2	30.06	24.82	82.5	13.98	9.41	1.22
	3	33.96	27.58	81.2	10.13	8.08	0.25
	4	26.60	21.66	81.4	7.29	5.49	0.18
	5	27.36	22.14	80.9	9.40	7.95	0.17
Biopac 90	1	9.50	7.82	82.1	1.57	1.44	0.50
	2	7.78	6.48	83.3	4.48	1.80	0.90
	3	12.04	10.30	85.5	4.97	4.17	0.30
	4	17.22	14.32	83.2	3.65	3.78	0.20
	5	14.40	12.24	85.0	4.84	3.89	0.09
Flocor M	1	10.92	5.65	51.8	0.24	0.24	0.21
	2	12.96	10.40	80.3	1.86	0.91	1.02
	3	6.59	5.66	85.9	1.66	1.89	1.55
Flocor E	1	5.79	3.03	52.4	0.87	0.19	0.26
	2	4.44	3.41	76.9	0.53	0.38	1.38
	3	4.68	3.90	83.5	1.97	0.73	0.01

Appendix 5.5.9a Monthly neutron moisture meter data. Mineral media.

		1979										1980								
Month		M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S
Filter medium																				
89/50	$\bar{x}$	50			29	16	16	22	30	38	50	45	53	48		25	30	17	16	21
Slag	Max.	81			50	27	21	29	36	52	97	90	85	86		41	46	22	39	30
	Min.	22			15	8	12	16	21	18	18	24	24	17		11	20	10	8	14
125/75	$\bar{x}$	51			33	16	18	20	29	37	42	40	35	27		25	23	14	18	17
	Max.	94			59	21	27	27	40	62	78	80	75	62		42	41	18	25	22
	Min.	13			9	7	7	11	20	14	16	24	10	2		9	13	7	10	9
89/50	$\bar{x}$	54			42	22	24	26	36	43	45	48	48	33		26	29	19	19	21
Granite	Max.	86			73	29	33	36	47	59	74	67	75	60		36	43	24	29	26
	Min.	25			21	13	15	22	28	23	18	26	21	14		13	21	12	13	14
125/75	$\bar{x}$	26			20	14	15	19	21	24	25	24	22	21		19	18	14	13	15
	Max.	38			30	20	19	24	27	35	37	36	50	39		27	28	20	17	19
	Min.	13			10	6	7	13	15	10	11	13	10	8		10	11	8	8	9

Data expressed as averaged percent saturation of voids with filter depth, together with the maximum and minimum percent saturations recorded within the filters.

Appendix 5.5.9b <u>Monthly neutron moisture meter data. Plastic media.</u>

							1979									1980				
Month		M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S
Filter medium																				
Biopac 50	$\bar{x}$	64			22	18	27	34	47	45	49	60	62	48		28	38		9	26
	Max.	77			28	21	32	68	69	71	72	84	76	72		79	75		19	43
	Min.	44			7	9	8	16	20	17	22	18	41	21		9	18		5	7
Biopac 90	$\bar{x}$	54			24	23	14	14	31	42	50	49	46	34		27	27		9	11
	Max.	72			58	44	20	19	43	59	71	74	72	62		62	45		14	15
	Min.	9			4	4	2	3	6	9	4	12	7	4		4	6		4	3
Flocor M	$\bar{x}$	15			12	8	3	5	11	8	7	11	13	8		12	10		7	9
	Max.	44			42	18	9	17	16	13	42	42	57	50		40	29		16	37
	Min.	4			2	3	1	2	4	5	3	4	3	2		2	3		4	3
Flocor E	$\bar{x}$	6			6	3	3	3	5	6	5	4	5	2		4	7		4	4
	Max.	25			26	14	8	11	14	18	41	16	22	5		15	24		8	14
	Min.	2			2	2	1	1	3	3	1	2	2	1		1	2		3	2

Data expressed as averaged percent saturation of voids with filter depth, together with the maximum and minimum percent saturations recorded within the filters.

Appendix 6.3.1a BOD data from routine sampling of secondary filter feed and effluents. Quarter 2.3. Jun. - Aug. 1979

BOD (mg/l)

Date		12/7	17/7	19/7	23/7	27/7	30/7	2/8	6/8	9/8	13/8	16/8	23/8	30/8
Shaken feed		125.5	191.5	156.5	67.5	79.0	81.5	69.0	66.0	66.5	68.5	114.5	112.5	130.0
Settled feed		123.5	158.5	138.0	46.0	68.0	70.0	54.0	47.0	57.0	39.0	97.0	98.5	118.0
Filter No :-	17	55.5	31.5	32.0	-	6.5	-	21.0	8.5	10.8	5.5	13.5	6.3	25.5
	18	36.5	20.5	15.0	-	2.5	-	13.5	5.0	9.5	5.3	14.0	5.3	22.8

Appendix 6.3.1b BOD data from routine sampling of secondary filter feed and effluents. Quarter 2.4. Sep. - Nov. 1979

BOD (mg/l)

Date		3/9	6/9	20/9	24/9	27/9	15/10	22/10	25/10	29/10	5/11	12/11	15/11
Shaken feed		98.0	141.5	125.5	122.0	269.5	138.0	300.0	198.5	214.0	148.0	217.5	194.0
Settled feed		72.5	107.5	111.5	69.0	241.5	112.5	236.0	155.5	170.0	95.5	181.0	183.5
Filter No :-	17	11.3	20.5	30.5	14.0	57.3	10.0	35.5	48.8	39.5	14.8	45.5	56.0
	18	7.8	13.8	22.3	9.5	37.3	9.0	30.5	46.3	21.0	10.0	18.3	22.3

Appendix 6.3.1c BOD data from routine sampling of secondary filter feed and effluents. Quarter 3.1. Dec. 1979 - Feb. 1980

BOD (mg/l)

Date		3/12	6/12	12/12	3/1	22/1	24/1	28/1	4/2	11/2	15/2	18/2	21/2	25/2
Shaken feed		152.5	175.0	152.5	106.0	121.5	124.5	101.5	64.0	110.0	84.5	87.5	111.0	67.5
Settled feed		104.0	144.0	134.5	48.0	76.0	69.5	45.0	38.5	36.0	60.0	45.5	71.0	28.5
Filter No :-	17	14.8	14.0	19.0	17.5	12.3	3.8	-	9.0	4.0	12.3	-	8.5	9.3
	18	10.5	12.5	17.3	12.5	5.8	2.3	-	7.0	5.3	6.5	2.8	5.8	5.5

Appendix 6.3.1d

Quarter 3.2, Mar. - May 1980 - no data collected.

Appendix 6.3.1e BOD data from routine sampling of secondary filter feed and effluents. Quarter 3.3. Jun. - Aug. 1980

BOD (mg/l)

Date		2/6	5/6	9/6	12/6	16/6	19/6	23/6	26/6	30/6	3/7	5/8	7/8	28/8
Shaken feed		178.0	168.0	80.5	97.5	71.0	117.5	88.0	105.5	120.0	107.0	124.5	118.5	44.0
Settled feed		107.5	141.0	73.0	64.0	40.5	94.0	76.5	75.0	80.5	86.0	102.5	103.5	38.0
Filter No :-	17	33.3	32.3	5.0	12.0	1.5	14.3	14.0	9.8	6.8	30.3	19.0	18.0	7.0
	18	42.5	28.5	5.8	11.0	2.0	13.5	11.3	9.8	4.0	17.0	12.0	12.5	8.5

Appendix 6.3.1f BOD data from routine sampling of secondary filter feed and effluents. Quarter 3.4. Sep. - Nov. 1980

BOD (mg/1)

Date		1/9	4/9	8/9	15/9	18/9	22/9	25/9	2/10	7/10	9/10	14/10	30/10	6/11	10/11	13/11
Shaken feed		108.5	131.5	121.0	95.5	161.0	106.0	149.5	142.5	98.5	107.5	68.5	155.5	216.5	162.5	171.5
Settled feed		53.5	85.0	70.5	61.0	118.0	49.5	88.5	100.5	65.0	84.5	56.5	132.5	200.0	104.0	151.0
Filter No :-	17	14.5	13.0	5.3	9.8	23.8	2.0	12.0	13.8	7.5	12.8	6.8	15.0	20.5	4.8	22.0
	18	11.0	7.3	5.3	10.3	21.3	0.5	12.8	8.8	3.0	8.8	5.8	11.3	12.8	1.5	11.5

Date		17/11	20/11	24/11	27/11
Shaken feed		122.5	192.5	131.5	244.5
Settled feed		97.0	169.5	105.5	225.0
Filter No :-	17	10.8	48.8	8.8	44.5
	18	6.0	20.8	1.3	21.0

Appendix 6.3.1g BOD data from routine sampling of secondary filter feed and effluents. Quarter 4.1. Dec. 1980 - Feb. 1981

BOD (mg/l)

Date		1/12	4/12	6/1	8/1	13/1	15/1	20/1	22/1	27/1	29/1
Shaken feed		150.5	236.0	140.5	201.5	163.5	129.5	202.0	175.5	220.0	172.5
Settled feed		125.5	216.0	109.0	141.5	123.0	96.5	130.5	124.5	157.0	107.0
Filter No :-	17	10.3	41.5	26.3	39.5	26.3	16.3	22.8	18.8	24.0	26.5
	18	5.3	30.8	17.5	34.3	20.0	15.5	13.3	14.5	18.5	15.5

Appendix 6.3.1h BOD data from routine sampling of secondary filter feed and effluents. Quarter 4.2. Mar. - May 1981

BOD (mg/l)

Date		3/3	7/3	10/3	17/3	19/3	24/3	7/4	15/4	21/4	28/4	29/4	5/5	7/5
Shaken feed		201.5	280.0	179.0	120.5	160.5	140.5	83.5	80.5	131.0	71.5	96.5	100.5	80.5
Settled feed		137.0	197.0	110.5	88.0	105.5	59.0	63.0	54.0	109.0	-	-	-	-
Filter No :-	17	15.8	46.5	20.5	15.8	25.3	17.0	-	17.0	67.5	15.3	14.3	31.3	10.5
	18	8.3	23.3	15.5	10.5	16.8	14.5	-	13.3	63.8	10.8	9.8	24.5	7.0

Appendix 6.3.2a COD data from routine sampling of secondary filter feed and effluents. Quarter 2.3. Jun. - Aug. 1979

COD (mg/l)

Date	12/7	17/7	19/7	23/7	27/7	30/7	2/8	6/8	9/8	13/8	16/8	20/8	23/8	30/8
Shaken feed	294	346	376	238	208	220	206	248	180	160	226	246	232	232
Settled feed	226	288	292	226	186	196	160	196	146	118	170	188	136	162
Filter No :- 17	164	114	106	130	104	-	76	98	78	64	74	90	62	78
18	132	98	82	84	90	-	72	84	60	62	56	76	56	61

Appendix 6.3.2b COD data from routine sampling of secondary filter feed and effluents. Quarter 2.4. Sep. - Nov. 1979

COD (mg/l)

Date	3/9	6/9	20/9	24/9	27/9	15/10	22/10	25/10	29/10	5/11	12/11	15/11	19/11
Shaken feed	256	278	244	324	416	332	532	336	376	344	358	334	360
Settled feed	194	196	180	190	326	254	414	284	266	240	296	288	230
Filter No :- 17	86	94	82	98	144	114	148	132	84	104	132	152	98
18	76	84	88	82	120	104	138	94	78	80	94	110	100

Appendix 6.3.2c COD data from routine sampling of secondary filter feed and effluents. Quarter 3.1. Dec. 1979 - Feb. 1980

COD (mg/l)

Date	3/12	6/12	12/12	3/1	22/1	24/1	28/1	31/1	4/2	11/2	15/2	18/2	21/2	25/2
Shaken feed	308	306	292	202	294	276	230	212	190	226	184	216	218	220
Settled feed	226	254	244	138	200	162	158	138	132	152	146	140	150	130
Filter No :- 17	90	84	82	64	88	56	70	62	58	76	68	54	54	48
18	74	70	72	60	96	50	76	56	62	70	68	60	48	58

Appendix 6.3.2d COD data secondary filter feed and effluents, Quarter 3.2, Mar. - May 1980 - no data collected.

Appendix 6.3.2e COD data from routine sampling of secomdary filter feed and effluents. Quarter 3.3. Jun. - Aug. 1980

COD (mg/l)

Date	2/6	5/6	9/6	12/6	16/6	19/6	23/6	26/6	30/6	3/7	5/8	7/8	28/8
Shaken feed	324	324	298	256	218	266	256	262	280	222	346	308	198
Settled feed	210	256	224	174	148	232	178	176	204	206	250	216	168
Filter No :- 17	100	140	122	86	74	104	86	94	86	118	118	98	120
18	186	122	112	88	72	98	92	84	88	90	108	176	156

Appendix 6.3.2f COD data from routine sampling of secondary filter feed and effluents. Quarter 3.4. Sep. - Nov. 1980

		COD (mg/l)						
Date		1/9	4/9	8/9	15/9	18/9	22/9	25/9
Shaken feed		284	328	288	260	390	324	310
Settled feed		192	234	192	212	274	170	236
Filter No :-	17	110	96	106	98	122	80	98
	18	102	74	88	90	104	66	102

Appendix 6.3.3a Settled sample suspended solids data from routine sampling of secondary filter feed and effluents.

Quarter 2.3. Jun. - Aug. 1979

Settled sample suspended solids (mg/l)

Date	12/7	17/7	19/7	23/7	27/7	30/7	2/8	6/8	9/8	13/8	16/8	20/8	23/8	30/8
Shaken feed	131	146	141	117	102	91	113	116	109	93	119	121	123	133
Settled feed	65	83	85	78	41	54	64	52	42	39	58	73	40	54
Filter No :- 17	39	21	31	23	10	-	22	12	13	15	22	35	11	19
18	44	21	19	16	11	-	19	11	11	16	16	28	13	15

Appendix 6.3.3b Settled sample suspended solids data from routine sampling of secondary filter feed and effluents.

Quarter 2.4. Sep. - Nov. 1979

Settled sample suspended solids (mg/l)

Date	3/9	6/9	20/9	24/9	27/9	15/10	22/10	25/10	29/10	5/11	12/11	15/11	19/11
Shaken feed	98	141	124	243	204	126	192	146	170	142	148	133	185
Settled feed	51	80	65	111	117	63	104	73	81	69	92	61	79
Filter No :- 17	13	47	28	59	41	15	22	35	31	23	35	32	26
18	13	32	29	58	41	11	24	13	24	12	29	22	19

Appendix 6.3.3c Settled sample suspended solids data from routine sampling of secondary filter feed and effluents.

Quarter 3.1. Dec. 1979 - Feb. 1980

Settled sample suspended solids (mg/l)

Date	3/12	6/12	12/12	3/1	22/1	24/1	28/1	31/1	4/2	11/2	15/2	18/2	21/2	25/2
Shaken feed	183	142	131	144	155	179	142	75	142	135	171	116	137	112
Settled feed	69	70	73	52	60	55	64	40	54	52	47	66	67	55
Filter No :- 17	26	13	15	28	20	13	21	44	18	29	27	19	21	21
18	23	14	15	28	17	11	19	22	16	28	21	17	22	22

Appendix 6.3.3d Settled sample suspended solids data from secondary filter feed and effluents, Quarter 3.3, Mar. - May 1980 - no data collected.

Appendix 6.3.3e Settled sample suspended solids data from routine sampling of secondary filter feed and effluents.

Quarter 3.3. Jun. - Aug. 1980

Settled sample suspended solids (mg/l)

Date	2/6	5/6	9/6	12/6	16/6	19/6	23/6	26/6	30/6	3/7	5/8	7/8	28/8
Shaken feed	119	128	162	140	128	134	128	125	158	124	118	132	142
Settled feed	74	73	77	67	62	75	55	64	68	62	66	36	69
Filter No :- 17	27	22	15	13	25	23	14	29	23	31	24	22	26
18	28	21	14	15	20	19	18	23	18	21	21	19	35

Appendix 6.3.3f <u>Settled sample suspended solids data from routine sampling of secondary filter feed and effluents.</u>

Quarter 3.4. Sep. - Nov. 1980

Settled sample suspended solids (mg/l)

Date	1/9	4/9	8/9	15/9	18/9	22/9	25/9	2/10	7/10	9/10	14/10	16/10	30/10	6/11	10/11
Shaken feed	162	187	207	123	179	233	244	255	155	222	169	116	139	170	137
Settled feed	61	89	85	75	75	50	112	114	121	104	66	35	73	86	97
Filter No :- 17	25	15	18	30	21	17	16	16	17	40	22	12	16	23	17
18	28	15	29	19	20	20	20	14	14	26	12	12	16	23	15

Date	13/11	17/11	20/11	24/11	27/11
Shaken feed	172	147	186	150	185
Settled feed	114	94	123	81	118
Filter No :- 17	37	25	58	16	53
18	28	11	38	8	36

Appendix 6.3.3g Settled sample suspended solids data from routine sampling of secondary filter feed and effluents.

Quarter 4.1 Dec. 1980 - Feb. 1981

Settled sample suspended solids (mg/l)

Date	1/12	4/12	6/1	8/1	13/1	15/1	20/1	22/1	27/1	29/1
Shaken feed	148	191	152	272	245	141	253	230	215	195
Settled feed	113	118	80	135	103	78	120	111	97	116
Filter No :- 17	19	39	29	41	22	18	37	38	18	46
18	21	30	33	39	20	11	25	29	17	25

Appendix 6.3.3h Settled sample suspended solids data from routine sampling of secondary filter feed and effluents.

Quarter 4.2. Mar. - May 1981

Settled sample suspended solids (mg/l)

Date	3/3	7/3	10/3	17/3	19/3	24/3
Shaken feed	189	239	175	126	146	194
Settled feed	107	141	87	82	81	52
Filter No :- 17	26	46	39	31	28	21
18	21	25	24	15	18	15

Appendix 6.3.4a **Shaken sample suspended solids data from routine sampling of secondary filter feed and effluents.**

Quarter 2.3. Jun. - Aug. 1979

Shaken sample suspended solids (mg/l)

Date	12/7	17/7	19/7	23/7	27/7	30/7	2/8	6/8	9/8	13/8	16/8	20/8	23/8	30/8
Shaken feed	131	146	141	117	102	91	113	116	109	93	119	121	123	133
Settled feed	65	83	85	78	41	54	64	52	42	39	58	73	40	54
Filter No :- 17	122	84	92	110	188	-	85	148	79	116	192	107	89	123
18	116	69	59	113	195	-	89	120	86	135	88	179	120	147

Appendix 6.3.4b **Shaken sample suspended solids data from routine sampling of secondary filter feed and effluents.**

Quarter 2.4. Sep. - Nov. 1979

Shaken sample suspended solids (mg/l)

Date	3/9	6/9	20/9	24/9	27/9	15/10	22/10	25/10	29/10	5/11	12/11	15/11	19/11
Shaken feed	98	141	124	243	204	126	192	146	170	142	148	133	185
Settled feed	51	80	65	111	117	63	104	73	81	69	92	61	79
Filter No :- 17	79	123	80	253	147	114	104	149	178	145	128	109	93
18	86	125	85	205	182	106	108	96	117	100	133	109	133

Appendix 6.3.4c Shaken sample suspended solids data from routine sampling of secondary filter feed and effluents.

Quarter 3.1. Dec. 1979 - Feb. 1980

Shaken sample suspended solids (mg/l)

Date		3/12	6/12	12/12	3/1	22/1	24/1	28/1	31/1	4/2	11/2	15/2	18/2	21/2	28/2
Shaken feed		183	142	131	144	155	179	142	75	142	135	171	116	137	112
Settled feed		69	70	73	52	60	55	64	40	54	52	47	66	67	55
Filter No :-	17	92	103	101	88	81	105	156	59	103	118	120	110	106	116
	18	128	91	92	75	86	103	120	53	98	116	113	124	110	122

Appendix 6.3.4d Shaken sample suspended solids data, secondary filter feed and effluents, Quarter 3.2, Mar. - May 1980

- no data collected.

Appendix 6.3.4e Shaken sample suspended solids data from routine sampling of secondary filter feed and effluents.

Quarter 3.3. Jun. - Aug. 1980

Shaken sample suspended solids (mg/l)

Date		2/6	5/6	9/6	12/6	16/6	19/6	23/6	26/6	30/6	3/7	5/8	7/8	28/8
Shaken feed		119	128	162	140	128	134	128	125	158	124	118	132	142
Settled feed		74	73	77	67	62	75	55	64	68	62	66	36	69
Filter No :-	17	71	104	89	77	81	83	83	113	73	114	178	109	102
	18	75	123	85	71	77	81	102	112	77	87	148	111	146

Appendix 6.3.4f **Shaken sample suspended solids data from routine sampling of secondary filter feed and effluents.**

Quarter 3.4. Sep. - Nov. 1980

Shaken sample suspended solids (mg/l)

Date	1/9	4/9	8/9	15/9	18/9	23/9	25/9	2/10	7/10	9/10	14/10	16/10	30/10	6/11	10/11
Shaken feed	162	187	207	123	179	233	244	255	155	222	169	116	139	170	137
Settled feed	61	89	85	75	75	50	112	114	121	104	66	35	73	86	97
Filter No :- 17	146	99	107	109	107	87	111	102	100	90	94	55	104	72	75
18	162	94	127	82	93	87	104	80	85	84	71	54	83	74	81

Date	13/11	17/11	20/11	24/11	27/11
Shaken feed	172	147	186	150	185
Settled feed	114	94	123	81	118
Filter No :- 17	117	89	131	92	112
18	94	87	101	69	92

Appendix 6.3.4g **Shaken sample suspended solids data from routine sampling of secondary filter feed and effluents.**

Quarter 4.1. Dec. 1980 - Feb. 1981

Shaken sample suspended solids (mg/l)

Date		1/12	4/12	6/1	8/1	13/1	15/1	20/1	22/1	27/1	29/1
Shaken feed		148	191	152	272	245	141	253	230	215	195
Settled feed		113	118	80	135	103	78	120	111	97	116
Filter No :-	17	92	102	128	125	95	77	122	122	94	124
	18	73	85	145	116	89	52	101	101	78	97

Appendix 6.3.4h **Shaken sample suspended solids data from routine sampling of secondary filter feed and effluents.**

Quarter 4.2. Mar. - May 1981

Shaken sample suspended solids (mg/l)

Date		3/3	7/3	10/3	17/3	19/3	24/3
Shaken feed		189	239	175	126	146	194
Settled feed		107	141	87	82	81	52
Filter No :-	17	58	79	77	84	79	61
	18	38	66	56	45	42	41

Appendix 6.3.5 Monthly averaged sludge production rate data. Secondary filters.

Data expressed as g sludge produced/g BOD removed.

			1979									1980								1981		
Month	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A
Filter - 17	1.16	1.41	0.85	0.67	0.67	0.56	0.83	1.20				0.70	1.08	1.46	0.81	0.78	0.45	0.42	0.55		0.29	
18	1.04	1.31	0.80	0.52	0.56	0.59	0.71	1.20				0.74	0.73	1.71	0.77	0.65	0.40	0.31	0.48		0.18	

Appendix 6.3.6 Monthly averaged feed and effluent temperatures. Secondary filters.

Data expressed as °C. Effluent temperature readings taken from filter no. 17, filter no. 18 assumed to have the same temperature.

			1979									1980								1981		
Month	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A
Feed				17.0	14.4	13.0	11.0	11.2	14.9	16.8	17.7	18.2	17.5	15.9			14.4	12.6	12.2	12.3	12.5	13.7
Effluent				14.8	12.9	10.2	10.2	10.9	14.1	15.5	16.0	16.9	16.3	14.1			12.9	11.7	11.3	10.4	12.2	13.4

Appendix 6.3.7a <u>Monthly averaged NH_3-N data.</u> <u>Secondary filters.</u>

Data expressed as mg N/1

	1979						1980												1981			
Month	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A
Feed	9.3	8.7	11.4	13.9	12.8	11.2	14.0	12.0			13.8	12.3	14.0	11.7	12.8	10.4	11.3	11.3	13.8	14.6	11.2	13.5
Filter -17	11.2	6.6	11.4	13.0	11.8	11.2	10.0	10.0			14.2	13.2	15.7	10.7	11.9	10.4	11.7	11.6	15.6	15.8	12.4	11.8
18	10.4	6.1	11.5	12.5	11.4	10.0	10.4	9.2			12.8	11.6	14.4	10.4	11.0	8.2	10.6	12.1	13.5	15.0	9.1	8.9

Appendix 6.3.7b <u>Monthly averaged total oxidised-N data.</u> <u>Secondary filters.</u>

Data expressed as mg N/1

	1979						1980												1981			
Month	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A
Feed	0.10	0.25	0.10	0.14	0.16	0.76	1.21	0.77			2.92	0.13	0.17	0.30	0.12	0.30	0.40	0.16	0.88	0.09	2.15	1.08
Filter - 17	0.30	1.02	0.30	0.28	0.13	1.20	1.37	4.58			1.75	2.99	1.10	2.69	2.66	1.37	0.40	0.26	0.43	0.24	1.06	1.74
18	0.50	2.16	0.69	0.63	0.35	4.40	1.34	5.37			4.02	4.53	2.72	5.74	4.09	3.27	1.31	0.33	1.68	1.52	3.38	3.39

Appendix 6.4.1 Biological sampling data. Secondary filters. Quarter 2.3. (July 1979)

Filter No.	Level	Film Dry wt (kg/m^3)	Film Volatile Solids (kg/m^3)	% dry wt as Volatile Solids	No. of invertebrates present (x 10^6/m^3) Psychoda larvae	Psychoda pupae	Enchytraeid worm spp.	Chironomid sp.	Species X (Diptera)	Spathiophora hydromyzina	Sylvicola fenestralis	Naid worm sp.
17	1	2.30	1.62	70.5	1.12	0.56	0.16	0.29	-	0.13	-	-
	2	3.44	2.80	81.5	1.69	1.63	0.34	0.77	-	0.03	-	-
	3	3.52	3.26	92.6	2.40	1.88	0.23	0.23	-	0.02	-	-
	4	-	-	-	-	-	-	-	-	-	-	-
	5	-	-	-	-	-	-	-	-	-	-	-
18	1	6.54	5.76	88.2	8.38	0.85	0.08	0.64	-	-	-	-
	2	7.06	3.62	51.3	6.17	1.95	-	0.04	-	0.02	-	-
	3	5.16	4.46	86.3	2.90	1.14	0.12	0.17	-	-	-	-
	4	4.94	4.26	86.2	1.18	0.92	0.17	-	-	-	0.17	-
	5	3.48	3.06	87.5	0.59	0.73	0.07	-	-	-	-	-

Appendix 6.4.2 Biological sampling data. Secondary filters. Quarter 2.4 (October 1979)

Column headings as in Appendix 6.4.1

17	1	4.20	3.32	79.0	0.31	0.30	2.10	0.07	0.07	0.02	-	-
	2	2.72	2.30	84.6	0.90	0.51	1.03	0.03	0.07	-	-	-
	3	2.22	1.82	82.0	1.02	0.72	0.77	0.04	0.05	0.01	-	-
	4	2.30	1.96	84.5	1.14	0.51	0.68	0.01	0.08	0.01	-	-
	5	-	-	-	-	-	-	-	-	-	-	-
18	1	5.42	4.56	84.1	3.07	1.74	2.35	0.30	0.12	-	-	-
	2	5.26	4.32	82.1	3.98	2.38	3.69	0.32	0.09	0.03	-	-
	3	3.44	2.82	82.0	1.02	0.87	2.61	0.17	0.07	0.01	-	-
	4	2.58	2.14	82.9	0.78	0.68	1.31	0.02	0.14	0.02	-	-
	5	-	-	-	-	-	-	-	-	-	-	-

Appendix 6.4.3 Biological sampling data. Secondary filters. Quarter 3.1. (January 1980)

Filter no.	Level	Film dry wt (kg/m^3)	Film volatile solids (kg/m^3)	% dry wt as volatile solids	Psychoda larvae	Psychoda pupae	Enchytraeid worm spp.	Chironomid sp.	Species X (Diptera)	Spathiophora hydromyzina	Sylvicola fenestralis	Naid worm sp.
					No. of invertebrates present (x 10^6/m^3)							
17	1	8.90	7.46	83.8	2.80	2.00	0.49	-	0.01	-	-	-
	2	15.72	13.08	83.2	5.09	5.94	1.82	-	-	-	-	-
	3	14.26	7.08	49.6	2.52	3.67	1.55	-	0.01	-	-	-
	4	-	-	-	-	-	-	-	-	-	-	-
	5	-	-	-	-	-	-	-	-	-	-	-
18	1	20.28	16.94	83.5	3.61	3.33	2.42	-	0.01	-	-	-
	2	18.54	15.26	82.3	8.07	7.46	4.58	-	0.03	-	-	-
	3	6.94	5.86	84.4	1.74	1.59	1.74	-	0.12	-	-	-
	4	7.58	5.68	74.9	0.61	0.67	1.21	-	0.03	-	-	0.35
	5	15.38	10.78	70.1	1.06	0.30	1.71	-	-	-	-	2.25

Appendix 6.4.4 Biological sampling data. Secondary filters. Quarter 3.2 (April 1980)

Column headings as in Appendix 6.4.3

Filter no.	Level	Film dry wt (kg/m^3)	Film volatile solids (kg/m^3)	% dry wt as volatile solids	Psychoda larvae	Psychoda pupae	Enchytraeid worm spp.	Chironomid sp.	Species X (Diptera)	Spathiophora hydromyzina	Sylvicola fenestralis	Naid worm sp.
17	1	2.66	2.24	84.2	0.77	0.17	1.34	-	-	0.06	-	-
	2	5.24	4.56	87.0	2.63	1.14	2.05	-	-	-	-	-
	3	3.14	2.72	86.6	1.22	1.05	0.64	-	-	-	-	-
	4	1.94	1.62	83.5	1.93	0.39	0.42	-	0.03	-	-	0.01
	5	-	-	-	-	-	-	-	-	-	-	-
18	1	4.34	3.74	86.2	1.27	0.49	2.15	-	0.30	-	-	-
	2	7.36	6.48	88.0	3.91	1.09	10.65	-	-	-	-	0.02
	3	4.42	3.72	84.2	1.70	0.56	1.44	-	0.38	-	-	0.07
	4	8.14	5.68	69.8	1.04	0.43	2.39	-	0.01	-	-	0.55
	5	-	-	-	-	-	-	-	-	-	-	-

Appendix 6.4.5 Biological sampling data. Secondary filters. Quarter 3.3 (July 1980)

Filter no.	Level	Film dry wt (kg/m^3)	Film volatile solids (kg/m^3)	% dry wt as volatile solids	Psychoda larvae	Psychoda pupae	Enchytraeid worm spp.	Chironomid sp.	Species X (Diptera)	Spathiophora hydromyzina	Sylvicola fenestralis	Naid worm sp.
					No. of invertebrates present (x 10^6/m^3)							
17	1	6.88	5.40	78.5	2.01	0.82	3.14	0.05	0.11	0.16	-	-
	2	9.56	7.36	77.0	2.81	1.18	4.98	-	0.11	0.02	-	-
	3	6.06	4.70	77.6	1.89	0.75	2.40	-	0.18	-	-	0.25
	4	-	-	-	-	-	-	-	-	-	-	-
	5	-	-	-	-	-	-	-	-	-	-	-
18	1	8.02	6.52	81.3	1.81	1.66	3.04	-	0.08	-	-	-
	2	7.18	5.82	81.1	1.99	1.42	2.37	-	0.11	-	-	0.22
	3	2.92	2.28	78.1	0.64	0.22	1.31	0.06	0.07	0.02	-	0.24
	4	1.94	1.56	80.4	0.25	0.15	0.72	-	0.01	-	-	0.50
	5	1.32	1.00	75.8	0.16	0.07	0.29	-	0.01	0.01	-	0.52

18 (Cont.) No. of invertebrates present

		Hypogastrura viatica
Level -	1	-
	2	-
	3	2.36
	4	0.85
	5	1.26

Appendix 6.4.6 Monthly neutron moisture meter data. Secondary filters.

Data expressed as averaged % saturation of voids with filter depth, together with the maximum and minimum % saturations recorded within the filters.

					1979								1980				
Month		J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S
Filter No :- 17	$\bar{x}$	0.3	1.1	0.3	0.7	1.6	2.6	2.1	5.5				1.3	2.3	1.3	1.4	1.4
	Max.	1.1	1.5	0.7	1.4	2.3	3.6	3.8	10.8				2.0	4.1	1.7	2.3	2.3
	Min.	0.1	0.8	0.1	0.5	1.0	1.9	1.0	2.1				0.7	1.1	0.8	1.2	0.6
18	$\bar{x}$	0.5	1.6	0.5	1.2	2.2	5.6	4.1	6.0				1.0	1.8	1.5	1.6	1.5
	Max.	1.1	1.9	1.0	1.6	3.1	6.8	7.7	14.8				2.0	3.4	2.4	2.5	2.1
	Min.	0.2	1.2	0.2	0.8	1.3	4.3	1.6	2.0				0.5	0.8	0.7	0.8	1.1

Appendix 7.2.1 Summary of sludge condition and conditionability data. 89/50 Granite.

Chemical and conc. of stock sol.	Month	Thickened Sludge			Chemical Dose					
		Initial $\bar{r}$ (10^{12}m/kg)	Sus-pended Solids (% dm)	Stability to shear (Water added)	'Minimum' $\bar{r}$ achieved (10^{12}m/kg)	Kg Chemical/ tonne dry solids	Cost £/ Tonne dry solids	Stability to shear after con-ditioning	'Minimum' Cost/dose index	Coagulant Demand (£/Tonne dry solids)
Al_2O_3 1%	Sep 79	22.9	4.13	1.19	1.3	309.7	46.5	1.46	72.4	13.0
	Nov	125.7	2.86	1.21	0.9	226.3	33.9	1.31	27.9	8.3
	Dec	76.8	3.74	1.37	1.6	171.8	25.8	1.80	52.8	13.2
	Jan 80	64.2	4.21	1.17	2.2	151.7	22.8	1.66	72.0	11.2
	Feb	208.9	4.08	1.01	2.3	156.7	23.5	2.15	116.0	11.6
	Mar	83.5	4.86	1.63	1.2	130.4	19.6	1.37	19.6	8.7
	Apr	77.3	4.13	1.26	1.8	154.6	23.2	1.74	56.6	11.0
	May	68.1	3.68	1.43	1.9	87.3	13.1	2,26	38.7	8.4
	Jun	68.4	3.04	1.43	1.6	106.3	16.0	1.47	25.9	8.7
	Jul	10.9	4.64	1.56	1.3	137.1	20.6	1.31	21.6	6.0
	Aug	72.3	3.09	1.17	1.0	104.4	15.7	1.65	22.8	7.2
	Sep	4.7	3.97	2.82	0.8	80.7	12.1	1.43	4.8	3.7
Average		73.2	3.87	1.44	1.5	151.4	22.7	1.63	44.3	9.2
Zetag 51 1%	Jan 80									
	Feb	208.9	4.08	1.01	0.8	47.0	14.1	7.22	82.7	9.2
	Mar	83.5	4.86	1.63	1.3	39.1	11.7	3.61	33.5	7.2
Average		146.2	4.47	1.32	1.1	43.1	12.9	5.42	58.1	8.2
Zetag 88 0.4%	Jul 80	10.9	4.64	1.56	0.3	16.5	26.3	1.44	7.5	4.3
	Aug	72.3	3.09	1.17	0.6	12.5	20.1	1.43	13.5	4.8
	Sep	4.7	3.97	2.82	0.3	9.7	15.5	1.64	2.8	1.2
Average		29.3	3.90	1.85	0.4	12.9	20.6	1.50	7.9	3.4

Appendix 7.2.2 Summary of sludge condition and conditionability data. 125/75 Slag.

Chemical and conc. of stock sol.	Month	Thickened Sludge			Chemical Dose					
		Initial $\bar{\bar{r}}$ (10^{12}m/kg)	Sus-pended Solids (% dm)	Stability to shear (Water added)	'Minimum' $\bar{\bar{r}}$ achieved (10^{12}m/kg)	Kg Chemical/ tonne dry solids	Cost £/ Tonne dry solids	Stability to shear after con-ditioning	'Minimum' Cost/dose index	Coagulant Demand (£/Tonne dry solids)
Al_2O_3 1%	Sep 79	88.7	3.70	1.19	0.8	173.3	26.0	1.34	18.0	11.6
	Nov	45.1	4.10	1.93	1.1	155.9	23.4	1.88	24.2	5.7
	Dec	28.6	3.97	1.46	2.2	141.4	21.2	2.19	69.4	12.2
	Jan 80	70.1	4.17	1.33	2.3	153.4	23.0	1.84	73.5	11.5
	Feb	134.3	4.38	1.52	2.6	145.6	21.8	2.37	88.5	10.7
	Mar	90.3	5.57	1.22	2.9	113.1	17.0	2.15	86.7	14.9
	Apr	75.4	4.17	1.28	1.5	76.6	11.5	2.02	27.6	5.6
	May	44.8	3.88	1.41	1.5	165.1	24.8	1.25	32.1	8.3
	Jun	61.0	3.12	1.09	1.4	103.4	15.5	1.52	29.6	9.6
	Jul	26.1	4.69	1.35	1.1	135.6	20.3	2.16	35.2	10.6
	Aug	80.2	3.33	1.48	1.1	96.7	14.5	1.58	17.0	7.2
	Sep	11.0	3.99	1.64	0.8	160.3	24.0	1.26	15.5	5.3
Average		67.1	4.09	1.41	1.6	135.0	20.3	1.80	43.1	9.4
Zetag 51 1%	Jan 80	70.1	4.17	1.33	1.2	46.0	13.8	3.56	44.7	7.6
	Feb	134.3	4.38	1.52	1.0	43.7	13.1	3.61	32.4	7.7
	Mar	90.3	5.57	1.22	1.8	33.9	10.2	5.38	79.9	8.8
Average		98.2	4.71	1.36	1.3	41.2	12.4	4.20	52.3	8.0
Zetag 88 0.4%	Jul 80	26.1	4.69	1.35	0.2	16.3	26.0	3.16	13.4	7.0
	Aug	80.2	3.33	1.48	0.6	11.6	18.6	1.40	10.7	4.6
	Sep	11.0	3.99	1.64	0.4	9.6	15.4	1.39	4.8	1.2
Average		39.1	4.00	1.49	0.4	12.5	20.0	2.00	9.6	4.2

Appendix 7.2.3 Summary of sludge condition and conditionability data. 89/50 Slag.

Chemical and conc. of stock sol.	Month	Thickened Sludge			Chemical Dose					
		Initial $\bar{r}$ (10^{12}m/kg)	Sus-pended Solids (% dm)	Stability to shear (Water added)	'Minimum' $\bar{r}$ achieved (10^{12}m/kg)	Kg Chemical/ tonne dry solids	Cost £/ Tonne dry solids	Stability to shear after con-ditioning	'Minimum' Cost/dose index	Coagulant Demand (£/Tonne dry solids)
Al_2O_3	Sep 79	69.6	3.54	1.39	0.8	181.7	27.3	1.34	21.6	12.6
1%	Nov	141.5	3.57	1.21	2.5	180.0	27.0	1.49	83.8	12.4
	Dec	106.2	3.75	1.08	2.5	171.2	25.7	2.42	141.0	21.6
	Jan 80	76.8	4.53	1.35	1.8	140.5	21.1	1.48	40.9	10.3
	Feb	119.3	4.32	1.33	2.6	147.6	22.1	1.94	83.6	19.6
	Mar	76.9	4.44	1.22	1.7	143.4	21.5	1.65	49.2	10.6
	Apr	90.8	4.25	1.27	2.1	150.4	22.6	1.69	62.7	11.0
	May	72.9	4.21	1.42	1.6	151.8	22.8	1.73	43.0	9.9
	Jun	42.0	3.36	1.45	1.4	95.8	14.4	1.72	23.0	7.0
	Jul	12.6	4.22	1.55	1.5	151.5	22.7	1.23	27.6	8.1
	Aug	109.7	3.54	1.19	1.5	181.7	27.3	1.12	38.5	12.5
	Sep	4.9	4.22	1.09	0.8	75.6	11.3	1.99	16.6	4.8
Average		76.9	4.00	1.30	1.7	147.6	22.1	1.65	52.6	11.7
Zetag 51	Jan 80	76.8	4.53	1.35	1.0	42.1	12.6	3.32	30.5	6.1
1%	Feb	119.3	4.32	1.33	5.5	44.3	13.3	15.46	844.4	==
	Mar									
Average		98.1	4.43	1.34	3.2	43.2	13.0	9.40	437.4	6.1
Zetag 88	Jul 80	12.6	4.22	1.55	0.3	18.2	29.1	1.26	7.3	5.0
0.4%	Aug	109.7	3.54	1.19	0.7	10.9	17.5	3.79	38.3	8.3
	Sep	4.9	4.22	1.09	0.6	4.5	7.3	2.80	11.9	0.8
Average		42.4	3.99	1.28	0.5	11.2	17.9	2.60	19.2	4.7

Where:- == denotes sludge which could not be conditioned to $\bar{r}$ of 4.0×10^{12} m/kg

Appendix 7.2.4 Summary of sludge condition and conditionability data. 125/75 Granite.

Chemical and conc. of stock sol.	Month	Thickened Sludge			Chemical Dose					
		Initial $\bar{r}$ (10^{12}m/kg)	Sus-pended Solids (% dm)	Stability to shear (Water added)	'Minimum' $\bar{r}$ achieved (10^{12}m/kg)	Kg Chemical/ Tonne dry solids	Cost £/ Tonne dry solids	Stability to shear after con-ditioning	'Minimum' Cost/dose index	Coagulant Demand (£/Tonne dry solids)
Al_2O_3 1%	Sep 79	139.4	3.66	1.29	0.9	175.6	26.3	1.29	22.9	12.6
	Nov	112.4	3.78	1.16	2.0	169.8	25.5	1.82	81.1	11.8
	Dec	46.9	3.99	1.12	2.0	160.6	24.1	2.24	94.9	12.6
	Jan 80	85.8	4.48	1.32	2.6	142.2	21.3	1.59	66.8	9.7
	Feb	130.1	4.18	1.15	3.4	152.7	22.9	2.38	160.7	21.9
	Mar	45.7	4.83	1.33	3.0	131.4	19.7	2.34	105.1	17.2
	Apr	62.0	3.83	1.33	1.8	167.4	25.1	1.64	55.1	10.4
	May	41.6	3.44	1.49	1.3	93.7	14.1	1.26	15.1	6.4
	Jun	51.3	2.81	1.48	1.6	115.5	17.3	1.26	23.2	8.2
	Jul	18.2	3.58	1.64	1.0	89.7	13.5	1.77	14.4	6.0
	Aug	146.7	3.53	1.15	1.5	182.1	27.3	1.48	53.4	13.5
	Sep	47.2	3.24	1.64	1.3	99.6	14.9	1.77	20.2	7.7
Average		77.3	3.78	1.34	1.9	140.1	21.0	1.74	59.4	11.5
Zetag 51 1%	Jan 80	85.8	4.48	1.32	0.8	42.7	12.8	2.50	22.5	5.7
	Feb	130.1	4.18	1.15	0.8	45.8	13.7	3.02	28.9	9.3
	Mar	45.7	4.83	1.33	1.0	39.4	11.8	3.33	30.2	5.9
Average		81.2	4.50	1.27	0.9	42.6	12.8	2.95	27.2	8.2
Zetag 88 0.4%	Jul 80	18.2	3.58	1.64	0.5	21.5	34.5	1.54	17.2	7.3
	Aug	146.7	3.53	1.15	0.5	21.9	35.0	1.11	15.2	11.8
	Sep	47.2	3.24	1.64	0.6	12.0	19.1	1.33	9.8	4.6
Average		70.7	3.45	1.48	0.5	18.4	29.5	1.33	14.1	3.4

Appendix 7.2.5 Summary of sludge condition and conditionability data. Biopac 50.

Chemical and conc. of stock sol.	Month	Thickened Sludge			Chemical Dose					
		Initial $\bar{r}$ (10^{12}m/kg)	Sus-pended Solids (% dm)	Stability to shear (Water added)	'Minimum' $\bar{r}$ achieved (10^{12}m/kg)	Kg Chemical/ Tonne dry solids	Cost £/ Tonne dry solids	Stability to shear after con-ditioning	'Minimum' Cost/dose index	Coagulant Demand (£/Tonne dry solids)
Al_2O_3	Sep 79	121.6	4.00	1.15	0.7	160.1	24.0	1.45	21.5	11.1
	Nov	126.1	3.68	1.25	0.8	174.7	26.2	1.58	25.5	11.3
1%	Dec	87.6	4.79	1.17	1.1	132.5	19.9	1.41	27.1	8.6
	Jan 80	105.7	3.89	1.09	1.3	82.3	12.3	1.56	23.3	8.6
	Feb	153.9	4.24	1.24	1.2	150.4	22.6	1.73	38.1	10.7
	Mar	117.8	4.64	1.12	1.2	137.0	20.6	1.35	29.5	8.3
	Apr	128.9	4.15	1.09	1.3	103.0	15.5	2.26	40.7	12.6
	May	84.3	4.82	1.24	1.5	131.7	19.8	2.00	48.7	9.4
	Jun	94.8	4.83	1.20	1.8	65.7	9.9	3.43	49.6	8.7
	Jul	77.8	4.16	1.21	0.9	153.7	23.1	1.11	19.0	6.4
	Aug									
	Sep	2.8	4.88	1.17	0.5	64.9	9.7	1.82	7.4	-
Average		100.1	4.37	1.18	1.1	123.3	18.5	1.79	30.0	9.6
Zetag 51	Jan 80									
1%	Feb	153.9	4.24	1.24	0.8	45.1	13.5	5.33	46.0	6.7
	Mar	117.8	4.64	1.12	0.7	41.1	12.3	2.40	17.7	7.0
Average		135.8	4.44	1.18	0.8	43.1	12.9	3.90	31.9	6.9
Zetag 88	Jul 80	77.8	4.16	1.21	0.7	9.2	14.8	1.98	16.7	6.8
0.4%	Aug									
	Sep	2.8	4.88	1.17	0.2	7.8	12.5	1.52	3.9	-
Average		40.3	4.50	1.19	0.5	8.5	13.6	1.80	10.3	6.8

Appendix 7.2.6 Summary of sludge condition and conditionability data. Biopac 90.

Chemical and conc. of stock sol.	Month	Thickened Sludge			Chemical Dose					
		Initial $\bar{r}$ (10^{12}m/kg)	Sus-pended Solids (% dm)	Stability to shear (Water added)	'Minimum' $\bar{r}$ achieved (10^{12}m/kg)	Kg Chemical/ Tonne dry solids	Cost £/ Tonne dry solids	Stability to shear after con-ditioning	'Minimum' Cost/dose index	Coagulant Demand (£/Tonne dry solids)
Al_2O_3	Sep 79	104.5	3.78	1.16	0.7	169.7	25.5	1.32	20.9	11.5
	Nov	103.4	4.16	1.18	1.3	153.7	23.1	1.52	37.7	7.8
1%	Dec	129.7	4.16	1.16	2.3	153.7	23.1	2.82	126.7	18.6
	Jan 80	89.7	4.70	1.23	1.7	135.2	20.3	1.46	41.4	8.9
	Feb	158.0	4.94	1.28	1.6	128.2	19.2	2.08	50.6	12.8
	Mar	100.8	4.52	1.50	1.2	140.7	21.1	1.32	22.9	5.7
	Apr	108.6	4.03	1.24	1.3	79.3	11.9	2.38	29.2	8.6
	May	141.5	4.42	1.11	1.8	144.2	21.6	1.62	55.2	10.7
	Jun	88.6	4.08	1.35	1.0	78.3	11.8	2.71	36.3	7.8
	Jul									
	Aug									
	Sep	34.8	3.69	1.46	0.9	86.9	13.0	1.87	14.5	6.1
Average		105.9	4.25	1.27	1.4	127.0	19.1	1.91	43.6	9.9
Zetag	Jan 80	89.7	4.70	1.23	1.7	40.6	12.2	4.54	75.0	9.7
51	Feb	158.0	4.94	1.28	1.7	38.5	11.5	7.33	110.4	10.3
1%	Mar	100.8	4.52	1.50	0.8	42.2	12.7	4.17	29.2	6.0
Average		116.1	4.70	1.34	1.4	40.4	12.1	5.35	71.5	8.7
Zetag	Jul 80									
88	Aug									
0.4%	Sep	34.8	3.69	1.46	0.5	10.4	16.7	1.23	7.2	3.2
Average		34.8	3.69	1.46	0.5	10.4	16.7	1.23	7.2	3.2

Appendix 7.2.7 Summary of sludge condition and conditionability data. Flocor E.

Chemical and conc. of stock sol.	Month	Thickened Sludge			Chemical Dose					
		Initial $\bar{r}$ (10^{12}m/kg)	Sus-pended Solids (% dm)	Stability to shear (Water added)	'Minimum' $\bar{r}$ achieved (10^{12}m/kg)	Kg Chemical/ Tonne dry solids	Cost £/ Tonne dry solids	Stability to shear after con-ditioning	'Minimum' Cost/dose index	Coagulant Demand (£/Tonne dry solids)
Al_2O_3	Sep 79	209.6	3.75	1.38	1.6	117.0	25.7	1.82	53.1	17.4
	Nov	179.2	3.65	1.14	4.0	176.2	26.4	1.93	178.5	26.4
1%	Dec	146.0	3.82	1.32	2.1	167.8	25.2	4.56	182.6	22.6
	Jan 80	118.5	3.22	1.41	5.1	121.0	18.2	3.18	206.7	*
	Feb	177.0	4.86	1.26	6.8	260.8	39.1	1.87	393.1	*
	Mar	235.3	5.62	1.57	2.5	223.8	33.6	1.81	96.0	23.8
	Apr	114.6	4.76	1.51	2.6	133.3	20.0	5.28	184.6	18.2
	May	273.3	4.08	1.20	3.5	156.7	23.5	2.84	194.7	23.1
	Jun	114.3	3.57	1.22	1.9	180.3	27.0	1.43	61.5	12.1
	Jul									
	Aug									
	Sep	146.5	3.89	1.19	1.6	164.7	24.7	1.62	54.8	12.3
Average		171.4	4.12	1.32	3.2	175.6	26.3	2.63	160.6	20.5
Zetag 51	Jan 80	118.5	3.22	1.41	2.8	36.3	10.9	5.99	128.1	10.3
1%	Feb	177.0	4.86	1.26	2.3	39.1	11.7	11.26	242.4	11.4
	Mar	235.3	5.62	1.57	2.8	33.6	10.1	11.68	208.3	9.8
Average		176.9	4.57	1.41	2.6	36.3	10.9	9.64	192.9	10.5
Zetag 88	Jul 80									
	Aug									
0.4%	Sep	146.5	3.89	1.19	0.9	9.9	15.8	3.54	30.1	8.4
Average		146.5	3.89	1.19	0.0	9.9	15.8	3.54	30.1	8.4

Where; * denotes sludge which could not be conditioned to $\bar{r}$ of 4.0×10^{12} m/kg

Appendix 7.2.5 Summary of sludge condition and conditionability data. Flocor M.

Chemical and conc. of stock sol.	Month	Thickened Sludge: Initial $\bar{r}$ (10^{12}m/kg)	Thickened Sludge: Suspended Solids (% dm)	Thickened Sludge: Stability to shear (Water added)	Chemical Dose: 'Minimum' $\bar{r}$ achieved (10^{12}m/kg)	Chemical Dose: Kg Chemical/ Tonne dry solids	Chemical Dose: Cost £/ Tonne dry solids	Chemical Dose: Stability to shear after conditioning	Chemical Dose: 'Minimum' Cost/dose index	Chemical Dose: Coagulant Demand (£/Tonne dry solids)
Al_2O_3	Sep 79	126.8	3.43	1.30	1.4	187.7	28.2	1.64	50.5	13.7
	Nov	323.2	3.28	1.25	4.6	196.8	29.5	1.43	156.4	*
1%	Dec	102.4	4.28	1.34	2.1	149.3	22.4	3.48	157.0	19.4
	Jan 80	66.6	5.24	1.33	3.2	120.7	18.1	3.05	131.6	32.5
	Feb	126.7	4.69	1.43	3.2	271.3	40.7	2.28	207.0	32.5
	Mar	56.3	4.52	1.22	1.8	140.8	21.1	2.39	72.8	10.5
	Apr	133.1	4.53	1.18	2.0	140.6	21.1	2.88	103.0	19.2
	May	240.6	3.78	1.11	1.6	169.8	25.5	1.45	52.6	17.7
	Jun	140.2	3.98	1.13	2.1	160.9	24.1	1.62	71.6	13.2
	Jul									
	Aug									
	Sep	84.1	4.75	1.25	1.9	133.6	20.0	1.76	53.6	15.0
Average		140.0	4.25	1.25	2.4	167.1	25.1	2.20	105.6	17.6
Zetag	Jan 80	66.6	5.24	1.33	2.4	36.2	10.9	7.21	143.6	10.2
51	Feb	126.7	4.69	1.43	3.2	40.7	12.2	15.98	432.5	11.9
1%	Mar	56.3	4.52	1.22	1.4	42.3	12.7	7.02	98.5	10.0
Average		83.2	4.82	1.33	2.3	39.7	11.9	10.07	224.9	10.7
Zetag	Jul 80									
88	Aug									
0.4%	Sep	84.1	4.75	1.25	0.4	16.0	25.7	0.98	8.4	13.9
Average		84.1	4.75	1.25	0.4	16.0	25.7	0.98	8.4	13.9

Where: * denotes sludge which could not be conditioned to $\bar{r}$ of 4.0×10^{12}m/kg.

Appendix 7.2.9 Summary of sludge condition and conditionability data. Flocor R2S.

Chemical and conc. of stock sol.	Month	Thickened Sludge			Chemical Dose					
		Initial $\bar{r}$ (10^{12}m/kg)	Sus-pended Solids (% dm)	Stability to shear (Water added)	'Minimum' $\bar{r}$ achieved (10^{12}m/kg)	Kg Chemical/ Tonne dry solids	Cost £/ Tonne dry solids	Stability to shear after con-ditioning	'Minimum' Cost/dose index	Coagulant Demand (£/Tonne dry solids)
Al_2O_3	Sep 79	28.1	2.72	1.47	1.1	238.3	35.8	1.44	39.5	12.9
1 %	Nov	130.9	3.74	1.23	1.8	342.7	51.4	1.10	80.4	23.7
	Dec	51.2	4.27	1.86	1.5	149.4	22.4	1.65	29.1	11.4
	Jan 80	97.6	4.15	1.06	1.4	153.9	23.1	1.85	54.8	10.5
	Feb	237.7	4.97	1.21	2.7	254.1	38.2	1.64	140.8	18.6
	Mar	362.0	4.88	1.10	1.8	259.9	39.0	1.41	89.2	15.9
	Apr	267.5	4.22	1.34	2.0	151.4	22.7	1.81	62.5	17.7
	May	106.9	4.58	1.33	2.5	277.5	41.6	1.45	111.5	19.8
	Jun	92.9	4.17	1.33	1.7	306.6	46.0	1.37	81.3	19.7
	Jul	78.9	4.02	1.44	1.8	317.9	47.7	1.23	71.5	21.8
	Aug	71.1	4.34	1.23	1.8	293.9	44.1	1.46	95.2	19.8
	Sep	69.2	4.40	1.37	1.4	289.4	43.4	1.32	57.7	16.8
Average		132.8	4.21	1.38	1.8	253.0	37.9	1.48	76.1	17.4
Zetag 51	Jan 80	97.6	4.15	1.06	0.9	46.2	13.9	1.60	19.4	5.3
1 %	Feb	237.6	4.97	1.21	0.7	38.2	11.5	2.75	18.8	5.4
	Mar									
Average		167.6	4.56	1.14	0.8	42.2	12.7	2.18	19.1	5.4
Zetag 88	Jul 80	78.9	4.02	1.44	0.8	9.5	15.3	3.40	28.1	7.4
0.4 %	Aug	71.1	4.34	1.23	0.5	17.6	28.2	1.14	13.9	7.9
	Sep	69.2	4.40	1.37	0.9	8.7	13.9	2.38	22.0	8.4
Average		73.1	4.25	1.35	0.7	12.0	19.1	2.31	21.3	7.9

Appendix 7.2.10 Summary of sludge condition and conditionability data. Flocor RS.

Chemical and conc. of stock sol.	Month	Thickened Sludge			Chemical Dose					
		Initial $\bar{r}$ (10^{12}m/kg)	Sus-pended Solids (% dm)	Stability to shear (Water added)	'Minimum' $\bar{r}$ achieved (10^{12}m/kg)	Kg Chemical/ Tonne dry solids	Cost £/ Tonne dry solids	Stability to shear after con-ditioning	'Minimum' Cost/dose index	Coagulant Demand (£/Tonne dry solids)
Al_2O_3 1 %	Sep 79	21.2	2.91	1.61	0.7	222.3	33.4	1.31	19.3	9.0
	Nov	22.2	2.75	1.41	0.9	235.9	35.4	1.24	28.0	15.6
	Dec	39.4	4.21	2.41	1.0	303.3	45.5	1.22	23.7	11.1
	Jan 80	109.0	4.25	1.18	1.6	150.1	22.5	1.62	50.4	10.8
	Feb	152.1	4.61	1.62	1.6	137.8	20.7	1.38	28.9	9.0
	Mar	188.2	5.18	1.22	2.4	121.9	18.3	2.01	72.1	14.8
	Apr	391.3	3.96	1.02	1.6	323.4	48.5	1.29	98.3	21.8
	May	97.3	4.56	1.24	2.2	278.8	41.8	1.42	105.5	19.3
	Jun	92.9	4.17	1.48	1.7	306.6	45.0	1.07	55.9	18.4
	Jul	66.7	3.87	1.15	1.7	331.5	49.7	1.37	99.5	22.5
	Aug	67.7	4.55	1.70	1.3	279.6	41.9	1.30	41.9	14.7
	Sep	95.6	3.16	1.54	1.8	404.3	30.6	1.73	60.7	15.2
Average		112.0	4.02	1.47	1.6	240.8	36.1	1.41	57.0	15.2
Zetag 51 1 %	Jan 80	109.0	4.25	1.18	0.7	45.0	13.5	1.51	12.1	6.3
	Feb	152.1	4.61	1.62	0.6	41.3	12.4	1.47	6.8	3.0
	Mar	188.2	5.18	1.22	1.2	36.6	11.0	2.09	21.8	5.3
Average		149.8	4.68	1.34	0.8	41.0	12.3	1.69	13.5	4.9
Zetag 88 0.4 %	Jul 80	66.7	3.87	1.15	0.8	10.0	15.9	3.39	35.6	11.1
	Aug	67.7	4.55	1.70	0.5	16.8	26.8	1.24	8.8	7.4
	Sep	95.6	3.16	1.54	0.7	24.5	39.2	0.76	13.0	9.6
Average		76.7	3.86	1.46	0.6	17.1	27.3	1.80	19.1	9.4

Appendix 7.2.11 Summary of sludge condition and conditionability data. Low rate humus sludge.

Chemical and conc. of stock sol.	Month	Thickened Sludge			Chemical Dose					
		Initial $\bar{r}$ (10^{12}m/kg)	Sus-pended Solids (% dm)	Stability to shear (Water added)	'Minimum' $\bar{r}$ achieved (10^{12}m/kg)	Kg Chemical/ Tonne dry solids	Cost £/ Tonne dry solids	Stability to shear after con-ditioning	'Minimum' Cost/dose index	Coagulant Demand (£/Tonne dry solids)
Al_2O_3	Jul 80	194.8	3.24	1.18	2.6	199.1	29.9	1.68	108.4	22.2
	Aug	89.0	3.27	1.25	1.3	197.3	29.6	1.30	40.6	7.9
1 %	Sep	105.5	2.66	1.25	1.4	122.1	18.3	1.54	31.4	7.5
Average		129.8	3.06	1.23	1.8	172.9	25.9	1.51	60.1	12.5
Zetag	Jul 80	194.8	3.24	1.18	0.4	23.9	38.2	0.91	10.6	9.2
88	Aug	89.0	3.27	1.25	0.7	11.8	19.0	1.37	14.1	4.7
0.4 %	Sep	105.5	2.66	1.25	0.6	14.7	23.5	1.31	15.8	4.9
Average		129.8	3.06	1.23	0.6	16.8	26.9	1.20	13.5	13.5

Appendix 7.2.12 Sludge conditioner costs

	Cost/Tonne (Active ingredient)	Conc. as received (%)	Cost/Tonne as received
Aluminium chlorohydrate	£1000	15	£ 150
Zetag 51	£ 300	100	£ 300
Zetag 88	£1600	100	£1600

Appendix 8.2.1a NH_3-N data, First Nitrification Test, July - August 1980

Filters	17/7	22/7	24/7	29/7	5/8	7/8	12/8	14/8	19/8	21/8
Common Feed	9.6	9.6	17.6	8.0	4.4	7.2	7.2	5.2	9.4	7.6
1	3.0	2.8	7.3	3.3	1.6	3.3	2.1	0.6	3.1	1.6
2	2.5	0.2	4.5	0.9	0.7	2.0	2.7	0.9	1.5	0.7
3	1.4	2.0	7.4	1.9	1.1	2.2	2.3	0.9	4.6	1.6
4	4.0	2.3	5.2	0.9	0.7	0.6	0.4	0.1	0.3	0.4
5	0.8	1.9	3.7	0.6	0.1	0.2	1.1	0.2	1.3	0.5
6	3.4	2.8	5.8	3.1	0.2	1.1	0.9	0.2	2,0	0.7
7	0.6	0.4	7.8	2.0	0.2	0.3	0.8	0.2	0.3	0.9
8	1.8	2.5	4.9	1.1	0.1	0.3	0.2	0.1	0.9	1.4
9	0.7	0.4	2.6	0.1	0.5	0.1	0.2	0.1	0.4	0.5
10	0.1	1.9	1.5	0.1	0.1	0.3	0.3	0.1	0.8	0.5
11	0.3	0.4	0.4	1.5	0.1	0.1	0.2	0.1	0.3	0.2
12	0.1	0.1	0.2	1.5	0.1	0.1	0.4	0.2	0.8	0.5
13	1.3	1.4	3.9	2.0	0.2	0.3	0.3	0.2	1.8	0.6
14	0.6	0.2	0.2	0.1	0.1	0.1	0.2	0.1	0.8	0.3
15	0.2	0.1	0.4	2.5	0.1	0.3	0.1	0.1	1.3	0.3

Data expressed as mg N/l.

Appendix 8.2.1b Nitrite -N data, First Nitrification Test, July - August 1980

Filters	17/7	22/7	24/7	29/7	5/8	7/8	12/8	14/8	19/8	21/8
Commom Feed	0.210	0.200	0.150	0.110	0.260	0.275	0.615	0.450	0.345	0.190
1	1,120	1.270	2.160	0.880	0.714	1.175	1.140	0.830	1.145	0.835
2	0.600	0.260	1.900	0.730	0.260	0.455	0.905	0.430	0.690	0.440
3	0.770	0.920	1.840	0.850	0.505	0.150	0.860	0.630	0.765	0.400
4	0.700	0.690	1.680	0.420	0.275	0.460	0.210	0.030	0.165	0.075
5	0.490	0.630	1.520	0.390	0.020	0.050	0.440	0.105	0.310	0.120
6	0.600	0.940	1.740	0.680	0.100	0.640	0.470	0.140	1.450	0.580
7	0.410	0.340	1.200	0.710	0.155	0.110	0.320	0.105	0.165	0.300
8	0.610	0.570	1.580	0.550	0.070	0.065	0.070	0.010	0.325	0.525
9	0.440	0.700	1.940	0.070	0.275	0.010	0.210	0.110	0.300	0.105
10	0.030	0.350	0.740	0.030	0.010	0.125	0.750	0.025	0.180	0.025
11	0.220	0.120	0.100	0.290	0.000	0.005	0.025	0.010	0.085	0.025
12	0.080	0.050	0.080	0.390	0.015	0.025	0.130	0.140	0.520	0.195
13	1.170	1.270	1.580	1.010	0.045	0.010	0.275	0.245	0.885	0.325
14	0.460	0.010	0.120	0.020	0.005	0.055	0.015	0.015	0.300	0.025
15	0.050	0.010	0.060	0.170	0.025	0.070	0.015	0.025	0.500	0.035

Data expressed as mg N/l.

Appendix 8.2.1c Total Oxidised -N data, First Nitrification Test, July - August 1980

Filters	17/7	22/7	24/7	29/7	5/8	7/8	12/8	14/8	19/8	21/8
Common Feed	1.060	0.755	0.700	0.615	0.710	1.125	2.165	1.500	1.345	0.740
1	6.470	6.870	9.910	5.385	2.840	4.925	6.390	5.130	5.345	4.885
2	5.450	7.860	11.800	6.685	4.310	3.705	5.555	4.830	7.390	5.240
3	7.620	7.225	5.140	5.950	3.555	4.950	5.960	4.630	4.415	3.750
4	5.150	6.840	12.180	6.975	4.275	5.760	7.860	4.630	7.965	5.475
5	7.640	7.080	13.120	7.195	5.220	6.250	7.540	5.305	7.260	5.520
6	5.350	6.390	11.890	4.680	4.500	6.090	8.170	5.340	7.500	5.930
7	8.015	8.140	11.450	5.665	4.305	6.660	7.620	5.105	7.865	4.200
8	7.760	6.570	10.930	6.405	4.470	6.065	7.870	5.410	7.025	5.875
9	6.840	6.950	11.490	6.275	5.325	4.810	8.710	6.110	7.600	6.255
10	8.430	6.105	10.595	7.030	3.810	6.625	8.300	5.425	8.980	6.425
11	7.975	7.920	11.855	6.195	4.400	7.000	6.825	5.210	8.085	6.225
12	7.680	8.655	13.280	6.195	5.215	4.225	7.880	5.740	8.170	7.745
13	7.220	7.220	10.730	5.715	4.845	7.210	7.925	5.995	7.585	5.425
14	6.815	8.815	13.670	8.025	5.005	6.055	7.615	4.815	6.850	5.625
15	7.455	5.010	8.460	4.925	3.225	7.070	3.415	4.025	5.300	3.635

Data expressed as mg N/l.

Appendix 8.2.1d Flow Rate Data, First Nitrification test, July - August 1980

Filters	17/7	22/7	24/7	29/7	5/8	7/8	12/8	14/8	19/8	21/8
Common Feed										
1	1.55	2.28	1.52	2.40	2.72	2.56	2.88	3.04	2.26	1.92
2	1.28	2.70	1.48	2.56	2.64	2.05	2.72	3.04	2.86	1.79
3	1.28	2.35	2.80	2.80	2.72	2.24	2.56	2.56	2.33	1.79
4	1.46	1.78	1.52	1.60	2.72	1.92	1.60	1.92	1.81	1.98
5	1.46	1.99	1.92	1.76	2.00	1.66	1.20	2.40	2.03	1.92
6	1.46	2.13	2.12	2.80	2.00	2.18	1.20	2.24	2.26	1.98
7	1.83	1.92	2.28	2.88	2.08	1.86	2.72	2.72	2.03	1.54
8	1.74	2.77	1.96	2.24	2.08	1.79	2.00	2.40	1.81	1.92
9	1.37	1.99	2.04	2.00	1.60	1.79	2.00	2,40	1.96	1.98
10	0.91	1.92	1.28	2.08	2.00	1.66	2.00	2.40	2.03	1.66
11	0.91	2.28	1.20	2.56	1.84	1.60	2.00	2.40	2.11	1.66
12	1.01	1.99	1.28	2.56	1.92	1.47	2.00	2.40	2.11	1.66
13	0.91	2.06	1.28	2.16	1.84	1.60	1.92	2.24	2.11	1.66
14	0.82	1.92	1.12	1.04	1.76	1.60	1.92	1.84	2.03	1.60
15	0.82	1.74	0.96	2.40	1.76	1.60	1.92	2.08	1.81	1.66

Data expressed as $m^3/m^3.d$.

Appendix 8.2.2a(i) BOD data. Nitrifying tower feeds and effluents. Acclimation period for experiment 2.

Data expressed as mg/l. Feeds designated W,X,Y,Z and V, supplying filter groups B,C,D,E and A respectively.

Feed and effluents	2/9	4/9	9/9	11/9	16/9	18/9	23/9	25/9	30/9	2/10	7/10	9/10	14/10	16/10
W	103.0	34.0	50.5	-	120.0	89.5	45.0	45.5	-	73.5	31.5	81.0	39.5	-
B1	34.6	8.8	2.9		4.8	5.5	9.8	5.0		3.8	5.4	8.9	9.1	
B2	33.8	9.6	2.9		4.8	5.5	10.3	3.8		5.8	5.5	10.9	9.1	
B3	35.5	9.9	14.1		4.3	6.0	11.0	5.0		6.0	5.4	16.4	8.4	
X	100.0	25.0	35.0	-	79.5	71.0	37.0	40.0	-	65.5	28.5	58.0	41.0	-
C1	37.8	10.4	9.3		11.8	6.5	3.0	3.5		7.3	15.0	15.1	8.8	
C2	27.1	23.1	8.4		12.0	6.8	3.5	5.3		5.3	12.1	13.8	8.1	
C3	32.5	10.3	9.3		24.3	8.7	4.0	7.0		5.3	9.3	12.4	8.1	
Y	53.5	19.5	26.5	-	51.5	63.5	18.0	28.0	-	47.5	8.5	24.5	27.5	-
D1	11.1	0.5	7.3		5.3	4.4	5.1	2.4		5.4	4.3	7.0	4.1	
D2	5.9	0.5	6.5		8.9	4.4	4.8	3.5		6.9	2.6	6.6	4.1	
D3	13.1	9.3	6.5		8.6	7.4	4.5	4.6		6.4	3.8	7.3	3.9	
Z	26.5	10.3	26.3	-	32.0	33.3	4.5	9.3	-	11.5	2.5	10.3	7.8	-
E1	11.1	2.6	6.4		5.6	5.6	4.0	3.1		4.4	2.4	4.1	4.1	
E2	5.0	1.1	5.6		5.3	4.9	4.4	2.6		5.0	1.5	5.1	4.4	
E3	8.6	2.4	5.1		4.9	7.4	3.6	4.5		6.1	1.5	4.1	4.1	
V	26.5	11.8	8.3	-	32.0	33.8	4.5	9.3	-	10.8	3.0	11.0	7.8	-
A1	10.6	4.6	5.6		9.1	5.3	3.4	3.5		4.6	9.5	4.4	5.6	
A2	10.6	3.8	5.4		7.1	5.6	3.6	2.8		5.8	3.8	5.4	4.4	
A3	13.0	4.4	5.1		7.1	5.6	3.8	3.1		6.0	3.0	4.4	4.6	

Appendix 8.2.2b(i) NH_3-N data. Nitrifying tower feeds and effluents. Acclimation period for experiment 2.

Data expressed as mg N/l. Feeds designated W,X,Y,Z and V, supplying filter groups B,C,D,E and A respectively.

Feed and effluents	2/9	4/9	9/9	11/9	16/9	18/9	23/9	25/9	30/9	2/10	7/10	9/10	14/10	16/10
W	14.8	7.6	7.4	11.4	13.2	12.4	8.0	12.2	9.6	11.8	3.4	8.4	7.4	4.6
B1	4.0	2.6	0.2	2.4	4.4	1.0	1.6	3.5	0.8	1.7	0.2	1.6	0.4	0.9
B2	3.7	2.2	0.5	2.9	0.6	0.3	0.3	0.7	0.2	0.4	0.1	0.3	0.2	0.4
B3	6.6	4.1	1.5	5.7	2.4	0.3	0.5	4.8	0.7	1.3	0.2	1.4	1.4	0.8
X	14.0	9.2	6.8	12.2	13.0	12.4	8.4	12.4	9.6	12.6	4.0	8.0	6.6	4.6
C1	5.2	2.6	0.3	2.3	2.3	1.3	0.3	0.3	0.6	0.7	0.3	0.7	0.9	0.4
C2	1.6	4.5	1.5	3.9	2.1	1.3	1.3	3.7	1.1	2.6	1.0	1.9	2.1	1.0
C3	2.0	3.3	0.8	1.9	6.9	4.2	1.7	2.4	0.4	0.8	0.7	1.5	0.6	0.2
Y	14.8	8.6	7.2	12.6	13.0	13.0	9.0	12.6	9.2	12.8	4.4	8.2	7.6	4.6
D1	0.4	0.3	0.3	1.9	0.3	0.3	0.1	0.3	0.3	0.3	0.1	0.2	0.4	0.1
D2	0.3	0.1	0.2	2.1	0.2	0.6	0.2	1.3	0.2	0.3	0.1	0.2	0.1	0.1
D3	1.3	3.6	0.3	2.4	0.2	0.4	0.3	1.5	0.4	0.6	0.1	0.4	0.3	0.2
Z	14.4	7.6	6.4	10.4	10.8	11.2	7.4	10.2	7.8	11.2	3.8	7.2	6.6	3.8
E1	1.3	0.3	0.4	2.4	0.2	0.8	0.3	0.9	0.2	0.2	0.1	0.5	0.9	0.1
E2	0.3	0.1	0.1	1.1	0.3	0.3	0.3	0.2	0.5	0.3	0.1	0.3	0.1	0.1
E3	3.5	0.5	0.2	2.1	0.1	0.5	0.1	0.1	0.2	0.3	0.1	0.6	0.4	0.1
V	12.4	7.8	5.8	10.6	10.6	11.0	7.2	10.4	7.6	11.2	3.4	7.4	6.6	3.8
A1	1.1	0.3	0.9	3.2	1.7	0.4	0.3	0.5	0.1	0.3	0.9	1.9	0.3	0.7
A2	2.4	1.2	0.9	1.9	1.1	0.1	0.1	0.2	0.2	0.3	0.4	1.3	0.6	0.2
A3	2.7	0.5	0.3	0.8	0.8	0.2	0.1	0.1	0.1	0.3	0.2	0.4	0.2	0.1

Appendix 8.2.2c(i) NO$_2$-N data. Nitrifying tower feeds and effluents. Acclimation period for experiment 2.

Data expressed as mg N/l. Feeds designated W,X,Y,Z and V, supplying filter groups B,C,D,E and A respectively.

Feed and effluents	2/9	4/9	9/9	11/9	16/9	18/9	23/9	25/9	30/9	2/10	7/10	9/10	14/10	16/10
W	0.03	0.02	0.01	1.00	0.03	0.24	0.05	0.01	0.01	0.07	0.62	0.01	0.03	0.09
B1	0.39	0.61	0.03	0.34	0.40	0.25	0.46	0.91	0.61	0.90	0.18	0.52	0.33	0.35
B2	0.71	0.60	0.14	0.61	0.25	0.13	0.23	0.48	0.08	0.24	0.04	0.16	0.15	0.20
B3	1.07	0.85	0.45	0.60	0.87	0.41	0.38	0.81	0.46	0.75	0.12	0.66	0.15	0.50
X	0.01	0.03	0.09	0.50	0.09	0.17	0.07	0.06	0.10	0.06	0.29	0.00	0.02	0.09
C1	0.85	0.92	0.21	0.89	1.02	1.09	0.15	0.15	0.65	0.60	0.17	0.41	0.45	0.16
C2	0.56	0.45	0.56	1.32	1.28	1.07	0.81	1.06	0.73	0.82	0.45	0.99	0.92	0.56
C3	0.76	0.59	0.41	0.79	0.74	1.03	0.80	0.63	0.33	0.67	0.40	0.72	0.48	0.16
Y	0.08	0.06	0.13	0.16	0.10	0.11	0.07	0.06	0.05	0.07	0.18	0.06	0.03	0.06
D1	0.13	0.08	0.16	0.58	0.04	0.13	0.05	0.08	0.06	0.21	0.03	0.06	0.18	0.04
D2	0.06	0.03	0.10	0.55	0.07	0.33	0.04	0.23	0.06	0.12	0.04	0.06	0.05	0.02
D3	0.90	0.55	0.15	0.98	0.23	0.34	0.15	0.62	0.14	0.41	0.04	0.32	0.29	0.12
Z	0.40	0.37	0.44	0.40	0.53	0.40	0.37	0.37	0.24	0.36	0.38	0.16	0.18	0.13
E1	0.71	0.40	0.42	0.89	0.17	0.83	0.20	0.89	0.23	0.06	0.12	0.35	0.52	0.02
E2	0.08	0.02	0.07	0.36	0.30	0.35	0.03	0.14	0.21	0.11	0.02	0.15	0.05	0.02
E3	0.74	0.30	0.25	1.30	0.09	0.48	0.04	0.04	0.17	0.17	0.04	0.26	0.25	0.05
V	0.44	0.44	0.56	0.41	0.67	0.39	0.39	0.36	0.32	0.41	0.33	0.19	0.20	0.13
A1	1.23	0.51	0.61	1.05	1.32	0.80	0.10	0.31	0.03	0.09	0.31	0.71	0.36	0.73
A2	1.54	0.88	0.29	0.49	1.00	0.23	0.03	0.09	0.04	0.31	0.05	0.40	0.14	0.05
A3	1.20	0.83	0.40	0.63	0.85	0.08	0.03	0.08	0.04	0.24	0.32	0.70	0.54	0.28

Appendix 8.2.2d(i) <u>Total oxidised-N data. Nitrifying tower feeds and effluents.</u> <u>Acclimation period for experiment 2.</u>

Data expressed as mg N/l. Feeds designated W,X,Y,Z and V, supplying filter groups B,C,D,E and A respectively.

Feed and effluents	2/9	4/9	9/9	11/9	16/9	18/9	23/9	25/9	30/9	2/10	7/10	9/10	14/10	16/10
W	0.10	0.06	0.15	0.05	0.08	0.79	0.10	0.06	0.01	0.22	0.87	0.06	0.13	0.84
B1	7.00	5.45	7.20	9.85	9.10	18.50	6.76	11.06	9.21	12.65	4.13	7.92	9.13	6.95
B2	8.35	5.80	7.30	10.50	11.30	17.28	8.48	13.18	11.63	14.94	5.84	10.71	9.50	7.30
B3	4.75	3.75	6.55	6.40	10.67	17.31	9.38	9.26	9.16	11.45	5.52	7.26	7.45	6.85
X	0.15	0.05	0.05	0.25	0.19	0.57	0.17	0.21	0.35	0.21	0.54	0.05	0.17	0.64
C1	5.90	5.85	6.70	8.75	8.72	12.39	8.70	11.70	8.50	10.95	4.17	7.91	9.65	6.31
C2	7.85	4.15	3.40	6.60	9.28	12.22	7.71	9.56	7.08	8.92	3.60	7.74	6.77	6.91
C3	7.15	5.35	5.15	9.35	5.24	9.83	7.50	11.23	7.98	10.62	4.59	8.07	8.08	7.31
Y	0.15	0.15	0.25	0.25	0.35	0.46	0.17	0.36	0.25	0.27	0.43	0.21	0.18	0.46
D1	9.35	8.80	6.90	10.10	10.44	11.08	8.05	11.88	8.46	11.71	6.43	10.06	8.33	6.84
D2	10.40	9.20	8.40	10.10	12.27	14.18	9.04	12.73	8.46	11.87	6.44	9.46	9.05	7.42
D3	6.86	5.70	8.55	9.10	12.53	13.74	8.50	11.42	7.84	10.61	6.04	9.27	8.14	7.27
Z	0.70	1.10	1.30	1.20	2.13	1.55	1.57	2.12	1.09	2.61	1.93	0.91	1.28	1.08
E1	10.45	8.70	8.10	8.50	11.67	12.33	8.10	11.14	8.48	10.46	4.52	6.45	6.32	3.82
E2	10.60	9.20	8.60	9.40	11.35	12.60	8.23	11.89	8.01	11.51	5.62	7.75	8.05	5.02
E3	8.55	8.25	7.50	7.90	12.09	11.98	8.04	10.64	7.12	11.12	4.24	7.16	7.35	4.45
V	0.80	1.15	1.30	1.20	2.32	1.54	1.54	2.16	1.12	2.81	1.93	0.99	1.30	1.08
A1	9.20	7.50	6.45	6.70	10.42	12.30	7.25	11.12	8.23	12.89	4.61	4.66	7.36	3.78
A2	8.65	7.15	6.35	8.45	10.65	13.68	7.83	12.43	7.84	12.89	4.57	7.05	6.09	4.53
A3	7.60	6.95	7.45	8.05	11.35	13.13	8.43	13.09	7.84	13.01	5.05	7.90	6.89	5.25

Appendix 8.2.2e(i) Flow rate data. Nitrifying towers. Acclimation period for experiment 2.

Data expressed as $m^3/m^3.d$

Date	2/9	4/9	9/9	11/9	16/9	18/9	23/9	25/9	30/9	2/10	7/10	9/10	14/10	16/10
Filter														
B1	1.92	2.56	1.92	1.80	1.84	1.00	2.43	2.12	2.08	2.00	2.00	2.52	2.00	2.52
B2	1.98	2.56	2.00	1.80	1.84	1.36	2.35	2.19	2.08	1.92	1.92	2.32	1.84	2.84
B3	2.05	2.56	1.76	2.29	2.00	1.36	1.96	2.27	2.24	2.16	2.16	3.04	2.84	2.68
C1	1.98	2.56	1.60	1.72	2.52	2.16	2.10	1.96	2.32	2.16	2.16	2.52	2.84	2.68
C2	1.66	2.56	1.92	1.80	2.08	2.00	2.43	2.12	2.08	2.32	2.32	2.84	2.68	2.52
C3	1.79	2.72	2.64	2.04	3.16	2.32	2.10	1.96	1.76	2.00	2.00	2.16	2.16	2.00
D1	1.34	1.44	1.76	2.61	1.76	2.32	1.56	2.05	2.32	2.16	2.16	1.56	2.16	1.56
D2	1.54	1.60	1.60	2.61	1.72	2.24	1.67	2.12	2.32	2.16	2.16	1.56	1.84	1.20
D3	1.41	1.92	0.88	2.61	1.65	2.08	1.81	2.12	2.32	2.08	2.08	1.56	1.56	1.36
E1	1.54	1.60	1.60	2.45	1.35	2.08	1.74	2.12	2.24	2.16	2.16	1.36	1.56	1.20
E2	1.41	1.60	1.76	2.61	1.36	2.00	1.59	2.12	2.60	2.16	2.16	1.56	1.56	1.20
E3	1.54	1.60	1.60	2.53	1.36	2.00	1.56	1.80	2.60	2.16	2.16	1.56	1.64	1.36
A1	2.18	2.00	2.24	1.92	2.24	2.40	2.43	2.63	2.44	2.52	2.52	2.16	2.32	2.68
A2	2.43	2.24	2.24	1.92	2.16	2.32	2.43	2.63	2.60	2.52	2.52	2.32	2.52	2.68
A3	2.94	2.48	2.24	1.92	2.16	2.32	2.43	2.63	2.68	2.52	2.51	2.52	2.52	2.68

Appendix 8.2.2a(ii) BOD data. Nitrifying tower feeds and effluents. Experiment 2.

Data expressed as mg/l. Feeds designated W,X,Y,Z and V, suppling filter groups B,C,D,E and A respectively.

Feed and effluents	30/10	6/11	10/11	13/11	17/11	20/11	24/11	27/11	1/12	4/12
W	93.5	100.5	52.0	81.0	62.0	134.5	66.0	143.0	106.5	147.0
B1	6.3	1.1	0.8	0.8	1.8	3.0	0.5	7.0	9.5	2.1
B2	6.4	6.0	2.5	0.5	0.6	2.6	2.3	3.2	3.4	4.4
B3	2.4	11.6	3.8	2.5	2.0	3.6	3.6	6.5	10.8	18.6
X	90.0	87.0	41.0	70.0	46.0	97.5	33.5	95.5	46.0	119.0
C1	2.1	13.0	7.9	3.5	2.0	3.5	4.1	5.1	0.9	4.4
C2	7.9	13.4	2.9	6.8	1.6	4.8	3.9	5.9	2.6	9.6
C3	10.3	3.5	8.4	3.9	4.5	32.8	15.1	7.5	2.1	4.8
Y	31.5	44.0	23.0	48.0	25.0	86.5	24.5	55.5	32.5	77.5
D1	2.1	0.3	0.8	1.3	1.6	1.0	1.6	0.6	0.4	5.0
D2	2.1	3.8	1.5	3.8	3.5	16.5	5.8	3.4	0.3	5.8
D3	2.8	1.0	1.6	5.6	3.0	19.5	6.4	8.4	4.5	7.8
Z	14.0	8.8	2.0	18.5	10.0	46.5	7.5	24.3	6.8	31.3
E1	5.1	1.9	1.3	2.5	6.3	19.5	5.5	4.5	0.3	5.4
E2	4.4	2.1	1.8	1.0	2.3	10.5	3.8	6.9	0.9	6.3
E3	4.0	2.6	2.3	3.9	2.0	19.9	3.9	7.3	0.4	9.9
V	15.3	8.5	2.0	18.0	9.0	46.8	6.8	25.3	6.8	31.8
A1	8.0	9.1	2.0	4.4	1.0	25.4	4.3	4.1	2.9	25.5
A2	7.0	2.8	3.0	4.3	4.6	25.6	4.3	9.5	2.6	17.6
A3	1.8	4.1	0.5	2.1	3.5	30.0	5.3	10.1	1.9	18.9

Appendix 8.2.2b(ii) NH_3-N data. Nitrifying tower feeds and effluents. Experiment 2.

Data expressed as mg N/l. Feeds designated W,X,Y,Z and V, supplying filter groups B,C,D,E and A respectively.

Feed and effluents	30/10	6/11	10/11	13/11	17/11	20/11	24/11	27/11	1/12	4/12
W	6.8	5.6	8.4	12.2	8.6	3.6	6.8	6.8	9.4	6.6
B1	2.9	0.5	0.3	0.9	2.8	0.2	0.5	0.7	4.1	0.3
B2	0.2	0.2	0.6	0.3	0.7	0.2	0.6	1.6	1.9	0.7
B3	1.0	1.0	2.9	3.6	3.0	0.3	0.5	1.9	3.5	0.5
X	6.8	7.2	9.8	12.8	8.2	3.4	6.0	5.6	6.8	6.2
C1	1.5	3.1	3.1	3.7	0.8	0.3	0.3	0.8	0.6	0.3
C2	3.7	3.3	3.3	6.0	2.0	0.2	0.9	1.5	3.1	1.1
C3	3.0	0.8	2.1	1.7	2.2	0.1	1.5	1.0	1.8	0.4
Y	8.2	5.6	10.0	12.6	8.4	4.0	7.4	6.0	9.2	8.2
D1	0.3	0.2	0.2	1.7	0.4	0.1	0.4	0.2	1.9	0.6
D2	0.9	0.4	1.3	3.1	1.1	0.2	0.6	0.2	1.7	1.2
D3	2.7	0.4	1.1	3.3	0.8	0.1	1.1	0.4	3.8	2.4
Z	8.4	3.6	9.4	13.8	9.8	4.6	7.6	6.2	9.4	7.8
E1	0.4	0.1	0.8	2.5	2.0	0.1	2.1	0.4	3.6	1.0
E2	2.7	0.6	0.4	1.4	0.4	0.1	0.4	0.7	1.6	0.5
E3	1.0	0.2	1.0	3.8	0.6	0.3	0.9	0.7	2.7	2.6
V	8.6	3.6	9.6	14.2	10.4	4.6	7.4	6.2	9.2	7.6
A1	0.7	0.9	3.1	4.5	0.6	0.3	0.6	0.1	3.5	0.3
A2	3.9	0.8	5.6	7.0	2.7	0.8	1.8	0.3	4.7	1.7
A3	0.4	0.8	0.8	4.3	0.8	0.4	3.7	0.7	4.3	1.9

Appendix 8.2.2c(ii) NO_2-N data. Nitrifying tower feeds and effluents. Experiment 2.

Data expressed as mg N/l. Feeds designated W,X,Y,Z and V, supplying filter groups B,C,D,E and A respectively.

Feed and effluents	30/10	6/11	10/11	13/11	17/11	20/11	24/11	27/11	1/12	4/12
W	0.01	0.43	0.51	0.02	0.04	0.01	1.21	0.00	0.17	0.01
B1	0.47	0.21	0.21	0.46	0.41	0.06	0.26	0.33	0.56	0.24
B2	0.12	0.03	0.32	0.11	0.23	0.03	0.28	0.24	0.42	0.12
B3	0.39	0.27	0.86	0.95	0.67	0.09	0.34	0.37	0.47	0.15
X	0.04	0.16	0.27	0.13	0.18	0.01	0.49	0.03	0.10	0.00
C1	0.85	0.37	0.84	0.84	0.56	0.09	0.21	0.27	0.19	0.11
C2	0.66	0.43	0.63	0.67	0.60	0.14	0.58	0.37	0.44	0.32
C3	0.58	0.30	0.78	0.78	0.73	0.02	0.54	0.39	0.54	0.20
Y	0.02	0.07	0.09	0.02	0.09	0.01	0.21	0.01	0.08	0.01
D1	0.09	0.02	0.03	0.47	0.03	0.01	0.10	0.05	0.29	0.15
D2	0.63	0.27	1.07	1.26	0.73	0.13	0.40	0.15	0.49	0.41
D3	1.07	0.33	1.03	1.20	0.48	0.11	0.53	0.19	0.56	0.49
Z	0.13	0.06	0.16	0.09	0.10	0.03	0.14	0.02	0.07	0.03
E1	0.55	0.03	0.66	1.03	0.98	0.07	0.72	0.12	0.63	0.50
E2	0.47	0.34	0.35	0.80	0.43	0.02	0.21	0.23	0.47	0.26
E3	1.28	0.09	1.03	1.32	0.77	0.20	0.74	0.30	0.60	0.46
V	0.13	0.06	0.16	0.09	0.10	0.04	0.14	0.03	0.06	0.03
A1	1.20	0.29	1.09	1.34	0.92	0.21	0.98	0.03	0.52	0.15
A2	1.21	0.30	0.87	1.16	1.50	0.32	0.80	0.17	0.62	0.54
A3	0.85	0.16	0.55	1.15	0.89	0.07	0.85	0.21	0.80	0.45

Appendix 8.2.2d(ii) Total oxidised-N data. Nitrifying tower feeds and effluents. Experiment 2.

Data expressed as mg N/l. Feeds designated W,X,Y,Z and V, supplying filter groups B,C,D,E and A respectively

Feed and effluents	30/10	6/11	10/11	13/11	17/11	20/11	24/11	27/11	1/12	4/12
W	0.06	1.13	0.91	0.02	0.09	0.01	3.31	0.05	0.42	0.01
B1	8.02	5.51	10.91	10.81	10.46	5.06	9.91	4.18	7.21	5.54
B2	7.52	4.03	7.87	9.86	10.48	5.23	7.28	2.34	7.87	2.87
B3	8.99	3.77	7.71	8.00	8.77	4.89	7.89	1.82	6.97	4.50
X	0.14	0.61	0.67	0.38	0.43	0.01	1.14	0.08	0.25	0.00
C1	7.35	4.12	7.54	9.39	9.76	4.49	8.91	3.57	7.44	5.31
C2	4.11	3.78	8.68	8.87	10.35	4.09	8.98	3.57	6.19	4.82
C3	4.73	5.90	8.28	12.13	9.23	2.82	7.59	3.39	6.64	5.35
Y	0.17	0.27	0.29	0.07	0.24	0.11	0.46	0.01	0.18	0.06
D1	9.09	4.42	9.83	9.77	8.83	4.01	8.25	5.45	9.54	7.50
D2	9.28	5.12	10.57	11.76	9.78	4.93	9.35	5.90	8.74	8.01
D3	7.12	4.98	10.58	11.95	9.48	5.31	8.73	5.54	7.36	7.39
Z	0.78	0.31	0.91	0.49	0.50	0.23	0.64	0.17	0.42	0.18
E1	8.65	4.43	9.61	10.88	8.53	3.67	5.82	5.07	6.03	7.00
E2	6.42	3.19	10.30	11.95	10.93	5.22	8.21	4.53	7.77	6.76
E3	7.78	4.09	9.78	10.22	11.02	4.55	7.44	5.15	6.60	4.81
V	0.78	0.31	0.91	0.49	0.50	0.24	0.64	0.13	0.41	0.13
A1	8.70	2.34	7.34	8.64	10.27	3.56	7.83	5.83	5.97	5.30
A2	5.51	2.55	4.67	7.61	[illegible]	3.17	6.60	4.92	5.17	5.49
A3	8.75	3.11	9.35	10.05	10.64	2.87	5.05	4.96	5.35	5.05

Appendix 8.2.2e(ii) Flow rate data. Nitrifying towers. Experiment 2.

Data expressed as $m^3/m^3.d.$

Date	30/10	6/11	10/11	13/11	17/11	20/11	24/11	27/11	1/12	4/12
Filter										
B1	2.08	1.84	1.80	1.72	1.69	1.73	1.62	1.75	1.72	1.56
B2	2.44	2.24	2.84	2.60	2.50	2.30	2.18	2.38	2.08	2.24
B3	1.72	2.44	2.60	2.52	2.50	2.37	2.30	2.33	2.32	2.24
C1	2.76	2.76	2.84	2.68	2.57	2.11	2.30	2.55	2.52	2.44
C2	2.60	2.44	2.60	2.44	2.34	2.30	2.11	2.35	2.16	2.16
C3	2.60	2.32	2.44	2.32	2.23	2.52	2.37	2.33	2.16	2.00
D1	2.32	2.00	1.92	2.44	2.57	1.96	2.18	1.96	2.08	2.24
D2	2.16	1.84	1.76	2.16	2.34	1.81	1.96	1.81	2.00	2.08
D3	2.16	1.84	1.84	2.24	2.50	1.88	2.03	1.88	2.08	2.16
E1	2.08	1.76	1.76	2.16	2.23	1.73	1.96	1.81	1.72	1.84
E2	2.16	1.84	1.84	2.16	2.23	1.81	1.96	1.81	1.92	2.08
E3	2.08	1.72	1.76	2.08	2.07	1.73	1.96	1.81	1.72	1.84
A1	2.76	1.84	1.56	2.00	1.92	2.03	2.18	1.20	2.32	1.92
A2	2.68	1.64	2.00	2.08	2.15	2.18	2.30	1.47	2.24	2.24
A3	2.68	1.64	1.56	1.84	1.84	2.03	2.11	1.54	2.44	1.92

Appendix 8.2.3a(i) BOD data)
Appendix 8.2.3b(i) NH_3-N data) Nitrifying tower feeds and effluents. Acclimation period for experiment 3.

BOD data expressed as mg/l, NH_3-N data expressed as mg N/l. Feeds designated W,X,Y,Z and V, supplying filter groups B,C,D,E and A respectively.

Appendix 8.2.3a(i) BOD data

Feed and effluents	6/1	8/1	13/1	15/1	20/1	22/1	27/1
W	80.0	120.5	100.0	54.0	64.5	56.5	-
B1	23.0	18.3	12.8	4.9	6.3	7.1	
B2	23.8	17.8	13.4	5.1	12.0	6.9	
B3	27.0	23.0	15.6	4.0	7.3	6.6	
X	66.0	69.0	83.0	43.0	55.5	48.0	-
C1	34.3	24.3	14.9	3.3	7.4	5.6	
C2	46.3	36.8	17.8	6.3	7.0	5.6	
C3	34.3	24.8	16.6	7.0	8.3	5.9	
Y	47.5	58.0	67.0	34.5	42.0	33.5	-
D1	26.6	27.0	16.5	6.4	23.8	8.9	
D2	29.9	26.1	16.3	5.9	15.4	9.6	
D3	35.4	21.6	16.8	6.1	24.1	8.1	
Z	19.8	31.8	22.3	10.8	16.3	14.3	-
E1	12.4	24.6	12.1	5.6	12.6	9.0	
E2	12.6	24.9	12.3	5.4	7.9	8.6	
E3	13.4	22.9	11.1	5.1	9.0	8.1	
V	19.0	32.5	24.5	9.3	18.3	13.8	-
A1	8.8	6.4	9.6	3.1	4.1	6.4	
A2	7.0	5.8	9.8	2.5	3.4	6.9	
A3	8.5	5.6	9.1	4.0	6.5	7.1	

Appendix 8.2.3b(i) NH_3-N data

Feed and effluents	6/1	8/1	13/1	15/1	20/1	22/1	27/1
W	11.0	10.2	11.2	8.0	10.8	12.8	11.2
B1	8.7	7.9	7.7	5.0	3.5	6.3	2.8
B2	8.0	5.8	5.1	2.9	4.9	6.0	4.6
B3	7.8	7.4	6.8	2.6	2.1	5.2	1.2
X	11.6	9.0	9.6	7.0	10.0	12.0	7.6
C1	9.7	6.8	6.3	2.7	3.3	3.8	0.8
C2	10.9	7.7	8.5	4.8	5.7	7.2	1.1
C3	9.1	5.7	4.4	2.0	2.5	1.8	1.6
Y	12.8	10.4	11.0	8.2	11.6	12.8	15.2
D1	11.3	9.5	8.8	6.2	9.2	8.6	5.9
D2	11.5	8.3	8.8	5.7	7.6	8.7	5.9
D3	13.5	10.1	11.2	8.3	10.7	10.6	10.9
Z	11.4	10.8	11.2	8.2	12.0	14.8	11.6
E1	10.3	9.7	9.5	5.1	8.3	10.1	4.0
E2	8.0	9.1	6.9	3.1	5.2	8.7	3.1
E3	10.7	10.1	9.7	5.6	8.0	10.6	6.5
V	12.0	11.0	12.0	8.4	12.4	14.6	11.6
A1	5.6	3.6	6.0	1.7	3.7	5.1	1.1
A2	6.0	4.6	6.0	2.4	2.0	2.4	0.9
A3	4.7	2.5	3.1	2.2	4.0	5.1	1.4

Appendix 8.2.3c(i) NO$_2$-N data)
Appendix 8.2.3d(i) Total oxidised-N data) Nitrifying tower feeds and effluents. Acclimation period for experiment 3.

Data expressed as mg N/l. Feeds designated W,X,Y,Z and V, suppling filter groups B,C,D,E and A respectively.

Appendix 8.2.3c(i) NO$_2$-N data

Feed and effluents	6/1	8/1	13/1	15/1	20/1	22/1	27/1
W	0.02	0.01	0.09	0.30	1.82	1.06	0.77
B1	0.10	0.12	0.15	0.28	0.36	0.61	0.66
B2	0.10	0.13	0.15	0.28	0.64	0.58	0.73
B3	0.40	0.21	0.33	0.34	0.41	0.48	0.50
X	0.13	0.01	0.06	0.23	1.22	0.58	0.72
C1	0.22	0.17	0.46	0.38	0.66	0.78	0.38
C2	0.30	0.18	0.45	0.55	0.86	0.95	0.49
C3	0.49	0.44	0.59	0.41	0.66	0.44	0.85
Y	0.07	0.01	0.04	0.10	0.22	0.14	0.22
D1	0.08	0.08	0.25	0.45	0.67	0.85	1.98
D2	0.14	0.24	0.44	0.68	1.02	0.84	1.90
D3	0.09	0.13	0.21	0.34	0.88	0.98	1.50
Z	0.12	0.04	0.07	0.09	0.10	0.04	0.08
E1	0.22	0.22	0.58	0.67	0.70	0.89	1.16
E2	0.27	0.22	0.54	0.71	0.96	1.00	0.78
E3	0.16	0.19	0.39	0.58	1.06	1.16	1.08
V	0.12	0.04	0.07	0.10	0.10	0.06	0.08
A1	0.20	0.64	0.25	0.34	0.47	0.78	0.30
A2	0.57	0.99	0.59	0.78	1.04	1.30	0.67
A3	0.32	0.70	0.31	0.46	0.49	0.76	0.53

Appendix 8.2.3d(i) Total oxidised-N data

Feed and effluents	6/1	8/1	13/1	15/1	20/1	22/1	27/1
W	0.07	0.01	0.30	1.65	2.02	1.81	3.17
B1	3.45	2.32	4.10	6.69	8.01	7.26	11.93
B2	4.90	4.08	6.65	7.88	6.99	7.58	9.18
B3	3.95	2.36	4.93	6.94	8.86	7.73	9.31
X	0.13	0.01	0.16	0.76	1.42	0.98	2.72
C1	4.32	2.52	5.16	6.73	7.71	9.68	7.68
C2	2.50	1.33	2.75	4.60	6.56	7.50	7.89
C3	4.24	3.24	5.99	6.56	8.71	11.04	7.45
Y	0.42	0.01	0.09	0.40	0.42	0.29	0.57
D1	2.88	1.28	2.80	3.95	4.32	6.35	9.68
D2	2.29	2.19	3.44	4.63	5.47	6.04	9.60
D3	1.09	0.53	0.91	1.49	2.93	3.76	4.90
Z	0.82	0.19	0.42	0.69	0.50	0.15	0.38
E1	1.72	0.37	2.58	4.02	4.00	4.94	6.41
E2	3.72	2.17	4.74	5.86	6.71	6.00	6.63
E3	1.46	1.14	2.54	3.38	4.51	4.86	4.43
V	0.82	0.14	0.47	0.75	0.60	0.20	0.38
A1	6.70	8.09	5.30	7.69	8.52	10.08	8.44
A2	5.82	6.24	5.59	6.83	9.69	12.20	9.17
A3	7.52	8.70	7.86	6.71	7.24	10.01	8.68

Appendix 8.2.3e(i) <u>Flow rate data. Nitrifying towers. Acclimation period for experiment 3.</u>

Data expressed as $m^3/m^3.d.$

Date	6/1	8/1	13/1	15/1	20/1	22/1	27/1
Filter							
B1	4.46	4.11	4.34	3.93	3.60	4.24	4.40
B2	5.19	4.48	4.26	4.10	3.88	4.16	4.12
B3	4.98	4.66	4.26	4.14	4.00	4.08	4.16
C1	4.98	4.57	4.26	4.31	4.08	4.08	4.12
C2	4.46	4.30	3.84	3.75	3.84	3.80	4.16
C3	4.77	4.48	4.09	4.01	4.00	3.96	4.16
D1	3.84	4.11	3.67	3.67	3.48	3.32	3.84
D2	4.88	4.66	4.26	4.27	4.08	4.08	4.12
D3	4.57	4.48	4.17	4.27	3.88	3.92	3.76
E1	4.77	4.48	4.01	3.80	3.88	3.88	3.12
E2	5.09	4.39	4.26	4.18	4.08	4.16	3.68
E3	4.77	4.39	3.84	3.88	4.04	3.84	4.08
A1	1.19	1.20	1.28	1.32	1.48	1.60	1.44
A2	1.19	1.20	1.12	1.32	1.36	1.44	1.44
A3	1.19	1.20	0.96	1.41	1.44	1.40	1.48

Appendix 8.2.3a(ii) BOD data. Nitrifying tower feeds and effluents. Experiment 3.

Data expressed as mg/l. Feeds designated W,X,Y,Z and V, supplying filter groups B,C,D,E and A respectively.

Feed and effluents	29/1	6/2	9/2	12/2	17/2	19/2	25/2	26/2	3/3	5/3
W	59.0	85.5	91.5	47.0	108.0	110.5	133.5	136.0	85.5	119.5
B1	7.1	2.9	11.3	4.9	8.9	11.6	15.3	15.3	12.1	25.0
B2	6.6	3.3	8.1	8.9	6.0	5.0	9.4	11.6	10.3	16.0
B3	6.8	5.6	9.7	5.6	18.5	5.3	9.0	12.3	8.9	14.4
X	43.0	61.5	54.5	35.0	83.5	95.5	87.5	112.5	51.5	92.0
C1	7.5	19.1	18.1	7.8	5.9	11.0	14.5	11.1	11.4	11.8
C2	5.3	8.4	19.0	8.4	7.3	21.3	18.8	33.4	12.4	16.5
C3	5.0	3.6	5.3	6.1	5.4	11.6	8.8	9.0	7.6	22.5
Y	36.5	40.5	35.5	32.5	52.0	64.0	43.0	83.5	34.0	72.0
D1	7.3	6.3	12.3	7.6	7.4	11.5	11.0	12.0	9.4	25.1
D2	4.4	2.9	7.0	6.9	8.1	10.1	10.4	12.3	7.8	24.8
D3	9.5	8.4	13.3	7.8	7.3	12.3	10.1	11.9	8.1	16.9
Z	13.8	18.3	13.5	9.8	19.3	19.5	13.0	22.8	9.8	30.3
E1	9.6	10.1	12.0	6.5	9.9	9.5	5.8	11.6	5.6	14.6
E2	1.8	3.8	10.8	6.0	9.9	9.6	6.5	13.4	5.1	13.6
E3	8.6	7.1	10.8	5.0	8.4	8.6	5.3	12.3	4.9	14.4
V	13.8	18.3	13.5	9.8	19.3	19.5	13.0	22.8	9.8	30.3
A1	3.5	7.3	6.9	1.6	7.4	5.9	4.0	5.9	1.4	9.8
A2	3.3	4.4	6.9	2.1	7.6	6.6	4.3	5.0	1.8	8.8
A3	2.8	2.9	7.8	1.5	7.4	6.4	4.3	6.1	1.8	9.3

Appendix 8.2.3b(ii) NH_3-N data. Nitrifying tower feeds and effluents. Experiment 3.

Data expressed as mg N/l. Feeds designated W,X,Y,Z and V, supplying filter groups B,C,D,E and A respectively.

Feed and effluents	29/1	6/2	9/2	12/2	17/2	19/2	25/2	26/2	3/3	5/3
W	10.7	11.5	15.8	11.5	11.0	13.1	13.3	14.9	7.8	11.8
B1	3.6	5.3	9.1	6.9	6.3	7.2	6.2	8.7	3.6	7.8
B2	2.8	3.3	4.2	1.5	1.2	1.0	3.3	2.6	1.1	5.0
B3	1.5	4.5	10.4	5.8	6.4	1.0	5.2	6.4	1.0	4.7
X	10.4	9.9	13.8	11.6	9.5	11.5	10.3	11.5	7.0	9.7
C1	3.3	5.0	8.2	3.7	3.2	4.2	2.6	2.6	1.3	3.4
C2	3.6	6.0	8.2	7.4	6.1	6.7	5.6	8.4	3.5	6.8
C3	1.4	3.8	5.0	3.6	2.6	2.7	2.0	2.3	0.5	3.9
Y	11.8	10.7	14.0	12.1	10.9	11.3	10.3	12.1	7.7	11.3
D1	6.6	6.3	8.3	4.7	2.6	3.1	2.3	4.0	0.8	6.7
D2	3.3	2.3	3.7	2.6	2.0	4.3	2.1	4.5	1.7	5.6
D3	8.3	6.9	8.7	3.3	2.7	4.2	0.8	3.8	2.2	4.7
Z	12.5	11.3	15.4	11.8	10.6	12.6	10.9	12.3	7.1	12.6
E1	9.6	5.9	10.0	4.6	3.5	3.4	1.9	2.6	0.6	1.8
E2	4.9	4.2	7.6	3.4	2.4	2.5	2.7	4.3	0.7	3.7
E3	8.3	5.5	9.5	4.9	2.7	3.3	1.6	3.2	0.5	5.0
V	12.6	11.3	15.4	11.8	10.6	12.6	10.9	12.3	7.1	12.6
A1	1.2	0.4	7.7	0.3	2.2	1.8	1.2	1.3	1.2	1.3
A2	1.9	0.2	7.7	1.9	1.8	1.9	1.0	0.8	0.4	0.7
A3	2.1	0.5	6.2	4.3	1.2	1.2	0.7	0.5	0.9	1.7

Appendix 8.2.3c(ii) NO_2-N data. Nitrifying tower feeds and effluents. Experiment 3.

Data expressed as mg N/l. Feeds designated W,X,Y,Z and V, supplying filter groups B,C,D,E and A respectively

Feed and effluents	29/1	5/2	9/2	12/2	17/2	19/2	25/2	26/2	3/3	5/3
W	0.02	0.01	0.70	1.21	0.01	0.01	0.61	0.14	0.35	0.02
B1	0.36	0.34	0.36	0.31	0.34	0.36	0.55	0.34	0.37	0.43
B2	0.63	0.55	1.20	0.82	0.57	0.40	0.58	0.61	0.55	0.81
B3	0.39	0.41	0.60	0.59	0.31	0.39	0.36	0.41	0.18	0.39
X	0.07	0.02	0.31	0.85	0.15	0.15	0.55	0.16	0.30	0.08
C1	0.46	0.40	0.58	0.53	0.40	0.33	0.31	0.34	0.27	0.37
C2	0.70	0.48	0.71	0.61	0.39	0.38	0.40	0.28	0.45	0.40
C3	0.45	0.49	0.68	0.59	0.39	0.50	0.41	0.46	0.24	0.55
Y	0.04	0.05	0.10	0.21	0.05	0.04	0.18	0.06	0.07	0.14
D1	1.28	1.06	1.09	1.96	1.48	1.30	1.22	0.92	0.76	0.82
D2	1.23	0.92	1.10	1.22	1.14	0.90	0.96	0.72	0.72	0.72
D3	1.03	0.85	1.07	1.34	1.04	1.06	0.56	1.16	0.88	1.28
Z	0.04	0.04	0.11	0.12	0.05	0.04	0.11	0.11	0.08	0.04
E1	0.99	0.90	0.98	1.30	1.20	1.36	1.14	1.84	0.56	1.22
E2	1.09	0.79	0.83	1.34	1.16	1.28	0.92	1.24	1.16	1.70
E3	1.03	0.96	0.86	1.34	0.96	1.22	0.84	1.06	0.66	1.14
V	0.04	0.04	0.11	0.12	0.05	0.04	0.11	0.11	0.08	0.04
A1	0.75	1.06	0.06	0.41	0.24	0.49	1.28	2.40	0.57	1.64
A2	1.21	0.78	0.18	0.98	0.46	1.06	0.84	1.64	0.24	1.78
A3	1.07	1.42	0.19	1.20	0.43	0.60	0.72	0.96	0.32	0.90

Appendix 8.2.3d(ii) Total oxidised-N data. Nitrifying tower feeds and effluents. Experiment 3.

Data expressed as mg N/l. Feeds designated W,X,Y,Z and V, supplying filter groups B,C,D,E and A respectively.

Feed and effluents	29/1	6/2	9/2	12/2	17/2	19/2	25/2	26/2	3/3	5/3
W	0.02	0.01	1.15	1.76	0.01	0.06	1.81	0.19	2.20	0.07
B1	5.76	3.39	5.16	5.16	3.74	9.36	9.55	7.54	5.17	5.28
B2	8.88	7.25	10.05	10.32	7.02	12.15	9.23	10.86	6.85	7.26
B3	6.94	5.01	3.90	5.69	2.76	12.34	5.36	6.41	6.68	6.24
X	0.12	0.02	1.11	1.35	0.30	0.35	1.20	0.16	1.45	0.13
C1	6.81	4.00	6.03	8.88	6.75	9.18	7.51	8.99	5.72	6.22
C2	7.30	5.03	7.71	6.11	4.94	6.58	4.55	3.33	3.80	4.10
C3	8.00	4.24	6.13	6.09	6.29	10.80	7.36	8.66	6.74	5.75
Y	0.04	0.10	0.30	0.36	0.15	0.24	0.33	0.11	0.27	0.24
D1	6.43	5.56	7.14	9.26	8.48	12.35	9.12	8.17	6.31	4.67
D2	8.78	8.42	10.40	10.02	8.30	10.44	8.90	8.11	5.27	4.97
D3	4.03	4.85	6.07	8.79	7.39	9.76	9.11	8.46	4.78	6.38
Z	0.24	0.19	0.51	0.47	0.30	0.29	0.41	0.26	0.58	0.19
E1	4.89	5.05	5.78	7.30	6.70	11.01	8.29	9.84	5.61	9.72
E2	10.09	6.54	7.63	8.59	7.06	12.13	8.27	7.84	5.46	8.50
E3	6.43	4.86	6.11	7.14	6.21	10.47	8.64	8.86	5.61	7.09
V	0.24	0.19	0.51	0.47	0.30	0.29	0.41	0.26	0.58	0.19
A1	12.55	9.46	7.26	11.41	7.49	12.39	10.43	12.20	5.22	10.64
A2	12.56	6.78	7.18	9.68	7.41	12.36	9.49	11.79	6.14	10.98
A3	12.32	9.17	7.54	6.60	7.53	13.05	10.17	11.86	4.97	10.30

Appendix 8.2.3e(ii) Flow rate data. Nitrifying towers. Experiment 3.

Data expressed as $m^3/m^3.d.$

Date	29/1	6/2	9/2	12/2	17/2	19/2	25/2	26/2	3/3	5/3
Filter										
B1	4.44	4.33	4.24	4.34	4.49	3.89	3.94	4.02	4.44	4.38
B2	4.01	4.06	4.00	4.26	4.17	3.95	3.84	3.93	4.14	3.79
B3	4.18	4.47	4.00	4.26	4.21	4.11	3.79	3.75	3.50	4.23
C1	4.10	4.42	4.00	4.26	4.21	3.63	3.99	3.93	4.14	4.09
C2	4.05	4.55	4.00	4.26	4.25	4.48	3.94	3.89	3.75	3.84
C3	3.93	4.42	4.08	4.22	4.21	3.95	3.99	3.98	4.18	3.74
D1	3.75	4.38	4.04	4.22	3.57	3.25	3.79	3.89	4.14	4.33
D2	4.01	4.15	3.84	4.26	3.84	3.52	3.59	3.66	3.58	4.23
D3	4.35	4.51	4.04	4.26	4.17	3.84	3.44	3.52	3.93	3.84
E1	4.39	4.33	4.08	4.26	4.17	3.41	3.28	3.66	3.54	4.14
E2	3.88	4.29	4.00	4.26	4.17	3.52	3.54	3.70	3.71	3.84
E3	3.80	4.29	3.92	4.22	4.00	3.57	3.49	3.61	3.88	4.23
A1	1.45	1.52	1.36	1.34	1.47	1.49	1.41	1.46	1.41	1.48
A2	1.41	1.34	1.36	1.42	1.47	1.44	1.41	1.28	1.02	1.13
A3	1.37	1.43	1.12	1.42	1.43	1.49	1.47	1.46	1.45	1.48

Appendix 8.2.4(i) BOD, NH_3-N, NO_2-N, total oxidised-N and flow rate data. Nitrifying tower feeds and effluents. Acclimation period for experiment 4.

	BOD (mg/l)			NH_3-N (mg N/l)			NO_2-N (mg N/l)			Oxidised-N (mg N/l)			Flow (m^3/m^3.d)		
Feed and effluents	17/3	19/3	24/3	17/3	19/3	24/3	17/3	19/3	24/3	17/3	19/3	24/3	17/3	19/3	24/3
W II	108.0	118.5	115.0	10.4	12.1	7.2	1.20	1.49	0.66	3.10	2.10	8.16			
Feed Ratio	50:50	50:50	100:0												
B1	22.3	19.3	12.0	5.2	9.1	5.1	0.96	0.68	0.98	8.26	5.68	11.18	4.34	4.04	4.00
B2	21.0	25.3	12.0	7.2	10.6	4.8	0.88	0.67	1.76	4.83	4.48	12.06	4.16	4.04	4.09
B3	23.5	21.0	11.0	6.0	8.8	5.0	0.47	0.42	0.84	3.32	2.57	6.74	4.07	4.08	4.17
X II	128.5	110.5	82.0	10.9	12.4	9.7	1.09	0.90	0.63	2.54	1.10	6.88			
Feed Ratio	33:67	33:67	67:33												
C1	32.8	26.5	11.6	7.0	10.3	9.1	0.71	0.67	0.98	3.81	4.27	8.18	4.43	4.08	4.00
C2	27.3	26.0	11.8	6.7	8.9	6.0	0.60	0.58	0.90	4.55	5.18	10.55	3.70	3.53	3.76
C3	32.8	23.3	9.8	5.9	9.6	5.1	0.69	0.64	1.18	4.99	5.44	12.33	4.11	4.04	4.09
Y II	121.5	*101.0	60.0	10.7	12.1	12.0	0.58	0.12	0.62	1.23	0.17	5.72			
Feed Ratio	67:33	67:33	33:67												
D1	22.3	23.3	7.8	4.7	7.5	6.6	0.50	0.72	1.10	5.30	5.67	11.30	3.75	4.00	4.09
D2	21.5	23.8	6.9	5.4	7.7	2.2	0.57	0.53	1.16	4.97	5.13	14.91	3.98	3.92	2.82
D3	21.8	26.0	8.5	4.7	7.4	5.7	0.86	0.76	1.92	4.76	4.76	12.17	3.84	3.72	4.09
Z II	75.5	83.5	49.0	9.9	12.1	14.7	0.81	0.88	0.52	1.76	1.08	4.72			
Feed Ratio	0:100	0:100	0:100												
E1	28.3	24.5	8.0	3.4	5.9	5.6	0.64	0.90	1.16	5.19	7.40	13.96	4.11	4.00	4.13
E2	32.8	26.0	10.3	5.1	8.0	6.3	0.63	1.04	2.14	3.98	5.54	13.59	3.75	3.84	3.92
E3	36.3	27.8	8.8	5.7	8.0	7.7	0.55	0.54	1.44	3.35	3.74	11.94	4.02	4.00	4.00
V II	15.5	22.3	15.5	9.5	13.3	14.7	0.12	0.11	0.28	0.82	0.54	2.38			
A1	8.9	5.9	6.6	2.5	1.1	3.7	0.24	1.42	0.21	6.49	11.57	11.71	1.66	1.60	1.47
A2	8.6	5.8	7.0	2.4	0.5	4.7	0.26	1.40	0.86	6.66	12.55	11.11	1.23	1.16	1.43
A3	8.0	5.8	7.1	2.3	3.1	8.7	0.14	0.53	0.24	7.24	10.13	6.89	1.37	0.96	1.47

Where Feed Ratio represents the relative proportions of primary settled sewage and secondary filter feed used in the feed mixture. * denotes filter 9 effluent used in place of primary settled sewage.

Appendix 8.2.4a(ii) BOD data. Nitrifying tower feeds and effluents. Experiment 4.

Feed and effluents	7/4	9/4	14/4	15/4	21/4	23/4	28/4	29/4	5/5	7/5
W II	141.0	141.0	162.0	146.5	203.0	414.5	179.0	172.5	162.5	164.0
Feed Ratio	100:0	100:0	100:0	100:0	100:0	100:0	100:0	100:0	100:0	100:0
B1	35.5	11.3	21.0	22.3	55.7	152.3	67.3	62.3	52.0	27.5
B2	27.0	15.0	19.0	22.8	54.0	105.3	67.5	61.8	52.5	11.0
B3	27.3	14.3	35.8	29.3	56.0	182.5	67.5	63.5	113.0	44.8
X II	108.5	109.0	78.0	122.5	164.0	326.5	138.5	128.5	134.5	125.0
Feed Ratio	50:50	50:50	*100:0	67:33	67:33	67:33	80:20	67:33	80:20	67:33
C1	22.5	14.5	18.8	17.3	70.8	96.5	62.3	42.3	49.5	25.5
C2	26.0	13.5	19.0	17.8	63.8	142.8	60.3	43.5	76.5	29.0
C3	22.8	18.5	17.8	15.5	67.3	73.8	61.0	39.0	33.0	8.5
Y II	82.0	90.0	69.0	104.5	135.5	214.5	104.5	105.5	122.5	101.0
Feed Ratio	*100:0	50:50	33:67	33:67	33:67	33:67	67:33	50:50	67:33	50:50
D1	7.5	12.5	16.5	15.3	59.8	32.3	15.8	31.8	48.5	6.0
D2	8.5	14.0	16.3	15.0	59.5	34.3	33.8	42.8	68.5	41.0
D3	8.5	14.3	16.0	13.8	60.3	46.3	41.3	28.3	88.5	15.0
Z II	67.0	68.5	46.0	67.5	112.5	113.5	75.5	80.5	116.5	82.5
Feed Ratio	0:100	0:100	0:100	0:100	0:100	0:100	33:67	20:80	50:50	20:80
E1	8.3	13.5	13.5	10.5	11.3	61.3	38.8	20.3	61.5	26.8
E2	14.8	17.0	13.5	10.3	14.3	63.3	29.8	22.3	67.0	8.5
E3	16.3	20.0	13.8	9.8	29.3	66.8	38.3	32.0	64.3	8.5
V II	14.0	11.3	9.5	15.8	19.3	66.8	14.8	14.8	34.3	9.3
A1	8.5	7.0	2.5	1.9	10.4	43.6	6.4	6.4	20.3	4.8
A2	8.8	7.0	2.8	2.9	11.1	43.6	6.4	6.4	22.4	4.8
A3	9.0	7.0	3.4	3.9	8.8	44.1	6.4	6.9	20.9	4.0

Where Feed Ratio represents the relative proportions of primary settled sewage and secondary filter feed used in the feed mixtures. * denotes filter 9 effluent used in place of primary settled sewage. Data expressed as mg/1.

Appendix 8.2.4b(ii) NH_3-N data. Nitrifying tower feeds and effluents. Experiment 4.

Data expressed as mg N/l. Feeds designated W II, X II, Y II, Z II and V II, supplying filter groups B, C, D, E and A respectively.

Feed and effluents	7/4	9/4	14/4	15/4	21/4	23/4	28/4	29/4	5/5	7/5
W II	30.8	33.2	31.6	28.4	33.2	32.4	29.2	29.6	28.4	30.0
B1	28.8	29.6	27.2	26.0	28.0	28.0	27.6	26.4	26.8	26.4
B2	26.8	29.2	26.4	25.6	26.0	24.0	23.2	22.8	22.8	24.0
B3	29.6	29.6	31.2	30.0	31.6	31.6	32.4	30.8	34.0	32.4
X II	36.8	32.4	32.4	30.4	34.8	33.6	26.0	28.4	30.8	30.8
C1	34.8	31.6	30.4	28.0	25.2	26.8	22.8	22.8	22.0	26.8
C2	32.0	28.4	28.0	25.6	27.2	30.4	26.8	26.4	28.4	28.8
C3	32.4	27.6	28.4	26.4	29.2	29.6	26.8	26.4	29.2	17.2
Y II	42.4	32.4	32.8	30.0	33.6	34.8	28.0	29.6	31.6	29.6
D1	30.4	20.0	16.4	17.2	23.6	22.4	20.8	22.8	27.6	24.4
D2	26.0	21.2	24.8	22.4	29.2	27.6	29.2	29.6	33.2	31.6
D3	29.2	20.4	22.4	19.2	25.2	26.0	24.4	25.6	27.2	26.4
Z II	38.4	31.6	31.6	31.2	37.2	35.6	28.0	26.8	30.8	31.6
E1	31.2	23.2	22.8	21.2	20.8	20.0	14.8	16.8	18.8	24.4
E2	35.2	26.8	27.2	25.6	28.0	27.6	20.4	20.0	22.8	21.2
E3	34.4	26.4	24.0	22.8	32.4	30.0	22.8	22.8	28.0	25.2
V II	44.0	31.6	33.2	30.0	34.4	34.8	24.8	25.6	30.0	30.4
A1	19.2	5.6	15.3	9.1	8.4	10.3	5.3	5.3	12.3	12.4
A2	24.8	9.6	15.3	6.7	5.6	5.1	10.9	10.9	21.2	13.5
A3	22.0	7.6	12.8	7.3	2.8	6.1	7.1	7.1	13.3	16.8

Appendix 8.2.4c(ii) NO_2-N data. Nitrifying tower feeds and effluents. Experiment 4.

Data expressed as mg N/1. Feeds designated W II, X II, Y II, Z II and V II, supplying filter groups B,C.D,E and A respectively.

Feed and effluents	7/4	9/4	14/4	15/4	21/4	23/4	28/4	29/4	5/5	7/5
W II	2.08	2.66	0.42	0.01	0.01	0.73	0.59	1.07	0.45	0.72
B1	2.02	0.58	0.46	0.31	0.48	0.67	1.13	0.68	1.40	0.48
B2	1.80	0.68	0.78	0.61	1.18	2.16	2.08	0.92	1.02	0.62
B3	0.52	0.12	0.03	0.02	0.07	0.06	0.33	0.09	0.29	0.01
X II	1.62	1.68	0.08	0.01	0.03	0.28	0.52	0.78	0.48	0.21
C1	1.00	0.44	0.57	0.42	1.52	1.14	2.60	1.14	2.58	0.74
C2	1.46	0.39	0.36	0.25	0.35	0.68	1.06	0.68	0.62	0.28
C3	1.32	0.88	0.41	0.27	0.80	0.72	0.81	0.54	1.12	0.46
Y II	1.06	1.44	0.20	0.01	0.02	0.01	0.65	0.73	0.41	0.03
D1	0.72	0.71	0.69	0.61	0.47	0.68	0.65	0.88	0.88	0.44
D2	1.08	0.84	0.47	0.32	0.44	0.60	0.89	0.02	0.08	0.03
D3	2.48	1.84	1.60	1.06	1.32	1.06	1.74	0.92	1.68	0.90
Z II	1.24	0.62	0.14	0.01	0.19	0.02	0.48	0.51	0.38	0.02
E1	2.02	1.16	1.32	1.02	2.66	1.94	2.06	2.26	2.30	1.00
E2	1.22	0.80	1.06	0.58	1.26	1.52	1.32	1.56	2.88	1.96
E3	1.52	0.68	1.36	1.00	0.84	0.94	1.40	1.38	1.56	1.08
V II	0.31	0.12	0.18	0.16	0.20	0.29	0.18	0.18	0.22	0.17
A1	1.26	1.68	0.17	0.82	3.40	8.48		1.23	0.56	2.44
A2	1.26	1.78	0.44	0.98	1.28	6.00		1.08	0.48	0.80
A3	1.32	1.73	2.32	2.90	3.16	6.36		0.70	0.48	2.50

Appendix 8.2.4d(ii) Total oxidised-N data. Nitrifying tower feeds and effluents. Experiment 4.

Data expressed as mg N/1. Feeds designated W II, X II, Y II, Z II and V II, supplying filter groups B,C,D,E and A respectively.

Feed and effluents	7/4	9/4	14/4	15/4	21/4	23/4	28/4	29/4	5/5	7/5
W II	11.13	4.66	0.82	0.06	0.06	1.13	8.34	8.07	5.30	1.02
B1	10.37	5.18	5.56	6.36	7.13	3.52	8.78	4.88	11.05	5.23
B2	11.40	5.43	5.53	5.76	11.18	7.06	13.23	8.67	13.87	8.97
B3	2.97	0.52	0.18	0.12	0.27	0.11	0.98	0.24	0.84	0.17
X II	6.47	2.33	0.18	0.06	0.08	0.43	7.37	6.23	4.63	0.31
C1	4.90	3.29	4.57	4.27	6.07	3.49	13.90	7.69	15.58	5.44
C2	8.96	4.69	4.86	4.75	7.05	1.33	8.31	3.93	6.92	2.48
C3	8.22	6.03	6.01	5.92	8.00	2.62	7.41	3.19	6.77	4.61
Y II	2.51	1.84	0.35	0.06	0.07	0.06	6.65	5.03	4.21	0.08
D1	11.02	13.47	16.44	14.56	13.12	8.08	12.90	6.88	9.18	8.99
D2	14.13	8.94	6.92	6.92	5.69	1.80	2.94	0.12	0.33	0.23
D3	12.58	9.84	9.65	10.36	12.87	6.01	9.29	5.12	9.73	6.20
Z II	2.74	1.62	0.24	0.01	0.44	0.07	4.43	3.86	3.53	0.07
E1	10.17	8.81	11.82	11.07	20.56	17.59	17.41	14.61	18.50	6.30
E2	5.62	5.50	8.56	6.53	10.41	10.22	13.67	10.71	16.48	10.61
E3	7.97	5.03	10.06	9.85	7.99	5.34	10.20	7.53	9.41	7.53
V II	1.76	0.62	1.58	1.11	2.10	1.24		1.53	2.02	1.27
A1	23.71	25.43	15.47	20.47	26.25	31.63		20.34	16.56	18.79
A2	17.86	22.53	17.09	23.03	31.03	33.20		14.58	9.48	16.50
A3	20.17	23.98	21.17	25.20	32.51	36.36		18.00	16.43	14.95

Appendix 8.2.4e(ii) Flow rate data. Nitrifying towers. Experiment 4.

Data expressed as $m^3/m^3.d.$

Date	7/4	9/4	14/4	15/4	21/4	23/4	28/4	29/4	5/5	7/5
Filter										
B1	4.06	4.11	3.79	3.72	3.79	4.00	3.84	3.89	3.72	4.59
B2	3.99	4.16	4.15	4.28	3.60	3.90	4.22	3.89	3.83	3.89
B3	4.80	4.14	4.77	4.03	3.72	4.14	4.32	4.66	4.62	3.79
C1	4.28	3.57	3.74	3.87	3.56	3.80	3.46	3.89	3.62	4.64
C2	4.43	4.43	3.58	3.66	3.87	4.04	3.84	3.84	4.04	4.05
C3	4.28	4.11	3.79	3.92	3.95	4.34	4.46	4.70	4.35	3.47
D1	4.36	3.20	3.58	3.82	3.60	3.80	4.51	4.42	4.72	3.41
D2	4.50	4.53	4.05	4.03	3.96	4.14	4.42	4.42	4.67	4.27
D3	4.28	4.32	4.26	4.23	3.52	3.85	4.42	4.51	4.51	4.37
E1	3.99	4.11	3.89	3.87	3.80	3.56	3.89	3.89	3.93	4.80
E2	3.91	3.95	3.89	3.97	4.00	3.72	4.32	4.27	4.62	4.59
E3	4.36	4.69	3.89	4.03	3.80	3.56	4.32	4.61	4.83	3.95
A1	1.55	1.39	1.50	1.34	1.46	1.35	1.39	1.39	1.36	1.39
A2	1.48	1.33	1.19	1.34	1.51	1.39	1.34	1.34	1.31	1.28
A3	1.48	1.36	1.50	1.39	1.56	1.39	1.39	1.39	1.31	1.33

Appendix 8.2.5a(i) BOD data. Nitrifying tower feeds and effluents. Acclimation periods for experiment 5.

Data expressed as mg/l. Feeds designated W, X, Y and Z, supplying filter groups B, C, D and E respectively.

	Acclimation period for first half of experiment								Acclimation period for second half of experiment		
Feed and effluents	6/1	8/1	13/1	15/1	20/1	22/1	27/1	Feed and effluents	17/3	19/3	24/3
Y	47.5	58.0	67.0	34.5	42.0	33.5	41.5	W	82.0	94.5	52.0
D1	43.8	37.9	31.1	11.3	27.4	17.9	12.4	B1	28.8	19.0	11.0
D2	38.4	27.9	33.0	11.8	26.0	12.1	12.8	B2	26.0	19.8	10.8
D3	43.5	35.4	28.3	11.9	17.6	11.6	10.4	B3	25.8	19.8	10.3
Z	19.8	31.8	22.3	10.8	16.3	14.3	16.8	X	51.5	59.5	43.5
E1	12.8	21.6	12.5	12.9	9.9	11.4	10.3	C1	20.5	15.3	9.8
E2	13.1	22.5	11.6	4.4	10.8	9.1	9.5	C2	18.8	16.0	9.6
E3	16.3	19.9	12.8	5.0	11.4	11.0	10.0	C3	32.8	21.8	11.3

Appendix 8.2.5b(i) NH_3-N data. Nitrifying tower feeds and effluents. Acclimation periods for experiment 5.

Data expressed as mg N/l. Feeds designated W, X, Y and Z, supplying filter groups B, C, D and E respectively.

	Acclimation period for first half of experiment								Acclimation period for second half of experiment		
Feed and effluents	6/1	8/1	13/1	15/1	20/1	22/1	27/1	Feed and effluents	17/3	19/3	24/3
Y	12.8	10.4	11.0	8.2	11.6	12.8	12.6	W	9.7	12.0	15.1
D1	13.0	10.0	11.2	7.3	10.4	11.6	5.9	B1	6.1	9.4	12.4
D2	13.0	10.3	10.9	6.2	8.9	9.5	6.2	B2	4.3	7.5	8.8
D3	12.8	10.1	9.7	6.2	6.2	6.6	2.3	B3	6.1	9.3	10.4
Z	11.4	10.8	11.2	8.2	12.0	14.8	10.4	X	7.4	11.3	16.2
E1	10.8	10.7	10.9	7.3	11.3	13.7	9.2	C1	5.0	8.2	6.7
E2	10.8	11.6	11.0	7.4	10.6	13.0	7.0	C2	1.5	3.1	10.0
E3	10.0	10.6	11.3	6.5	10.1	11.2	3.9	C3	4.2	8.2	10.7

Appendix 8.2.5c(i) NO_2-N data. Nitrifying tower feeds and effluents. Acclimation periods for experiment 5.

Data expressed as mg N/l. Feeds designated W, X, Y and Z, supplying filter groups B, C, D and E respectively.

	Acclimation period for first half of experiment								Acclimation period for second half of experiment		
Feed and effluents	6/1	8/1	13/1	15/1	20/1	22/1	27/1	Feed and effluents	17/3	19/3	24/3
Y	0.07	0.01	0.04	0.10	0.22	0.14	0.23	W	0.82	0.86	0.54
D1	0.11	0.08	0.24	0.53	0.56	0.60	1.98	B1	0.49	0.68	1.10
D2	0.12	0.11	0.64	0.96	1.26	1.20	1.06	B2	0.41	0.52	0.94
D3	0.51	0.41	0.68	0.55	1.02	1.06	0.80	B3	0.84	0.77	1.36
Z	0.12	0.04	0.07	0.09	0.10	0.04	0.08	X	0.52	0.49	0.66
E1	0.19	0.09	0.24	0.27	0.25	0.36	0.23	C1	1.04	1.23	2.28
E2	0.21	0.10	0.22	0.29	0.38	0.56	0.74	C2	0.45	0.63	1.42
E3	0.69	0.33	0.25	0.48	0.62	1.13	1.38	C3	1.00	0.95	1.92

Appendix 8.2.5d(i) Total oxidised-N data. Nitrifying tower feeds and effluents. Acclimation periods for experiment 5.

Data expressed as mg N/l. Feeds designated W, X, Y and Z, supplying filter groups B, C, D and E respectively.

	Acclimation period for first half of experiment								Acclimation period for second half of experiment		
Feed and Effluents	6/1	8/1	13/1	15/1	20/1	22/1	27/1	Feed and effluents	17/3	19/3	24/3
Y	0.42	0.01	0.09	0.40	0.42	0.29	0.68	W	1.62	1.16	4.79
D1	0.26	0.18	0.49	1.28	1.41	1.65	6.68	B1	2.89	3.48	6.30
D2	0.27	0.16	0.69	1.86	2.91	3.20	5.31	B2	3.96	4.37	9.34
D3	0.71	0.46	1.49	1.90	4.52	5.26	7.70	B3	3.64	3.52	8.81
Z	0.82	0.19	0.42	0.69	0.50	0.21	0.43	X	0.97	0.84	5.06
E1	0.64	0.24	0.84	1.37	1.25	1.26	1.03	C1	2.44	3.88	14.63
E2	0.76	0.25	0.67	1.14	1.53	1.71	2.94	C2	4.11	6.38	10.97
E3	1.39	0.63	1.00	2.03	2.67	3.63	5.53	C3	2.60	2.65	10.32

Appendix 8.2.5e(i) Flow rate data. Nitrifying towers. Acclimation periods for experiment 5.

Data expressed as m^3/m^3.d.

	Acclimation period for first half of experiment								Acclimation period for second half of experiment		
Date	6/1	8/1	13/1	15/1	20/1	22/1	27/1		17/3	19/3	24/3
Filter											
D1	5.49	6.03	6.01	5.97	6.04	5.20	5.68	B1	5.49	5.68	6.13
D2	5.85	6.58	6.09	6.40	6.28	6.48	6.00	B2	5.58	5.96	6.25
D3	5.49	6.40	6.34	6.57	6.00	6.08	6.08	B3	5.67	6.00	6.29
E1	7.59	6.95	7.85	7.64	5.88	6.32	5.92	C1	5.53	5.88	6.25
E2	5.94	6.31	6.26	6.02	5.64	6.08	5.68	C2	5.21	5.44	5.96
E3	6.49	7.04	7.10	6.95	5.92	6.24	5.84	C3	5.58	5.44	6.13

Appendix 8.2.5a(ii) BOD data. Nitrifying tower feeds and effluents. Experiment 5.

Data expressed as mg/l. Feeds designated W, X, Y and Z, supplying filter groups B, C, D and E respectively.

Feed and effluents	7/4	9/4	14/4	15/4	21/4	23/4	28/4	29/4	5/5	7/5
W	68.5	65.0	34.0	71.5	102.5	119.5	38.5	66.0	71.5	61.0
B1	17.0	20.5	15.0	10.3	29.5	66.8	26.5	25.8	28.8	6.5
B2	17.0	21.8	17.0	17.5	26.3	64.8	18.3	20.8	35.8	15.0
B3	18.0	20.5	15.0	17.8	30.3	69.8	17.0	18.8	45.8	17.5
X	61.0	60.0	29.0	57.5	96.5	134.5	31.5	46.5	54.5	45.0
C1	17.5	14.5	18.3	13.8	22.8	100.3	10.8	15.3	49.3	18.5
C2	8.0	17.3	16.5	14.5	17.5	87.3	18.8	17.3	50.8	24.8
C3	9.5	12.8	14.0	13.8	33.3	101.8	24.8	18.8	50.5	12.0
	29/1	6/2	9/2	12/2	17/2	19/2	25/2	26/2	3/3	5/3
Y	35.5	48.5	38.5	32.0	51.5	64.5	45.0	84.0	34.0	73.0
D1	7.0	8.4	12.9	18.0	16.4	22.8	16.5	33.1	14.6	37.5
D2	17.0	9.4	8.5	6.4	16.6	16.0	9.5	31.6	13.5	32.5
D3	5.0	14.8	22.3	26.5	15.0	22.8	14.3	26.9	9.6	21.9
Z	14.5	15.8	15.0	10.3	19.5	18.5	13.3	23.3	10.0	30.5
E1	7.3	6.9	8.3	3.3	9.4	9.3	9.3	16.5	5.1	15.4
E2	7.8	8.8	9.4	5.5	7.8	10.6	6.4	15.8	4.0	13.8
E3	5.0	6.1	10.4	4.8	8.0	11.4	6.9	15.9	5.6	14.8

Appendix 8.2.5b(ii) <u>NH_3-N data. Nitrifying tower feeds and effluents.</u> <u>Experiment 5.</u>

Data expressed as mg N/l. Feeds designated W, X, Y and Z, supplying filter groups B, C, D and E respectively

Feed and effluents	7/4	9/4	14/4	15/4	21/4	23/4	28/4	29/4	5/5	7/5
W	21.6	10.4	13.6	12.0	18.8	17.2	8.4	8.8	14.1	13.3
B1	18.0	9.2	9.7	8.2	12.1	10.0	3.6	3.4	9.1	8.6
B2	13.6	7.2	8.9	8.6	12.5	12.1	5.1	6.1	11.2	10.7
B3	17.6	8.4	8.6	7.4	12.5	12.1	4.6	3.7	10.4	9.6
X	23.2	9.6	12.8	11.2	18.0	16.8	7.2	8.0	12.6	12.3
C1	20.0	7.2	8.6	7.3	13.0	12.1	3.4	4.6	9.7	9.1
C2	15.6	3.6	8.6	2.9	7.7	5.4	0.4	1.3	9.1	10.4
C3	20.0	6.0	4.6	7.0	13.0	12.0	5.2	5.8	10.3	9.9

	29/1	6/2	9/2	12/2	17/2	19/2	25/2	26/2	3/3	5/3
Y	12.6	10.9	13.2	12.0	10.7	12.6	10.1	11.6	7.4	11.2
D1	7.1	1.9	3.4	4.0	3.6	5.0	1.9	4.4	3.4	7.4
D2	8.3	3.0	2.8	1.5	2.0	3.4	2.4	4.3	2.2	6.6
D3	3.2	2.3	4.9	5.3	4.7	5.3	2.9	4.8	1.3	4.6
Z	12.6	10.9	15.8	12.1	10.6	12.6	10.7	12.8	7.0	12.5
E1	10.9	3.8	7.3	3.6	2.9	3.1	5.0	8.1	2.4	7.3
E2	8.0	6.9	8.9	6.1	4.6	6.1	2.1	5.6	0.2	2.2
E3	7.3	3.3	8.4	3.7	3.4	5.5	4.5	6.6	1.3	6.8

Appendix 8.2.5c(ii) NO_2-N data. Nitrifying tower feeds and effluents. Experiment 5.

Data expressed as mg N/1. Feeds designated W, X, Y and Z, supplying filter groups B, C, D and E respectively.

Feed and effluents	7/4	9/4	14/4	15/4	21/4	23/4	28/4	29/4	5/5	7/5
W	1.56	0.87	0.18	0.02	0.03	0.16	0.37	0.44	0.27	0.22
B1	1.38	0.78	1.03	0.69	2.02	1.34	1.16	1.44	1.96	1.64
B2	0.80	0.44	0.51	0.32	1.22	1.60	1.26	0.82	1.42	1.38
B3	1.10	0.98	1.28	0.64	1.22	1.14	1.08	1.22	1.16	0.94
X	0.94	0.60	0.25	0.03	0.22	0.09	0.40	0.32	0.21	0.35
C1	1.90	1.16	1.22	0.90	1.46	1.42	1.44	1.06	1.14	1.20
C2	1.18	0.82	1.08	0.69	1.06	0.50	0.24	0.46	0.60	0.70
C3	1.74	1.16	0.74	0.68	0.76	0.88	0.46	0.72	1.16	1.24
	29/1	5/2	9/2	12/2	17/2	19/2	25/2	26/2	3/3	5/3
Y	0.05	0.04	0.14	0.20	0.06	0.04	0.07	0.12	0.12	0.14
D1	0.89	0.90	1.07	1.24	1.70	1.48	1.06	1.20	0.78	0.66
D2	0.64	0.90	1.09	1.04	0.84	1.00	0.78	0.76	0.74	0.68
D3	0.76	1.12	1.28	1.62	1.74	1.10	1.00	1.04	0.92	1.14
Z	0.04	0.04	0.08	0.10	0.08	0.06	0.08	0.05	0.09	0.04
E1	0.45	1.34	1.30	1.22	1.34	1.36	1.68	1.62	1.74	2.08
E2	0.81	0.87	0.79	1.04	1.20	1.20	0.92	0.82	0.39	1.14
E3	0.86	1.06	1.10	1.56	1.50	1.22	1.48	1.56	1.64	1.54

Appendix 8.2.5d(ii) <u>Total oxidised-N data. Nitrifying tower feeds and effluents. Experiment 5.</u>

Data expressed as mg N/l. Feeds designated W, X, Y and Z, supplying filter groups B, C, D and E respectively.

Feed and effluents	7/4	9/4	14/4	15/4	21/4	23/4	28/4	29/4	5/5	7/5
W	3.06	1.27	0.28	0.07	0.60	0.21	2.32	1.89	1.42	0.27
B1	4.48	2.63	3.78	3.44	6.92	5.09	6.31	5.79	8.41	6.89
B2	6.90	3.34	4.06	2.92	5.07	4.75	4.86	2.87	6.12	3.88
B3	4.80	3.43	5.13	4.29	5.82	4.14	5.73	5.42	6.81	4.44
X	2.99	0.85	0.40	0.08	0.22	0.09	1.75	1.27	1.06	0.50
C1	6.05	3.06	5.02	4.40	5.61	4.17	5.19	3.86	4.79	3.90
C2	9.73	5.17	5.13	7.24	9.01	6.15	7.39	6.51	4.70	2.85
C3	7.04	3.86	7.44	4.48	5.11	3.68	3.51	2.97	4.81	3.74
	29/1	6/2	9/2	12/2	17/2	19/2	25/2	26/2	3/3	5/3
Y	0.10	0.09	0.29	0.35	0.11	0.09	0.22	0.17	0.32	0.24
D1	3.79	7.40	9.42	8.04	6.55	8.29	8.01	6.50	3.13	3.16
D2	2.54	5.65	8.44	8.74	6.94	10.15	7.08	6.36	4.34	3.83
D3	6.16	7.22	7.93	7.57	6.24	7.60	6.60	6.14	5.22	6.29
Z	0.24	0.14	0.53	0.45	0.28	0.31	0.33	0.20	0.54	0.19
E1	1.80	6.09	7.60	6.62	6.59	10.01	5.88	4.77	4.54	5.88
E2	4.36	3.42	5.54	5.29	4.90	7.00	7.77	6.22	5.54	8.49
E3	5.21	6.11	6.90	7.76	6.25	7.72	6.13	6.06	5.29	5.24

Appendix 8.2.5e(ii) Flow rate data. Nitrifying towers. Experiment 5.

Data expressed as $m^3/m^3.d.$

Date	7/4	9/4	14/4	15/4	21/4	23/4	28/4	29/4	5/5	7/5
Filter										
B1	6.06	6.56	6.43	6.04	5.90	5.61	5.76	5.86	6.14	6.29
B2	5.61	6.29	5.86	5.99	5.51	5.19	5.66	6.00	6.14	6.29
B3	6.20	6.83	6.69	6.25	5.85	5.54	5.57	5.81	5.98	6.45
C1	6.06	6.67	6.59	6.14	5.51	5.19	5.52	5.66	5.98	6.24
C2	5.98	6.51	6.49	5.68	5.75	5.61	5.47	5.66	5.72	6.29
C3	6.06	6.61	6.59	6.09	5.46	5.11	5.71	5.86	6.03	6.19
	29/1	6/2	9/2	12/2	17/2	19/2	25/2	26/2	3/3	5/3
D1	6.35	5.85	6.00	6.09	5.72	6.40	5.56	5.94	6.57	6.01
D2	6.27	6.16	5.60	5.93	6.05	5.28	5.36	5.62	6.31	6.06
D3	5.97	5.36	5.04	5.18	6.41	5.44	5.36	5.58	5.76	6.30
E1	6.23	5.80	5.89	5.72	5.76	5.56	5.76	5.76	6.49	6.30
E2	6.06	5.76	7.97	5.88	5.49	5.41	5.68	5.58	5.80	5.66
E3	6.23	5.36	5.47	5.92	6.45	5.76	5.36	5.99	6.74	6.01

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