

**Title Page**

**THE RELATIONSHIP BETWEEN ORGANIC COLOUR AND  
METALS IN WATER AND ITS IMPLICATION FOR WATER  
TREATMENT.**

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**A thesis submitted to the University of Manchester for  
the degree of Doctor of Philosophy in the Faculty of  
Science.**

**Department of Environmental Biology.**

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## Abstract

Much natural water contains low concentrations of dissolved solids, has low conductivity and possesses little alkalinity, so it is highly susceptible to the effects of acid precipitation. This water may also be yellowish or brownish in colour which indicates that it contains significant concentrations of natural organic acids. The occurrence of organic acids (mainly fulvic and humic acids) in natural water has been well documented. Runoff from upland catchment areas into streams and reservoirs is often highly coloured; especially after prolonged dry periods, as a result of non-point source loading. This yellowish or brownish colouring is mainly due to the presence of complex organic compounds and inorganic compounds derived from the water soluble and insoluble constituents of soil humus, peat and rocks. Many water supplies in Britain are treated for colour, but some treatment plants have not been able to remove the colour to a satisfactory level. This has led to consumer complaints, and so colour in the water has significant economic implications for both suppliers and consumers.

Field studies were carried out to investigate the inter-relation between colour, metals and other parameters in six different streams and the treatment plant at Longdendale Valley, with soil moisture deficit, rainfall and other factors such as the landform of the catchment areas; this includes altitude, slope, length of the streams, the underlying geology, type of soil cover, the thickness of the layers, type of vegetation and other, and to determine the implication on the quality of stream water. There were considerable variations (spatial and temporal) between the levels of colour and metals at the streams. The underlying geology, soil and vegetation of the individual stream seem to play very important role on the quality of stream waters. Each of these factors may play an important role at a certain time, also the other factors (such as the thickness of layers, slopes, altitude, size of the catchment area, temperature, rainfall, the soil moisture deficit and bacterial activity) indicate a strong influence on the colour and metals levels in the streams. At the works the rainfall and the soil moisture deficit indicate an influence over the colour and metals. Over viewing the catchment area by using of the remote sensing data shows some promise on the management of water quality, and the organization of the collection of stream water may lead to a better quality of water for the treatment plant.

Experimental studies in the field and in the laboratory (lysimeters, monolith tins and arylsulphate activity) were also carried out to investigate the effect of the type of soils (peat, peaty soil, lime and unlimed soil), temperature and other factors on colour and metals generation. In general the results indicate that the desorption of organic material was affected by the temperature and types of soils and bacterial activity.



### DECLARATION

No portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification of the University of Manchester or any other university or institution of learning.

**Fadhel Banjar**



### EDUCATION

I obtained a B.Sc. degree in Public Health Studies at Eastern Kentucky University (USA) in 1981. Thereafter, I worked in Saudi Arabia for the Department of Environmental Health in the Ministry of Health and then as Director of a Health Centre.

DEDICATION

For my God "Allah"

For my mother, brothers and my only sister.

For my darling wife Abeer

For my daughter Mawaddah.

### ACKNOWLEDGMENTS

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# **Chapter 1**

## **Introduction.**

## 1.1 Introduction.

A public water supply should have no noticeable colour, should be safe and not be harmful to human beings. The health of the community depends greatly on the ample provision of a wholesome water supply. In addition, water which is used for many industrial purposes such as paper making, dyeing, photographic film manufacture and ice-making must be entirely free of colour.

Water authorities have a duty to make sure that the water, in any waterworks belonging to them, through which they supply for domestic purposes, is wholesome. They are obliged under U.K. law and by E.E.C. directive, to make sure that the water quality reaches certain prescribed standards (E.E.C., 1980); table 1.1 shows the recommended guide levels and Maximum Admissible Concentrations (M.A.C's) for some water quality parameters and colour intended for human consumption.

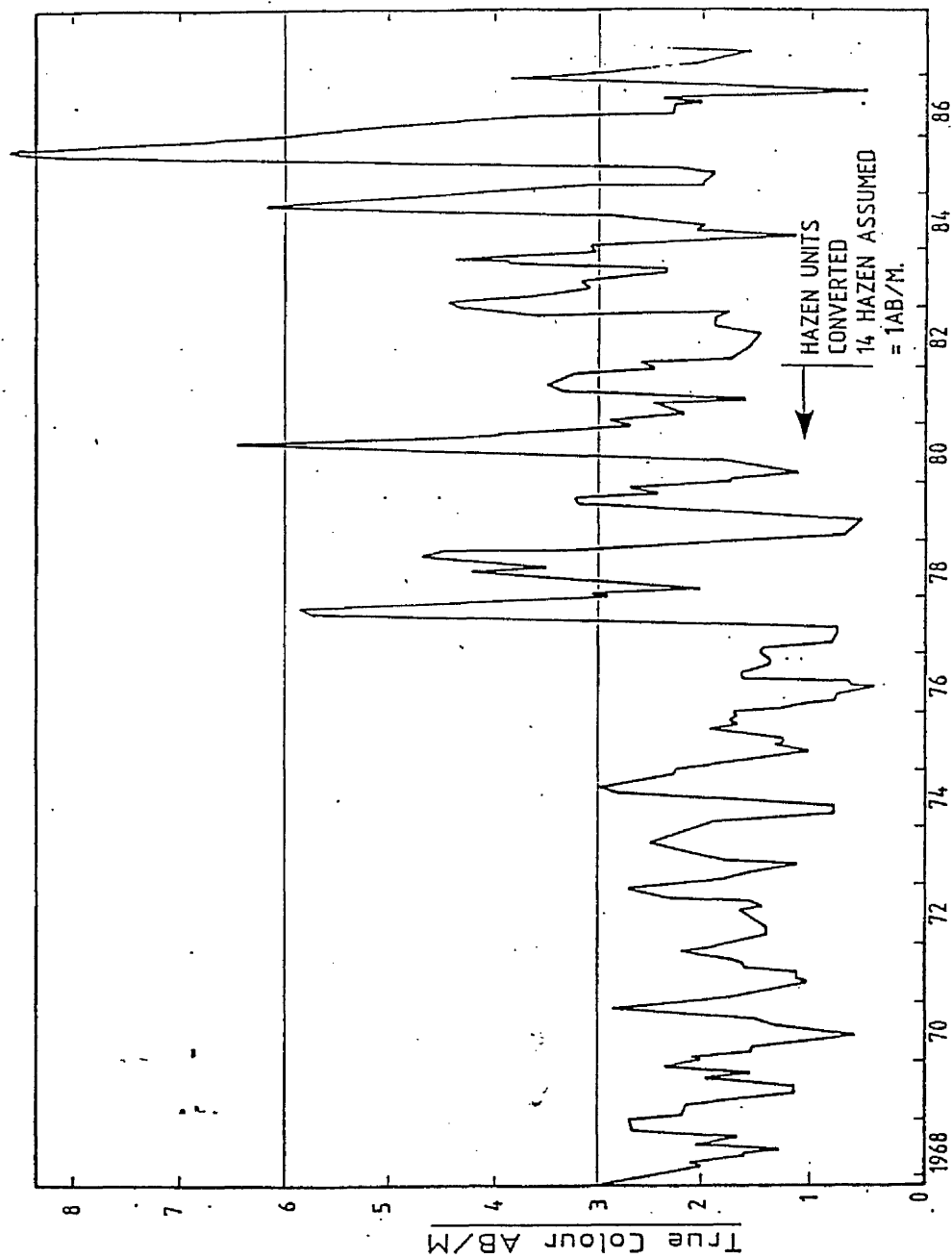
**Table 1.1 E.E.C. drinking water standards (From E.E.C., 1980); Council Directive 80/778).**

Parameter	Units	Guide level	M.A.C's
Colour	mg/l Pt/Co scale (Hazen unit '')	1	20
pH		6.5 > pH < 8.5	
Iron	PFb or (mg/l)	50 or (0.05)	200 or (0.2)
Manganese	PFb or (mg/l)	50 or (0.05)	200 or (0.2)
Aluminium	PFb or (mg/l)	50 or (0.05)	200 or (0.2)
Calcium	mg/l	100	
Magnesium	mg/l	30	50

\* Hazen unit = colour produced by 1 mg/l platinum in the form of chloroplatinic acid in the presence of 2 mg/l of cobaltous chloride hexahydrate (I.W.E., 1960, and H.M.S.O., 1981).

The moorlands of Britain are a cheap source of drinking water being in areas of high rainfall. In Victorian times many reservoirs were built in these areas and authorities such as the North West Water PLC obtain much of their supply from upland catchments. Over the last decade the quality of such waters has been deteriorating. This is especially noticeable in terms of the amount of colour. Edwards (1987) demonstrated the long temporal variation of colour at Thornton Moor Reservoir (west of Bradford); Figure 1.1 illustrates the monthly mean variation of colour in the raw waters over a period of 18 years (from 1968 to 1986). Edwards notes that the peak levels recorded for the autumns of 1976, 1980 and 1985 each occurred a year after a period of unusually severe summer drought. Naden and McDonald (1987) also noted a significant increase in the levels of colour and other water quality parameters in the raw water at the Upper Nidd catchment. Table 1.2 shows the range of these parameters over the period between April 1979 and December 1985. It can be seen quite clearly from the table that the trace metal and other parameter levels in the surface waters at the Upper Nidd catchment often exceeded not just E.E.C. guide levels, but also the M.A.C's. In some other Pennine catchments, the levels of some of these parameters have more than doubled in the last decade. In recent years there has been evidence that some reservoirs have become more discoloured, particularly following the 1976 and 1985 droughts. Some treatment plants have not been able to remove the colour

Figure 1.1 Raw water colour : Thornton Moor Reservoir (monthly means) (From Edwards 1987).



**Table 1.2 Water quality levels at The Upper Nidd catchment (From Naden and McDonald, 1987).**

	1979*	1980	1981	1982	1983	1984	1985
Colour ab.m <sup>-1</sup>	4.83	4.68	5.29	4.54	4.58	4.33	6.65
pH	6.14	6.44	6.56	6.53	6.55	6.55	6.53
Turbidity ftu	4.99	6.78	5.27	10.33	7.14	10.32	11.5
Conductivity ms.cm <sup>-1</sup>	73.9	69.3	71.5	84.2	74.0	88.2	81.2
Aluminium mg.l <sup>-1</sup>	0.13	0.17	0.15	0.15	0.12	0.27	0.35
Iron mg.l <sup>-1</sup>	0.55	0.70	0.68	0.69	0.59	1.10	1.13
Manganese mg.l <sup>-1</sup>	0.05	0.07	0.04	0.07	0.06	0.23	0.22

\* from April

to a satisfactory level. This has led to consumer complaints. Edwards (1987) and Howarth (1987) note that the operating costs of many of the water treatment works in Britain have risen due to increased colour because of the increasing amount of chemicals which have had to be used and the quantity of sludge produced. Also McDonald and Naden (1987) noted an increase in the cost of the treatment by as much as ten times at works, and a loss of customer satisfaction. One of the greatest difficulties in the treatment of water is that removal of colour. The colour of the water varies greatly both from reservoir to reservoir and also over time. A strong seasonal variation in the cycle is characterised by higher colour levels in late autumn and early winter. It may also adhere to seasonal patterns in its production, being particularly coloured after very dry summers (Edwards, 1987). Water in most of the Pennine reservoirs is soft (low in calcium carbonate), oligotrophic and acidic. The indication is that



the average pH of the rainfall in the region is between 4.2 and 4.5; and some reservoir waters are markedly acidic (less than pH 5). These reservoirs have not been populated with fish, since they were constructed in the latter half of the nineteenth century (Edwards, 1987). In many reservoirs containing coloured waters, metals are naturally present as well, the commonest ones are iron, manganese and aluminium (Naden and McDonald, 1987).

Brown coloration develops in the water as a result of the dissolution of humic substances (HS) which are dark coloured macromolecules derived from soil and peat (Packham, 1964). In upland areas many reservoir catchments are substantially covered with peat. This means that the nutrient status of the reservoirs remains low (oligotrophic) and biological problems are fewer. The peat was in some places up to 5 m in depth, and this has been subjected to widespread erosion over the past 50 years or so. The erosion has been attributed to many factors such as climatic conditions.

Humic substances are naturally occurring products of biological activity in the aquatic and terrestrial environments. The humic substances in natural waters are often dissolved (Connor, 1986). Humic and fulvic acids are the two major types in natural water due to their appreciable solubilities (Thurman and Malcolm, 1983). They are known not to be harmful to health. These substances, although of little health concern by themselves, can form trihalomethanes (THMs) and other halogenated organic

compounds during chlorination at concentrations required for water disinfection. They also can transport toxic materials such as pesticides and heavy metals from the environment into the water (Bellar et al. 1974, and Snoeyink and Chen, 1985). These organohalides (THMs) may not constitute any immediate threat to public health but possible long term effects warrant further research. They also reduce disinfection efficiency. Probably of most significance to environmental health is their ability to form complexes with heavy metals. The interaction between aluminium and humic substances is of particular interest at present, due to recent findings that dietary intake of elevated levels of soluble aluminium in drinking water may be a contributory factor to Alzheimer's disease (Martyn et al., 1989).

## 1.2 Organic substances and their role in the environment.

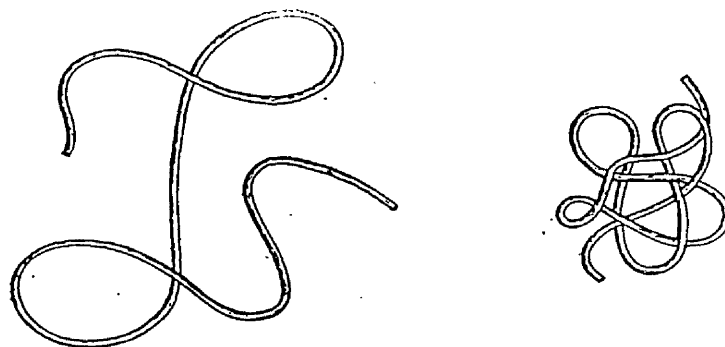
Humic acids are the most abundant macro-molecular (polyelectrolytes) substances on earth, and they are found in all soils and waters. They are also a major component of lignite and brown coal formed from peats by the coalification process (Bolin et al., 1979). All surface waters contain natural organic products derived from both terrestrial and aquatic decomposition processes (Midwood and Felbeck, 1968). Natural humic substances are among the most prevalent of organic materials occurring in soil (Kononova, 1961), rivers, (Lamar, 1968) and lakes (Shapiro, 1957a).

Humic substances may be defined as " a general category of naturally occurring, biogenic, heterogeneous organic substances that generally be characterised as being yellow to black in colour, of high molecular weight, and refractory " (Aiken et al., 1985). In natural waters humic substances account for 40-80 % of dissolved organic matter (Thurman and Malcolm, 1983). The total concentration of organic carbon (TOC) in potable water rarely exceeds 10 mg/l. In most cases it is below 5 mg/l and ground water generally contains less than 1 mg/l (Shapiro 1964, Ghassemi and Christman, 1968).

In most of the literature on humic substances the humic substances have been separated into three fractions on the basis of solubility : Humins (H<sub>2</sub>O, base, and acid insoluble), Humic acid (base soluble, acid insoluble, colloidal in H<sub>2</sub>O) and Fulvic Acid (H<sub>2</sub>O, base and acid soluble). However, because humic substances are complex mixtures, they do not possess a unique molecular weight. Instead, they have been characterized by number-average molecular weight or weight-average molecular weight values. Recently, Hayes et al., (1989) attempted to give a simpler classification of the properties and behaviour of polyelectrolytic macromolecules, to help gain a better understanding of the nature of humic substances. The authors concluded that the average molecular weight values of the highly polydisperse humic substances in freshwater are very much lower than those in soils, and those for freshwater humic acids are of the order of three times

greater than those for the corresponding fulvic acids. Thus the molecular weights of freshwater humic substances are more closely grouped and less polydisperse than those of soil, and most of the values reported are of the order of 1000 daltons or less. Most of the values for unfractionated extracts of soil humic acids fall within the range of  $20 \times 10^3$  -  $100 \times 10^3$  daltons and appear to be dependent upon the method of determination; many of the average values tend to group within the narrower range of  $30 \times 10^3$  -  $70 \times 10^3$  daltons. Swift (1989), suggested the shape of the macromolecules are more randomly structured random coils. "A random coil flexes and winds with respect to time and space, which results in a molecule that is roughly enclosed by a sphere within which there is a Gaussian distribution of the molecular mass (for example, the mass density is greatest at the center and decreases to zero at the outer limits of the sphere)". Although the spherical shape of a random coil of the macromolecule is not rigid but is constantly changing over a period of time, it tends to adopt the average shape of a sphere. Figure 1.2 shows the short random coil with two possible conformations for the same molecule as illustrated by Swift 1989. Also Swift discussed the concept of random coil conformation theory which may explain many of the observed properties of the humic substances such as expanding and collapsing. He pointed out the effect of the electrostatic charge on the shape of the Gaussian distribution of molecules (depending on the extent of molecular expansion) under different

Figure 1.2 Diagrammatic representation of a relatively short, flexible, linear random coil showing the same molecule in two possible conformations at different times. (From Swift, 1989).



conditions in solution, which may be explained by the random coil model. For example, he discussed that if a molecule of humic acid was to be a flexible, linear polyelectrolyte with negative charges occurring at fixed points along the macromolecular strand, then the negative charges tend to repel one another and this causes the molecule to expand; Since the negative charges on the macromolecule are balanced by an equal number of positive charged cations, and this tends to prevent full molecular expansion. He noted that electrostatic repulsion between the negative charged groups causes the macromolecules to

expand and eventually the molecules go into solution. Also Swift suggested that, the differences between the solution conformations and solid-state forms of humic substances may be considered mainly in terms of the extent of molecular expansion. As the humic macro molecules are precipitated from the solution, solvent is excluded, intramolecular charge repulsion decreases, and intramolecular interaction increases. Sometimes, under extreme conditions, the molecules are unlikely to collapse completely, and will still retain an ability to expand, depending upon the amount of water in, and the ionic composition of the immediate environment. He also suggested that, the hydrophobicity of humic substances in soils and peats when subjected to extreme drying can be explained by using the random coil model. As the flexible humic macromolecule gradually dries out, the last water to be removed is entrained within the molecule. At this stage, the charged sites and other hydrophilic sites will attempt to be solvated by water and will tend to accumulate and/or orientate towards the centre of the molecule. Hydrophobic sites will tend to accumulate and/or orientate towards the outside, drier part of the molecule. When the peat or soil is rewetted, the behaviour of the molecule is dictated by the surface of the molecule which exhibits hydrophobic properties initially. Only when sufficient time has elapsed for water to penetrate the molecule thoroughly and resolvate the polar sites will the more typical wetting behaviour characteristic of hydrated humic substances be

observed.

The literature on humic substances is vast, but often contradictory, and much remains to be learned about them, particularly their detailed chemical composition and structure.

There are many problems associated with the study of organics in coloured water. There is no reliable method for quantitative measurement and their stability is unknown. However, in recent years, significant advances have been made in the technology of isolation and concentration of humic substances from an aquatic environment, such as filtration, vacuum distillation, ion exchange etc. Advantages and disadvantage of all methods have been fully discussed by Aiken (1985, 1988).

Not many investigators have studied metal association with organic matter. Shapiro (1966a and 1966b) studied different lakes and found a general relationship between iron and organic acids, with higher molecular weight compounds mostly associated with iron. He also suggested the possibility of the involvement of colourless organic acids. He quoted, for example, one low coloured water can held more iron per unit colour than more highly coloured water. Zajicek and Pojasek (1976) studied the relationship between the fulvic acid and the transport of manganese in natural streams. He found that the highest concentrations of colour were coincident with the highest manganese concentrations.

High concentrations of dissolved iron commonly found

in acidic streams are associated with enhanced concentrations of dissolved organic matter. This leads to the alternative view that the dissolved iron in river water is carried mainly in the form of organic complexes (Perdu et al., 1976) or, as has been widely considered more likely, as a colloid stabilised by organic material (Shapiro, (1964), Boyle et al., (1977); Sholkovitz et al. (1978); Moor et al. (1979)).

The ability of humic acid to absorb metal has been demonstrated in a number of investigations (Szalay (1964), Chowdhary and Bose (1970), Rashid (1974), Bunzl et al. (1976), Kerndorff and Schintzer (1980), Thanabalaisingam and Pickering (1986)), and the results vary widely depending on the method of analysis used.

Kerndorff and Schnitzer (1980) demonstrated that the order of metals sorption on humic acid as:

At pH 2.4, the order of sorption is:

Hg>Fe>Pb>Cu=Al>Ni>Cr=Zn=Cd=Co=Mn

At pH 3.7, the order is:

Hg=Fe>Al>Pb>Cu>Cr>Cd=Zn=Ni>Co=Mn

At pH 4.7, the order is:

Hg=Fe=Pb=Cu=Al=Cr>Cd>Ni=Zn>Co>Mn

At pH 5.8, the order is:

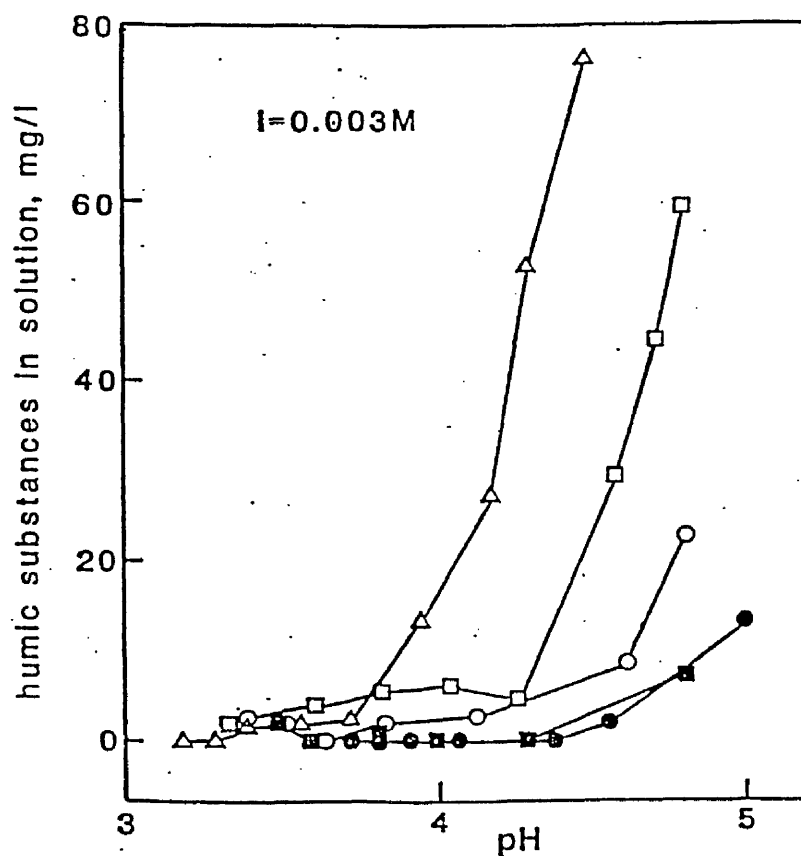
Hg=Fe=Pb=Al=Cr=Cu>Cd>Zn>Ni>Co>Mn

Tipping (1987) notes that solubility of soil humic substances increases with increasing pH, the solubility of soil HS is governed by their net electrical charge. As the charge increases, the more soluble are the humic



substances. When soils are treated with NaOH- virtually all the HS pass into solution; because the net charge is very high, at low pH the charge is much lower and so is the solubility, although sufficient HS can dissolve to make the water obviously coloured. Figure 1.3 illustrated the effect of the pH on the humic substances in solution for different type of soils.

Figure 1.3 Concentration of humic substances in solution plotted against pH for 5 organic soils (soil characteristics were not specified) from Mosedale, Cumbria (see Tipping, 1987; for more details).



Bourbonniere and Van Halderen (1989) demonstrated that half of the humic acid (HA) precipitates at pH values from 3.4 to 4.6, higher than the traditionally defined value of 2.0. These preliminary results have implications for the solubility of dissolved organic matter (DOM) in waters that experience pH decreases, and for the capacity of DOM to complex metals.

The two major mechanisms by which metals interact are complexation (or chelation) and surface absorption (Huljev, 1986). Shapiro (1964) suggested iron is held in solution by peptisation or chelation mechanism, i.e. the peptisation mechanism by which iron is held in solution, as follows: "iron, precipitated as ferric hydroxide, is dispersed by each particle of positively charged ferric hydroxide absorbing and thus becoming surrounded by a 'sheath' of yellow acids, whose carboxyl groups would be ionized and negatively charged to form negative sol. The particles of which would be mutually repulsive". Both peptisation and chelation are operative in coloured water. Although Ghassemi and Christman (1968) explained the process as chelation, iron present in the high molecular weight fraction may be bound by another mechanism other than chelation. There is a controversy concerning the oxidation state of iron. Shapiro (1964) believed it to be ferric, on the other hand Gjessing (1965) thought that complexes of ferrous iron are formed. The capacity of organic acid to hold iron is pH dependent, up to pH 10 found by Shapiro (1964) but Ghassemi and Christman (1968) found that the

degree of association was less at pH 7 - 8 than at a higher and a lower pH.

Humic substances are considered as important contributors to the acidity of natural water (Oliver et al., 1983). The studies on peatland acidity have demonstrated that pH is controlled by weak organic acids (Hemond, 1983; McKnight et al., 1985; Urban et al., 1985). Mineral acids deposited in peatlands can be neutralised through sulphate reduction and nitrate uptake (Hemond, (1983); Bayley and Schindler, (1985); Urban and Bayley, 1986). The relatively slow rate of sulphate uptake may cause increased acidity of surface water, following input of acid sulphate (Urban and Bayley (1986).

As with other aspects of humic substances there is a significant lack of information on their biological characteristics. However, it seems certain that aquatic humic materials play an ecologically more significant role than terrestrial humic; probably due to their greater relative abundance and bioavailability, the predominant effects of humic substances on biological systems have been reported largely in terms of beneficial effects. These include (a) increases in growth, root initiation, yield, nutrient uptake, chlorophyll synthesis, and seed germination, (b) stimulation of the various physiological and biochemical processes associated with cellular metabolism, and (c) attenuation of toxicity of heavy metals and other toxic compounds (Prakish and MacGregor, 1983).

The metal complexing ability of humic substances is

extremely important because it plays a vital role in the nutritional physiology of not only unicellular algae but also of higher plants. It has been shown that humic substances of lower molecular weight fractions are biologically more active than those of higher molecular weight fractions and are able to complex two to six times more metal (Rashid, 1971).

Organic matter has been shown either to inhibit (Briska et al., 1973), enhance (Zurawski and Piss, 1971) or have no effect (Davison and Clay, 1972) on the microbial mineralisation of pesticides in soil. Yet much remains to be learned about the nature of these interactions. Little is presently known about the way in which terrestrial and aquatic organic matter affects microbial mineralisation.

### 1.3 Sources of colour, trace elements, and acidity in water and soil.

The presence of organic substances (Humic or Fulvic), metals (iron, manganese and copper), industrial discharges (pigment and dyes) in water produces discolouration.

Yellow or brown colour in water is usually due to the presence of organic matter which is mainly derived from the soil. The organic colour in natural water must have its origin in the multitude of organic molecules comprising the forest vegetation. Trees and plants in all stages of growth and decay litter the ground with leaves and needles, and forest soil itself is available for aqueous extraction of

organic molecules. More specifically as described by Christman and Ghassemi (1966), colour in water could arise from the aqueous extraction of living woody substances, the form solution of degrading products in decaying wood, and form the solution of soil organic matter or a combination of these processes.

Organic matter present in potable water had been classified by Hyde et al. (1983) into three groups; natural compounds (humic and fulvic acids), synthetic compounds (from industry, municipal discharge and agriculture) and compounds synthesised during treatment (such as trihalomethanes). Packham (1964) found that dissolved humic acids yield a relatively much higher colour intensity than dissolved fulvic acids.

The main sources of metals in soil are atmospheric deposition and the parent material. The metal concentrations in soil are determined by the amounts present in the parent material from which the soil formed, plus the amounts added through wind, and human activities, minus the amount removed through leaching, surface runoff and by vegetation.

The trace elements are defined as those metals which generally occur in water at concentrations of less than 1 mg/l, such as iron, manganese and aluminium. Trace elements may be derived from the weathering of rocks or, from the atmosphere and hydrosphere to which the metals have been released by human activities. Metals are released from impermeable mining activities which break up the rocks and

expose them to water. Rapid alteration of minerals containing sulphide occurs with exposure to oxygen. High concentrations of trace elements, regardless of their source generally do not persist as they are transported through aquatic systems. Whether a particular trace goes into solution during weathering depends on the mineral in which the element occurs, and on the intensity of chemical weathering (Harriss and Adams (1966), Kronberg et al. (1979)). Iron, manganese and aluminium are the major cations found in granite, basalt, shale and sandstone (James, 1982). Calcium and magnesium are the first members of the alkaline earth group of metals, and they are the major cations found in basic igneous rocks and they also occur in shale and sandstone. The kind of salt carried by any stream depends largely on the climate. Adjacent rocks affect the composition of a stream e.g.  $\text{Ca}^{2+}$  may be present in limestone areas,  $\text{Mg}^{2+}$  in dolomite areas, alkali-metal ions and silica in granite areas. Vegetation, absorption processes and mixing with tributaries also change the composition of the water to a type responsive to the climate. Decaying vegetation in humid climates provides an abundant amount of  $\text{CO}_2$  which reacts with  $\text{H}_2\text{O}$  to generate  $\text{CO}_3^{2-}$ ,  $\text{HCO}_3^-$ ,  $\text{H}_2\text{CO}_3$ , and also produces an acidic stream which easily dissolves limestone. In arid regions where sufficient  $\text{CO}_2$  is not present to acidify the water,  $\text{Ca}^{2+}$  and  $\text{Co}^{2+}$ , are precipitated in the soil (Krauskopf, 1979).

Water quality has been judged by the nature and concentration of materials found in solution. However, only

a fraction of the chemical load transported by a stream at any given time might be in the dissolved phase, depending on the amount and nature of suspended sediment, (because of the large surface areas of silt, clay and organic matter available for absorption). A fraction of chemical constituents are transported by suspended sediment. Jenne (1977) has reported that "the most significant role played by clay size minerals during trace element transport by fluvial systems, is acting as a mechanical substrate and the major sinks are oxides of iron and manganese, sulphides, carbonates and organic matter".

Numerous authors have noted that at least 65% of the iron found in natural water is associated with suspended solids (Kopp and Kroner, (1967), Gibbs, (1973), Perhac, (1974), Trefry and Presley (1976); Brown, (1977), Shuman et al, (1978); Martin and Meybeck, (1973); Tessier et al, (1980), Yeat and Bewer, (1982), Habib and Minski (1982); Hart et al, (1982) Abaychi and Douabul, (1985). The reason for this is primarily due to the fact that a state ferric oxidation predominates in well aerated water of near neutral pH. This readily hydrolyses, causing the iron to precipitate as hydrous ferric oxide (Pagenkopf, 1978). Very often this precipitate will be absorbed by organic particles in water. Non-metal elements such as sulphur, carbon and nitrogen are introduced into the atmosphere by human activities in many ways. Burning of fossil fuels and smelting of ores put metals into the atmosphere, where they are washed out by rain into surface water.

The pH of most natural water is controlled by a reaction involving acids and bases. Acid is defined as a substance containing hydrogen which gives-off free hydrogen ions when dissolved in water and we describe the characteristic properties of acid as the properties of hydrogen ion. All bases have been ascribed to hydroxide ion, the term being generally restricted to compounds like NaOH and  $\text{Ca(OH)}_2$ , which dissociate to give this ion directly. Acidity can occur in many ways, for example as a result of  $\text{H}_2\text{SO}_4$  and  $\text{HNO}_3$ , which are generated by oxidation of  $\text{SO}_2$  and nitric oxide in the atmosphere. The main sources of  $\text{SO}_2$  and nitric oxide are the burning of fossil fuels, automobile emissions and industrial effluent. Also exposure of pyrites ( $\text{FeSO}_4$ ) and other minerals to atmospheric oxygen and moisture, generates acidity. The variations in the pH of the water in streams depend on the climate and pollution. (e.g. acid rain,  $\text{CO}_2$  rich atmospheres) the passage of the water through different rocks and soil types (e.g. limestone dissolved in water gives  $\text{Ca(OH)}_2$ , and the composition of the atmosphere).

#### 1.4 Objectives of the study.

As mentioned before, it has been known that humic substances can significantly influence the levels of colour and metals in natural waters. However, the majority of work carried out to investigate the inter-relationships between humic substances and trace metals is laboratory based. Of the small amount of such work carried out in the form of



field studies of the natural aquatic environment, relatively little has applied to upland catchment areas. Therefore the objective of this study is:

- To determine the natural levels for colour, dissolved iron, aluminium, manganese, calcium, magnesium, pH, suspended solid and other parameters in some stream waters of Longdendale Valley.

- To correlate changes observed in the colour and concentration of metals in the streams with changes in locations; this includes altitude, slope, aspect area, length of the streams, underlaying of rocks, types of soil, types of vegetation and temporal changes.

- To investigate the mechanisms which might be responsible for changing the colour of the water.

- To investigate the inter-relationships between colour, metals and other parameters, with soil moisture deficit, rain and other factors, and to determine the implications on the quality of stream waters.

- To make recommendations which may help to alleviate the problem of intermittent peaks in colour, trace metals and acidity associated with prolonged periods of seasonal changes, which may help to improve drinking water treatment under changing conditions.

## **Chapter 2.**

### **Description of the study area.**

## 2.1 History and background of Longdendale Valley.

The Longdendale Valley lies wholly in the Peak District National Park. It is an area of outstanding natural beauty situated in the south west of the Pennines. The valley is a major source of potable water for North West Water PLC (N.W.W.) which supplies most of Manchester. Sources of water include the Longdendale reservoirs at Woodhead, Torside, Rhodeswood, (total capacity 18,200 Ml supplying about 110 Ml per day to Manchester) Valehouse and Bottoms (supplying 45 Ml per day compensation water to the River Etherow). In addition, there are two smaller reservoirs, Hollingworth and Arnfield, which were constructed in the lower Longdendale Valley on the Ogden and Arnfield Brook respectively, and these were used in conjunction with those in the main valley. They are not part of the main flow system and neither of them is any longer used for public supplies. The water is transported mainly under gravity over great distances by aqueducts. The movement of water from one reservoir to another is controlled by sluices and valves which are controlled by N.W.W.

A by-pass water course, which stretches along the northern shore of the five reservoirs for their whole length, ensures some degree of safety during times of flood by enabling a substantial fraction of the flood waters to by-pass the three supplying reservoirs. Also this by-pass acts as a buffer zone in which all land drainage and minor feeder stream drainage from the northern half of the

catchment area undergo a certain amount of mixing and dilution before entering the reservoirs. The majority of this water enters Bottoms Reservoir.

The Longdendale reservoirs were designed and constructed by J.F. La Trobe Bateman from 1847-1885 from watertight earthen embankments across the valley, comprising a central vertical clay core wall or an upstream clay blanket. North West Water under the 1930 Reservoirs (Safety Provisions) Act, and the Reservoirs Act 1975, is required to increase the safety provisions of the Longdendale reservoirs to withstand the condition known as probable maximum flood (P M F). Over the last years the Water Authority and its Consulting Engineers have examined methods for achieving the level of flood protection which is required. For more information see N.W.W. (1985 and 1986).

The Longdendale Valley provides a trans-Pennine link between Manchester and Sheffield. The A628 road, the disused Manchester - Sheffield railway and a CEGB 400kw electricity transmission line also pass through the valley. The current recreational use of the valley is divided into two categories; countryside and water based recreation. This makes the valley a good location for studying land and water management. For more details see Lishman and Ringham (1988).

The water supplied from the catchment area is generally of good quality, being soft, acidic and relatively constant in most of its characteristics. It is

suitable for textiles, foodstuffs manufacturing and other industries. In its raw state water from the valley sometimes contains significant levels of aluminium, iron and manganese. It may be discoloured by the peat and can show marked turbidity (N.W.W., 1988). Also there are problems with peat erosion in the catchment area which have resulted in the loss of up to 10% of the useable storage capacity of the reservoirs due to the accumulation of eroded material.

## 2.2 Environmental changes in the Pennines and the possible impact on water quality.

Since the 1950's there have been many changes in the Pennines area such as land use changes, rainfall acidity and climatic variability. The atmospheric chemistry since 1750 has affected the uplands (Binns and Redfern, 1983). A reduction in the amount of Sphagnum moss, caused by climatic factors, has led to increased erosion (Phillips et al., 1981). The nature of the problem and possible factors affecting the water quality in the Pennines have been reviewed by (Edwards (1987), Howarth (1987), Naden and McDonald (1987)).

Edwards (1987), for instance, identified nine environmental changes in the Pennines which may have had an impact on water quality. These are:

- 1- Climate- both natural and man-induced variations
- 2- Gripping- moorland drainage for grouse or sheep

management.

- 3- Fire- controlled heather burning and more damaging accidental fires.
- 4- Grazing- the density of sheep affects the regeneration of vegetation.
- 5- Agricultural improvement- involving drainage and the application of lime and fertilizers.
- 6- Forestry- including pre-planting, land preparation and harvesting.
- 7- Recreation- footpath erosion.
- 8- Air pollution- arising from the nearby industrial belt.
- 9- Moorland restoration- revegetation of bare, eroded peat.

During the Industrial Revolution, many textile, paper and associated industries became established along the river banks in the Mersey catchment, and by the 1920's it was recognized that Etherow had the worst pollution problems in the Mersey catchment (Pearson 1939; Palmer 1950, Barber, 1969, Harding et al., 1981). At Longdendale Valley probably the anthropogenic environmental processes have a relatively stronger influence on the quality of the water at the valley.

## 2.3 The geology of Longdendale Valley.

The geology of the valley is millstone grit with bands of shale and clay overlaid with extensive beds of peat providing a catchment area of about 7770 hectares. In the millstone grits the shales are coloured uniformly

throughout, but the grits and sandstone are shown by four colours for the main groups, These are: the Rough Rock Series, the Middle Grits, the Kinderscout Grits and the Shale Grit (for more details see Bromehead et al., 1933). The "High" or "Dark" peak is a region of high hill moors and plateaux dissected by deep valleys eroded through a succession of mid-carboniferous sandstone, mudstones and shales. Figure 2.1 illustrates the predominant geology of Longdendale catchment area. The high moorland lying at heights between 250-610 m O.D. and at their borders massive beds of sandstone outcrop to form cliffs or 'Edges' that overlook and contrast sharply with the less steeply sloping valley side. Because these heavy rocks are of sandstone strata, the slopes are inherently unstable. Many forms of mass movement have occurred in Longdendale Valley ranging from superficial types such as mudslides and soil creep through to deep seated phenomena such as landslides and rockfalls.

Johnson and Walthall 1979 and Johnson 1980, 1981 and 1989, identified the distribution of the major geological formations which outcrop in this drainage basin, the mass movement land forms and the slope units of the land surfaces (see figure 2.2). As shown in the figure, the nature of the valley system was complex, in which slopes have evolved to create a variety of soil materials. In this system geomorphic processes have played a key role but their influence is strongly controlled by a climate which was glacial in the past and even today is relatively severe



NAMURIAN (MILLSTONE GRIT SERIES:

KINDERSCOUTIAN (R.)

MARSDENIAN (R<sub>1</sub>)

YEADONIAN (G.)

### PLEISTOCENE AND RECENT

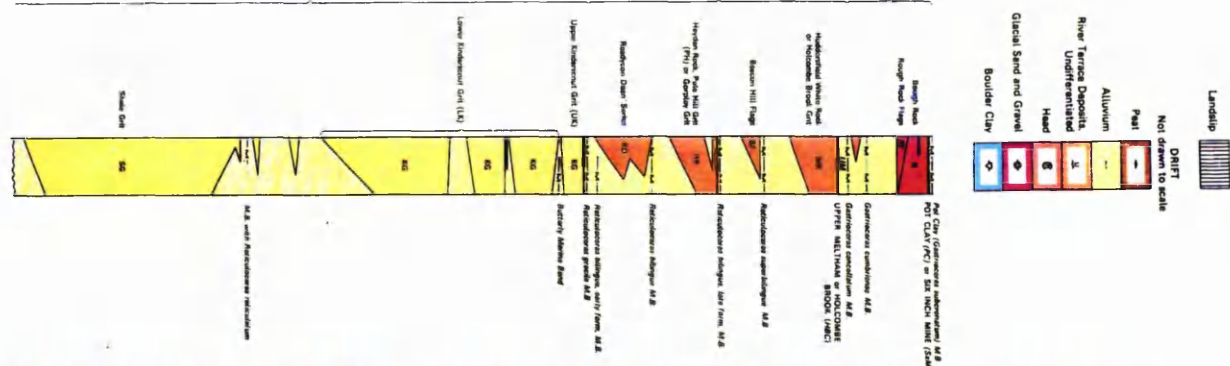
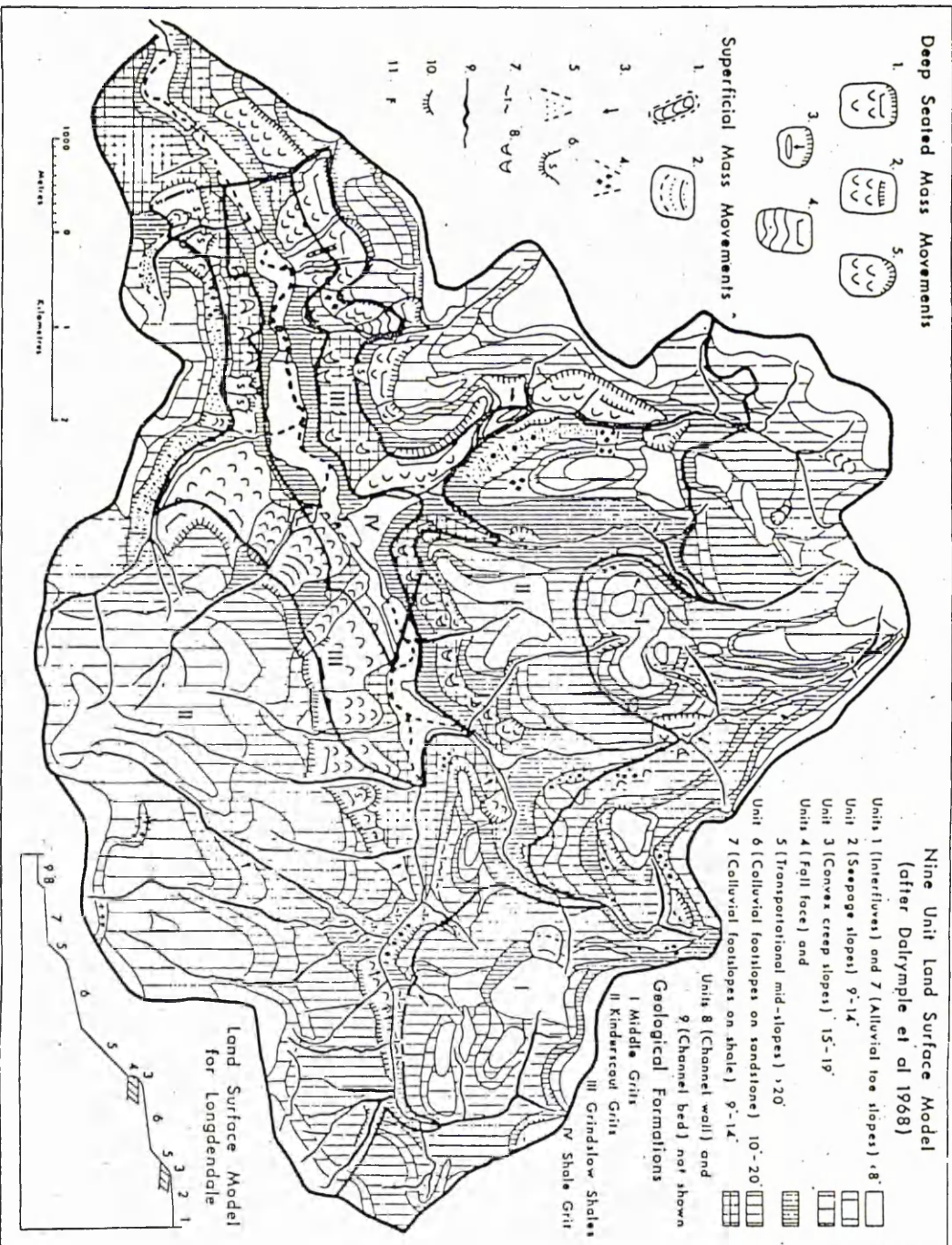


Figure 2.1 Map of the geology in Longendale catchment area (from Geological Survey of GB, 1981).



Figure 2.2 Mass movement in Longendale (by Johnson 1989).



when compared with other local areas.

The mudstones, siltstones, sandstones and shales of Namurian "upper carboniferous" were deposited during the pleistocene. They are known locally as the Shale Grit, Grindslow Shales and Kinderscout Grit series. They were deposited in a complex system of channels within a delta sited close to a continental shelf edge (Wright (1964), Collinson (1972)).

Johnson (1980 and 1981) studied the variety of rock types and the complexity of the stratigraphy and lithology in that area in detail and also the formation of the rocks. The Kinderscout Grit consists of thick leaves of sandstone separated by shales in varying thicknesses up to 190 meters. Most of the sandstones are pebbly and were deposited as fluviatile beds within a Namurian delta. The Grindslow Shales formation comprises shales and mudstone interbedded with siltstones. A variable sequence of strata of thirty to sixty metres thick was deposited as a slope association on the forward slopes of a delta. On the western and central part of the Longdendale Valley there is a marked thickening of the basal sandstone in the Kinderscout Grit formation forming a "cap rock" on the valley sides. It is more than 33 metres in thickness. Under this cap of rock the hillslopes are eroded in a thick succession of alternating beds of variable thickness and lithology. Since the degree of cohesion of the mudstones, siltstone, shales and other rocks are different, their permeability and rock strengths are different and since the

beds are only a few metres thick they provide a weakness in which sliding might start. The gradient, stability of the slopes and the composition of the rocks, provide ideal water catchment facilities, which also provide additional zones of weakness in the strata. The catchment has been exposed to a series erosion of carboniferous rocks which consist almost entirely of sandstone and shale belonging to the millstones grit formation. These rocks alternate with each other throughout the series but vary from place to place in thickness and resistance to erosion (Bromehead et al., 1933 and Johnson 1979, 1980, 1981 and 1989 described it more fully).

## 2.4 Soil, soil moisture deficit and vegetation.

Soil is the product of physical and chemical weathering processes involving rocks exposed at the surface of the earth. These biogeochemical systems constitute a highly heterogeneous mixture of organic and inorganic constituents, the proportion of which depend on the factors which influence soil formation: time, climate, topography, the biota, and parent materials (Sposito and Page, 1984).

The major soil associations overlaying the Longdendale catchment area are shown in figure 2.3. The soil associations in the figure were identified from the soil survey map (Soil survey, 1983) and were explained by Jarvis et al., (1984). Table 2.1 summarizes the description of the soil associations of the main types of soil in the Longdendale Valley, and table 2.2 describes the soil

wetness classification. As shown in figure 2.3 and table 2.1 the formation of the six main soil types which overlay the Longdendale catchment area are considerably influenced by the climate and topography. In the plateaux of the valley, high rainfall, low temperatures and flat or gently sloping sites encourage poor drainage conditions and the build up of organic matter due to the inhibition of the microorganisms responsible for mineralisation processes. This leads ultimately to the formation of peat. Consequently the majority of the upland plateaux are covered with thick layers of the Winter Hill Association which consists of raw oligo-fibrous peat soils. The potential soil moisture deficit (SMD) is often less than 40mm and the peat soils are almost permanently waterlogged being wetness class VI, as described in table 2.1. Consequently these soils do not absorb excess rainwater and run off is rapid. This can have important implications for the colour of the catchment water. Also since the class wetness of the other soils (Revidge, Belmont and Wilcocks) were between IV and VI, they are easily eroded, hence they too can have important consequences for water quality in the catchment area.

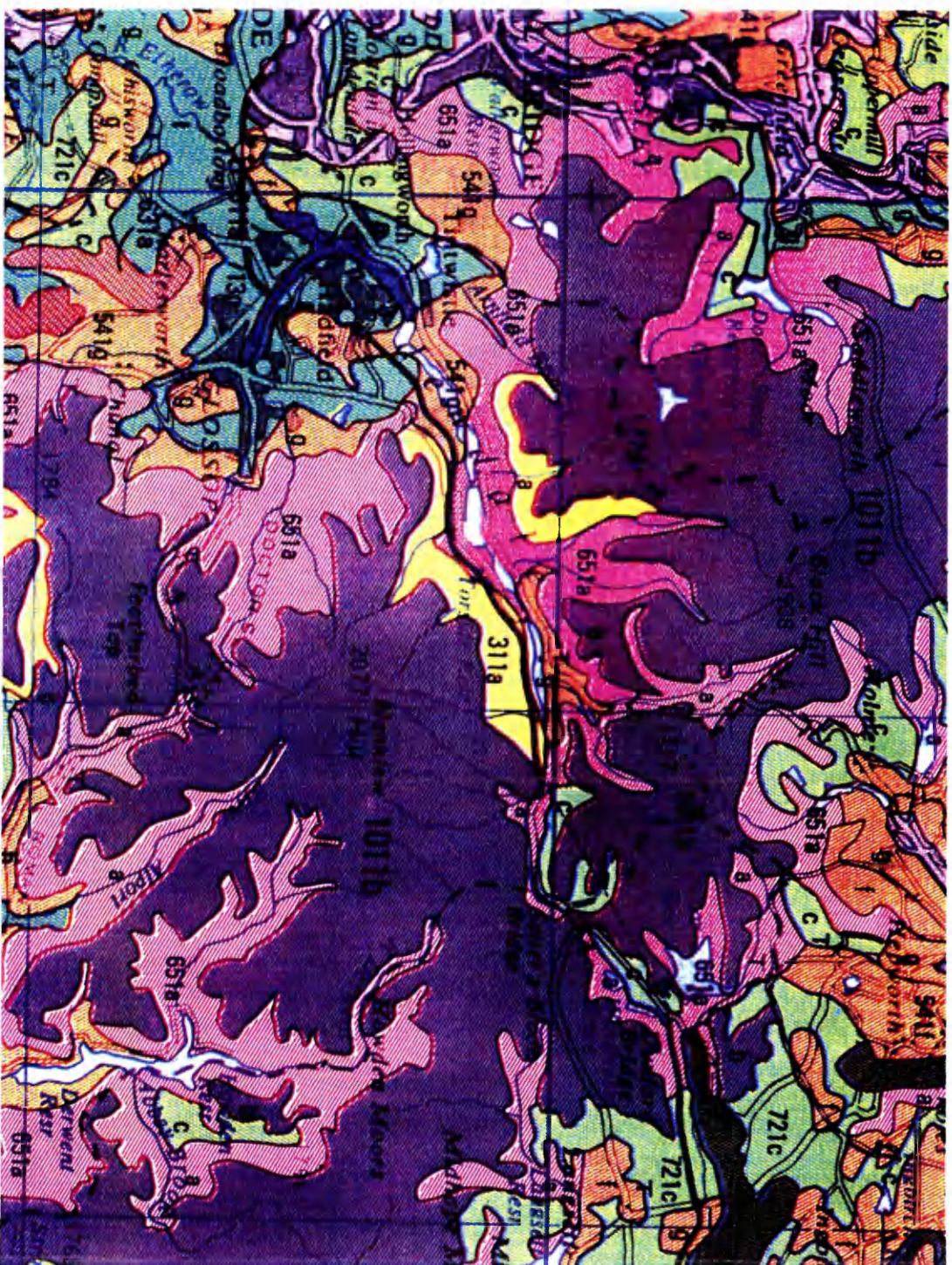
**Table 2.1 Summary of soil associations at Longdendale Valley**

(information taken from Jarvis *et al.*, (1984).

Association	Description of soil Associations	Class of wetness	Vegetation	Locations in the valley	Remarks
Winter Hill	Blanket peat, fibrous peat, amorphous peat. Thicker peat up to 6 Meter. SHD < 40 mm	VI	Mainly covered with moss and cotton-grass.	It covered most of the hill sides above 460 m O.D.	Soil does not absorb excess rain water (Rapid run-off).
Revidge	0-20 cm Dark reddish brown to black, humified peat or dark reddish brown, stone less hums sandy loam; moderate fine blocky structure. At 20 cm Hard sandstone or grit or extremely stony sand loam. SHD 40-100 mm	IV or V	Mostly covered with heather, some patches carry bog moss, purple moor grass and cotton grass.	It covered the steep slopes at the base of the valley cliffs, which stretch along the full length on the south side of the reservoirs and the western half of the north side.	Shallow, very acid, easily poached and eroded. Rapid run off and erosion after storm or heavy rain. On the steep slopes most surplus water moves laterally.
Belmont	0-15 cm Black, humified peat; weak sub angular blocky structure. 15-25 cm Greyish brown, slightly stony sandy loam; weak medium angular blocky structure. AT 25 cm thin ironpan. 25-50 cm strong brown, moderately stony sandy loam or clay loam; weak medium sub angular blocky structure. At 50 cm Hard sandstone or yellowish brown, very stony sandy loam. SHD 40-100 mm	V or VI	The predominant covering vegetation includes heather, bilberry, mat grass and wavy hair grass.	The majority of this type of soil covers the south facing slopes of the valley where the gradients are generally less than those of the north facing slopes.	Iron enriched sub-soil, rapid run off and erosion after storm or heavy rain.
Willcocks	0-20 cm Black, stoneless humified peat or humus clay loam. 20-50 cm Light brownish grey, mottled, slightly stony clay loam or sandy clay loam; weak sub-angular blocky structure. 50-100 cm Grey with many ochreous mottles, moderately stony clay loam; weak medium blocky or prismatic structure; high packing density. SHD 40-60 mm	V or VI	Most of this soil under moorland dominated by heather, purple moor grass, mat grass. With cotton grass, heath rush and bog moss on the wetter ground.	It covers a gently sloping site at the extreme upper end of Longdendale Valley.	Large available water capacity, are not susceptible to summer drought; rapid run off, stony soil in greyish drift derived from carboniferous and lower palaeozoic rocks. Also an acid organic surface layer 10-40 cm thick, it usually fines winter hill peat.
Rivington	0-20 cm Dark greyish brown, slightly stony sandy loam or sandy silt loam. 20-50 cm yellowish brown, slightly or moderately stony sandy loam or sandy silt loam; weak medium sub angular blocky structure. At 50 cm Hard or soft sandstone or extremely stony sandy loam.	I	Most of this soil is covered with grassland; particularly the common bent, mat grass and wavy hair grass.	On the gently sloping foot hills stretching along the full length of the northern shores of woodland Reservoir, and also on the lowland on either side of bottoms and Valehouse Reservoirs at the western end of the Longdendale valley.	These soils predominantly Carboniferous, it is well drained, susceptible to poaching or erosion. The winter rain water generally passes rapidly down words through the permeable subsoil.
Brickfield	Greyish subsoil, contains mainly loamy and clayey surface-water grey soils derived from sand stones and shales.	IV	These soils are mostly grassland with the common bent.	It occurs on a small area of land at the extreme lower end of Longdendale Valley.	They are waterlogged for long periods in winter.



Figure 2.3 Map of the soil association in Longendale catchment area (from Soil Survey of England & Wales, 1983).



**Table 2.2 Soil wetness classification** (From Jarvis et al., 1984)

Wetness Class	Duration of Waterlogging
I	The soil is not waterlogged within 70 cm depth for more than 30 days in most years.
II	The soil profile is water-logged within 70 cm depth for 30-90 days in most years.
III	The soil profile is water-logged within 70 cm depth for 90-180 days in most years.
IV	The soil profile is water-logged within 70 cm depth for 180 days, but not waterlogged within 40 cm for more than 180 days in most years.
V	The soil profile is water-logged within 40 cm depth for 180-335 days, and is usually waterlogged within 70 cm for more than 335 days in most years.
VI	The soil profile is water-logged within 40 cm depth for more than 335 days in most years.

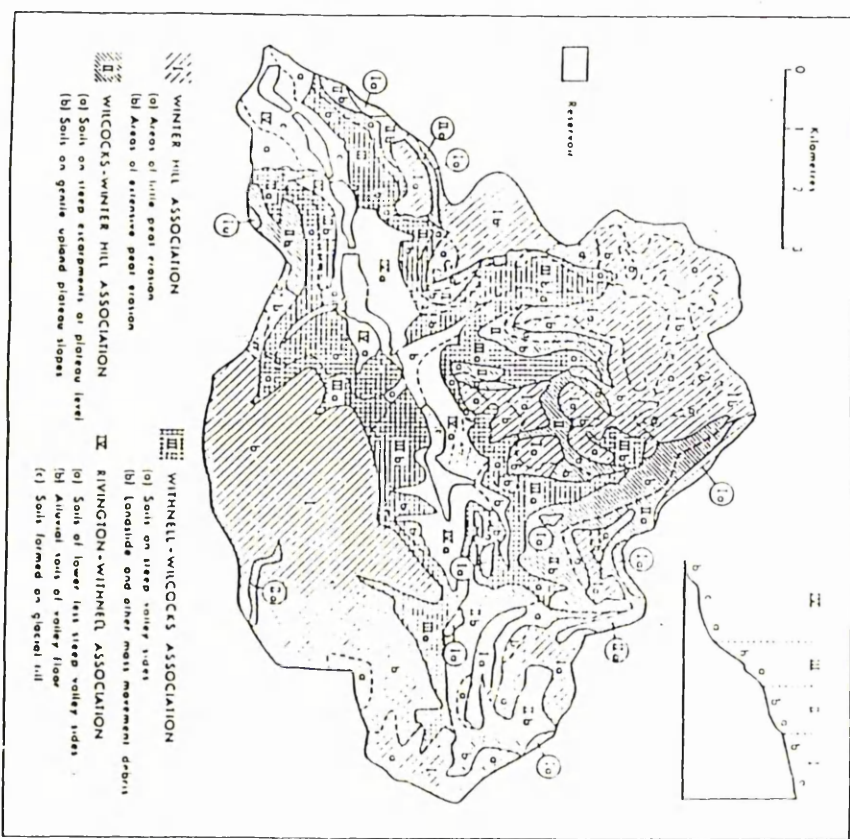
("In most years" is defined as more than 10 out of 20 years.)

Johnson (1981 and 1989) also studied the soil of the catchment area of Longdendale Valley by using aerial photographs. The associations were similar in character to others identified by the soil survey in East Lancashire and West Yorkshire. He identified four major physiographic elements. These are: the plateau summit areas, which are covered by moorland and peat-bog vegetation, the intermediate upland plateaux which are located above the steep valley sides and backed by steep escarpments that rise to the upper plateau summits, the steep valley sides which are often disturbed by land slippage, and the lower valley slopes and floor upon which there has taken place some land improvement work for permanent pasture and forestry (see figure 2.4).

Aerial photographs have been traditionally used in soil surveys for soil-boundary detection, land form analyses and visual perception of tonal qualities associated with the spatial variation of soils. Resource managers require rapid and accurate methods for acquiring and interpreting data for the development and management of our natural resources. A case in point would be the use of high-resolution aerial photography to generate maps for regional planning. It may take several months to obtain a coverage over a large area. It may then take several years to analyse the photographs, employing standard photographic interpretation techniques, and to produce a final product going through all the steps in the cartographic production process. When the product has been published, the utility



Figure 2.4 Soil association map for Longendale Valley (by Johnson 1981).



of the information portrayed can be questionable, particularly in areas experiencing rapid changes.

Landsat data have recently been shown to be most useful for generalized soil and land-system surveys. The application of landsat data to soil investigation has progressed beyond the research stage to its use in extensive soil surveys. Yet remote sensing technology offers numerous advantages over traditional methods of conducting soil surveys. Myers (1983) revealed some advantages of remote sensing such as, the potential for accelerated surveys; the capability of achieving a brief view under relatively uniform lighting conditions; availability of multi-spectral data providing increased information; capability of repetitive coverage to depict seasonal and long-term changes; the relatively low cost of monitoring from space; the opportunity of integrating existing surveys into an updated monitoring system; the change detection capabilities needed by regulatory programs for updating information on vegetation/terrain conditions; availability of imagery with minimum distortion, thereby permitting direct measurement of important agrophysical parameters; and also the fact that remotely sensed data provide a permanent record.

Specific resources and conditions can be monitored to include soils, vegetation, land use, erosion, soil moisture, high water table, salinity, and desertification. Moore and Myers (1977) outlined examples of remote sensing users on various levels ranging from global users to

the individual farmer. Each of these levels of users has unique requirement that affect the dissemination of information.

Hydrologic remote sensing is defined as the study of the earth's water resources by the use of electro magnetic radiation (E M R) which is either reflected or emitted from its surface in wavelengths ranging from 0.3 micrometers to 3 meters. Within this wavelength interval, most remote-sensing instruments record spatial variations in (E M R) coming from the earth's surface in different spectral bands (Salomonson, 1983).

Remote sensing of the earth's resources utilizes electromagnetic energy which ranges from short wavelength ultraviolet through visible, near infrared, and thermal infrared, to longer wavelength active radar and passive microwave systems. All of these wavelengths are applicable to and useful for agricultural remote sensing. Soils often can be distinguished from one another by their photographic tone and/or colour characteristics - factors which derive from properties of the soil materials themselves. In addition electromagnetic radiation can be sensed by detectors that respond in spectral regions beyond those discernible by the human eye-specifically in the ultraviolet, infrared and microwave regions (Myers, 1983).

Obukhov and Orlov (1964) found that all of the soils that they investigated had spectral reflectance characteristics related to soil colour. Minimum reflectance occurred in the blue-violet portion of the spectrum and

ranged from 13% for the A horizon of thick chernozem to 18% for the same horizon of sod-podzolic soils. Maximum reflectance was in the red region of the spectrum where the reflection coefficient of the same samples increased from 15% to 44%. Accurate classification of soils depends on many indirect as well as direct observations. Indirect factors may often be observed more easily from space or aircraft imagery than from ground observations because of the brief view it provides. Therefore, mapping of soils on an appropriate level of detail is vital for water management. However, variability of soil characteristics observed by remote sensors also results in confusion when observing and classifying the range of vegetation. The orderly study of soil and vegetation together in the context of remote sensing interpretations is rapidly solving many of the difficulties that were experienced earlier. Myers (1983), revealed some difficulties in measuring the reflectance from soils under natural field conditions. These are:

- 1-  $O_2$  and  $CO_2$  and water vapour absorption reduce incoming solar radiation in certain wavelength bands.

- 2- Illumination from the sun varies in intensity with atmospheric conditions and solar radiation.

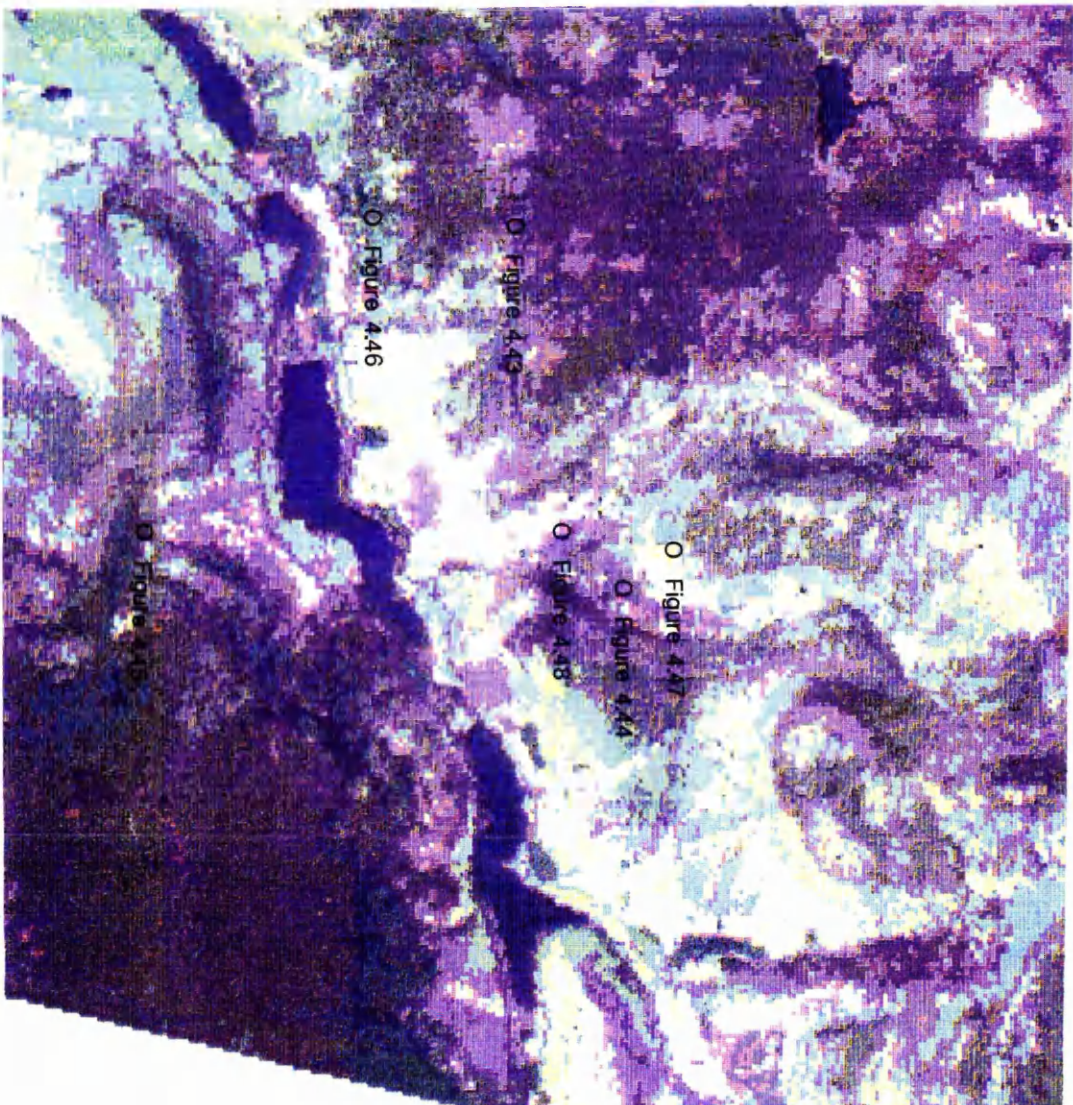
- 3- Radiance from soils is affected by soil structure and other factors.

- 4- The intensity of the spectrum of the sun peaks at about  $0.5 \mu m$  falling off rapidly at shorter and longer wavelengths.

Although the peat is detectable with conventional aerial photographs, the landsat imagery provides essential new data for their interpretation. A complete picture of classifications of the peatland vegetation in Longdendale Valley is illustrated in figure 2.5 through the remote sensing of the types of vegetation at the valley; this imagery was produced by Salford University from a landsat image produced during May 1988. Correlation between in-situ observation and remote sense data are illustrated in section 4.15.

During low rainfall and high temperature, soils lose more moisture by evaporation and transpiration and this leads to soil moisture deficit (SMD). Soil moisture deficit has been defined as "the amount of water which needs to be added to bring back the original soil capacity, whatever the absolute value of such a state as field capacity may be" (H.M.S.O, 1967). During the cold season of late autumn, winter and early spring the rainfall is considerably in excess of the moisture loss from the soil by evaporation and transpiration. This net gain of moisture to the soil replaces that which has been extracted during the previous growing season and the surplus is either drained away into the streams or penetrates deeply into the soil to replenish underground storage. In areas such as the British Isles, in most years the soil contains its maximum quantity of water at the end of the cold period. Thereafter the rate of the moisture loss from the soil to the atmosphere can, and often does, exceed the rate of replacement by rainfall

Figure 2.5 Classification of the peatland vegetation in Longendendale valley using landsat image (produced by Salford University during May 1988).



- Reservoir.
- Peat (Type I).
- Peat (Type II).
- An area of extensive peat erosion (red spot).
- Trees or forest area.
- Bare rock, with little or no vegetation present.



during the months of the summer.

McDonald et al. (1987) have shown that the soil/peat moisture deficit could be an important driving force of colour generation. This moisture deficit can lead to a build up of readily soluble, coloured material arising from the decomposition of vegetative matter, which will then be leached out into the catchment waters following the replenishment of the deficit by rainfall. Moisture in the upper layers of the soil profile is an important portion of the total water balance of the earth-atmosphere system and is an important parameter in many disciplines related to hydrology such as weather, climate and agriculture. In hydrology, the moisture content of the soil is important for partitioning rainfall into its run off and infiltration components. The use and application of remotely sensed data for soil-moisture determination is still very much under development, there have been many reviews of the status of remote sensing for soil moisture over past years, some helpful and representative examples are those by Schumgge (1978), Schumgge et al. (1978).

In summary, the most important characteristics of the valley soil, from the point of view of this research, is their high organic content, their high susceptibility to erosion, their thickness, their moisture deficit and their high degree of acidity.

## 2.5 Climate and land use at Longdendale Valley.

The annual mean rainfall in the valley is very high, being between 1500-1650 mm, and generally increases progressively moving up the valley. The mean temperature in the lowlands is about 15.6 °C in summer and 2.8 °C in winter, the temperatures in winter being slightly below the average for central England. The climate in the Longdendale catchment area imposes severe limitations on the land use. The length of the growing season depends on location and altitude and is as little as 180 days at 600 m and 220 days at 180 m (M.A.F.F., 1968). Most of the upland areas in the catchment are classified as grade 5, and meadowland as 4. These land grades are poor due mainly to the climate.

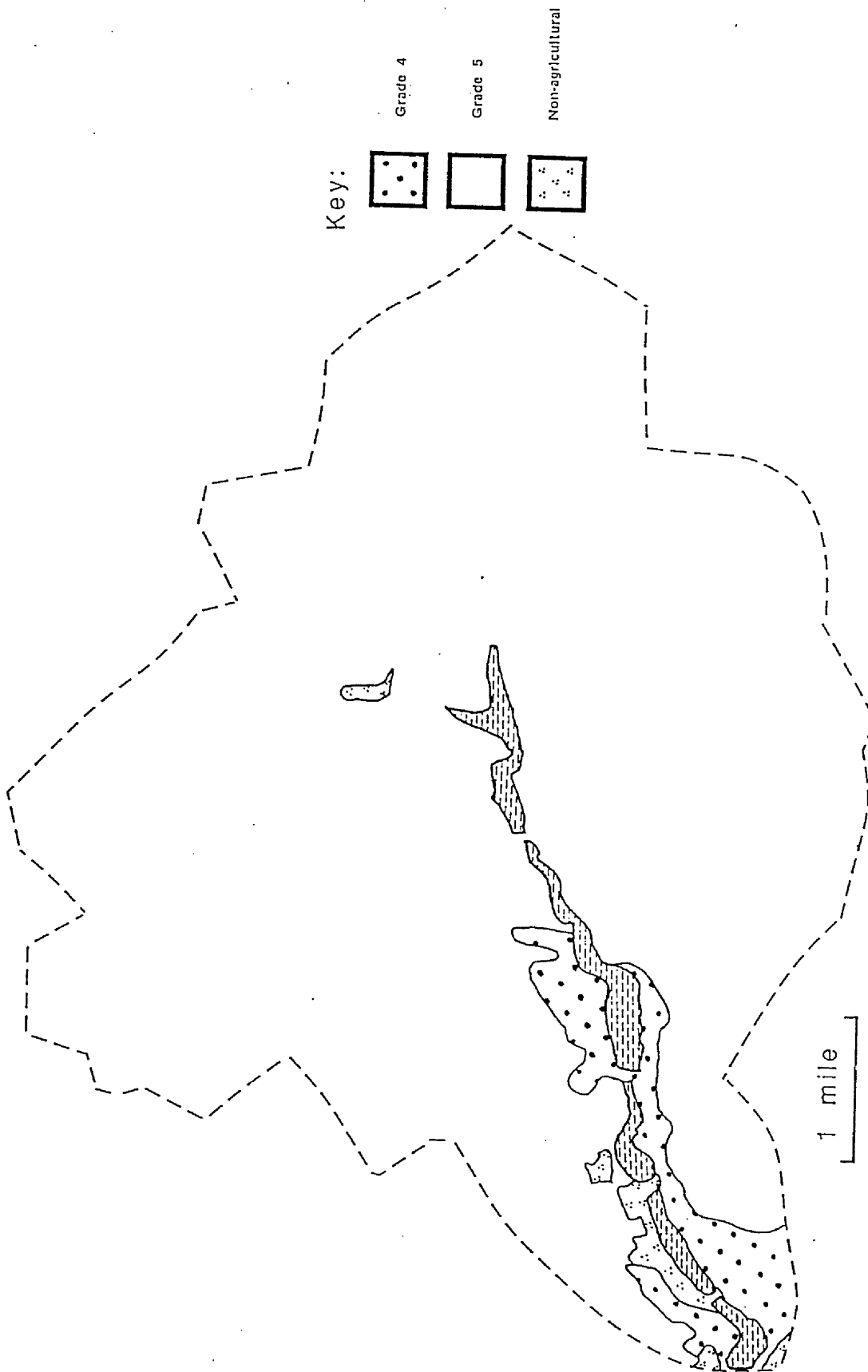
Figure 2.6 and Table 2.3 illustrate the agricultural land classification grades in the Longdendale Valley. At the present time the N.W.W. owns most of the valley land and a large part of the moorland catchment area. The Authority owns a total of 14 farms, with 4 parcels of land let for grazing and/or mowing on annual licences. An estate of 3.500 acres around Shining Clough Moss, south and south east of Woodhead reservoir, is in private ownership. (N.W.W., 1986).



**Table 2.3 Agricultural Land Classification** (From M.A.F.F., 1968)

<b>Grade</b>	<b>Degree of limitation to agricultural use due to adverse soil, relief or climate or a combination.</b>
<b>1</b>	<b>Very minor or none</b>
<b>2</b>	<b>Minor</b>
<b>3</b>	<b>Moderate</b>
<b>4</b>	<b>Severe</b>
<b>5</b>	<b>Very Severe</b>

Figure 2.6 Map showing the M.A.F.F. agricultural land classification of Longendale Valley (from M.A.F.F., 1967).



## 2.6 Description of sampling sites.

The feeder streams were chosen with respect to the drainage area, with regard to soil types, vegetation, geology, altitude and their locations. The accessibility was also considered. Since the water quality of the streams varies from place to place within the valley, the sampling location will rarely be a fair representation of the stream. Initially it had been decided to select a small number of representative feeder streams; each stream chosen with regard to its drainage area.

Figures 2.7 and 2.8 and tables 2.4 and 2.5. show the location of each of the sampling sites. The altitude, types of soil, vegetation and geology of each stream are also illustrated. It can be seen that each is different from the other - either in the type of soil, the geology of the drainage area or other physical or topography difference. All streams drain from an area covered with peat (Winter Hill Association) except Ogden Clough. The peat layers at Coombes Clough and Torside Clough were thicker (>60 cm), highly susceptible to the risk of erosion and the plateaux were flat or gently sloping while in the other streams the peat was thinner (<60 cm), less susceptible to the risk of erosion and the plateaux were steadily sloping; the steep slopes were gullies (classification of vegetation are given in section 4.15). Longside Clough was the only stream which drained land covered with the Wilcocks Association, and the geology of the stream mainly consisted of the Readycon Dean Series (RD); which is a development of sandstone, tilestone

Figure 2.7 Map showing location of (A) the Longendale Valley in the British Isles and (B) the drainage area of the sampling site.

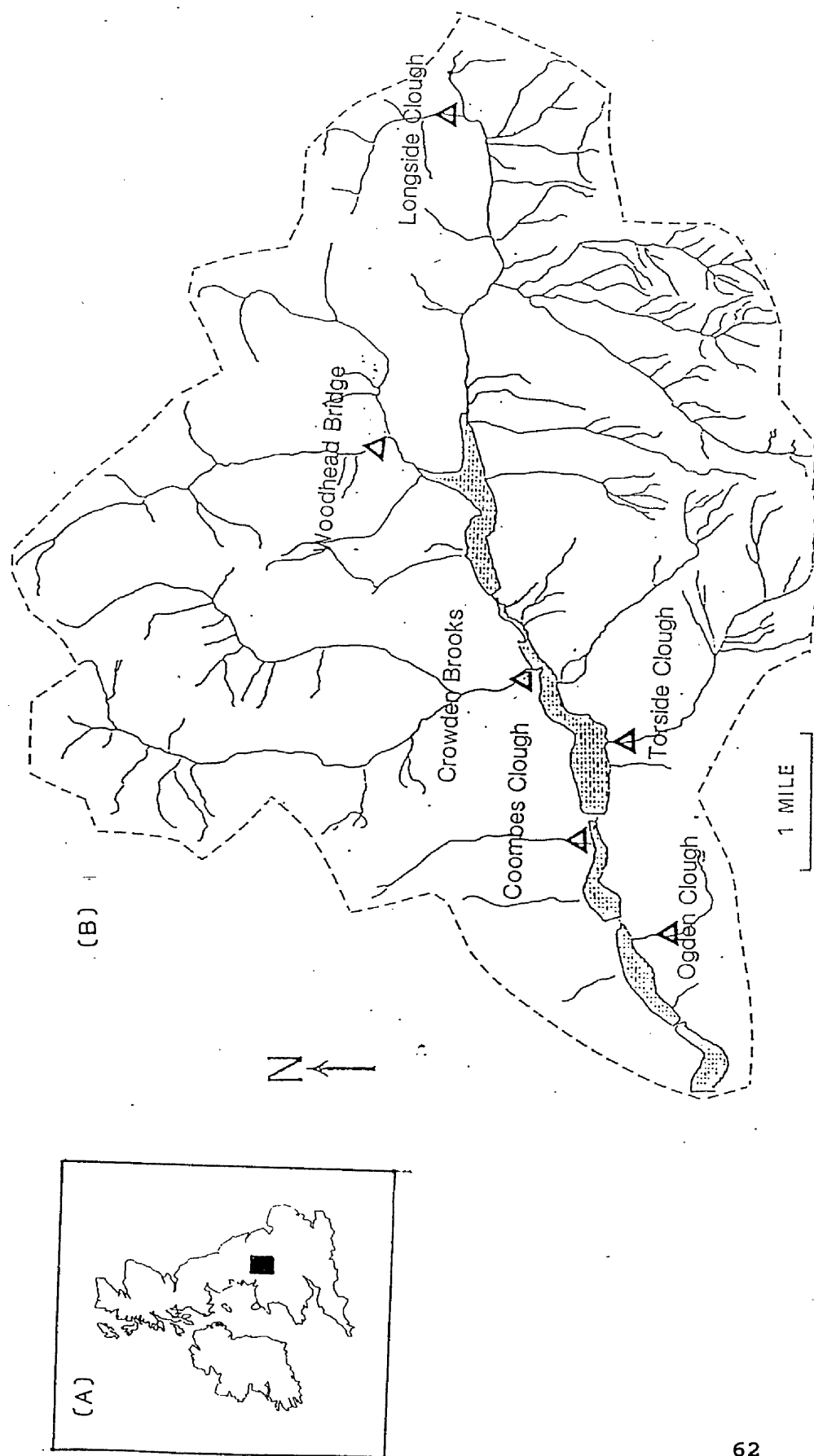
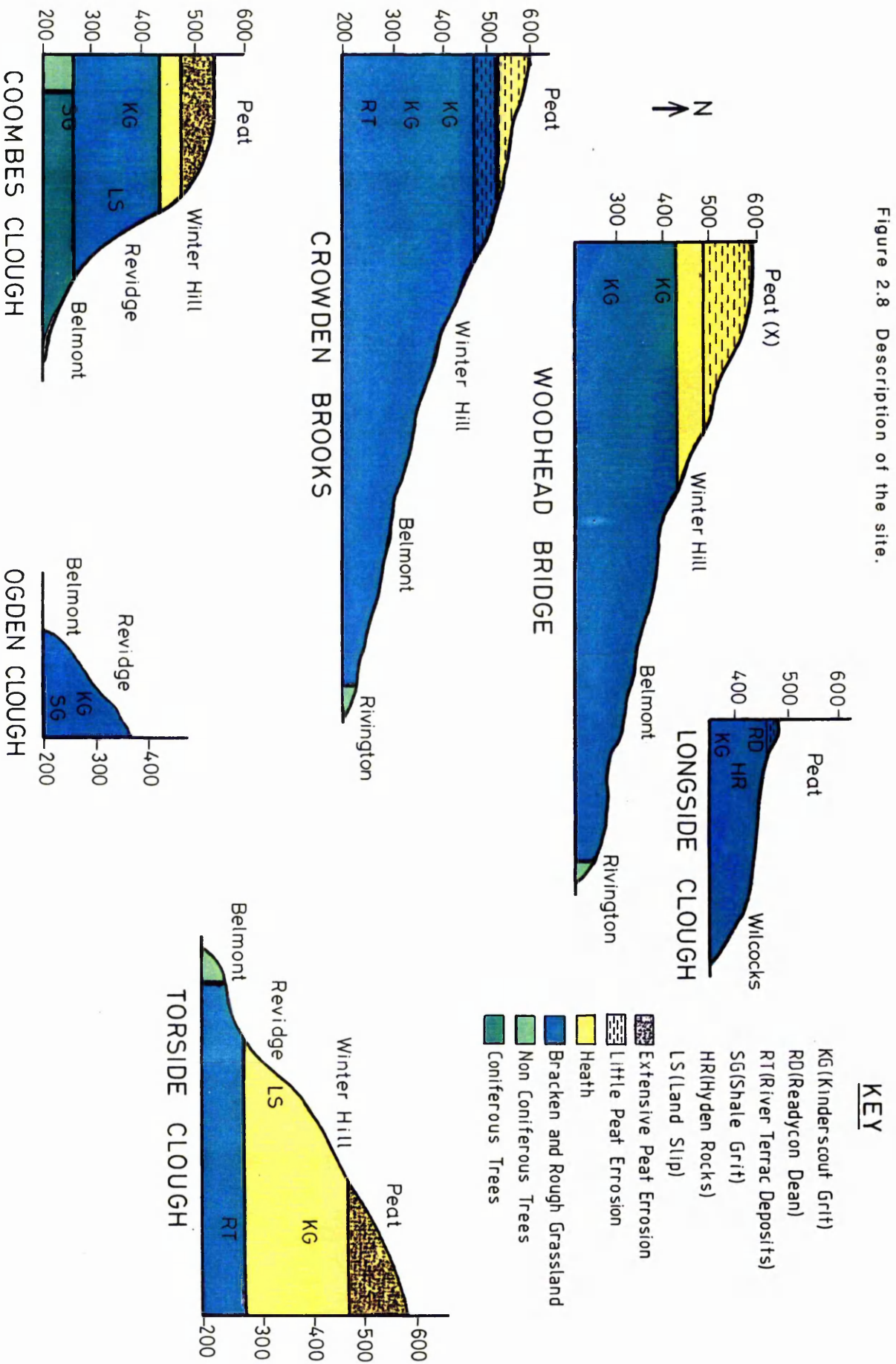


Figure 2.8 Description of the site.



and flags with interbedded shale and occasional ganister and fireclay beds (up 300 ft. in thickness), the Heyden Rock (HR); which is a well-developed bed of grit or sandstone (60 to over 100 ft. thick), and Kinderscout Grit (KG); which consists of coarse, massive grit with a number of thin shale partings (400-800 ft. thick). Bromehead et al. (1933) explain the types of rocks more fully and Pettijohn (1975) illustrates the distribution of element in the shale and various types of sandstone (see table 2.6). As the table shows silicate, aluminium, iron, magnesium and calcium are the major composition components of these rocks.

As figure 2.8 shows, major soil associations overlaying Coombes Clough, Torside Clough and Ogden Clough were the same except that there was no peat covering the uplands of the stream (Ogden Clough) as mentioned before. The geology of the areas was the same except in the lower part of Torside Clough there were layers of River Terrace Deposits (RT), and there were landslip at Coombes Clough and Torside but not at Ogden Clough. Also the figure shows the major soil association overlaying Crowden Brook and Woodhead Bridge were the same (Winter Hill, Belmont and Rivington Associations), also the geology of the streams was almost the same except in the lower part of Crowden Brook where there were layers of River Terrace Deposits (RT). The largest catchment area and the highest altitudes were at Crowden Brook and Woodhead Clough while the smallest and the lowest altitudes were at Ogden Clough. As

shown in table 2.5 the main types of vegetation covering the streams were bracken, rough grassland and heath. Table 2.5 and figure 2.8 also show that there were quite large forest area at the lower part of Coombes Clough, consisting of coniferous and non coniferous trees, with some non coniferous trees at Crowden Brook and Torside Clough. This variation in the type of soil, vegetation, gradient and the geology of the streams may have important consequences for the water quality of each stream.

**Table 2.4 Location of sampling Sites.**

<b>Stream name</b>	<b>Grid reference</b>
<b>Coombes Clough</b>	<b>Sk 053 988</b>
<b>Crowden Brook</b>	<b>SK 072 992</b>
<b>Woodhead Bridge</b>	<b>SE 098 009</b>
<b>Longside Clough</b>	<b>SK 139 998</b>
<b>Torside Clough</b>	<b>SK 064 981</b>
<b>Ogden Clough</b>	<b>SK 042 978</b>

**Table 2.5 The gradient, length of stream and the vegetation types at the sampling sites.**

O.D.	Coombes Clough		Crowden Brook		Woodhead Bridge		Longside Clough		Torside Clough		Ogden Clough	
	Length	Veg.	Length	Veg.	Length	Veg.	Length	Veg.	Length	Veg.	Length	Veg.
550-600	-	-	300	BR & H	650	BR & H	-	-	400	H	-	-
500-550	1000	H	900	BR & H	350	BR & H	-	-	420	H	-	-
450-500	300	BR & H	700	BR	750	BR & H	250	BR	450	H	-	-
400-450	150	BR	500	BR	600	BR & H	1150	BR	450	H	-	-
350-400	300	BR	800	BR	1200	BR	520	BR	280	H	200	BR
300-350	200	BR, C	800	BR	950	BR	-	-	300	H	250	BR
250-300	300	BR	1200	BR, N-C	1100	BR, C	-	-	450	BR, some N-C	250	BR
200-250	650	BR, C & N-C	900	BR, N-C	-	-	-	-	750	BR, N-C	350	BR
Gradient	215-540 m	O.D	205-590 m	O.D	266-523 m	O.D	391-496 m	O.D	230-600 m	O.D	262-386 m	O.D
Approx length	2.9 Km		6.1 Km		5.6 Km		1.92 km		3.5 Km		1.05 Km	
* Erosion	Little & extensive		Little *		Little		Little		extensive		NO erosion	

BR = Bracken & Rough grassland

H = Heath

C = Coniferous trees

N-C = Non coniferous trees

Length = Metres.

Km = Kilometres.

O.D = above sea level.

\* (Johnson 1981).



**Table 2.6 Chemical composition of average Shale and major Sandstone types. (Data from Pettijohn 1975, Tables 7-3 and 8-7).**

	Average Shale (%)	Ortho-quartzite (%)	Graywacke (%)	Arkose (%)
SiO <sub>2</sub>	58.1	95.4	66.7	77.1
Al <sub>2</sub> O <sub>3</sub>	15.4	1.1	13.5	8.7
Fe <sub>2</sub> O <sub>3</sub>	4.0	0.4	1.6	1.5
FeO	2.5	0.2	3.5	0.7
MnO	-	-	0.1	0.2
MgO	2.4	0.1	2.1	0.5
CaO	3.1	1.6	2.5	2.7
Na <sub>2</sub> O	1.3	0.1	2.9	1.5
K <sub>2</sub> O	3.2	0.2	2.0	2.8
CO <sub>2</sub>	2.6	1.1	1.2	2.8
C	0.8	-	0.1	-
H <sub>2</sub> O	5.0	0.3	3.0	0.9

**Chapter 3**  
**Method of study.**

### **3.1 Time and frequency of sampling.**

The aim of the present study was to determine the factors which may affect the change in the levels of colour and metals in water with particular reference to the Longdendale Valley. These changes in levels vary from place to place due to the nature and extent of spatial heterogeneity and also with time.

The changes in the parameters were studied as follows:

- 1- Differences between streams in the valley.
- 2- Changes within individual streams with time.
- 3- Overall changes in the valley water as seen by the treatment works.
- 4- The change in controlled laboratory conditions and in field experiments.

As weather conditions eg. rainfall and dry spells, could be important to frequency of sampling was, to a certain extent, governed by weather events like storms, length of dry spell .. etc.

### **3.2 Water and soil analyses of field samples.**

A range of physical and chemical analyses were carried out on water samples collected from different streams with a view to explaining the changes in the quality of stream waters. Laboratory analyses of the stream water included colour, pH, iron, manganese, aluminium, magnesium, calcium and suspended solids. Organic carbon and some metals in the soil (iron, manganese, aluminium, magnesium and calcium)

were also analysed.

The measurements of soil moisture deficit, rainfall and air temperatures were obtained from the Meteorological Office. Also the North West Water Authority provided the measurement of colour and other water quality parameters, which might be associated with changing levels in colour (e.g pH, turbidity, iron, manganese, aluminium and water temperatures) for the raw waters arriving at Arnfield water treatment plant.

### **3.3 Materials and methods.**

#### **3.3.1 Preparation of glassware and other apparatus.**

In order to avoid contamination all apparatus (1 litre polyethylene sampling bottles, 25 ml screw capped polyethylene bottles and other laboratory glassware) with which the water samples came into contact were cleaned according to the following procedure:

- 1- Washed with laboratory detergent and rinsed with tap water.
- 2- Soaked in 20 % nitric acid "Analar, B.D.H. grade" for at least 24 hours.
- 3- Rinsed 3-5 times with double-distilled water.
- 4- Finally oven dried at 50 °C. and stored covered until needed.

For the apparatus which used to collect and filter the water sample for colour measurement, such as polyethylene sampling bottles and filter holders were previously cleaned with dilute chromic acid before the above procedure was

followed.

### 3.3.2 Water and soil collection and storage.

Six water samples were collected in one litre polyethylene bottles. Three of them were acidified with 3 ml of 50% v/v hydrochloric acid ("Aristar" B.D.H grade); to minimize both the absorption of trace metals onto the walls of the bottle and the precipitation of any trace metal compound out of the solution. The other three were untreated.

The water samples were collected just below the surface of the stream waters and the container was completely filled. Samples were stored in the dark and at a controlled temperature of 4 °c in a refrigerated room immediately upon arrival at the laboratory. The filtration, measurement of pH and colour were carried out in the laboratory the same day as sampling. Trace metal analyses were carried out within a period of 3-5 days of the sampling date.

### 3.3.3 Water sampling preparation for analysis.

#### 3.3.3.1 The dissolved and suspended solid in water.

Trace metals and other chemicals may exist either as dissolved or particulate matter in water. The two categories are not clear cut, however, and difficulties can arise in differentiating whether some compounds are dissolved or colloidal. The distinction between dissolved or particulate was operationally defined first by Goldberg et al. (1952). Nowadays the widely accepted pore size cut-off is 0.45  $\mu\text{m}$  (Dannielsson, 1982; Mora and Harrison,

1983).

In the present study 0.8  $\mu\text{m}$  membrane filters (millipore, 47 mm) were used. Initially, water samples were directly filtered through a 0.45  $\mu\text{m}$  membrane filter under partial vacuum. For a 500 ml sample it took 1-2 hours which 1 litre sample took more than 5 hours. Obviously this is too slow for routine filtration. Therefore 0.8  $\mu\text{m}$  membrane filters were chosen to speed up the filtration processes. Glass fibre filter papers were not used for filtration; as they may contain 5.9% ferric oxide and 3.9% of zinc oxide (Whatman glass microfibre filter paper, publication 603L, 1979) and therefore contaminate samples. The measurement of suspended solids was determined as follows:

- 1- 20-30 pads of 0.8  $\mu\text{m}$  membrane filters were separately soaked in 10% HCl for at least 12 hr, rinsed thoroughly with double-distilled water and dried at 50°C for two days, then kept in a desiccator.
- 2- The filter was then weighed and one litre or a suitable known volume of water sample (non acidified) was filtered under partial vacuum, using a millipore filter holder (Pyrex).
- 3- The filtered water sample was used for colour measurement and the filter paper was then dried at 50°C for two days.
- 4- The difference in weight before and after filtration gave the total suspended solids in water, the concentration was calculated as follows:

$$\text{Suspended Solid (S.S)} = F1 - F2 / V \times 1000 = \text{mg/l.}$$

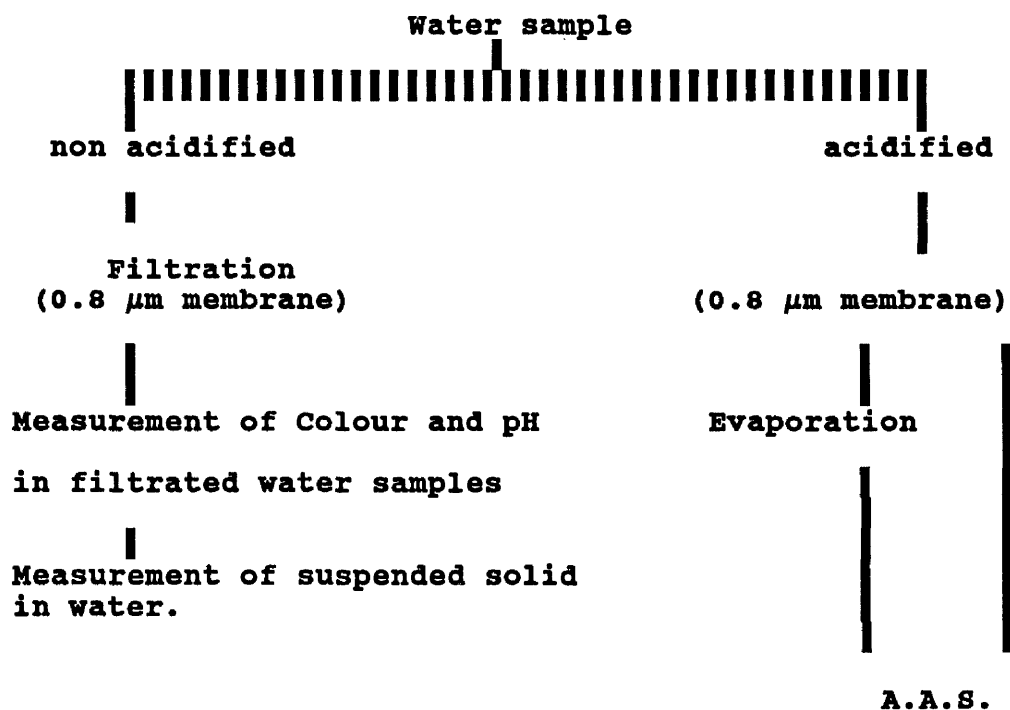
where F1 = initial mass of filter pad prior to  
filtration in grammes (g).

F2 = final mass of filter pad after  
filtration in g.

V = volume of sample filtered in ml.

The overall treatment and preconcentration  
methods/techniques are summarised in figure 3.1.

Figure 3.1 Water sample treatment and analytical scheme.



### 3.3.3.2 Evaporation.

When levels of manganese were too low for detection  
evaporation was used to concentrate the sample. 100 ml of  
the sample was transferred to a weighed dish and placed  
over a water bath and evaporated to dryness, cooled and the

dish wall was rinsed thoroughly with about 6 ml concentrated HNO<sub>3</sub>. The residues were made up to 10 ml with double-distilled water, and the metals recovered were analysed by Atomic Absorption Spectrophotometry (AAS).

#### 3.3.3.3 Metal concentration in the suspended solid.

The 0.8  $\mu$ m membrane filter papers with the suspended solid were acid digested (concentrated HNO<sub>3</sub>), for 3 1/2 hrs., and then analysed for metal concentrations using the AAS (Fe, Mn, Al, Ca, and Mg).

### 3.4 Sample preparation for analysis of trace metals in soil.

#### 3.4.1 The preparation of the soil.

All soil were dried in a clean acid wash beaker in the oven at 40 °C for two days before it kept in a polyethylene bag.

#### 3.4.2 Organic carbon content in the soil.

In order to investigate the correlation between the organic carbon and trace metal content in the soil the loss on ignition method was used for estimating the organic matter present. Allen (1974) and others have found that for a wide range of soils satisfactory results can be obtained for organic content by heating the sample to 450 °C and measuring the loss on ignition. In the present study, the soils were ignited at 450 °C in a muffle furnace for approximately 3 1/2 hrs. 1 g dried samples were transferred to a weighed dish and placed in a muffle furnace, the temperature was increased slowly to 450 °C and held for approximately 3 1/2 hrs. Then the sample was cooled and



weighed. The weight difference before and after the ignition was taken as ignition loss and used as estimate of organic matter present.

#### 3.4.3 Soil digestion.

0.5 or 1 gram of the dried soil from each sample "site" were placed into a 50 ml Kieldahl flask, 10 ml of HNO<sub>3</sub> was added to each flask and heated for approximately 3 1/2 hrs until the solution was clear. The digests were allowed to cool down. Then the solutions were filtered through GF/A grade Whatman filter paper and then made up to 10 ml in a volumetric flask with double-distilled water. The filtrate was transferred into small plastic bottles, and analysed as soon as possible.

### 3.5 Measurement of the parameters.

#### 3.5.1 Colour measurement.

The procedures which are used to measure colour can be divided into two; visual or instrumental. Visual methods use coloured solution or coloured glasses matched to the solutions, with which the sample is compared. Instrumental methods mainly use calibrated glasses of red, yellow and blue colours with which an exact match of any colour may be obtained.

A wide variety of different methods of colour measurement have been used in the past and present. This makes it difficult to interpret the trends in the past and compare the results between localities. It is therefore recognized by many of those in the water industry that

there is a strong need to adopt a standard method for measurement of colour in water, rather than the range of "Apparent", "Hazen" and "True" units currently used (Buckley et al, 1987).

The most favoured internationally accepted method is the C.I.E. (International Commission on Illumination) 1976 ( $1^*a^*b$ ) method, usually written "CIELAB" (H.M.S.O., 1988a), and for this reason it was the method used in the present study. The principle of this method is based on the fact that every colour irrespective of the material, can be quantified by the "Tristimulus Values" X,Y and Z, as defined by the C.I.E. These values are based on the amounts of monochromatic red, green and blue light which when mixed together would match the colour. These XYZ values can then be transformed into  $1^*a^*b$  values which define a uniform three dimensional "colour space", CIELAB, in which the distance between any two points is linearly related to the perceived difference in colour between the corresponding samples.

Colour was analysed using a Pye-Unicam visible/UV spectrophotometer, model SP8-100. The procedure of the measurement was:

- 1- The device was calibrated for the transmittance measurements according to the manufacturers instructions.
- 2- Two cuvettes, A and B, each of optical path length 1 cm (silicate), were filled with double-distilled water. They were then placed in the respective cuvette

holders in the spectrophotometer.

- 3- The transmittance values, on a scale 0.00-1.00, were recorded from 360 to 780 nm at intervals of 20 nm.
- 4- Cuvette B was removed from the device, emptied and rinsed three times with the filtered water sample before the final filling with the filtered water samples obtained during suspended solids analysis. (See 2.12). The cuvette was then replaced in the spectrophotometer alongside cuvette A which still contained double-distilled water.
- 5- Step 3 was repeated to measure the transmittance value.
- 6- Spreadsheet (lotus 1-2-3) were used to calculate the CIELAB \*E units according to the method. \*E value were converted to the equivalent colour Hazen unit (HU), to allow a comparison with water colour data from other studies.

### 3.5.2 pH measurement.

The determination of hydrogen ion content in soft natural waters has been the subject of severe scrutiny due to the difficulties and uncertainty involved in the pH measurement (Bates 1964, McQuaker et al. 1983; Davison and Harbinson, 1988). The potential problems include poor handling procedure resulting in CO<sub>2</sub> loss or gain, residual junction potential caused by the extreme ionic strength difference between the sample solution and reference solution (usually saturated KCl). and streaming potential from stirring the solution.

A systematic error in electrode pH measurement exists in dilute natural water occurs due to the interference of dissolved organic carbon and suspended solids. Also when determining the pH of water low electrical conductivity ( $<100 \mu\text{s}/\text{CM}$ ) such as rain water and many upland waters, problems occur which can cause relatively large error. Also the use of indicators or indicator papers is not a satisfactory method of measuring the pH of these waters because they are poorly buffered and contain metals such as iron, manganese and aluminium, which cause inferences by complexing with the indicator (H.M.S.O., 1988b).

In the present study the pH was determined on immediate return to the laboratory using a Corning pH meter (Model type 125) and the pH analysis was carried out under controlled conditions as recommended by the H.M.S.O. (1988b) method.

### 3.5.3 Analysis of trace element by (AAS) and Skalar Autoanalyser.

Concentrations of metal in surface water were generally low; often below or near the detection limit of routine and analytical methods. Reliable and sensitive analytical methods have an important role in determining and combating the environmental impact of metal pollution.

The use of flame absorption spectra instead of emission spectra was first developed by Walsh (1955), The atomic absorption method (AAS) enables elements to be determined with remarkable sensitivity and accuracy and is currently one of the most prevalent method of metal

analysis of water and effluents. Atomic absorption spectrophotometry (AAS) has a wide application in analysis of metal ions in natural and treated water and waste effluents because of its speed, low cost per analysis, simplicity, and its ability to analyse complex mixtures without prior separation. Therefore iron, manganese, calcium and magnesium were determined by the AAS. (H.M.S.O., 1977a, 1977b and 1983). Aluminium was determined by using a Skalar Auto-analyser, after hydrolysis the sample is mixed with a colour reagent (Hydrolysis reagent, phenontrol reagent and catechol violet), in a buffered medium (Hexamine buffer and phthalate buffer). Aluminium forms a coloured complex. The absorption is measured at 580 nm and the concentration of aluminium can be determined (H.M.S.O., 1987).

#### 3.5.3.1 Standard solutions.

Two standards were used for producing a calibration curve in the AAS (low / high concentration). All the standards were freshly made by mixing the stock solutions of magnesium chloride, calcium chloride, ferric chloride, and manganese nitrate (standard solution for atomic absorption) in 2M HNO<sub>3</sub>.

### **3.5.3.2 Optimized condition for (AAS).**

The optimized setting for the AAS (Model 157) recommended by the user manuals is :

Species	Wavelength nm	Slit width	Bandpass
Fe	248.3	80	0.3
Mn	279.5	320	0.5
Ca	422.7	320	1.0
Mg	285.5	320	1.0

A hollow cathode lamp and air-acetylene fuel were used throughout the study.

### **3.5.3.3 Interferences.**

The interferences occurring in the direct flame AAS are well documented (Apha, 1975; Price, 1979). Interferences can occur in many ways, chemical, ionization, matrix or non-atomic absorption. In the field of water analysis, chemical and ionization interferences are the most commonly encountered interferences (Smith et al, 1983). Silicon, aluminium, phosphate, titanium and sulphate depress calciums and magnesiums sensitivity. In order to overcome this, 0.1 to 1% (W / V) Lanthanum chloride was added to the samples and standards. For more detail about the methods see (H.M.S.O., 1977a and 1977b).

### **3.6 Field and laboratory experiments.**

#### **3.6.1 Field experiment (Lysimeters).**

##### **Materials and method.**

Plastic gutters (lysimeters), 5 x 12 x 70 cm, were used to collect the water samples. Gutters were soaked in 10% nitric acid over night and rinsed many times with double-distilled water to minimize any possible contamination before it was used to collect the water samples. In the field; the gutters was placed 30 cm beneath the surface of the soil in horizontal position at a vertical facing site (See figure 3.2).

Two locations were selected in such a way to represent two types of soil, peat and peaty soil. The peat was located at the top of the hills at Longdendale Valley (SE 096 039) and the peaty soil were in North Wales (the Migneint SH 776 448); to see the effect of different types of soil (peat, peaty and (lime and unlimed)), location on the chemistry of the stream water especially colour.

Six lysimeters were used in this study, three were placed in the peat at Longdendale Valley at three locations; 5 meters apart. The other three were placed in North Wales sites, where an area of one acre had been artificially limed previously with fine limestone powder. The lime has been used to study primarily at the effect of lime on the vegetation, invertebrates and also to mitigate surface water acidity. One of the lysimeters was placed in a control area in the top of the hill, one in the limed and one below the limed area, about 400 meter a part.

Figure 3.2 A picture showing the Lysimeter.



5 x 12 x 70 cm.

Plastic gutter

Collection bottle.



### **3.6.2 Laboratory experiment (Monolith Tins)**

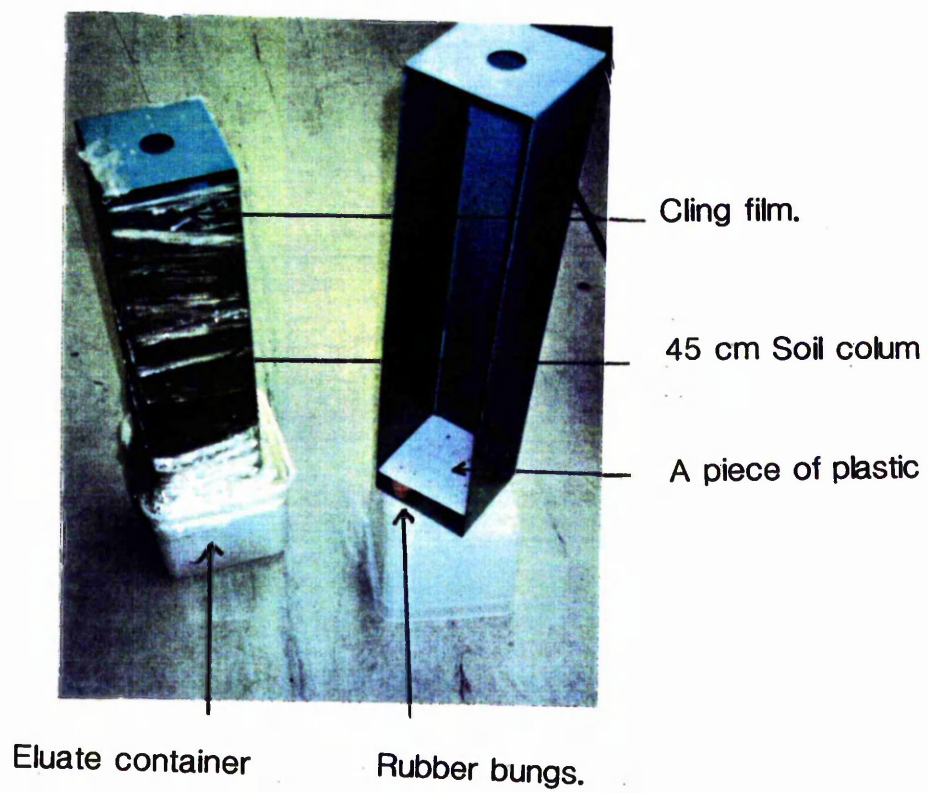
#### **Materials and method.**

A monolith tin, 12 x 12 x 60 cm long was made from steel and coated with fusion bonded epoxy resin to avoid the corrosion and metal contamination. It had been soaked over night in 10% nitric acid and rinsed several times with double-distilled water.

In the field a vertical facing site was chosen and the monolith was placed in a vertical position and driven into the soil profile by hammering. Vertical cuts through the soil were made by a shovel to get the monolith out. Then the monolith was sealed with cling film to prevent moisture loss and kept in vertical standing position while it was transported to the laboratory to avoid any disturbance to the sample.

Six monoliths were brought to the laboratory from different locations. Two were from the top of the hill and two from the bottom of the hill at Longdendale Valley, while two were brought from North Wales, one from limed area and one from unlimed. The concentration of the organic matter and some parameters measured in these soils were shown in table (3.1). In the laboratory, a piece of plastic (12 x 12 cm acrylic sheet) with small holes in it was placed at 45 cm intervals from the surface of the sample. Rubber bungs were used to make an air-filled space between the sample and the bottom of the monolith (the plastic and the rubber bangs were soaked over night in 10% nitric acid and rinsed with double-distilled water prior to use (See

Figure 3.3 A picture showing the Monolith Tins.



**Table 3.1 Concentration of some parameters in the monolith tins soil samples.**

Sample	% Organic	Fe mg/g	Mn mg/g	Al mg/g	Ca mg/g	Mg mg/g
Top 10 °C	89	1.467	0.010	1.844	0.437	0.144
Top 20 °C	94	1.240	0.011	1.502	0.449	0.162
Bottom 10 °C	32	15.66	0.183	2.693	0.483	0.939
Bottom 20 °C	38	13.77	0.191	2.360	0.563	0.855
lime 10 °C	64	17.77	0.019	0.401	0.391	0.107
unlime 10 °C	61	0.813	0.002	0.680	0.233	0.180

figure 3.3).

One of each of the samples which had been brought from the top and bottom of the hill were kept at a temperature of 20 °C  $\pm$ 2°C while the other four were kept at 10 °C  $\pm$ 2°C. All six monoliths were left standing for one week before any water was added (to settle any disturbance in the samples). A natural soft water (from Woodhead Bridge), hard waters (from Derbyshire Peak District) and double-distilled water was used to simulate rain; This is mainly to see the effect of the buffering capacity on releasing colour from different types of soils. The water samples kept at the same temperature as the monolith. The concentration of the parameters is shown in table (3.2).

50 ml of the natural water was evenly pipetted over the surface of the soil in the monolith every 24 hr. To avoid any possible evaporation to the eluate the monolith was well sealed with cling film. The eluate was collected

**Table 3.2 Concentration of the waters which it used as leaching agent.**

Type of water	pH	Colour Hazen	Fe mg/l	Mn Mg/l	Al mg/l	Ca mg/l	Mg mg/l
Natural (A)	4.26	11.9	0.19	0.03	0.27	2.60	1.30
Double-distilled (B)	4.00	-	-	-	-	-	-
Hard (C)	7.60	3.1	0.04	0.00	0.05	166.00	45.00
Natural (E & F)	6.55	5.20	0.20	0.02	0.17	11.60	1.35

in a plastic container; acid washed previously. Every 72 hr the water which had percolated through the monoliths was collected and eluted volume of each one was recorded. Three replicates of the water were used in determination of the parameters, and the same general procedure as before was used for analysis. Both soft and hard natural waters as well as double-distilled water were use as leaching agents, over varying periods of time; over 200 days including 45 days dry period. This was in order to obtain general information on the affect of dryness and temperature on the generation of colour; adsorption or desorption of metals; and pH of the eluate from the soils.

### 3.6.3 Arylsulphatase activity in soil.

Since the activity of microorganisms may play a significant role in the decomposition of vegetative matter and hence the generation of soluble coloured material in the soil which will then be leached out into the catchment waters following the replenishment of the deficit by rainfall. Therefore it is thought to be important to measure the numbers of microorganisms to get a rough indication on the effect of them on the colour in the

waters. The numbers of the microorganisms were measured indirectly by monitoring enzyme activity in the soil. In this study the arylsulphatase activity in the soil was measured. Arylsulphatase is a principal enzyme involved in the soil sulphur cycle and it catalyses the removal of the sulphate ion from a large number of arylsulphate esters. These enzymes hydrolyse the sulphate esters.

#### Materials and methods.

The method is similar to that of Tabatabai and Bremner (1970).

#### Reagents

- 1- Acetate buffer (0.5 M, pH 5.8) 64.0 gram of sodium acetate trihydrate was dissolved in double-distilled water, 1.70 ml of 99 % glacial acetic acid was added to the solution, and made up to one litre with double-distilled water.
- 2 - Toluene.
- 3 - p-Nitrophenyl Sulphate Solution (500 mM), was made by dissolving 0.1287 g of potassium p-nitrophenyl sulphate in the acetate buffer, and the solution was diluted to 100 ml with the buffer, and the solution was stored in a refrigerator.
- 4 - Calcium Chloride Solution (0.5 M). 73.5 g of  $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$  was dissolved in one litre of double-distilled water.
- 5 - Sodium Hydroxide Solution (0.5 M). 20 g of NaOH was dissolved in one litre of double-distilled water.
- 6 - Stock standard p-Nitrophenol Solution. 1.0 gram of

p-nitrophenol was dissolved in one litre of double-distilled water, and the solution was stored in a refrigerator. Six standards containing 0, 10, 20, 30, 40 and 50  $\mu$ g of p-nitrophenol were made by diluting 1 ml of the stock standard p-Nitrophenol Solution with 99 ml of double-distilled water in 100 ml in a volumetric flask, then 0, 1, 2, 3, 4, and 5 ml of this diluted standard solution was again diluted in 5 ml flasks to the mark. This final standard solution was used to produce the calibration curve.

#### Enzyme assay.

Arylsulphatase activity was measured in five surface (5-10 cm) samples of peat and peaty soil which were collected from the top of the hill of the six streams (Coombes Clough ... etc) during August 1990 and from locations at least 5 meters apart and from the soils of the Monolith tins experiment. Arylsulphatase activity was measured within 24 hours of collection by the following the procedure :

Five replicates of peat or soil (0.5 g) were placed in a boiling tube with 4 ml of sodium acetate buffer, 0.25 ml toluene and 1 ml of the substrate (5 mM potassium p-nitrophenyl sulphate). The contents of the tube were mixed for 45 Sec with a Vortex mixer and held at 30 °C for 1 h. The reaction was stopped by the addition of 1 ml of 0.5 M CaCl<sub>2</sub> followed by 4 ml 0.5 M NaOH. The contents of the tube were mixed again and after centrifugation at 1000

g for 20 min, the yellow colour of p-nitrophenol (p-NP) formed was determined spectrophotometrically using the same method as for measuring the colour in the water. The concentration of p-nitrophenol in the content was calculated by referring to the calibration graph which was obtained by plotting the results of the fresh made standards. Five controls were performed by the immediate addition of 0.5 M  $\text{CaCl}_2$ , 0.5 M NaOH and 1 ml of p-nitrophenyl sulphate.

## **Chapter 4**

### **Results**



## **Part I**

### **Field study.**

#### **4.1 Introduction.**

Part I refers to results recorded for the streams in the Longdendale Valley and the water works at Arnfield. part II the experimental study. However, full details of all the numerical results for these analyses are presented in appendices as follows:

- 1- Data for water analyses within the streams at Longdendale Valley are given in Appendix I
- 2- Data for water analyses for the streams at Longdendale Valley are given in Appendix II
- 3- Data for raw waters arriving at Arnfield water works, daily rainfall at Swineshaw, and soil moisture deficit in the Buxton area are given in Appendix III.
- 4- Data for the lysimeter experiments are given in Appendix IV.
- 5- Data for the leaching experiments are given in Appendix V.

In all, about 30 surveys were carried out for six different streams at Longdendale Valley from May 1988 to December 1990. For the first six surveys, the spatial variation along the length of two chosen streams were studied in order to monitor the variation in the levels of the parameters within the streams at different events. For

the rest of the surveys, the spatial variation of the parameters between six different streams were studied. Since a change in the level of colour and metals occurs after certain events, the time intervals were partly chosen according to weather changes.

Since the mobilization, solubilization and generation of colour might be different than for metals, the first section of the part will deal with the results of colour (at the streams and at the treatment works) and the possible factors which may affect the generation of colour, whereas the second section will deal with metals. In figures, the spatial graphs refer to the variations in the levels of the parameters between the sites (the levels of the parameters at different locations along the streams or at different streams), while the temporal figures show details of the linear variation, the time intervals and also the spatial variation of the parameters at each site.

## **Section I**

### **Colour and possible factors which may affect colour.**

#### **4.2 Spatial variations of colour in the streams.**

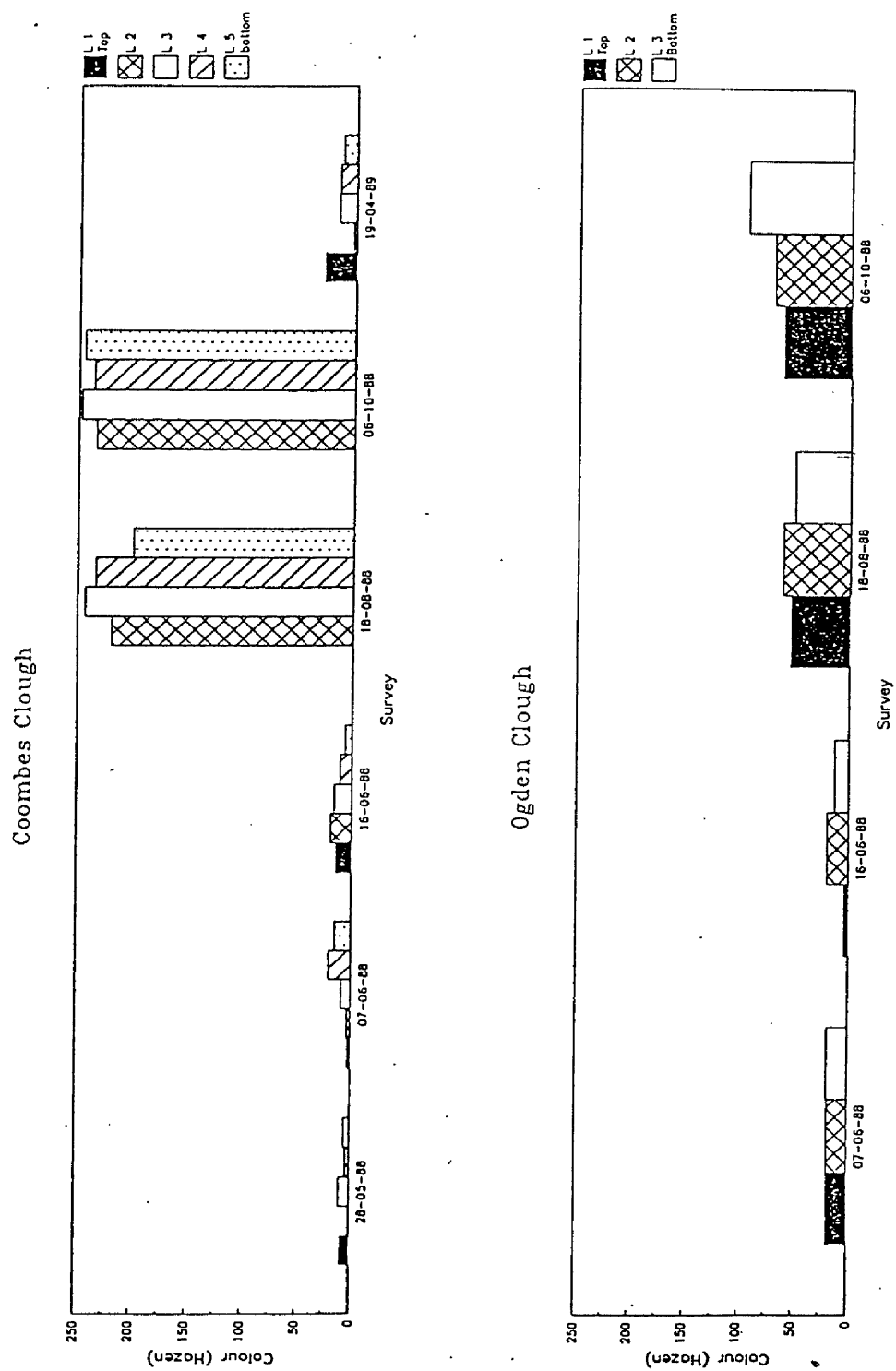
##### **4.2.1 Variation in colour levels along the length of selected feeder streams.**

In order that the spatial variation within each stream could be monitored, water samples from several known points (about 400 meters apart at Coombes Clough and 250 meters

at Ogden Clough) along the length of selected streams, Coombes Clough and Ogden Clough, were taken during the first six sets of water sampling. The reason for choosing these two streams is mainly because the first one drains from the North facing area which is covered with peat, the second stream drains from the South facing area which is not covered with peat. (see figure 2.7).

Figure 4.1 shows the difference in the colour levels in Coombes Clough and Ogden Clough as water flows down the stream on different occasions (Ogden Clough was not monitored on the first and last occasions). On the first two occasions the weather was warm, the third was after a long hot dry period, on the fourth and fifth occasions it was hot and heavy rain was falling. The final occasion was after a long, cold dry period (see appendix I). As the above mentioned figures show the levels of colour were much higher on occasions 18-8-1988 and 6-10-1988 than on other occasions at both streams, and the level at Coombes Clough was higher than at Ogden Clough, being exceeded by 200 Hazen units at Coombes Clough and less than 100 at Ogden Clough. On these two occasions water samples could not be obtained from the top site (L1) because, as mentioned before, on those two occasions there was very heavy rain falling and it was difficult and dangerous to climb to the top of the hill at Coombes Clough to obtain samples. On those two occasions the levels at the third location at Coombes Clough (L3) were the highest. The colour levels at the middle to bottom region of Ogden Clough were usually

Figure 4.1 Spatial variation of colour within Coombes and Ogden Clough at different occasions; at known locations within the stream.



greater. The levels of colour on the other occasions were relatively low in both streams and it varied erratically from one location to another over a narrow range.

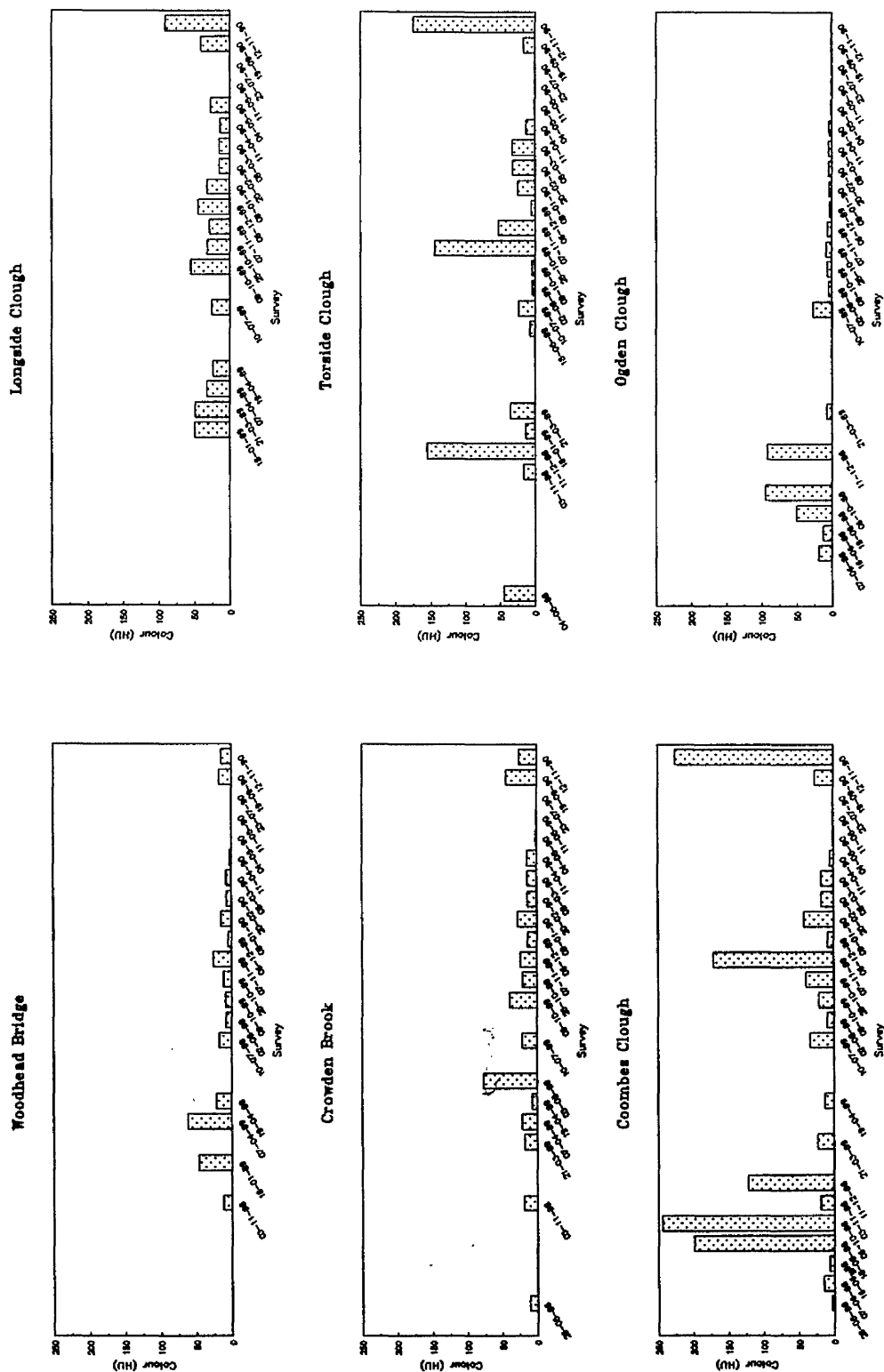
Generally, only very small differences in the colour levels could be detected moving down the stream, but clear significant differences could be detected from one occasion to another, especially when there was heavy rain (see appendix I).

There was no clear visible difference in the levels of colour as the water flowed down stream, and the negligible change will not have any significant impact on the treatment works. Considering this fact and the manpower and the time difficulties involved in "multi-point sampling", it was decided to take water samples at one known point on each of the major feeder streams in the catchment area with regard to its drainage.

#### 4.2.2 Colour variation in the feeder streams.

Figure 4.2 illustrates the variation of colour levels observed during the study of the six different streams: Coombes Clough, Crowden Brook, Woodhead Bridge, Longside Clough, Torside Clough and Ogden Clough. It can be seen quite clearly that colour levels varied from stream to stream and from survey to survey within the streams. The colour levels at Ogden Clough were relatively low during the sampling period with exceptions on three occasions in 1988 when the colour level rose to about 100 Hazen units. The lowest colour levels of all the streams were recorded during summer 1990 in May and July.

Figure 4.2 Variation of colours levels observed during the study at the streams.



The highest levels of colour were recorded at Coombes and Torside, being between 150-250 Hazen units at the former and over 150 Hazen units at the latter. Also the figure shows that in general the lowest colour levels in the stream were as follows:

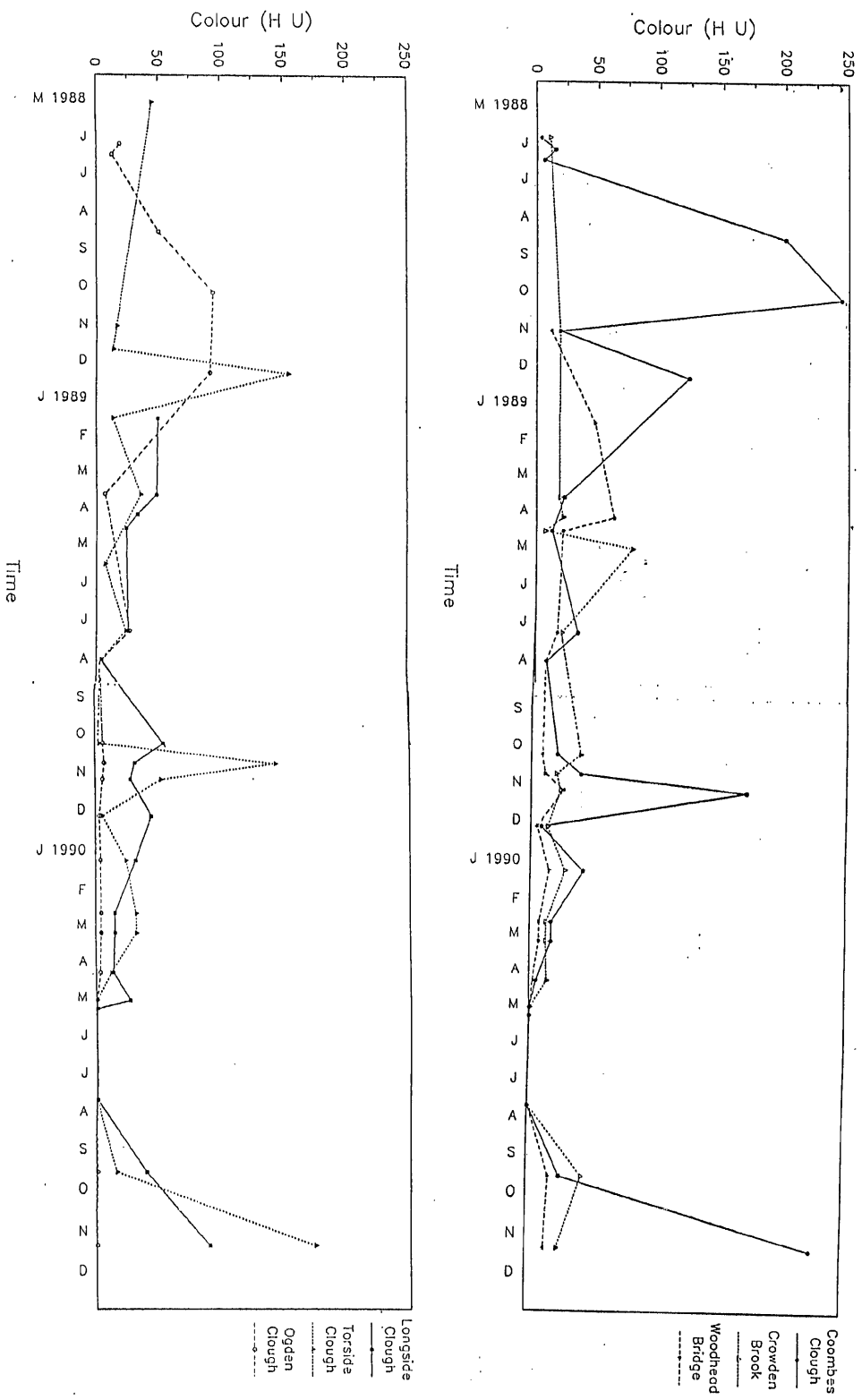
Ogden Clough > Woodhead Bridge > Crowden Brook >  
Longside Clough > Torside Clough > Coombes Clough.

#### 4.3 Temporal variations of colour levels in the feeder streams.

Figure 4.3 shows the temporal variation of colour in each of the feeder streams. Although there was considerable variation between the streams colour levels were generally higher in the winter periods (although not always so). They were also generally lower during prolonged dry periods such as in June and July 1990.

Colour levels in Coombes Clough were very high in the summer, autumn and winter of 1988-1989 with the exception of the November sampling occasion. They then declined through the summer before rising again the following winter. The winter rises in 1989-1990 and 1990-1991 were greater than in 1988-1989. The dry summer of 1990 produced clear waters and colour levels did not rise again until the winter of 1990. A similar though less marked pattern was observed in Torside Clough, although Ogden Clough showed high winter colour levels in the winter of 1988-1989 the peak was not repeated in either of the subsequent winters.

Figure 4.3 Temporal variation of colour in the feeder streams





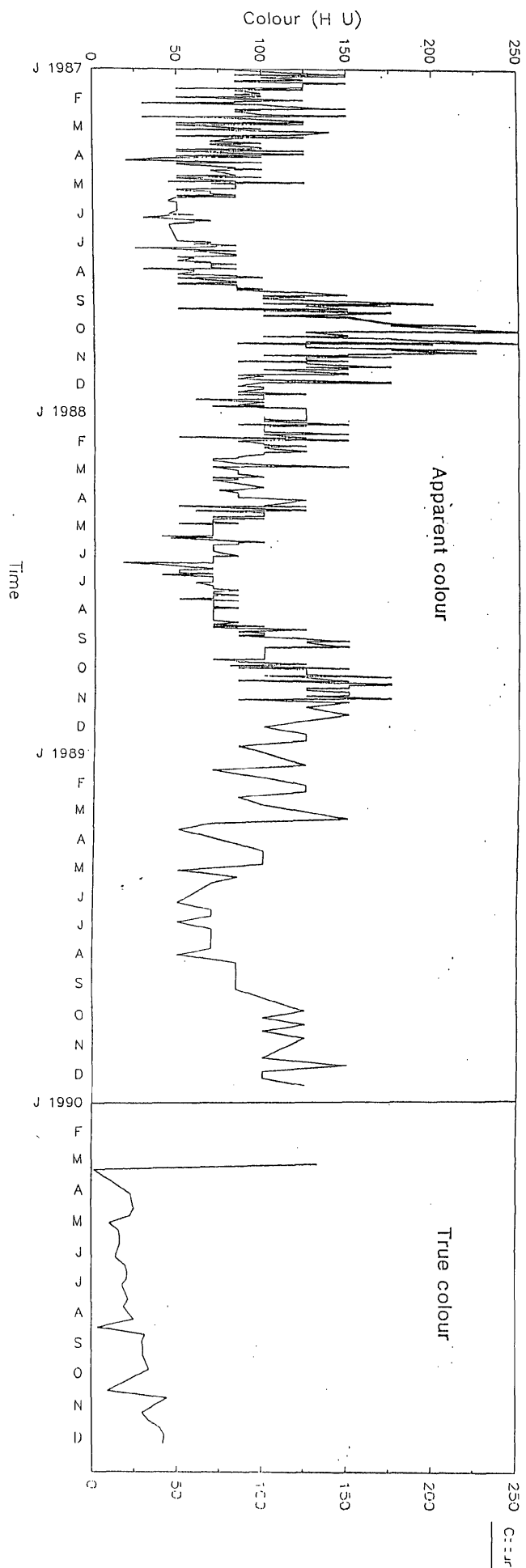
The winter 1988-89 colour peak in Crowden Brook and Woodhead Bridge tended to be delayed until the spring of 1989. Although there was no marked increase in the following winter there were signs of a spring increase but these did not develop significantly. The winter 1990 rise was earlier than in the previous two years.

The figure shows that colour levels varied from stream to stream and from time to time. As can be seen, the colour may be attributed to the seasonal changes. Also the figure shows that the colour levels remain generally low in some streams, such as Ogden Clough, during sampling period with only slight fluctuation, except during the autumn of 1988 when there was a jump in the colour levels. On the other hand the colour level in other streams such as Longside Clough, remained generally higher than in the other streams when the colour of the other streams is low. The colour of this stream constantly varies between 30-60 Hazen units most of the time.

#### **4.4 Spatial and temporal variation of colour in the water at Arnfield works.**

Figure 4.4 illustrates the level of colour in raw waters arriving at Arnfield treatment works between 1987-1990. These represent the integration of most streams and reservoirs in the Longdendale Valley. The frequency of measurement of the parameters at the water works for 1987 and 1988 was recorded on a working daily basis. In 1989 the

Figure 4.4 Pattern of colour levels from 1987 to 1990 at Arnfield Treatment Plant



measurements of the parameters were carried out only once every two or three weeks or when there was a strong jump in the colour levels. In 1990 the method was changed from "apparent" (Hazen unit without filtration) to "true" (Hazen unit after filtration with 0.45  $\mu\text{m}$  membrane filter) colour measurement; also the authorities decided to concentrate on measuring the colour within the distribution system rather than in the raw waters.

As the above mentioned figure shows that while the colour varied from day to day there were considerably marked seasonal and year to year variations. The lowest colour levels in the raw water was in the summer months and they usually showed a marked increase in the autumn and winter. Similar patterns of increases or decreases occur at the streams especially at the ones which recorded high levels of colour such as Coombes Clough (see figure 4.3). Generally the colour level started to increase after August and remained generally high until the first one or two months of the following year. Also the figure shows that the colour level in the winter months of 1987 was higher than in the winter months of 1988 or 1990. Between January and May 1987 the colour level decreased dramatically until it reached 50 Hazen units and remained low during May and July then the colour the levels increased steadily to a peak of > 250 Hazen unit in the autumn of 1987 (in November), then they declined through the winter of 1988 until they reached their lowest level in June. The levels of colour in the summer were lower than the levels in the

autumn and winter and generally the levels were higher than in the previous summer. Again the colour levels rose during the autumn of 1988, the increase started in August; while in the previous year the colour levels started to increase earlier (in July). The levels increased gradually through the autumn until they reached their highest peak of around 150 Hazen unit in November and December but the peak was not as high as the peak in the previous year of 1987. Then the levels declined through the winter and spring of 1989 with exception of a peak during March, the levels remained lower during the summer compared with the winter, and then the levels started increasing again during in the autumn of 1989 reaching a peak in November but the peak was lower than the peak in the previous two autumns. In 1990 the colour levels (True colour) seemed to follow a similar pattern as the apparent colour (1987 to 1989), that the levels were lower in the summer than in the autumn and winter; the levels showed a slight upward trend except in August and November when there was a drop in the colour levels followed by a peak especially in November. The different methods of colour measurement which had been used in the past and the present, make interpretation of past trends and comparisons difficult.

## 4.5 Temporal variation of pH and water temperature at

### Arnfield works.

Figure 4.5 illustrates the pattern of pH and water temperature in the raw water at the treatment plant for the years 1987-1990. It shows both seasonal and yearly variations in water temperature and pH. The figure shows that the water temperature declined during the autumn usually between September and December, and remained low during the winter; then the water temperature increased during the summer time, from April or May, it rose steeply until August or September and then decreased dramatically until it reached its lowest level during the winter months. The temperature during the summer time was usually treble the temperature during the winter time, the highest temperature were recorded during summer 1989 and the lowest were in winter 1988. Usually the water temperature increased gradually through the spring until it reached its highest during the summer, then decreased dramatically during the autumn and remained low at around 5 °C during the winter. The pH of the raw water most of the time ranged between 6 and 7 pH units but during the late winter and early spring there was a drop in the levels especially in the winter of 1989/1990. The drop in the levels of pH in 1989 was more than that in 1990. In general the levels of pH in the winter were lower than in the summer, the levels of pH increased gradually through the spring and summer and remained low during the winter.

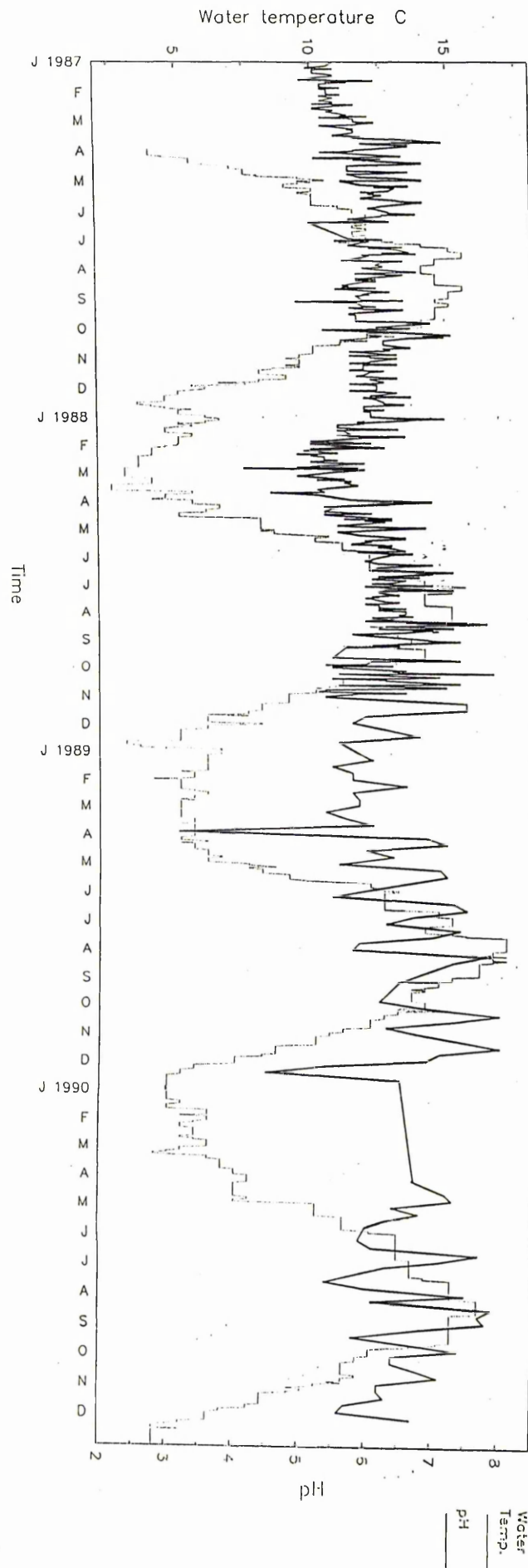


Figure 4.5 Pattern of water temperature and pH in the raw water at Arnfield works from 1987 to 1990

#### 4.6 The temporal variation of soil moisture deficit and rainfall.

Figure 4.6 illustrates the total monthly rainfall and soil moisture deficit at Swineshaw (G. R. : SK(043)043956). The nearest station which measures the rainfall, and the nearest station which measures the soil moisture deficit is at Buxton (area 6 station 107494. Meteorological Office). The reason for choosing the Buxton Station is not only because it is the nearest station, but also because it is located at a similar altitude to the Longdendale Valley and it receives a similar amount of rainfall, therefore the soil moisture deficit would be comparable.

The figure shows clearly year to year variations in the total monthly rainfall and soil moisture deficit. The deficit in the soil moisture deficit in the last two years was higher than in 1987 and 1988. This is probably due to the global world changes in the weather. The deficit in the soil was largely dependant on the amount of rainfall and losses of water from the soil (by evaporation and transpiration ... etc). As the figure show, as the total amount of monthly rainfall increased the total soil moisture deficit decreased. The deficit in soil can happen at any time of year as long as there is not sufficient rain to replace the deficit which had been lost from the soil. During the summer low amounts of rain fall on the soils, high air temperatures increase the evaporation of water and it is the growing season for plants. All this makes the

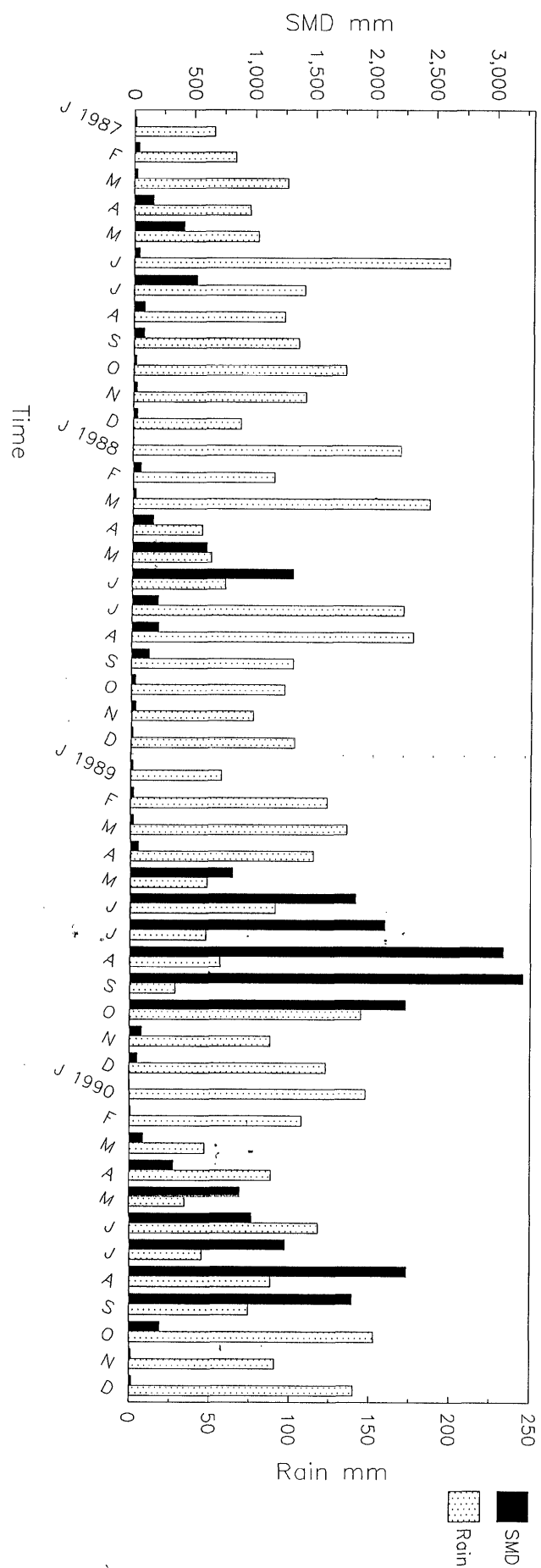


Figure 4.6 Total monthly rainfall at Swineshaw and total monthly soil moisture deficit at Buxton (from 1987 to 1990)



soils lose water; this leads to high soil moisture deficit, while in the autumn and winter there are high amounts of rainfall and less water is lost from the soil; This leads to low soil moisture deficit. When there is a wet summer such as in 1987 there was low soil moisture deficit mainly due to the large volume of rainfall, when there was a dry summer such as 1989 and 1990, there was a high soil moisture deficit (due to the low amount of rainfall ... etc). The deficit in the soil moisture can occur any time of year as long as there is not sufficient rainfall to replace the deficit, and the deficit varies from time to time. For example, during the autumn of 1989 there was an almost continuous dry period for about a month (between 11th November and 11th December). There was a deficit (the highest deficit being 6.5 mm) and during summer 1987 there was a wet period (between 1th July and 1th August), there was a deficit (the highest deficit being 32.2 mm). However, in the first case the deficit was less than the second case, while it should be higher than in the first; this is probably due to the cold weather where less evaporation takes place and less water is lost by transpiration because it is not a growing season (see appendix II). In general the deficit usually starts in the spring and the replacement of the deficit is in the autumn, but it varies from year to year. Usually lower soil moisture deficits occur during the winter and the highest are during the summer. The longest period and highest soil moisture deficit was in 1989 and 1990, and the lowest deficit was in 1987.

## **Section II**

### **Metals and some other parameters.**

#### **4.7 Spatial variation of metals in the streams.**

##### **4.7.1 Spatial variation of metals and other parameters along each stream.**

Figures 4.7 and 4.8 illustrate the spatial variation of iron, manganese, calcium, magnesium, pH and suspended solids within Coombes Clough and Ogden Clough. The levels of these parameters varied from stream to stream. For example, as shown in the figures the levels of iron were lower at Ogden Clough than at Coombes Clough. At Coombes Clough the iron levels tended to decrease as the water flowed down the stream with an exception on 16-08-1988 when there was heavy rain falling. Manganese tended to rise in the middle zone then it decreased as iron at the lower part of the stream. Also in the stream the levels of both calcium and magnesium were higher in the middle to lower part than the upper part with an exception when there was a heavy rainfall; it actually decreased. The pH levels were generally higher downstream but were not so when there was heavy rain; it was acidic at all locations in the stream. The levels of the suspended solids were variable and the levels increased during the heavy rainfall; this might be due to erosion. At Ogden Clough the levels of iron were generally low with an exception when there was heavy rain and the levels increased. The levels of calcium and

Figure 4.7 Spatial variation of some parameters within Coombes Clough at different occasions; at known locations within the stream

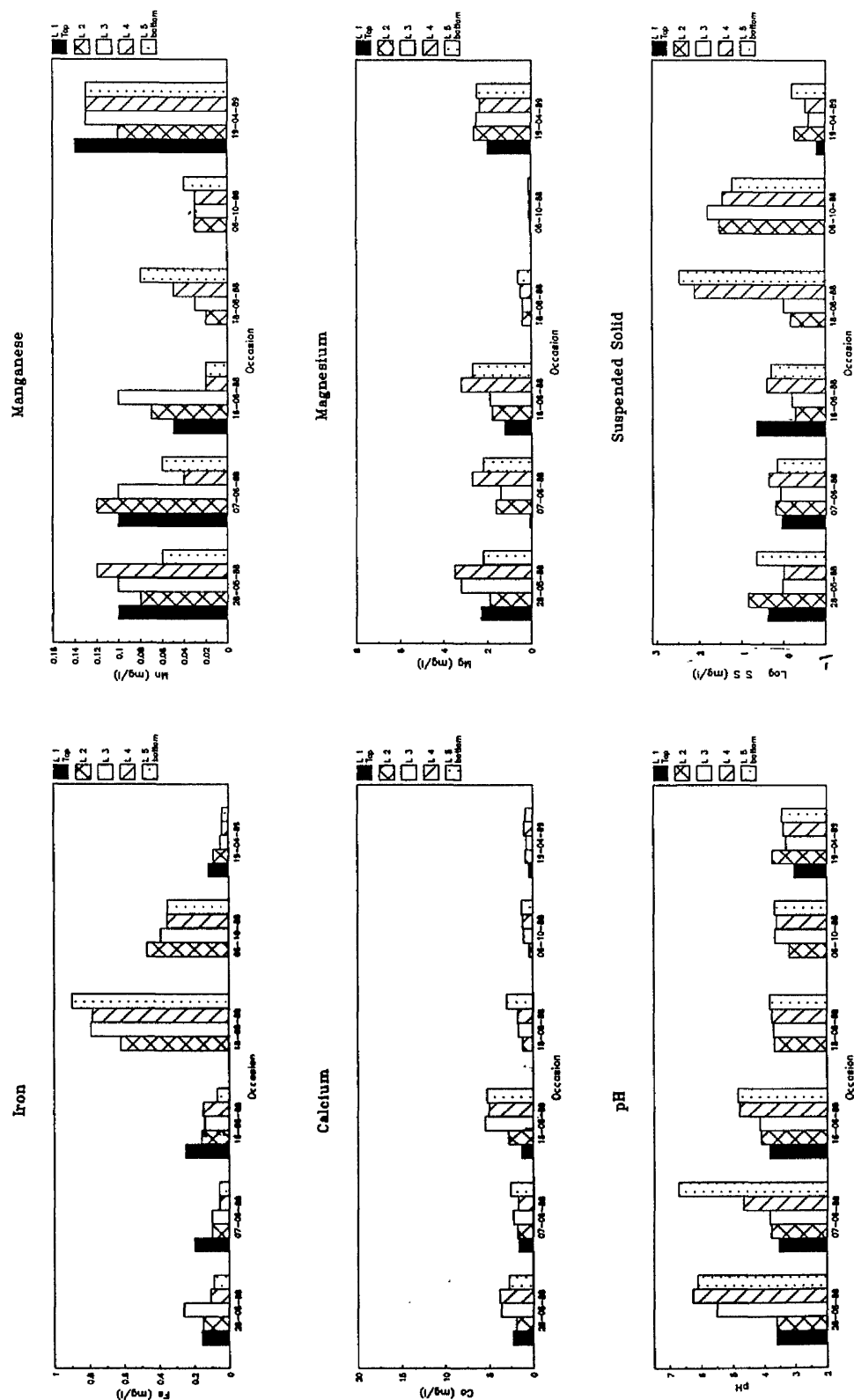
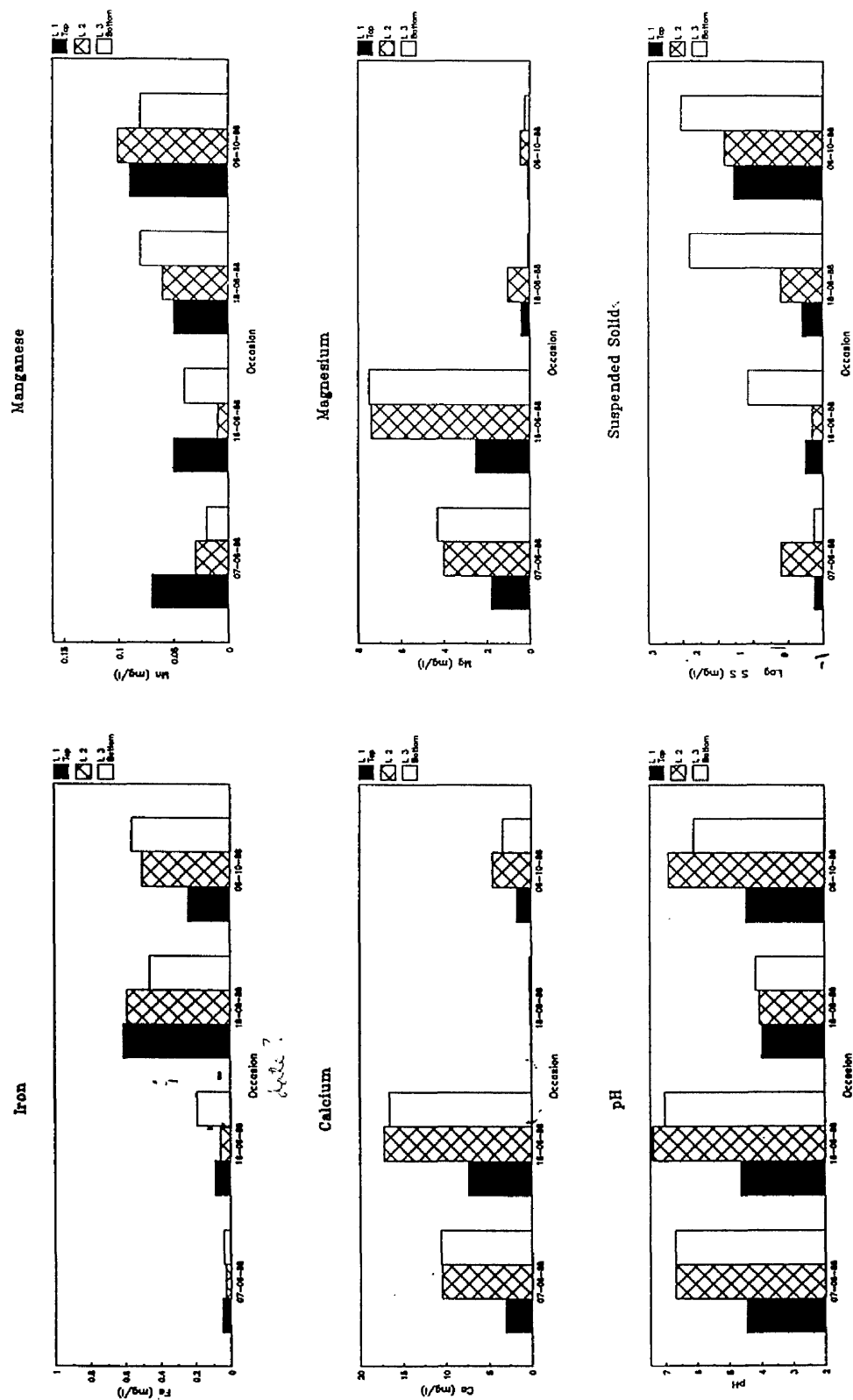


Figure 4.8: Spatial variation of some parameters within Ogden Clough at different occasions; at known locations within the stream



magnesium were higher in comparison with the levels at Coombes Clough; as in the case of Coombes Clough the levels decreased when there was heavy rain. Also the levels of the pH were generally higher downstream; as with Coombes Clough the levels decreased when there was heavy rain. The levels of the suspended solids also were variable and the levels increased during heavy rain.

In general, the pH levels of the water increased noticeably as the water flowed down the stream during its dry period and slightly increased when wet, while iron levels tended to decrease as the water flowed down the stream especially at Coombes Clough. When there was heavy rain the levels of some parameters such as iron and the suspended solids increased, while the levels of some other parameters decreased such as calcium, magnesium and pH.

#### **4.7.2 Spatial variation of metals between different streams.**

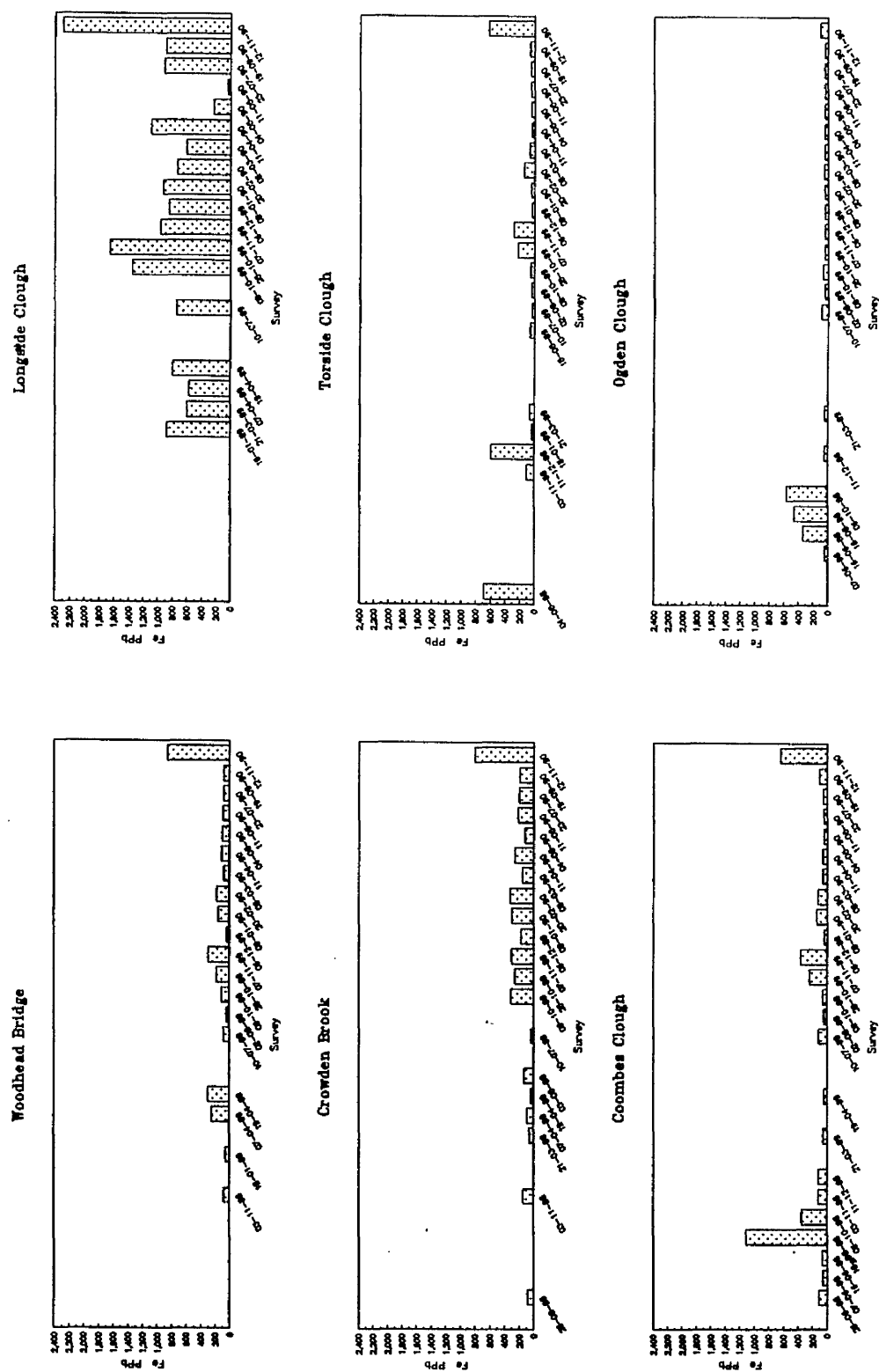
##### **4.7.2.1 Iron levels in the streams.**

As shown in figure 4.9, the highest concentration of iron was in Longside Clough, being greater than 400 PPb most of the time, whilst levels in all the remaining streams were generally low, with exceptionally marked peak concentrations in streams Coombes Clough and Torside Clough being between 500 and 1,200 PPb.

Comparing the overall relative levels of iron in the streams, in order of decreasing concentration in the streams they were:

Longside Clough > Coombes Clough = Torside Clough >

Figure 4.9 Variation of iron concentrations observed during the study at the streams.



Crowden Brook > Woodhead Bridge > Ogden Clough.

#### 4.7.2.2 Manganese levels in the streams.

Figure 4.10 illustrates the variation of manganese levels in the streams. As the figure shows the concentration of manganese varied from stream to stream, and from occasion to occasion. The highest concentration was at Longside Clough, varying most of the time between 100-450 PPb. On the other hand manganese in the other streams was relatively low. The concentration of manganese in the other streams varied over a narrow range of 30 or close to the limit of detection and 80 PPb at Ogden Clough and Torside Clough, and between the range of 30 and 150 PPb at Coombes Clough, Crowden Brook and Woodhead Bridge. Comparing the overall relative levels of manganese in the streams, in order of decreasing concentration in the streams they were:

Longside Clough > Coombes Clough = Crowden Brook = Woodhead Bridge > Torside Clough > Ogden Clough.

#### 4.7.2.3 Aluminium levels in the streams.

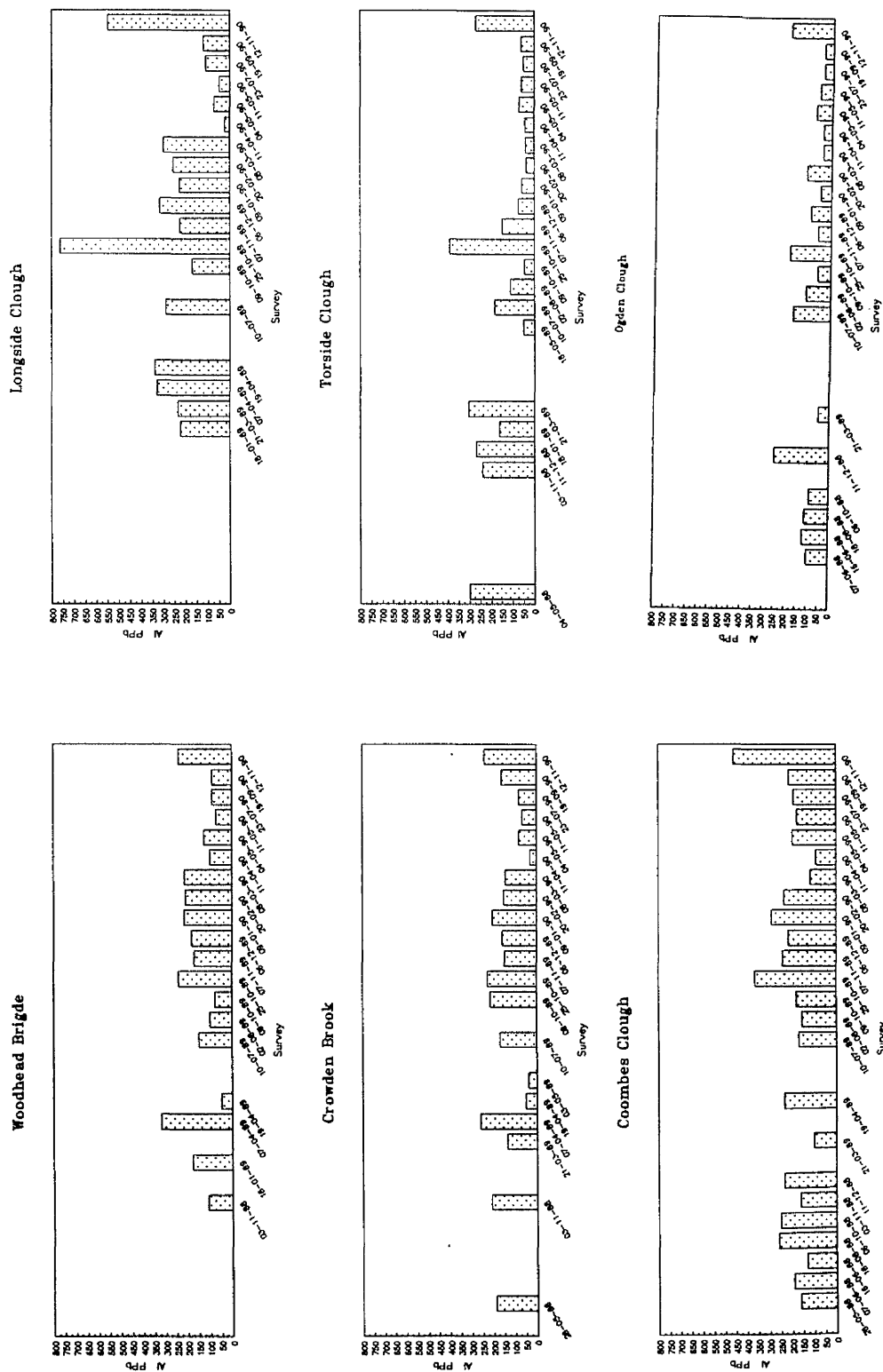
As shown in figure 4.11, there was no apparent pattern to spatial variations of aluminium in the streams, with levels rising and falling erratically in each stream. The highest and lowest levels of aluminium recorded during the study was at Longside Clough, being as high as 550 PPb and as low as 25 PPb. In general the levels of aluminium varied from moderate to extremely high in some streams, such as Coombes Clough, Longside Clough, Torside Clough, and low to moderate in others such as Ogden Clough, Crowden Brook

The figure consists of six horizontal bar charts, each representing a different location. The y-axis for all charts is pH, ranging from 3 to 8. The x-axis represents survey dates. The bars are filled with a stippled pattern.

- Longside Clough:** Shows pH values for surveys from 1980-11-12 to 1990-07-10. Most values are between 4 and 7.
- Torside Clough:** Shows pH values for surveys from 1980-04-26 to 1990-07-10. Values range from approximately 3.5 to 7.5.
- Ordan Clough:** Shows pH values for surveys from 1980-04-26 to 1990-07-10. Values range from approximately 3.5 to 7.5.
- Woodhead Bridge:** Shows pH values for surveys from 1980-11-12 to 1990-07-10. Values range from approximately 3.5 to 7.5.
- Crowden Brook:** Shows pH values for surveys from 1980-11-12 to 1990-07-10. Values range from approximately 3.5 to 7.5.
- Coombes Clough:** Shows pH values for surveys from 1980-04-26 to 1990-07-10. Values range from approximately 3.5 to 7.5.



Fig 4.11 Variation of aluminium concentrations observed during the study at the streams.



and Woodhead Bridge. Generally all streams have a low concentration of aluminium compared to other metals.

#### 4.7.2.4 Calcium levels in the streams.

Figure 4.12 illustrates the variation of calcium in the streams. As shown in the figure, the concentration was generally low in all the streams, being in the range of less than 20 mg/l most of time. The levels of calcium varied from one stream to another and also from one survey to another. The lowest levels were mostly at Coombes Clough while the highest were at Torside Clough.

#### 4.7.2.5 Magnesium levels in the streams.

As in the case of calcium levels, magnesium levels were also low in all the streams during the study as figure 4.13 shows, being less than 10 mg/l. Like magnesium, the levels in the streams varied from one stream to another. In general, the levels in Torside and Ogden Clough were noticeably higher than in the other streams.

#### 4.7.2.6 pH in the streams.

As shown in figure 4.14, the pH of the water in all the streams varied over the range 3 to 7.5. Some of the streams were generally highly acidic, such as Coombes Clough and Longside Clough while others were generally neutral (6-7) such as Torside and Ogden Clough.

#### 4.7.2.7 Suspended solids in the streams.

Figure 4.15 shows the level of suspended solids in the streams. As the figure shows, the levels in each stream varied from survey to survey. they can be as low as 0.2 mg/l and so high as to exceeded 2800 mg/l in some streams

Fig 4.12 Variation of calcium concentrations observed during the study at the streams.

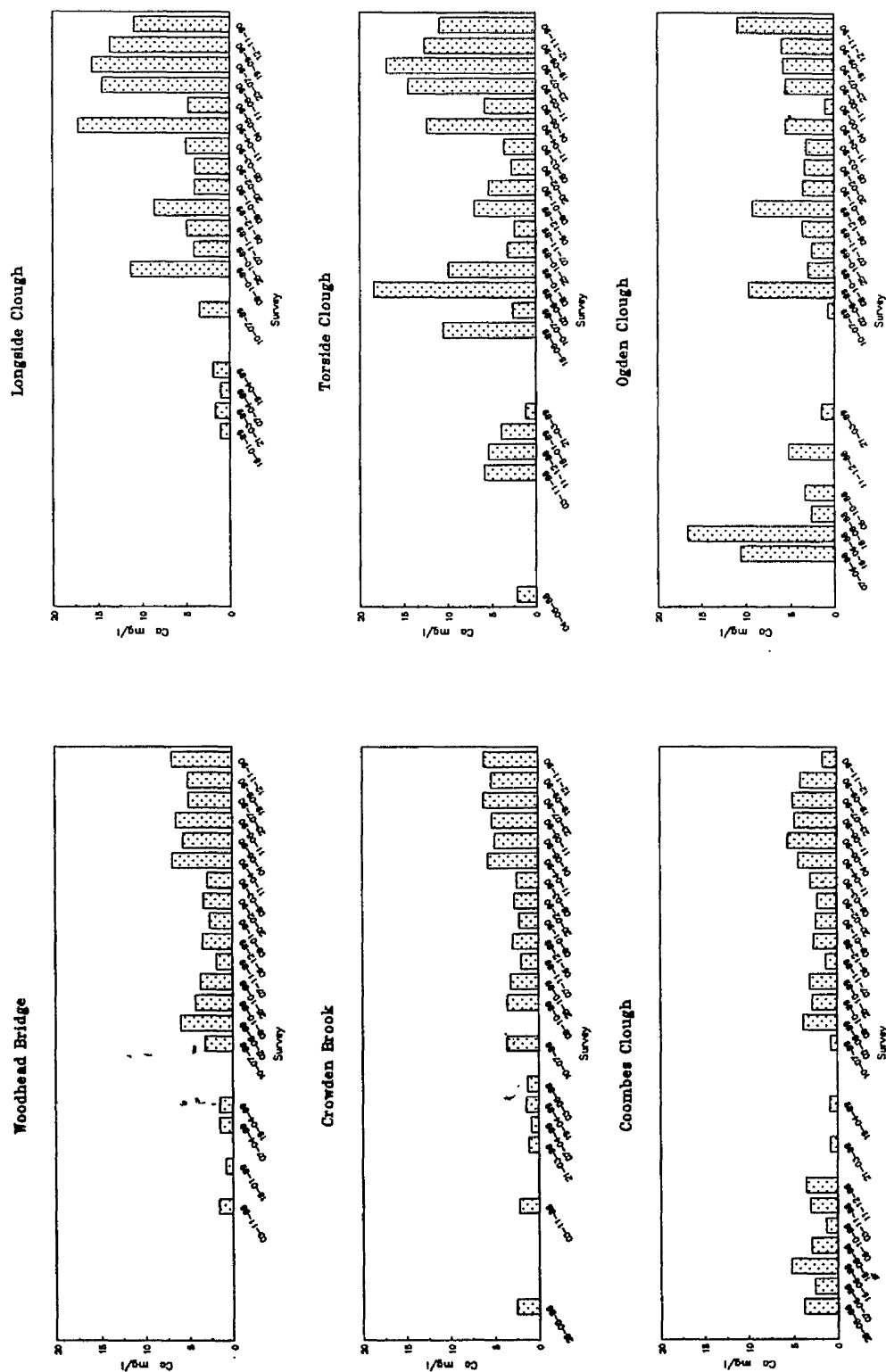


Fig 4.13 Variation of magnesium concentrations observed during the study at the streams.

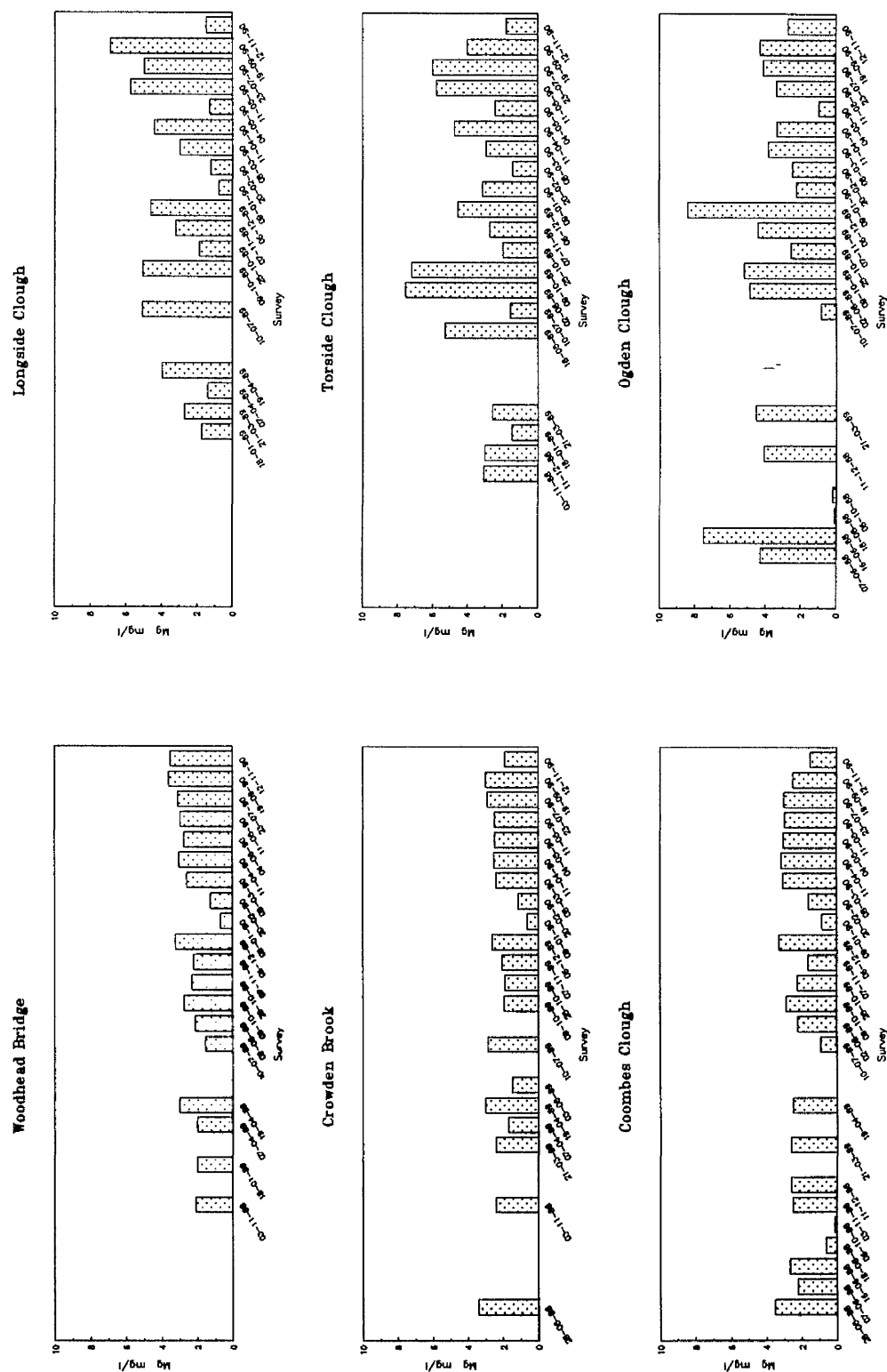


Fig 4.14 Variation of pH levels observed during the study at the streams.

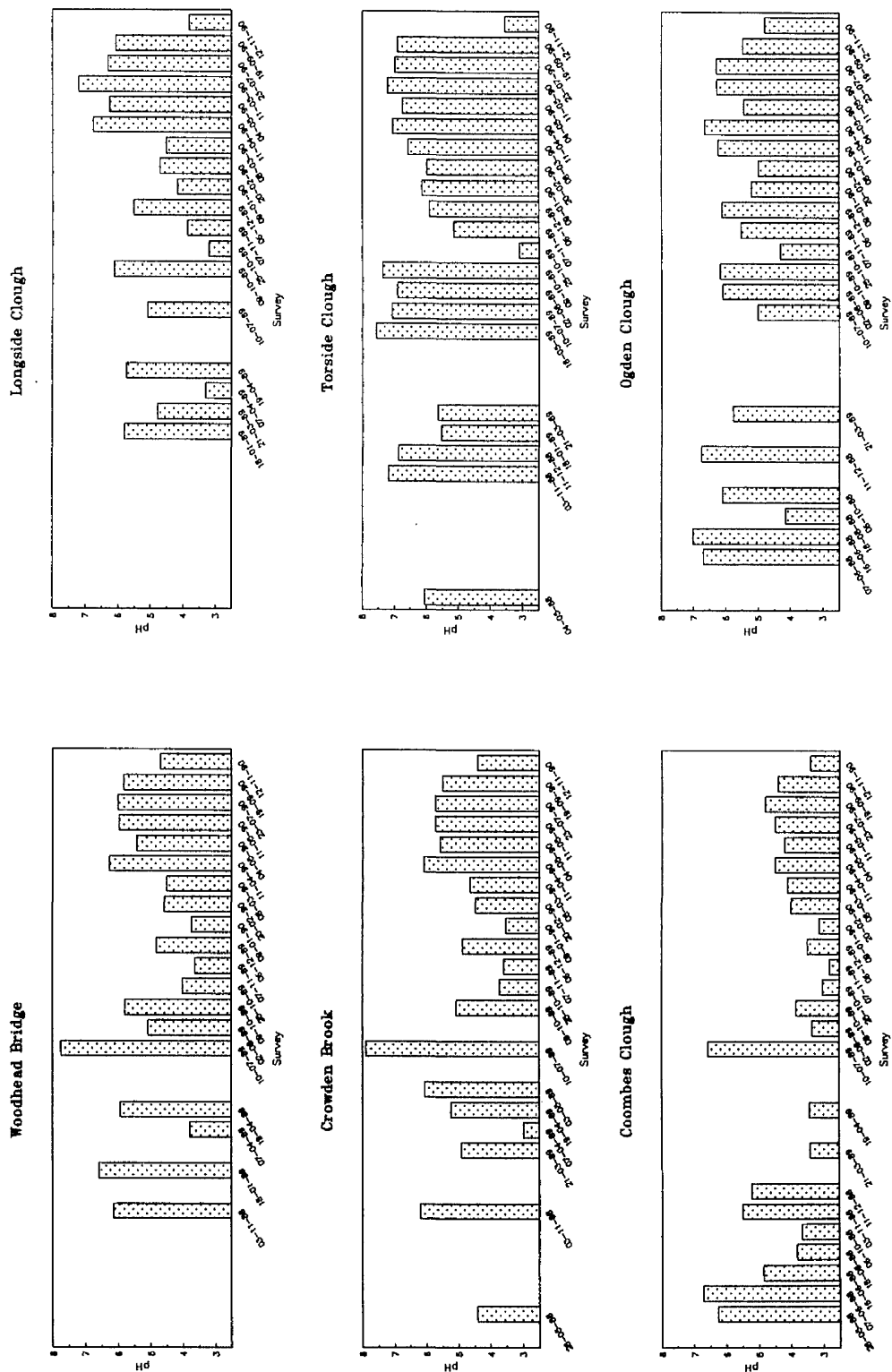
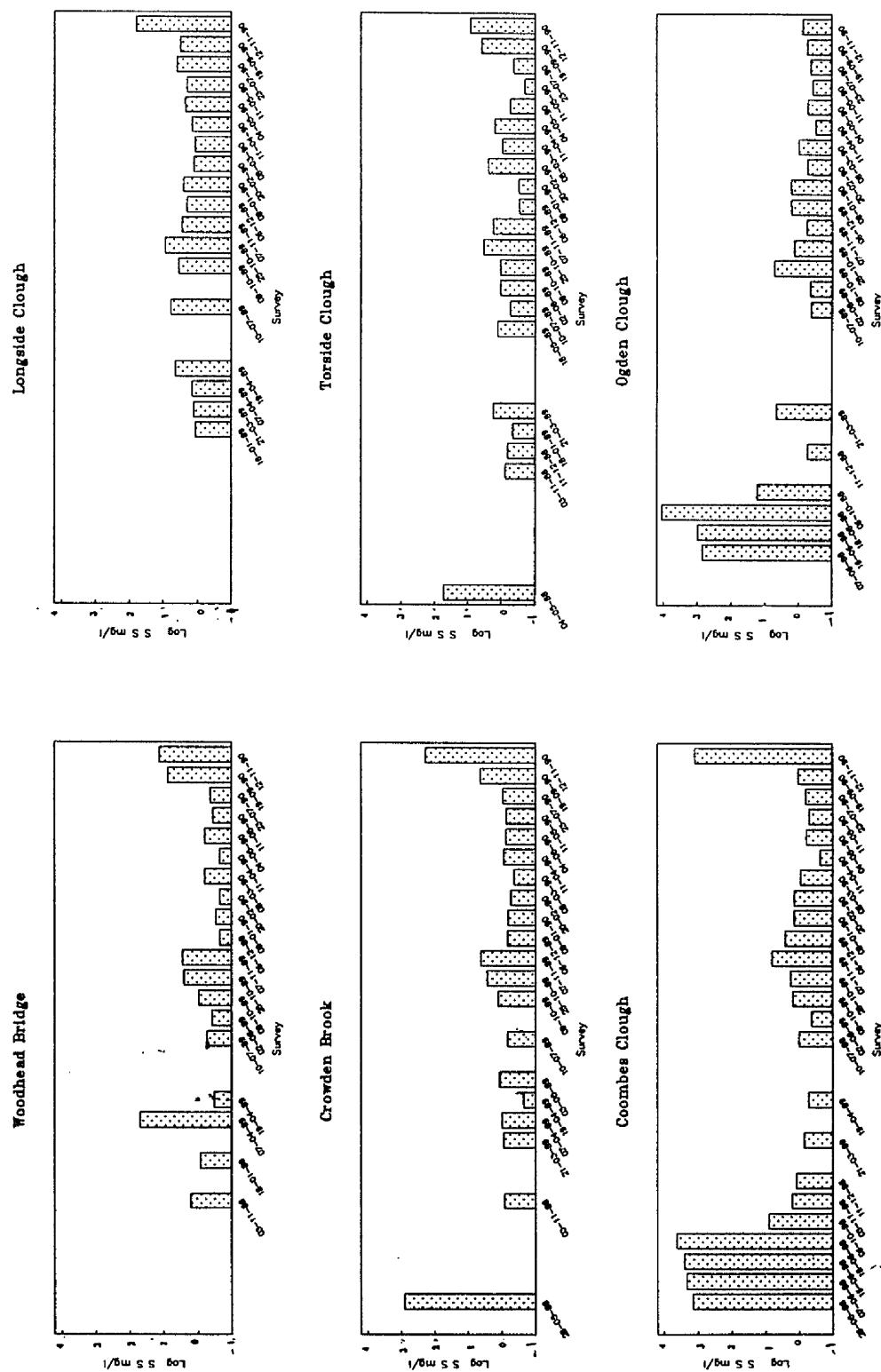


Fig 4.15 Variation of suspended solid observed during the study at the streams.



such as Coombes Clough.

The levels of the suspended solids in the streams were generally quite low and moderate or extremely high when there was a peak. It also varied from one stream to another. The highest peaks recorded during this study were at Coombes Clough, Ogden Clough and Crowden Brook in 1988. As mentioned before, the levels of the suspended solids in the streams were low most of the time, and the levels were consistently higher at Longside Clough than in the others when there were no peaks.

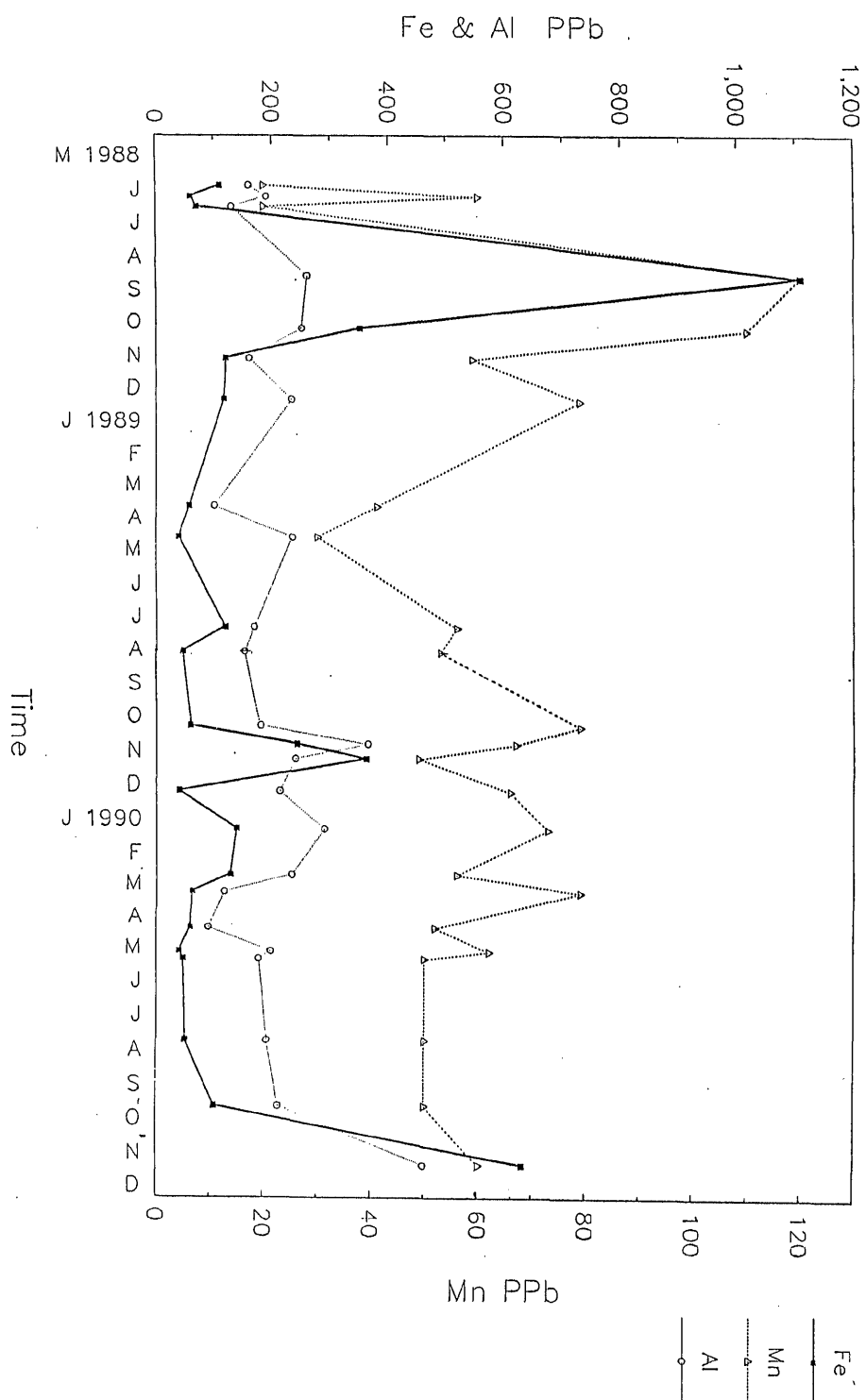
#### **4.8 Temporal variation of metals in the streams.**

##### **4.8.1 Temporal variation of metals, pH and suspended solids at Coombes Clough.**

###### **4.8.1.1 Iron, manganese and aluminium.**

Figure 4.16 illustrates the temporal variation of iron, manganese and aluminium concentrations at Coombes Clough during the period of May 1988 to December 1990. Sampling in this stream and Ogden Clough started earlier than in the other streams (summer 1988), because at the beginning of the study the surveys were carried out monitoring the spatial variation of the parameters along the length of the streams. During the summer of 1988 the levels of iron, manganese and aluminium were low, below the E.E.C standard with the exception of a small peak in the concentration of manganese in June, then in August the levels increased sharply for all the three metals. Then in the autumn the levels of iron decreased to around 100 PPb

Figure 4.16 Temporal variation of iron, manganese and aluminium at Coombes Clough.



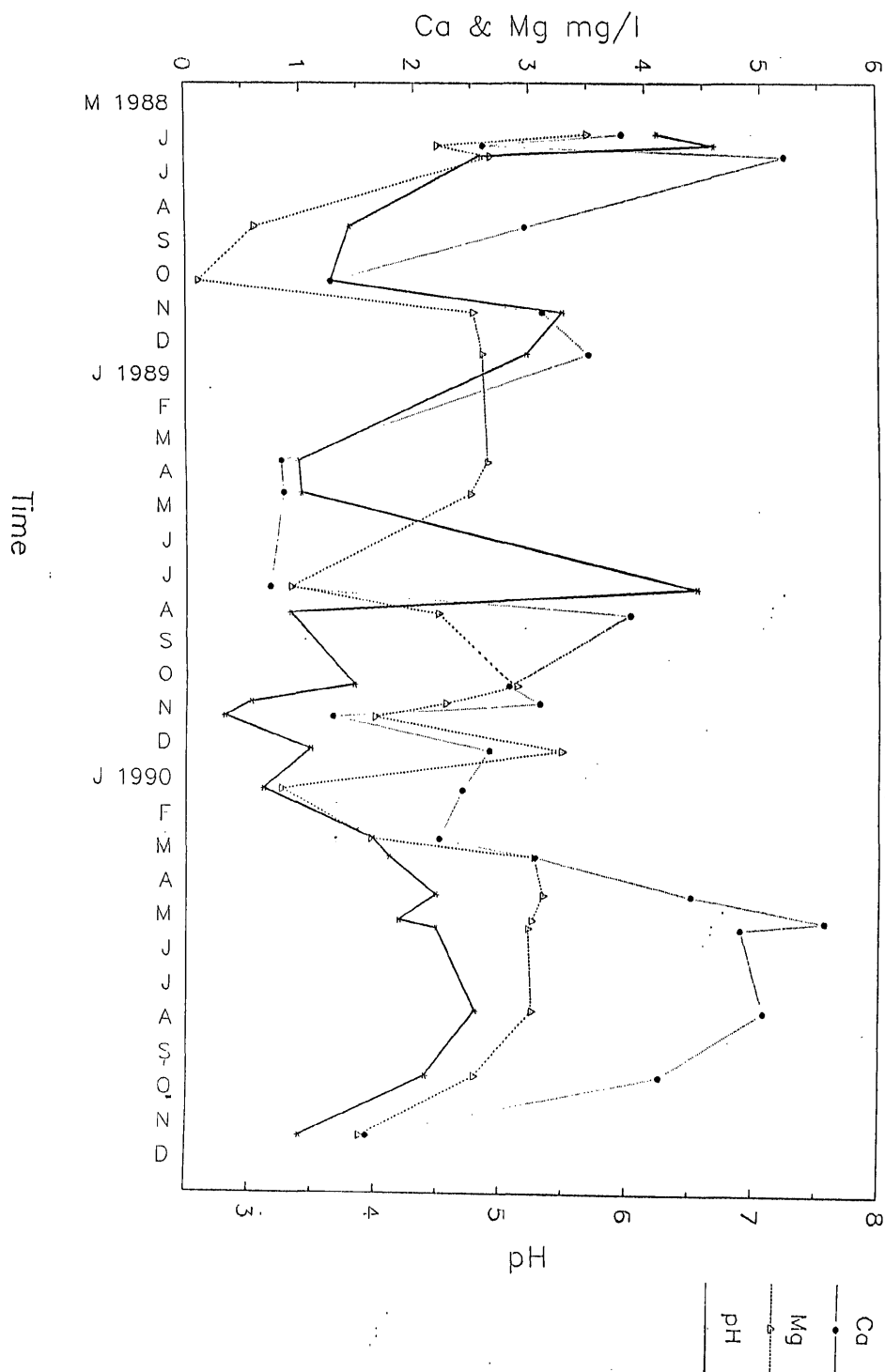


and remained low through the winter, spring and summer of 1989 with the exception of a small peak in July. Then again there was a peak in the levels of iron during the autumn of 1989 (in November); but the peak was not as high as the peak in the summer of 1988. The levels decreased again in the winter of 1990 and remained quite low and then increased again in the autumn to a peak; the peak was higher than the previous one in the autumn 1989 but not as high as the 1988 peak. Also after the peak of summer 1988 manganese levels decreased through the autumn and winter of 1989 with the exception of a peak in December until the levels reached their lowest of 30 PPb in May. Then the levels increased again until their highest in September and the level fell and rose erratically over a narrow range of 50-80 PPb through the autumn and winter of 1989-1990. In summer 1990 the concentration levelled off at 50 PPb then increased slightly in November. After the peak of 1988 the aluminium levels remained high then decreased in November and increased again in December, In the spring of 1989 (March) the levels decreased again and increased in April and remained high through the summer. In the autumn of 1989 (October) there was a peak of 360 PPb in the aluminium levels and then the levels remained high through the winter of 1990. The levels declined in the spring afterward; the levels increased again in the summer and remained quite high during the summer. Again in autumn 1990 there was another peak in the concentration of aluminium and the peak was higher than the peak in the previous autumn.

#### 4.8.1.2 Calcium, magnesium and pH.

Figure 4.17 illustrates the temporal variation of calcium, magnesium and pH at Coombes Clough. As the figure shows, calcium and magnesium were extremely low in the stream, below the E.E.C. standard. The levels of both calcium and magnesium fell markedly through summer 1988 and at the same time the pH does, then the levels of the three parameters rose through the autumn. Both the levels of calcium and pH declined through the spring of 1989, the calcium levels remaining low through the summer, while in July the level of the pH shot up to its highest of 6.56 but by August had declined sharply to 3.33 and remained extremely low during the autumn and early winter of 1990. In the spring of 1990 the pH levels increased slightly through the summer and then decreased again in the autumn. In August 1989 the levels of calcium increased again but then declined through the autumn and then increased again by the end of the autumn, decreasing slightly during the winter of 1990 and in the spring and the summer the level increased dramatically until it reached its highest-ever level of 5.53 mg/l. The levels of calcium remained high during the summer and then decreased again through the autumn. The magnesium levels after the declined in summer 1988, increased at the end of the autumn and then levelled off at around 2.5 mg/l during the winter of 1989 then decreased during the summer. Between July and Oct the levels of magnesium increased to about 3 mg/l but then decreased to about 1.7 by November. Then the level

Figure 4.17 Temporal variation of calcium, magnesium and pH at Coombes Clough



increased again in December but by January it fell again. During spring 1990 the level of magnesium increased to about 3 mg/l then the levels remain just the same during the summer but it had declined again by the autumn of 1990.

Generally the water in this stream was extremely acidic or moderate during the whole sampling period, also the concentrations of calcium and magnesium were extremely low; sometimes there was an increase in the concentration during the summer.

#### **4.8.1.3 Suspended solids.**

As shown in figure 4.18 there was a marked rise in the levels of the suspended solids to a peak during summer 1988. During the first four surveys the levels were at their highest ever levels of 2,821 mg/l but this had declined to less than 2 mg/l by November. Then it remained around this level until November of the following year 1989. There was a steady increase in the levels of the suspended solids through autumn followed by a gradual decline through the spring of 1990 until April, and then the levels increased slightly in the summer but there was a marked rise to a peak of 785 mg/l in November.

#### **4.8.2 Temporal variation of metal, pH and suspended solids at Crowden Brook.**

##### **4.8.2.1 Iron, manganese and aluminium.**

Figure 4.19 shows the temporal variation of iron, manganese and aluminium at Crowden Brook. From May 1988 to July 1989 the level of iron was low; only a slight fluctuation within the range of 40-150 PPb, then in October

Figure 4.18 Temporal variation of suspended solids at Coombes Clough.

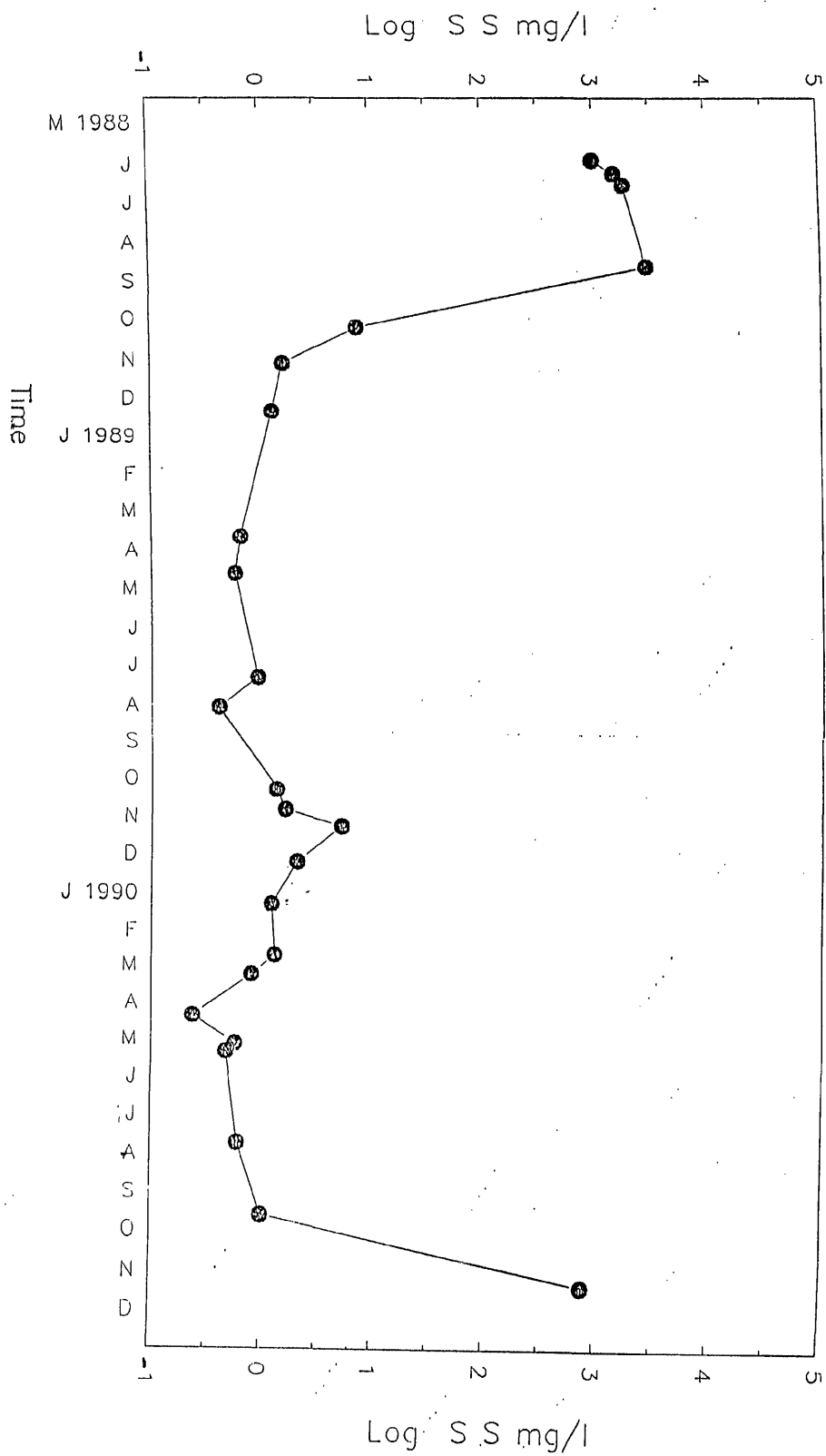
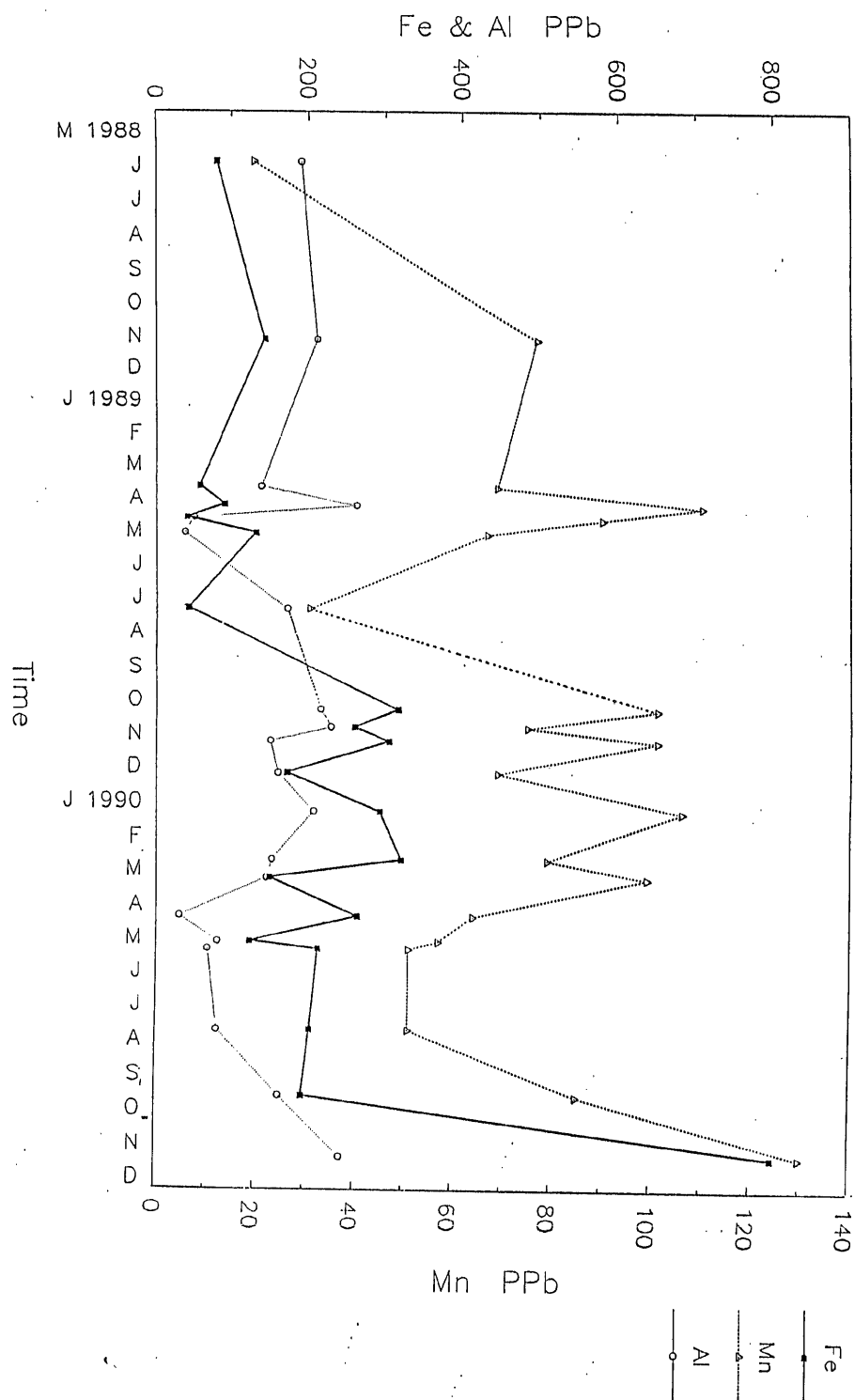


Figure 4.19 Temporal variation of iron, manganese and aluminium at Crowden Brook.



increased to just over 300 PPb and remained high during the autumn and early winter of 1989-1990 with a slight decrease in November. In the spring of 1990 the levels decreased slightly and fluctuated between the range of 150-260 PPb then remained quite high through the summer. Then there was a peak in the concentration up to 800 PPb during the autumn (in November).

The level of manganese in summer 1988 was low but it increased to 80 PPb in the autumn (in November) and remained high through the winter and spring of 1989. There was a peak in the level of manganese to 110 PPb in April but by the summer (July) it had declined to 30 PPb, then it increased markedly in the autumn to 100 PPb and remained high through the winter and the spring of 1990; fluctuating between the range of 70-100 PPb. By the summer the level had declined and remained high around 50 PPb then there was a dramatic increase in the level through the autumn of 1990 to its highest-ever level of 130 PPb. It appears that iron and manganese follow similar patterns in this stream.

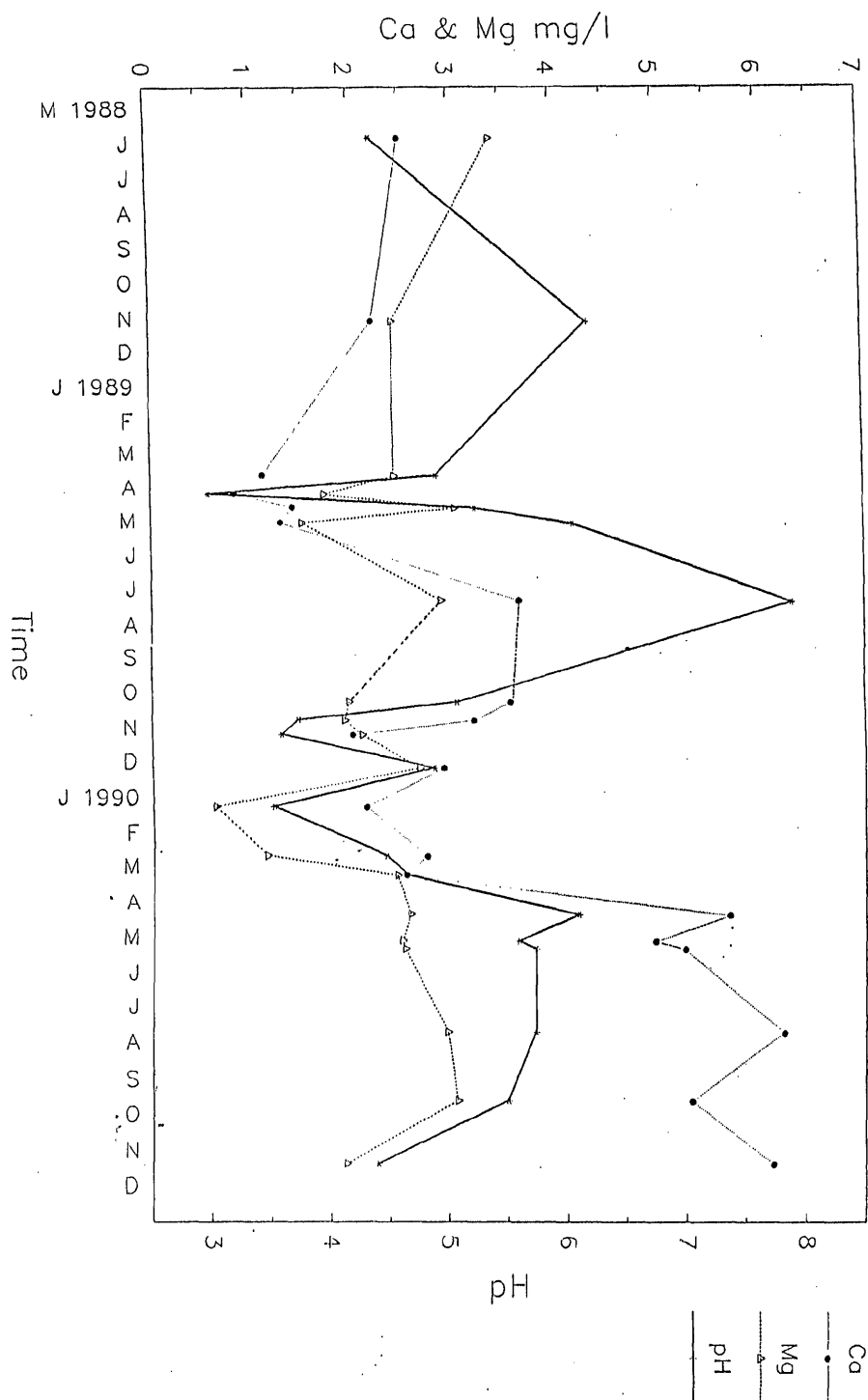
The aluminium levels were high during the summer and autumn of 1988, the levels decreased slightly in the spring of 1989 but then there was a peak of 260 PPb in the beginning of April; by the end of the month it declined to 50 PPb then it remained low through the summer. In July the level increased again and remained high through the autumn and winter of 1989-1990, then it declined through the spring and remained low during the summer 1990. The level increased gradually again through the autumn to 240 PPb.

#### 4.8.2.2 Calcium, magnesium and pH.

As shown in figure 4.20, calcium, magnesium and pH in the Crowden Brook followed almost the same pattern as in Coombes Clough, by having in general higher levels of calcium, magnesium and pH during the summer, also generally the levels of calcium, magnesium and pH were low as in Coombes Clough. Between May and November 1988 the levels of calcium decreased slightly, then there were further decreases through the spring of 1989. In April the levels started to increase steeply until by July the levels had reached around 3.6 mg/l, and then the levels remained high throughout the summer. In the autumn of 1989 they declined to around 2 mg/l, then there was a fluctuation in the levels during the winter of 1990 over the range of 2-3 mg/l. By March again the level of calcium increased to 5.2 mg/l, then the level remained just the same through the summer and autumn of 1990. It seemed to be that magnesium followed almost the same general pattern as calcium. As mentioned before, the level of pH in this stream were low with the exception that there was a sharp peak in the levels to pH 7.89 in July 1989. The water was extremely acidic (2.99 pH units) in spring 1989 (April), then the levels increased through the summer. The pH of the water sometimes dropped sharply and sometimes increased sharply. In general, it was above 5 during the summer time except during summer 1988 and below that in winter time. It appears that there was a seasonal and year on year variation in the level of these parameters.



Figure 4.20 Temporal variation of calcium, magnesium and pH at Crowden Brook.



#### **4.8.2.3 Suspended solids.**

Temporal variations of suspended solids at Crowden Brook are shown in figure 4.21. As the figure shows, the temporal variations of the suspended solids followed a similar temporal pattern to that for Coombes Clough except that the levels of the peaks were smaller. In general, the levels were low during the whole sampling period, but there were occasional peaks in the concentration of the suspended solids and although these peaks occurred mostly during the autumn and winter with the exception of the summer peak of 1988, the amounts of the peaks varied from year to year.

#### **4.8.3 Temporal variation of metals, pH and suspended solids at Woodhead Bridge.**

##### **4.8.3.1 Iron, manganese and aluminium.**

Data for metals in this stream from May to November 1988 are not available, but the temporal variation of iron, manganese and aluminium from November 1988 until November 1990 are shown in figure 4.22. As the figure shows, the level of iron was low during the autumn of 1988, then it increased through the spring of 1989 to a peak of 300 PPb (in March) and then it declined through the summer until it reached 40 PPb. The level increased again through the autumn (in November) to a peak; the peak was similar to the previous peak at the end of the spring and then the levels dropped to 40 PPb in December. During the winter of 1990 the level rose again to around 200 PPb and remained high through the winter, then it declined through the spring and levelled off at around 100 PPb in the summer. During the

Figure 4.21 Temporal variation of suspended solids at Crowden Brook.

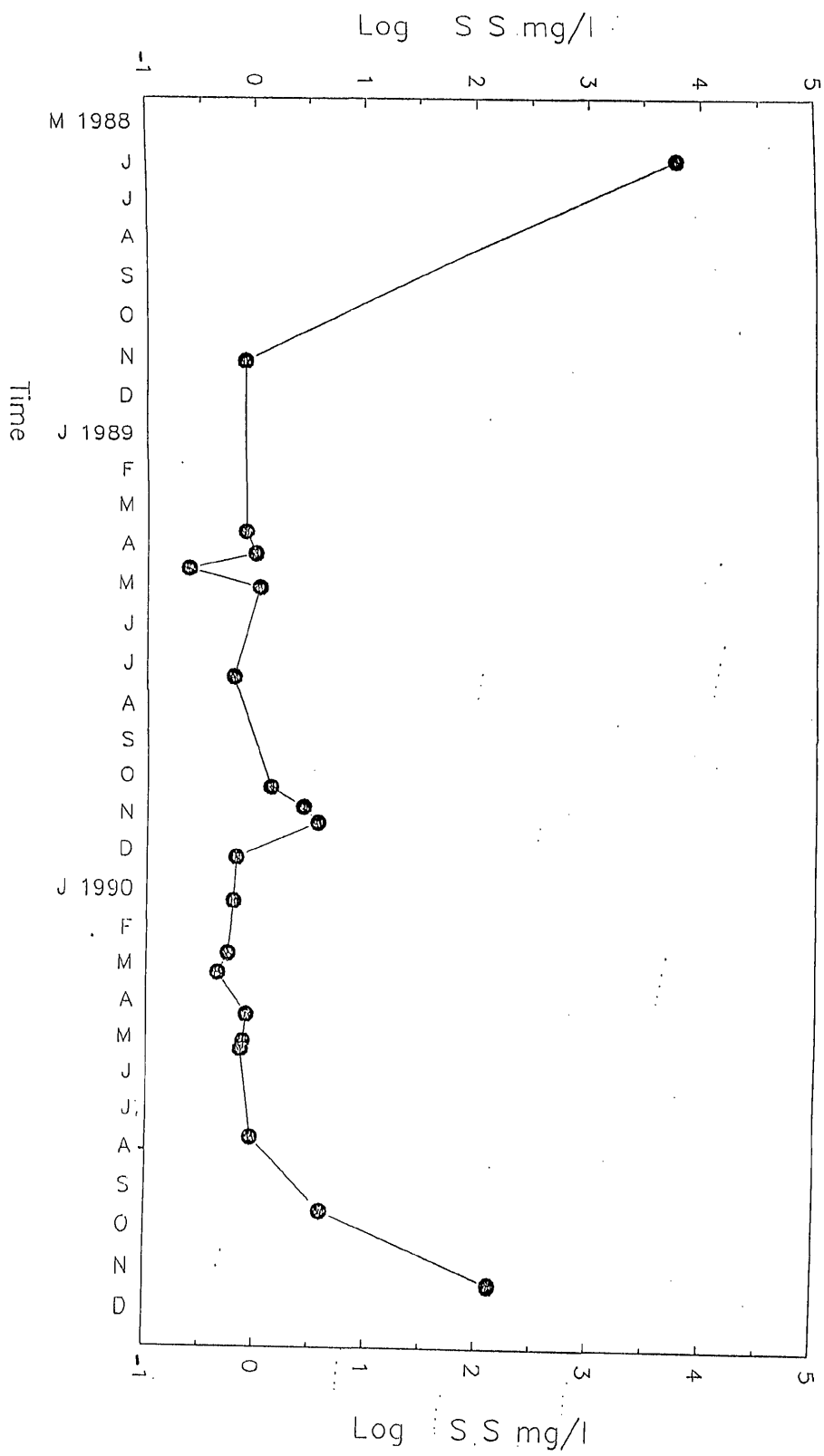
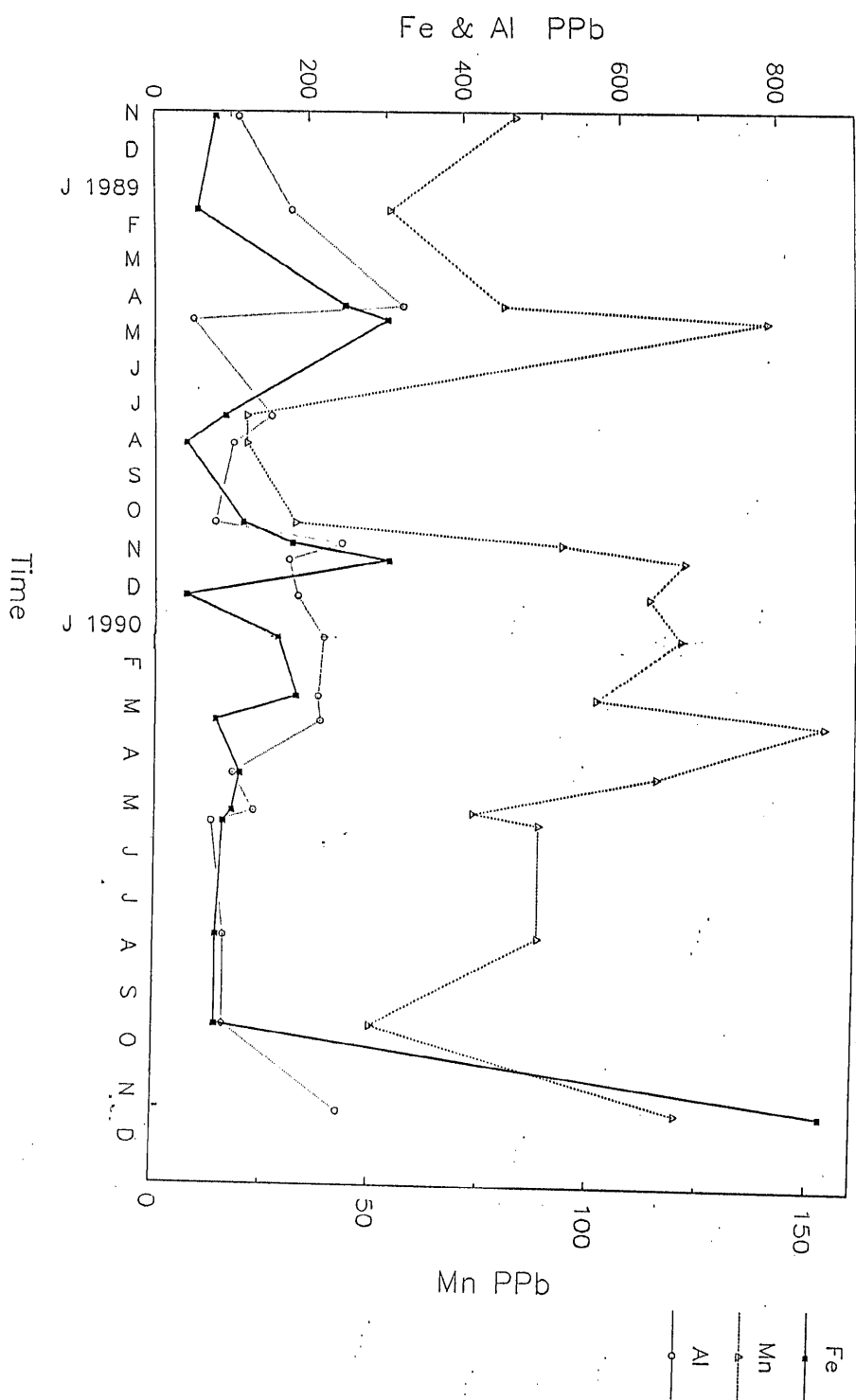


Figure 4.22 Temporal variation of iron, manganese and aluminium at Woodhead Bridge.

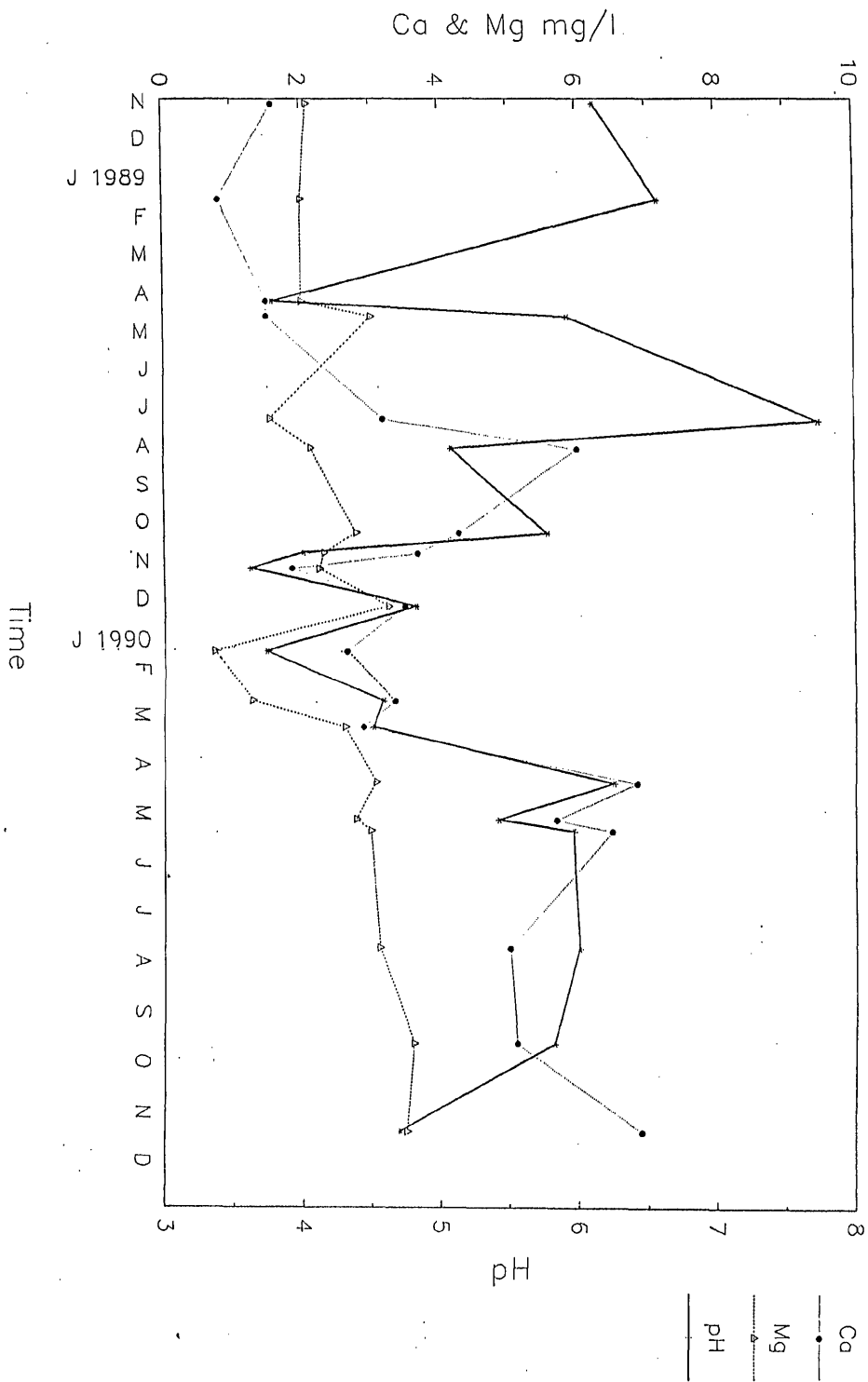


autumn of 1990 there was a jump in the levels up to 860 PPb (in November). Manganese appeared to follow the same pattern as iron with exception that there was a peak in the spring of 1990 in the manganese concentration while there was not in the iron level. The level of manganese was always high, above the E.E.C standard with the exception of the period between July and October 1989 the level was quite low. Also the level of aluminium was high, In November 1988 the level increased dramatically to a peak of 320 PPb by April 1989, then the level decreased by the end of April. Then it rose slightly again in July and fell slightly by the end of the summer. In the autumn the level increased again to 240 PPb then the levels remained high through the winter of 1990 before declining at the beginning of the spring. During summer 1990 the level of aluminium remained around 100 PPb then again in the autumn the levels increase to 240 PPb (in November). Generally the levels were high in the autumn and winter and lower in summer.

#### 4.8.3.2 Calcium, magnesium and pH.

Figure 4.23 illustrates the temporal variation of calcium, magnesium and pH. As the figure shows the level of magnesium levelled off at around 2 mg/l through the autumn and winter of 1988-1989 and in the spring (April 1989) there was an increase in the level to 3 mg/l. The level of magnesium declined through the summer to 1.55 mg/l in July, again they increased slightly during the autumn and until December 1989; then the level dropped to 0.7 mg/l

Figure 4.23 Temporal variation of calcium, magnesium and pH at Woodhead Bridge.



in the winter of 1990 (in January). After that the level rose through the spring, for the last eight months there has been an upward trend in the level of magnesium.

Calcium and pH appear to follow seasonal, and year on year variations, similar to the patterns for Coombes Clough and Crowden Brook. The levels of these parameters distinctly increased to a peak during the summer and then decreased in the winter (some times sharply). Generally the levels of calcium and magnesium were extremely low.

#### **4.8.3.3 Suspended solids.**

Figure 4.24 illustrates the temporal variation of suspended solids at Woodhead Bridge, As the figure shows, the levels in this stream were lower than in the previous streams. However it followed the same general pattern; that is: suspended solids levels remained relatively low but the levels increased significantly in some surveys. This increase appeared to follow seasonal variations, usually during the autumn and winter there was a peak in the concentration but it varied from year to year.

#### **4.8.4 Temporal variation of metals, pH and suspended solids at Longside Clough.**

##### **4.8.4.1 Iron, manganese and aluminium.**

Figure 4.25 shows the temporal variation of iron, manganese and aluminium at Longside Clough. The concentrations of iron, manganese and aluminium in this stream were generally high during the whole of the sampling period, with the exception of two surveys in the spring of

Figure 4.24 Temporal variation of suspended solids at Woodhead Bridge.

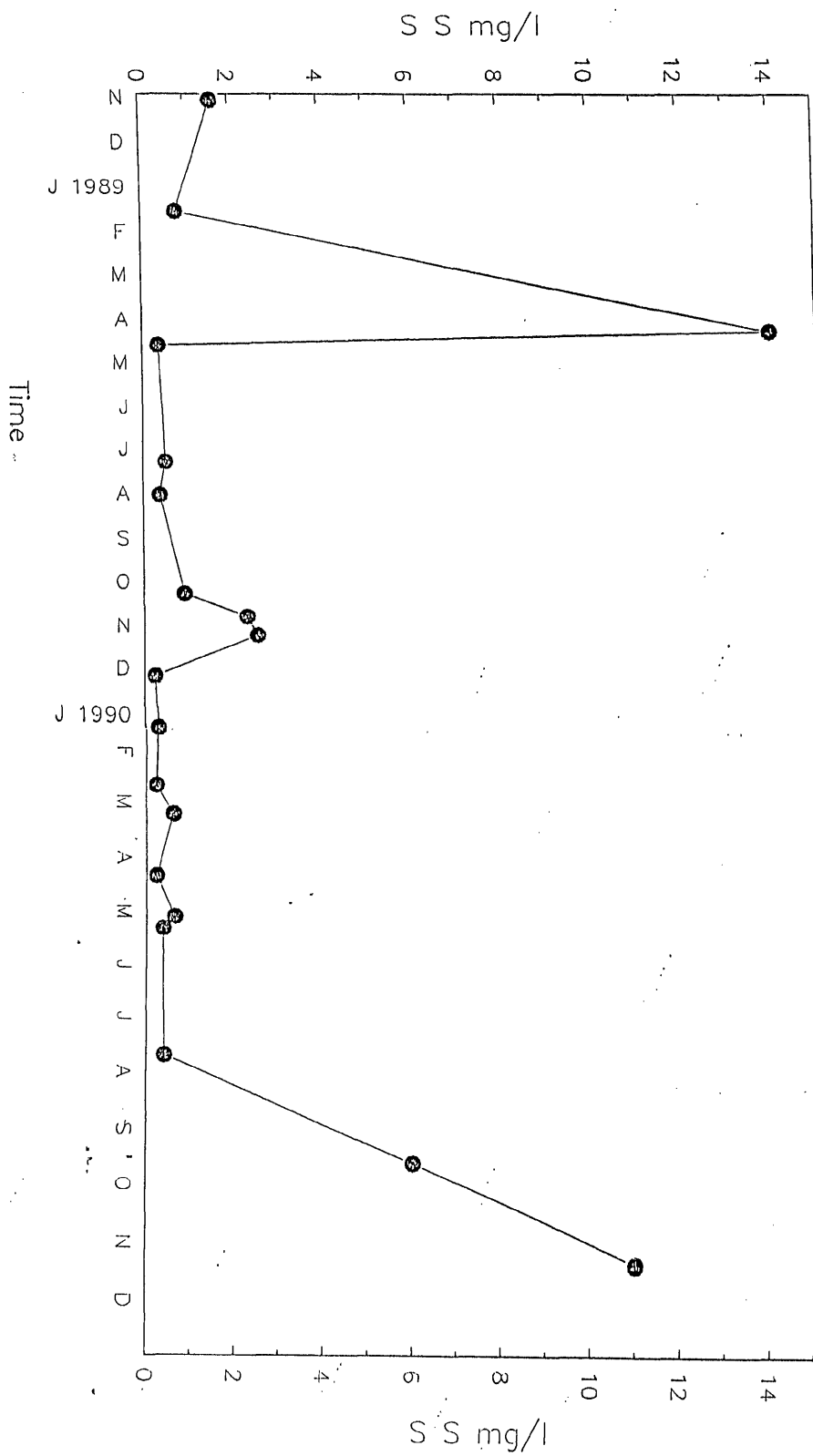
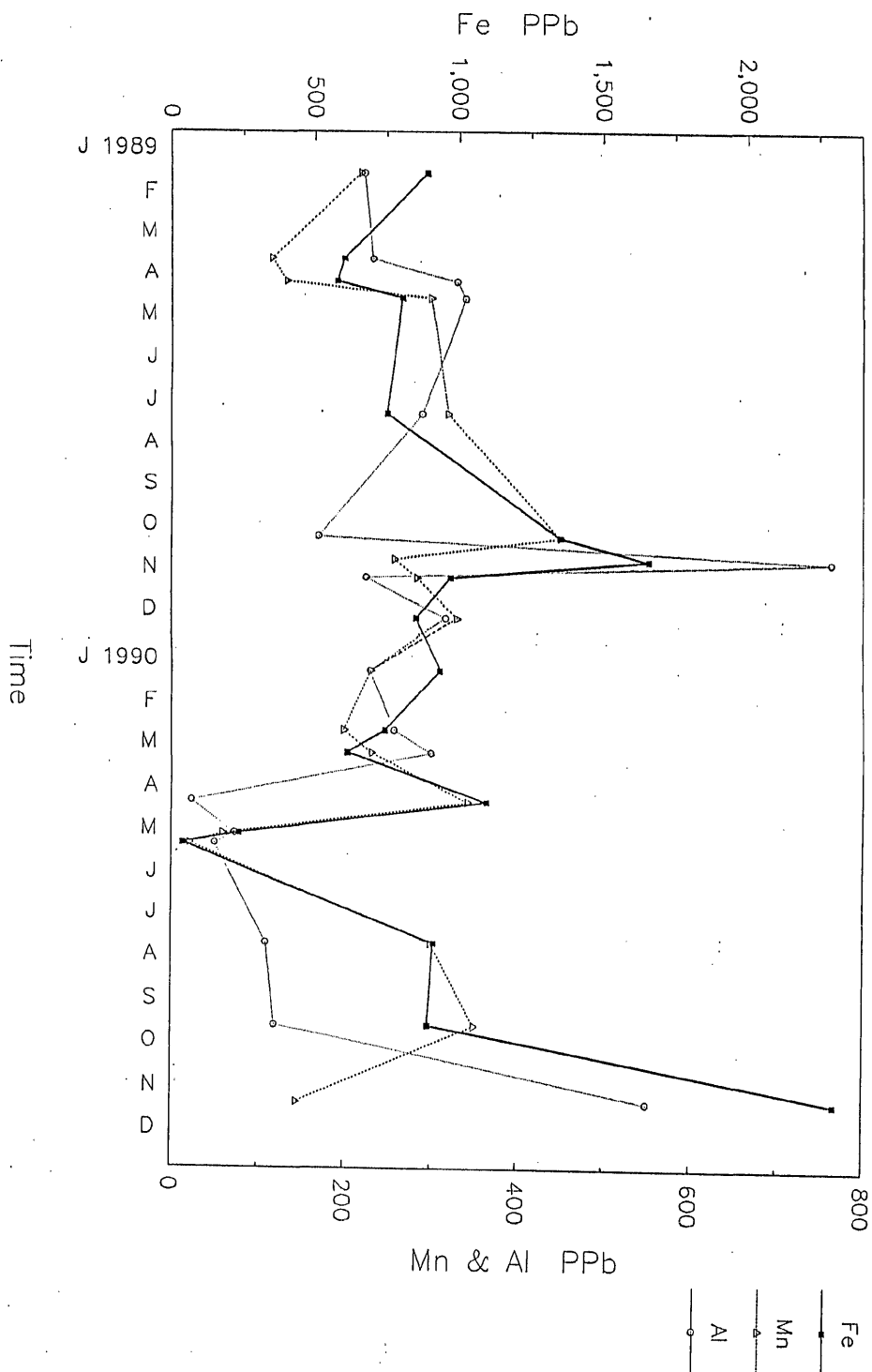




Figure 4.25 Temporal variation of iron, manganese and aluminium at Longside Clough.



1990. At the beginning of the survey at Longside Clough, in January 1989, the iron levels decreased through the spring from 890 PPb to around 600 PPb. In April it increased again to 800 PPb and there was a fairly slight decrease in the summer. However, between July and October the level shot up to a peak of 1,600 PPb, the highest level of the year. In November the level dropped sharply to around 900 PPb and continued to decline gradually through the winter and spring of 1990 with the exception of a peak in April and then there was a sharp drop in May to around 40 PPb. Then the level started to increase steeply with a very slight decrease in September in the summer months through the autumn until it reached its highest ever peak of 2,300 PPb at the end of the year. The peaks in the concentration of iron occurred on a similar time, in the autumn, in both years, but the peak in 1990 was higher than that in 1989.

Similar peaks at similar times occurred with aluminium but not with manganese. The highest peak for the aluminium however, was in 1989 as compared with that of the iron, which was in 1990. The levels of both the iron and the aluminium were higher in the autumn than in the summer. In the summer of 1990, where the level of iron was at its lowest, the level of the other metals were also low.

The manganese seem to show a similar patten to iron with the exception of time the autumn. When there was a peak in the concentration of iron but there was not always a peak in the concentration of manganese. In general the

concentration of manganese varied between 200-300 PPb throughout the year. The figure shows that the level of iron, manganese and aluminium were high throughout the sampling period with iron being especially high.

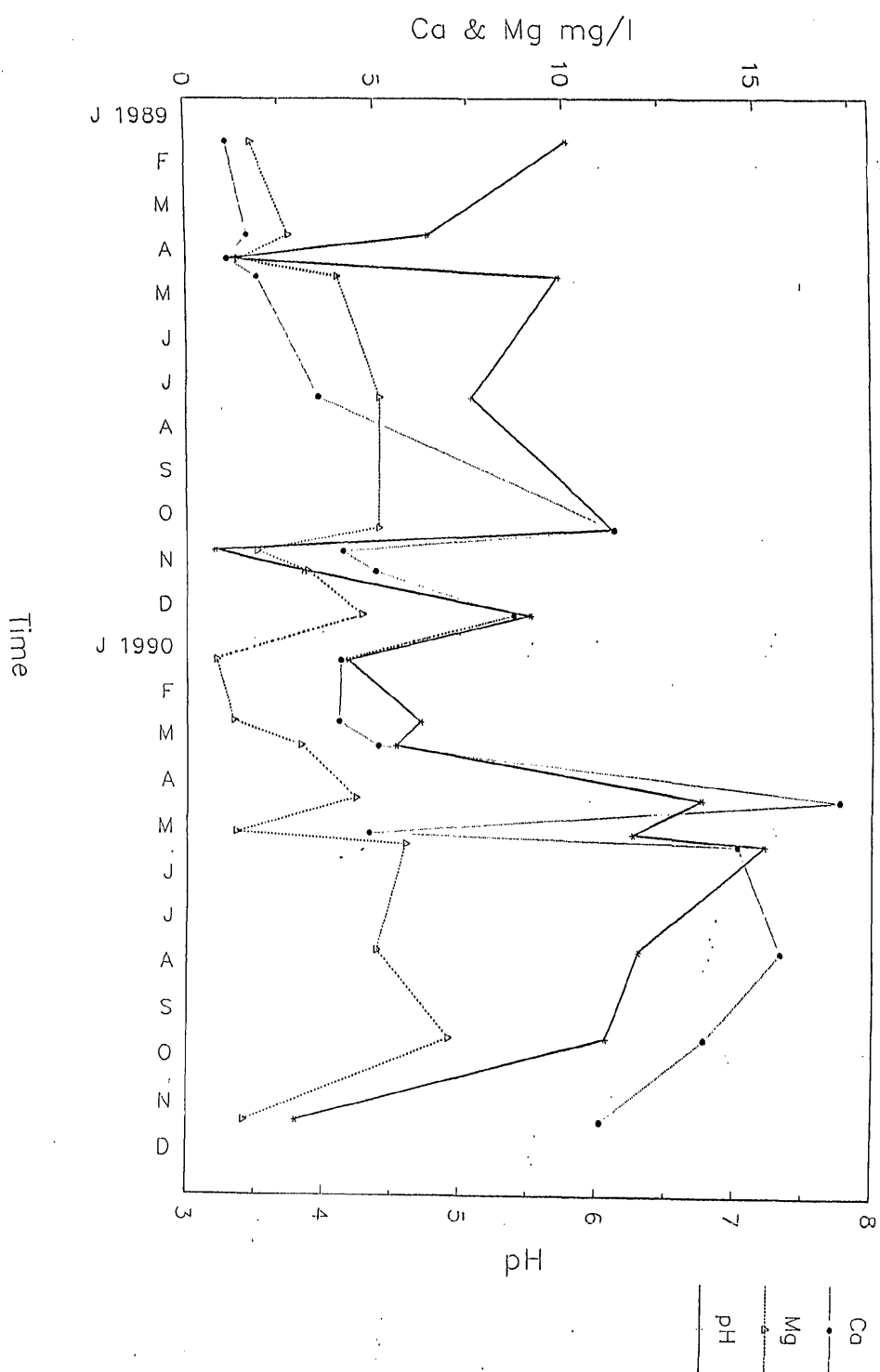
#### 4.8.4.2 Calcium, magnesium and pH.

Temporal changes in calcium, magnesium and pH levels at Longside Clough are shown in figure 4.26. As with the previous streams the concentration of calcium and magnesium were generally low. The pH also was generally low, sometimes extremely acidic, especially during the autumn.

At the beginning of the survey the pH was moderate, around 6 pH units, then the level dropped sharply to 3.3 pH unit becoming extremely acidic in April 1989. Later in the same month there was a sharp increase back to a moderate level of around 6 pH unit, staying between 5 and 6 through the rest of the spring and summer until October when the level dropped sharply reaching as low as 3.2 towards the end of the month. At this point the level rose steadily to around 5.5 in the winter, dropping to around 4 in January, remaining at this level through the spring of 1990. By mid-May the level had increased to around 7.2, the highest level recorded in the study. The level of pH during the summer of 1990 was moderate but by November it was extremely acidic.

Both magnesium and calcium seems to follow a similar pattern to the pH, the highest levels especially that of calcium, being during the summer of 1990. There was a variation in the concentration of these parameters from

Figure 4.26 Temporal variation of calcium, magnesium and pH at Longside Clough.



year to year and from season to season, and seasonal fluctuation. The levels of these were slightly higher in 1990 than in 1989.

#### **4.8.4.3 Suspended solids.**

Figure 4.27 shows the temporal variations of suspended solids at Longside Clough. During the two years of survey of this stream the concentration of the suspended solids was quite low, varying between 1-5 mg/l except for peaks in the autumn of both years, reaching as high as 8.9 mg/l in 1990.

At the beginning of the survey, in January 1989, the level of suspended solids was around 1 mg/l and remained quite low until April when it rose steeply to around 5 mg/l and stayed around that level during the summer, dropping to 3.4 mg/l in October. The November peak up to 7.2 mg/l, then occurred briefly, dropping to a low level in the winter and spring. In 1990 the level of suspended solids followed a similar pattern to the previous year except that the rise in April was more gradual, reaching only 3.3 mg/l followed by a slight decrease in October and then the November peak up to 8.9 mg/l. In general the levels of suspended solids in this stream were slightly higher than in the other streams except when were peaks in the levels in the other streams.

#### **4.8.5 Temporal variation of metals, pH and suspended solids at Torside Clough.**

##### **4.8.5.1 Iron, manganese and aluminium.**

Figure 4.28 illustrates the temporal variation of

Figure 4.27 Temporal variation of suspended solids at Longside Clough.

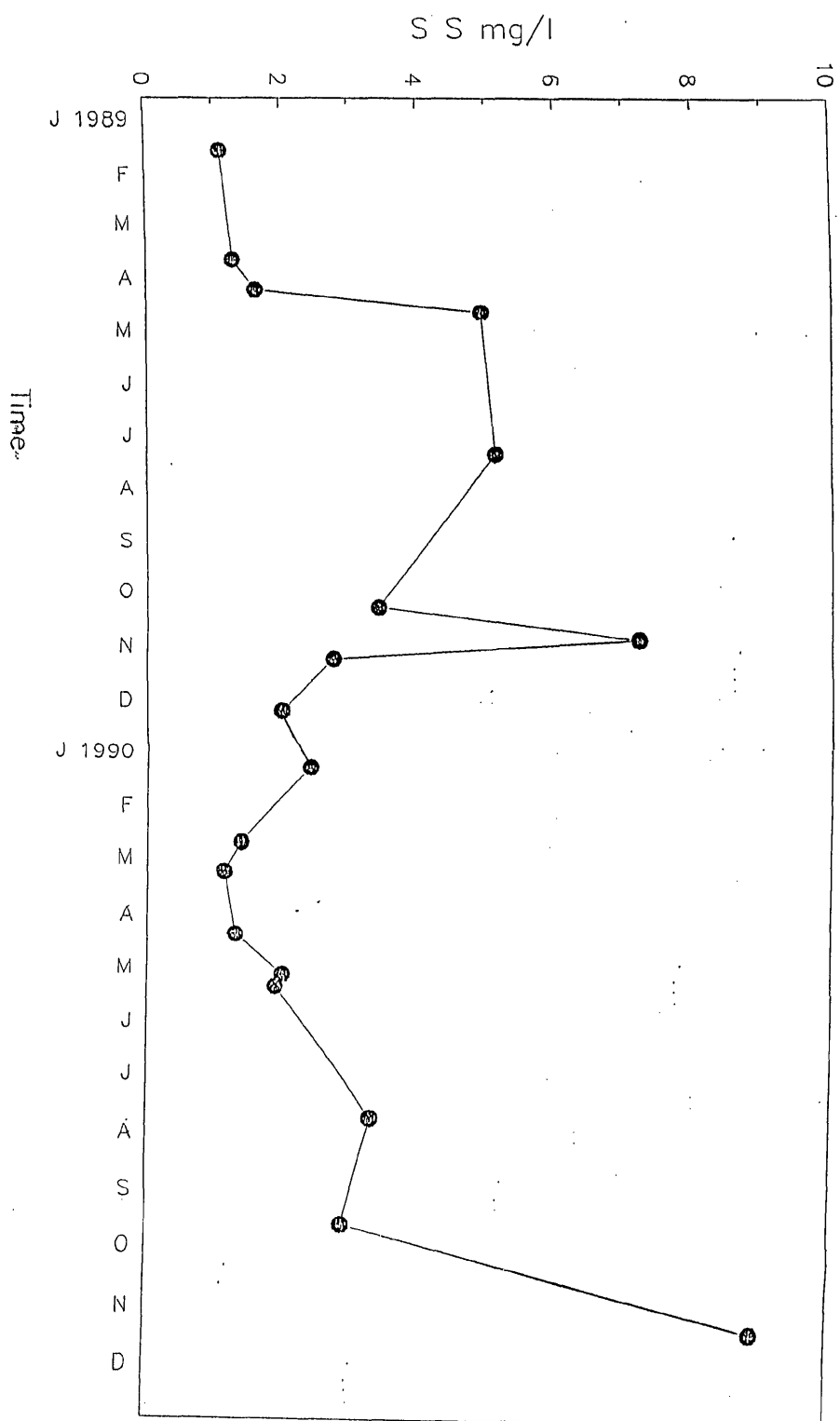
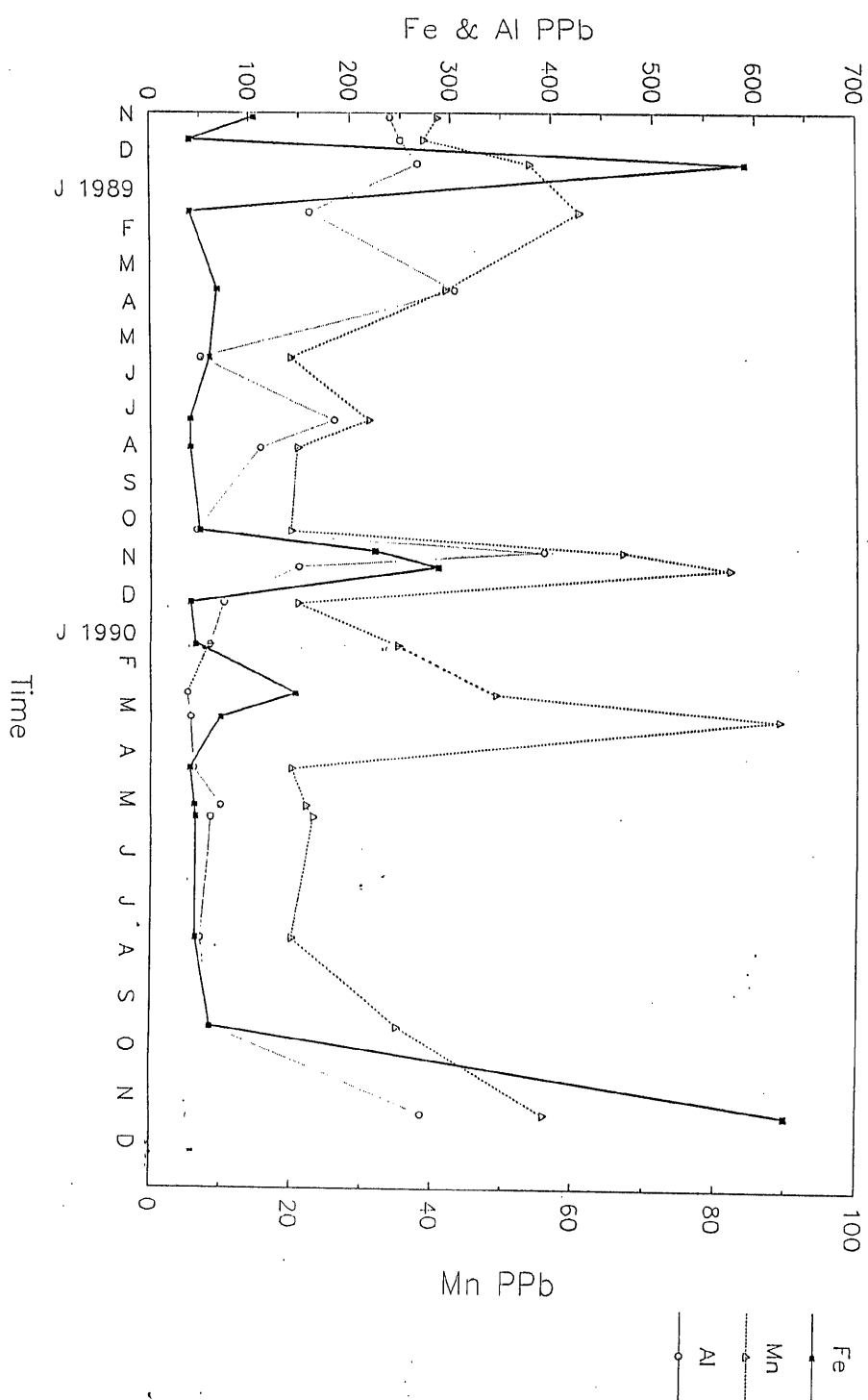


Figure 4.28 Temporal variation of iron, manganese and aluminium at Torside Clough.



metals during the sampling period at Torside Clough. In general the concentration of iron, manganese and aluminium in this stream were low during the sampling period with the exception of several surveys throughout the study.

At the beginning of the survey in November 1988, the iron level was around 100 PPb. Then the level decreased to around 60 PPb, followed by a sharp increase in December to around 600 PPb. By January the level had dropped to around 40 PPb and remained low through the spring and summer until the end of October 1989 when there was a peak to around 300 PPb. The level then dropped again in December and remained low in January until another small peak of 140 PPb occurred in February followed by a drop in the level to around 70 PPb in March. Concentration of iron then declined in the spring, through into the summer when it levelled at around 40 PPb. In November 1990 there was an extreme rise in the level of iron to 630 PPb.

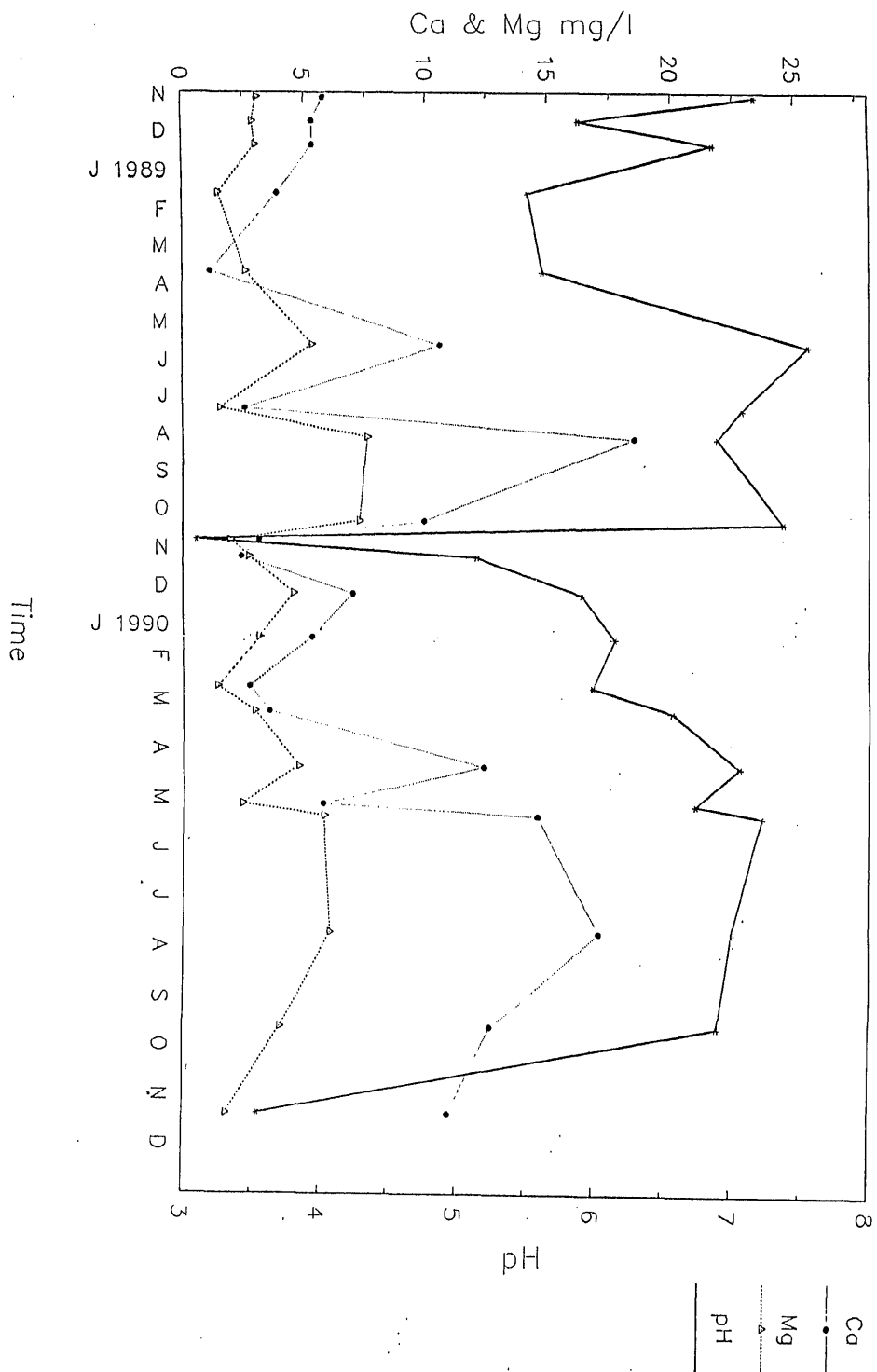
Manganese follows a similar pattern to iron with the exception of a slight increase in the concentration in July 1989. Aluminium on the other hand, has similar peaks the autumn of each year, but there were also several rises and falls during the spring and summer 1989. The figure shows that the peaks in the concentration usually occur during the autumn and winter, as with the other streams.

#### 4.8.5.2 Calcium, magnesium and pH.

Figure 4.29 illustrates the temporal variation of calcium, magnesium and pH at Torside Clough. In general the levels of pH were moderate during the whole study with the



Figure 4.29 Temporal variation of calcium, magnesium and pH at Torside Clough.



exception of two sample periods in the autumns of 1989 and 1990. The level of calcium was higher than it was in the previous streams. The concentration of magnesium was similar in the previous streams.

At the beginning of the survey in November 1988 the level of the pH was higher than in the previous streams, being around 7 pH units. In the winter months of 1988/1989 the level dropped to less than 6 pH units but by the spring started to rise and reached its highest level of the surveys, 7.56 pH units, in April. The level remained around 7 pH units through the summer and into the autumn and then there was a sharp drop to 3.1 pH units, the lowest level of the surveys, in late October 1989. The level started to rise and continued to rise until May with two slight decreases in February and late April. The level remained around 7 pH units until September when it dropped to 3.55 in November 1990.

Both calcium and magnesium follow a similar pattern to pH, with a similar increase in the concentration of calcium and magnesium occurring at a similar time as the pH, in both years especially with magnesium. In the autumn of both years, where the level of pH was at its lowest, the levels of calcium and magnesium were also low. There is a variation in the level of these parameters from year to year and from survey to survey. The level of pH in this stream was generally higher than in the previous ones.

#### **4.8.5.3 Suspended solids.**

Temporal changes in the suspended solids at Torside

Clough are shown in figure 4.30. As the figure shows, generally the levels were low at this stream. Some rapid increases and decreases between November 1988 to October 1989 between the range of 0.5-2 mg/l. There was a slight jump in mid October 1989, then the levels rose and fell until August 1990. The levels then increased gradually until they reached the highest observed levels for the year. The figure shows that the levels of the suspended solids were low the summer, but it seems that the peak in the levels occurs mostly during the autumn and winter.

#### 4.8.6 Temporal variation of metals, pH and suspended solids at Ogden Clough.

##### 4.8.6.1 Iron, manganese and aluminium.

Figure 4.31 shows the temporal variation of the levels of metals at Ogden Clough. As the figure shows, the concentration of iron is generally low through all the surveys. On only three occasions there was a marked increase in concentration. That was during the period of January - October 1988. As was mentioned before, sampling in this stream and Coombes Clough started earlier than in the other streams (summer 1988), because at the beginning of the study the surveys were carried out monitoring the spatial variation of the parameters along the length of the streams. At the beginning of the summer of 1988 (7th of June) the level of iron was 40 PPb. By the middle of the month, the level jumped to 340 PPb and then the level continued to increase sharply through the summer until it reached 560 PPb in October. In December the level dropped

Figure 4.30 Temporal variation of suspended solids at Torside Clough.

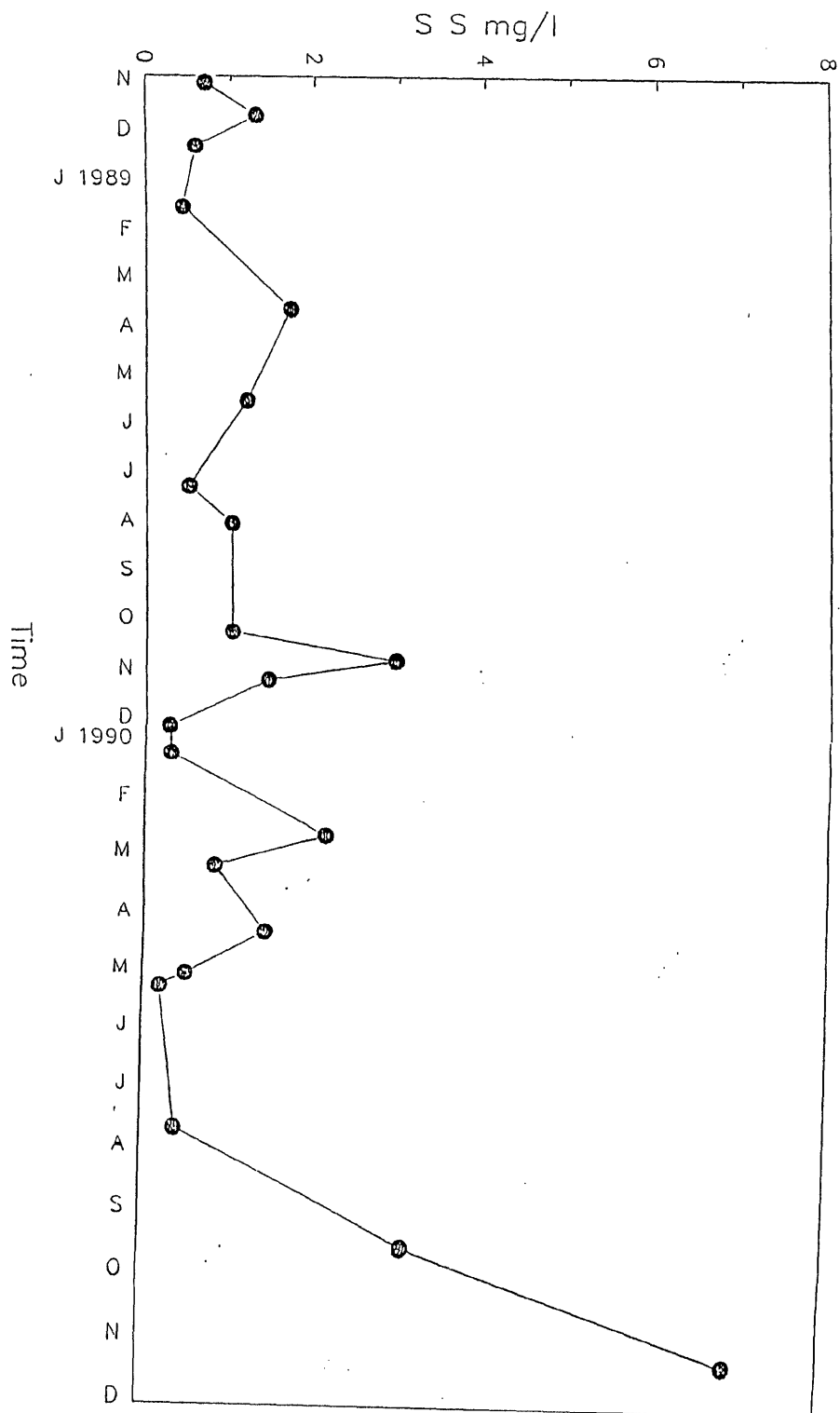
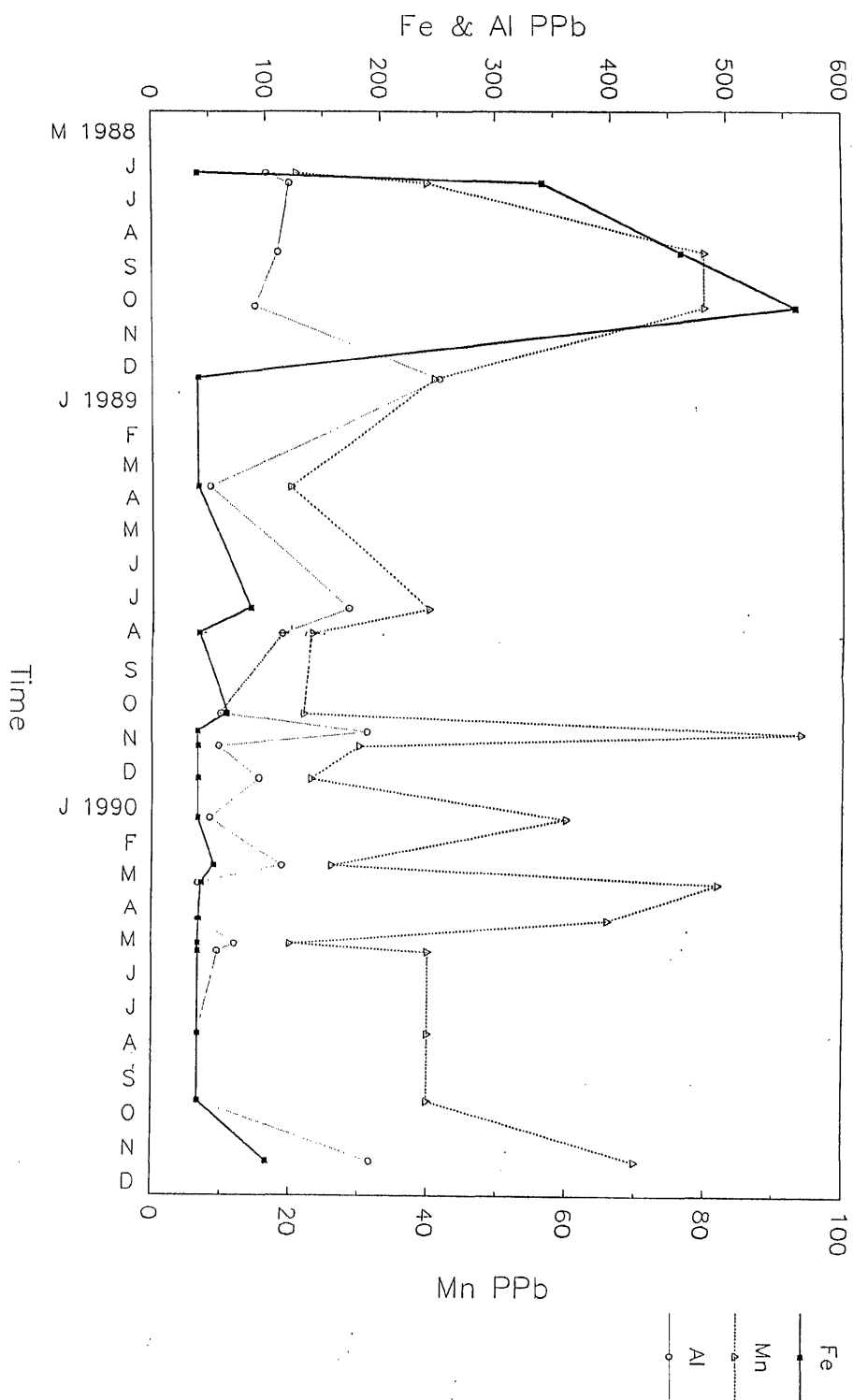


Figure 4.31 Temporal variation of iron, manganese and aluminium at Ogden Clough.



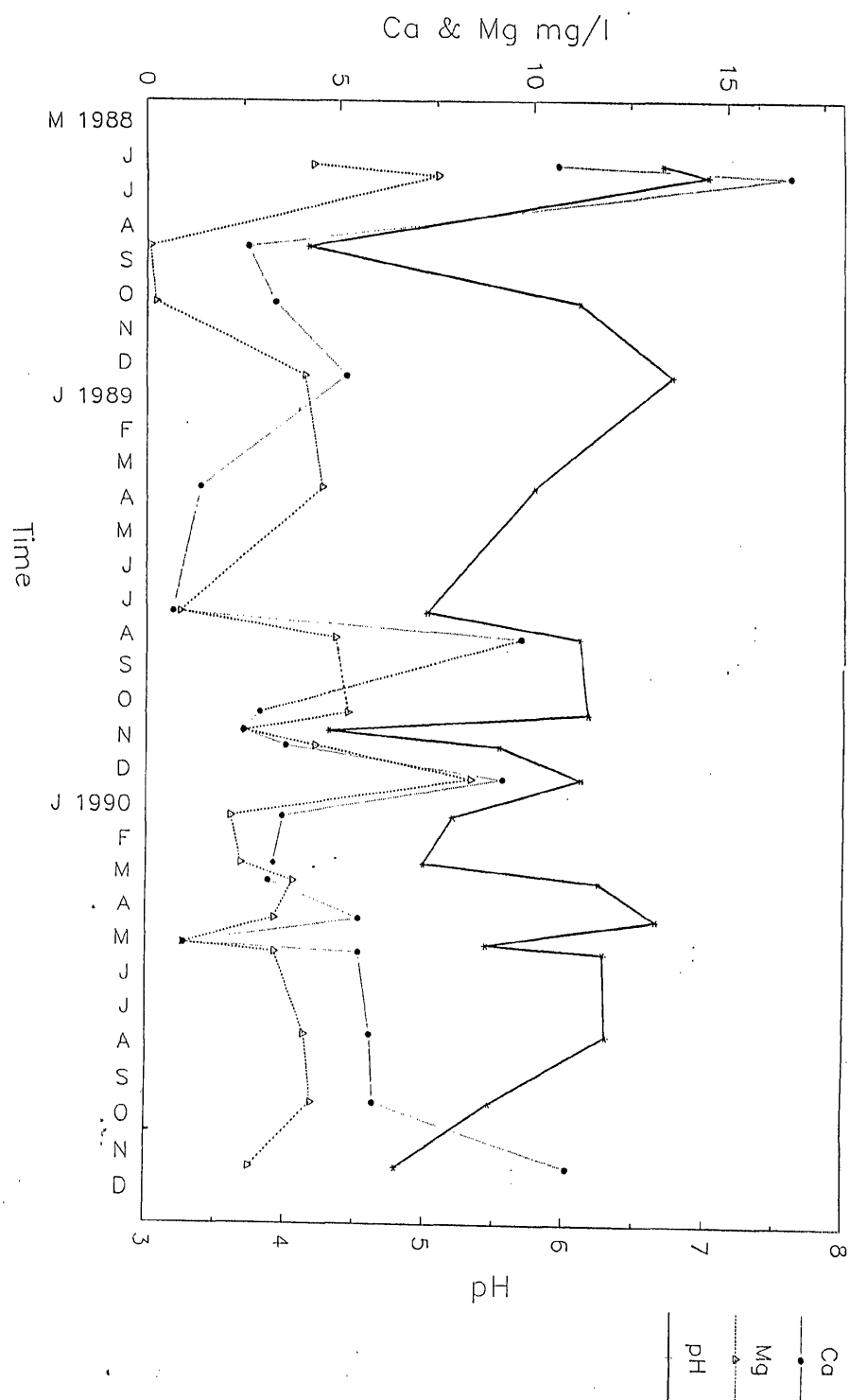
to around 40 PPb and remained low throughout 1989 and 1990 with the exception of a slight increase to 80 PPb in July 1989 and to 100 PPb in November 1990.

Manganese follows a similar pattern to iron, repeat of similar peak in the autumn of 1988 and in July 1989 with the exception after October 1989. In October 1989 there was a peak in the concentration of manganese to 90 PPb, but there was not with iron. During the winter and spring of 1989/1990 there was a fluctuation in the levels between 20-80 PPb, in the summer of 1990 the level levelled at 40 PPb and in November the level increase to 70 PPb. Generally aluminium levels seemed not to follow a clear pattern, the concentration rose and fell between the range of 100-200 PPb and the high level usually occurred during the autumn and winter as with the other streams. In comparison with the other stream the concentration of iron was low with an exception in 1988. As the figure shows the level of manganese was high and the level of aluminium was moderate, also it shows year to year and season to season variations.

#### 4.8.6.2 Calcium, magnesium and pH.

Figure 4.32 shows the temporal variation of calcium, magnesium and pH at Ogden Clough. Generally the pH of these streams was higher than in the other streams, being between the range of 5-7 pH unit most of the time with exceptions at two surveys where it dropped to just below 5. In the beginning of summer 1988 the pH was quite high by August the level dropped to around 4 pH units, then the level increased through the autumn to around 7 pH units. During

Figure 4.32 Temporal variation of calcium, magnesium and pH at Ogden Clough.



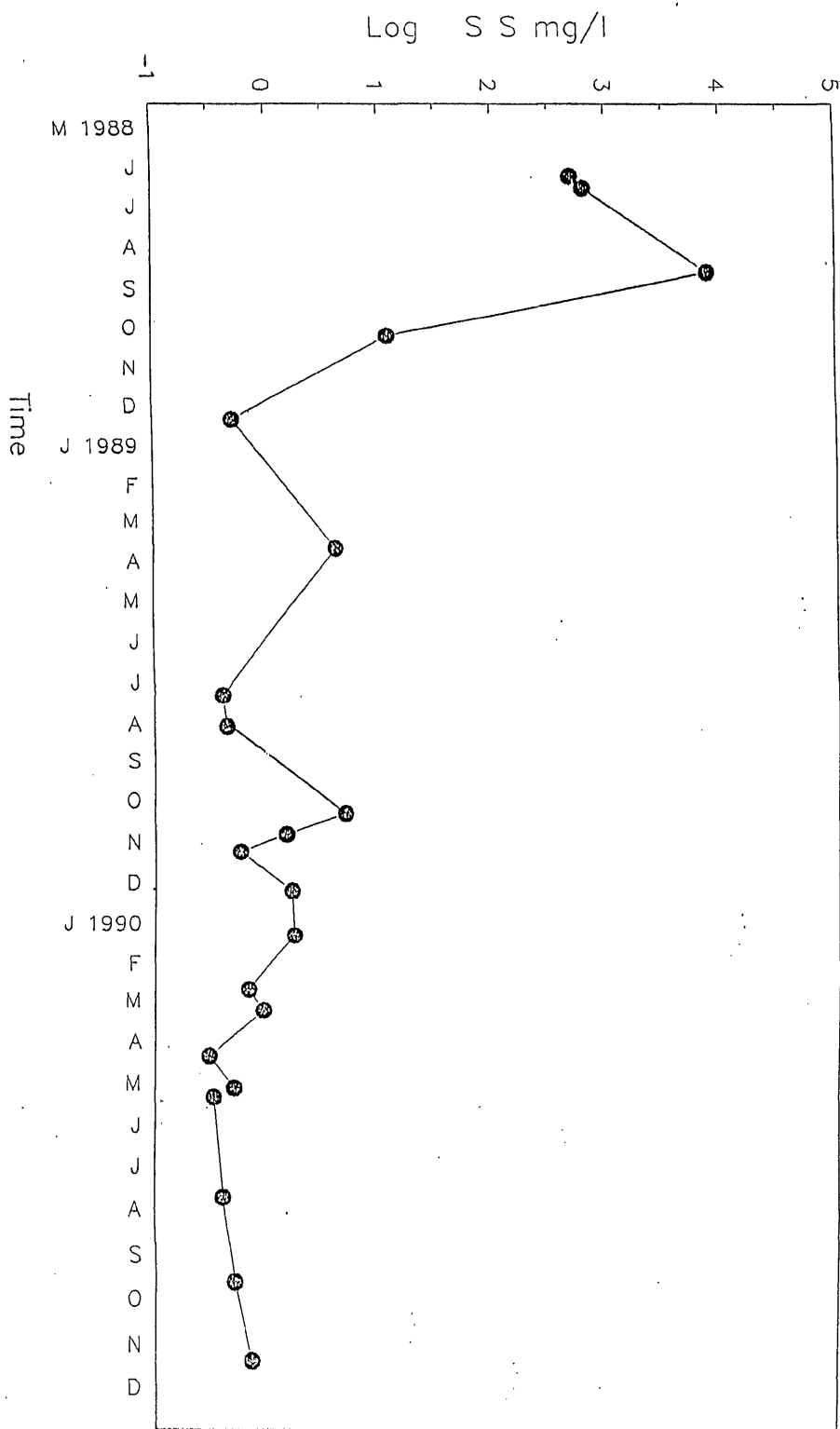
the winter of 1989 the level decreased slightly through the spring to 5 pH unit, then the level rose to around 6 and remained almost constant until the beginning of October. By the end of the month the level dropped to 4.3 pH units and then increased to just above 5. In 1990 the pH levels fluctuated around 5-6 pH units. Both calcium and magnesium seemed to follow a similar pattern as the pH, similar peaks at similar times. Generally the level of the pH was quite high but the levels of calcium and magnesium were low, in keeping with the other streams.

#### 4.8.6.3 Suspended solids.

Figure 4.33 illustrates the temporal variation of suspended solids at Ogden Clough. During the study the levels of the suspended solids was low, varying between 5-0.5 mg/l with the exception of the level in 1988. In the beginning of summer 1988 (June) the level of the suspended solids was very high, more than 500 mg/l. By August there was a sharp peak in the concentration, up to 7600 mg/l. Then the level declined through the autumn so that by the beginning of December the level was 0.5 mg/l. In the spring of 1989 (March) there was a small peak of 4 mg/l. The level decreased during the summer to 0.4 mg/l and remained low during the summer of 1989. During the autumn and winter of 1989/1990 the levels increased, there was a peak of 4.7 mg/l in October, the peak was similar to the peak of spring 1989, but not as high as the one in summer 1988. The level declined through the spring until reached its lowest level of 0.3 mg/l (in April), then the level remained low through



Figure 4.33 Temporal variation of suspended solids at Ogden Clough.



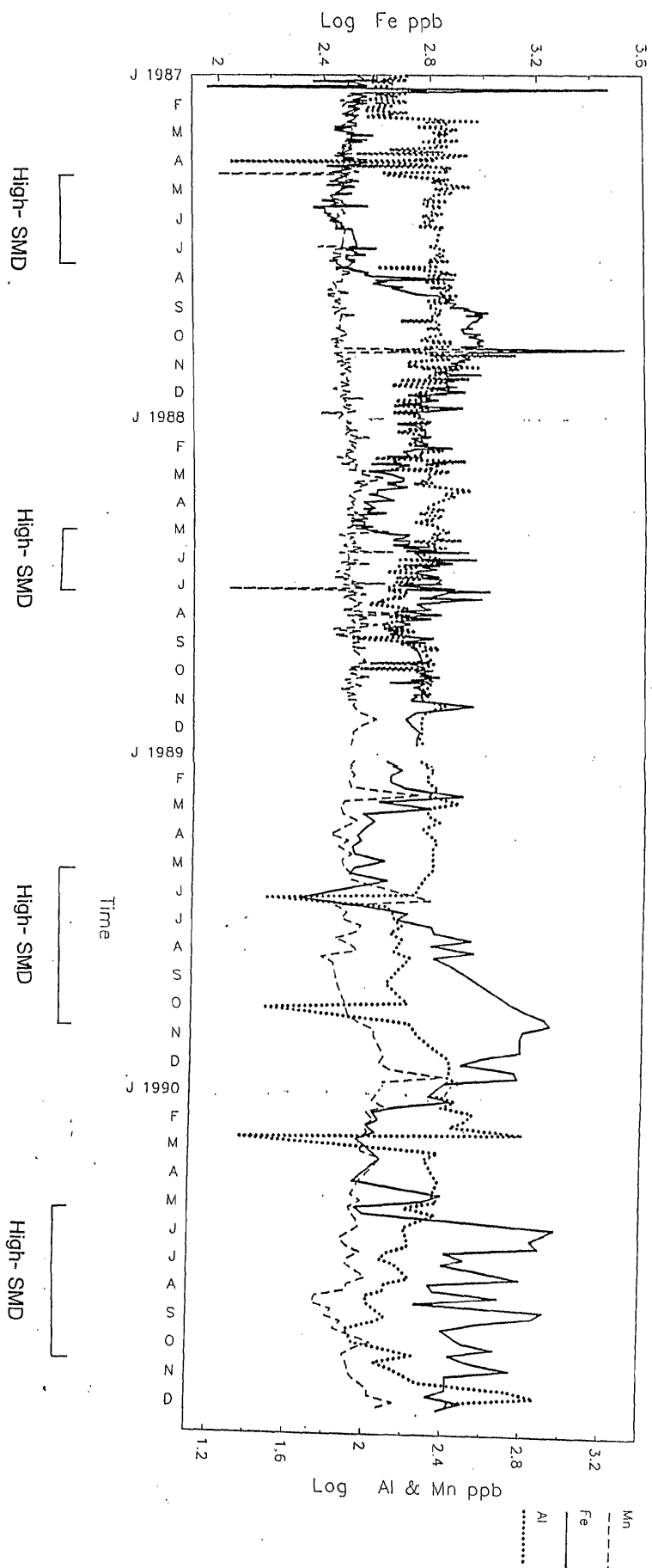
the summer and autumn of 1990. In general the levels of the suspended solids were low except that there was a significant increase in the level in 1988. The high level of the suspended solids in 1988 occurred at the same time as the high level of iron and manganese.

#### **4.9 Temporal variation of metals in raw waters received at Arnfield treatment works.**

In order to gain a more complete picture of metal temporal variation, it was decided to show the daily concentration of the metals at the works. Figure 4.34 shows the data which is available, almost on a daily basis especially for 1987 and 1988. For 1989 and 1990 this was once every week or two weeks or when there was a strong jump in the level. As shown in the figure mentioned above, there were marked seasonal and year on year variations in the levels of iron, manganese and aluminium. Likewise it shows extreme peaks in the concentration of metals on two occasions (on the 16 June and 16 October 1987).

The levels of metals in the raw water were always quite high, and above the E.E.C. standard. As the figure shows, the levels, especially of iron increased to double or more than double usually during autumn and winter compared to normal values; then it decreased, but the increase did not always start at the same time every year, for example in 1987 the levels started to increase in August while in 1988 it was in May, and in 1989 in June,

Figure 4.34 Pattern of metal levels from 1987 to 1990 at Arnfield Treatment plant.



and in 1990 in May. In January 1987 the level of iron was high, between 300-400 PPb, by the middle of the month (the 16th) there was a sharp peak in the concentration up to 2,950 PPb, then the level dropped sharply to its original level before the peak. The level remained high through the winter then the level decreased slightly during the spring between 250-300 PPb. In July they increased gradually until they reached around 1,000 PPb in October. On the 16th of October there was a sharp peak in the concentration up to 2,990 PPb, the highest level recorded in the last four years. The peak was similar to the peak in the winter. Then the level declined through the winter and spring of 1987/1988 until by May the level was around 300 PPb. During the summer the level gradually increased to around 600 PPb. There was fluctuation in the level in the summer between 600-1,000 PPb. The level remained high through the autumn and winter of 1988/1989. There were two peaks, one in November and one in February, but they were small compared with the peaks in 1987. The level declined through the spring of 1989 until it reached its lowest of around 200 PPb, in June. The level again increased dramatically through the summer until it reached its highest of the year (in October), being 1,766 PPb, then the level declined through the autumn and the winter with the exception of a small peak in December. By February the level was around 400 PPb, then the level remained almost constant until April. In April there was a peak in the level of iron up to 800 PPb, also there was another one in the summer (May),

this peak was sharper than the previous one, being 1,600 PPb. The level remained high through the summer and autumn, rose and fell between 8,00-1600 during the summer and between 800-1200 PPb in the autumn.

Manganese quite often followed a similar pattern to iron, but the increase in the concentration of iron was not always concomitant with an increase in manganese. Generally, similar increases in the level of manganese occurred when there was an increase in iron levels, but the magnitude of increase was not always as great as with iron. In general the level of manganese varied most of the time between of 50-150 Ppb.

The temporal variations of aluminium were completely different to the other two metals, sometimes there was a peak in the level not necessarily necessary at the same time as the peak with iron or manganese, the levels of aluminium increasing and decreasing dramatically. In general, the levels of these metals were high during the autumn and winter, with lower levels during the summer. Also as the figure shows there is a variation in the concentration of these metals from year to year, season to season and even from day to day, the level of these were generally higher in 1989 and 1990 than previous in the years especially iron. The levels of iron seemed to be affected by the soil moisture deficit; usually they increased during the high soil moisture deficit with an exception during 1987 after the prolonged dry period.

## **Part II**

### **Experimental study.**

#### **4.10 Introduction.**

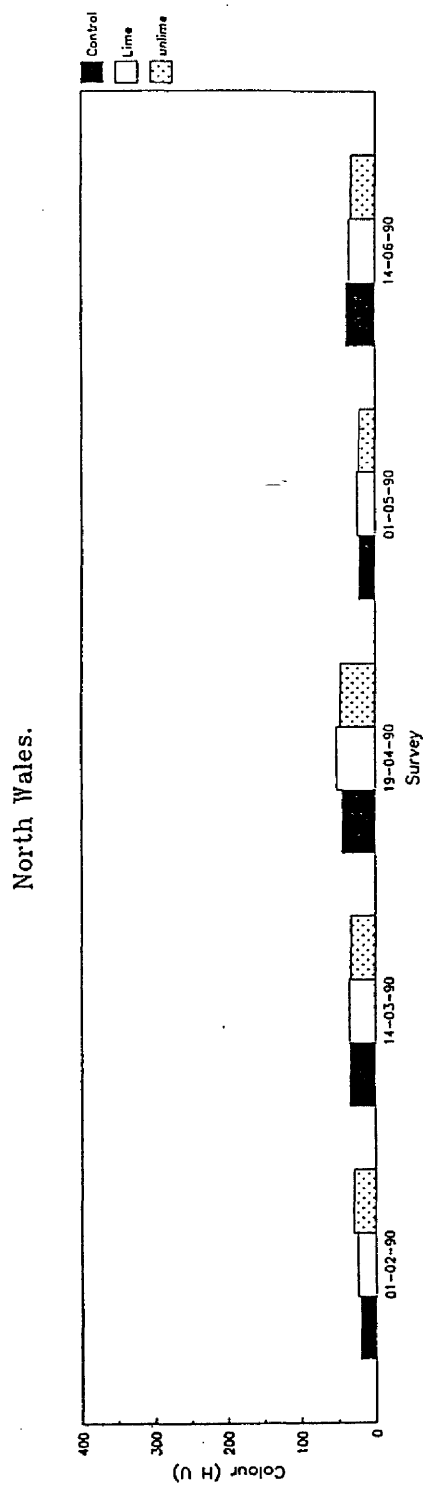
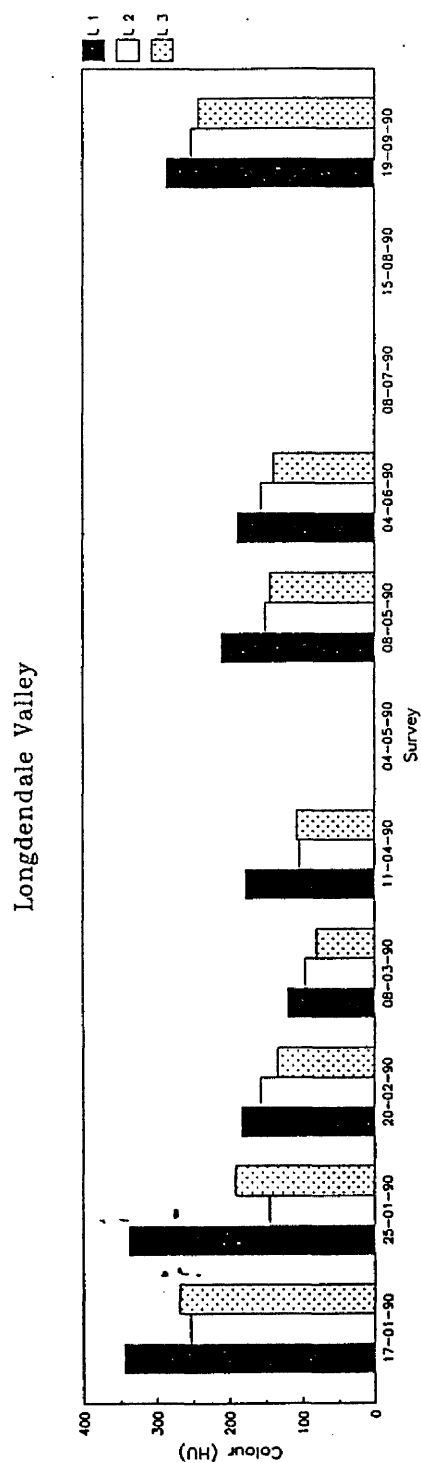
In order to gain some idea on the desorption of metals and colour from different type of soils, field and laboratory experiments were carried out. Lysimeters, which were placed at different sites at Longdendale Valley and North Wales. Also the monolith tins; which were collected from different sites at Longdendale Valley and North Wales. Also to gain a rough idea on the activities of bacteria in soil, arylsulphatase activities were measured. The location of the lysimeters, and the place of collection of the soil samples (for the monolith tins and arylsulphatase activities are shown in section 3.6).

#### **4.11 The Lysimeter experiments.**

##### **4.11.1 Spatial variation of the levels of colour in the lysimeters.**

Figure 4.35 illustrates the levels of colour in the three lysimeters in the Longdendale Valley and the other three in North Wales. The figure shows clearly the differences in the level of colour between the lysimeters in Longdendale Valley and in North Wales, being high between the range of 100-400 Hazen units at Longdendale Valley and low between the range of 20-60 in North Wales. On occasions 4-5-1990, 8-7-1990 and 15-8-1990 at the

Figure 4.35 Spatial variation of colour levels in the lysimeters



Longdendale lysimeters water was not percolating through the soil, and therefore no samples were obtained.

The highest colour was in lysimeter (L1) in all the surveys, while it varied in the other two. The levels of colour in the North Wales lysimeters show differences in the colour levels from one survey to another, but it did not show visible difference between the three locations.

#### 4.11.2 The temporal variation of colour in the lysimeter.

The temporal variation of colour levels is shown in figure 4.36. As the figure shows the colour levels varied from time to time. The highest colour levels leached through lysimeters at Longdendale Valley were recorded during the winter months and either very low or non-existent leachings were recorded during the summer. On three occasions; there was not sufficient sample to be measured (this was in May, June and July 1990).

There was no visible differences in the levels of colour in the North Wales lysimeters during the five surveys. Due to a lack of in the information (such as the rainfall, soil moisture deficit data ... etc), time, and manpower, it was quite difficult to obtain more samples from North Wales. But it is not important as there was no indication of significant colour variation.

#### 4.11.3 Spatial variation of other parameters in the lysimeters.

Figures 4.37 and 4.38 illustrate the spatial variation of some metals and pH levels in the samples of water which had been leached through the soil into the lysimeters.



Figure 4.36 Temporal variation of colour levels in the lysimeters.

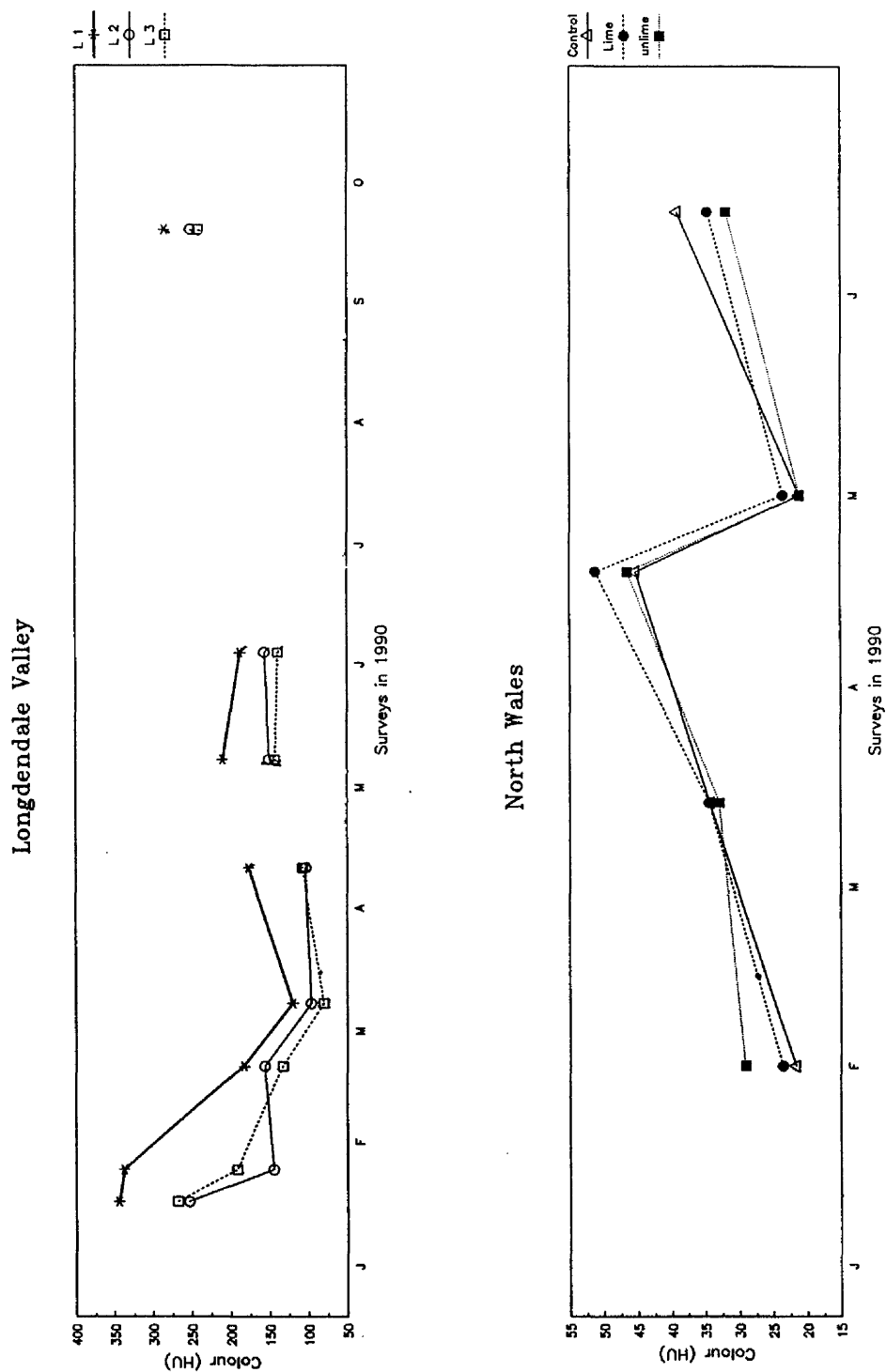


Figure 4.37 Spatial variation of metals and pH levels in Longendale Valley lysimeters.

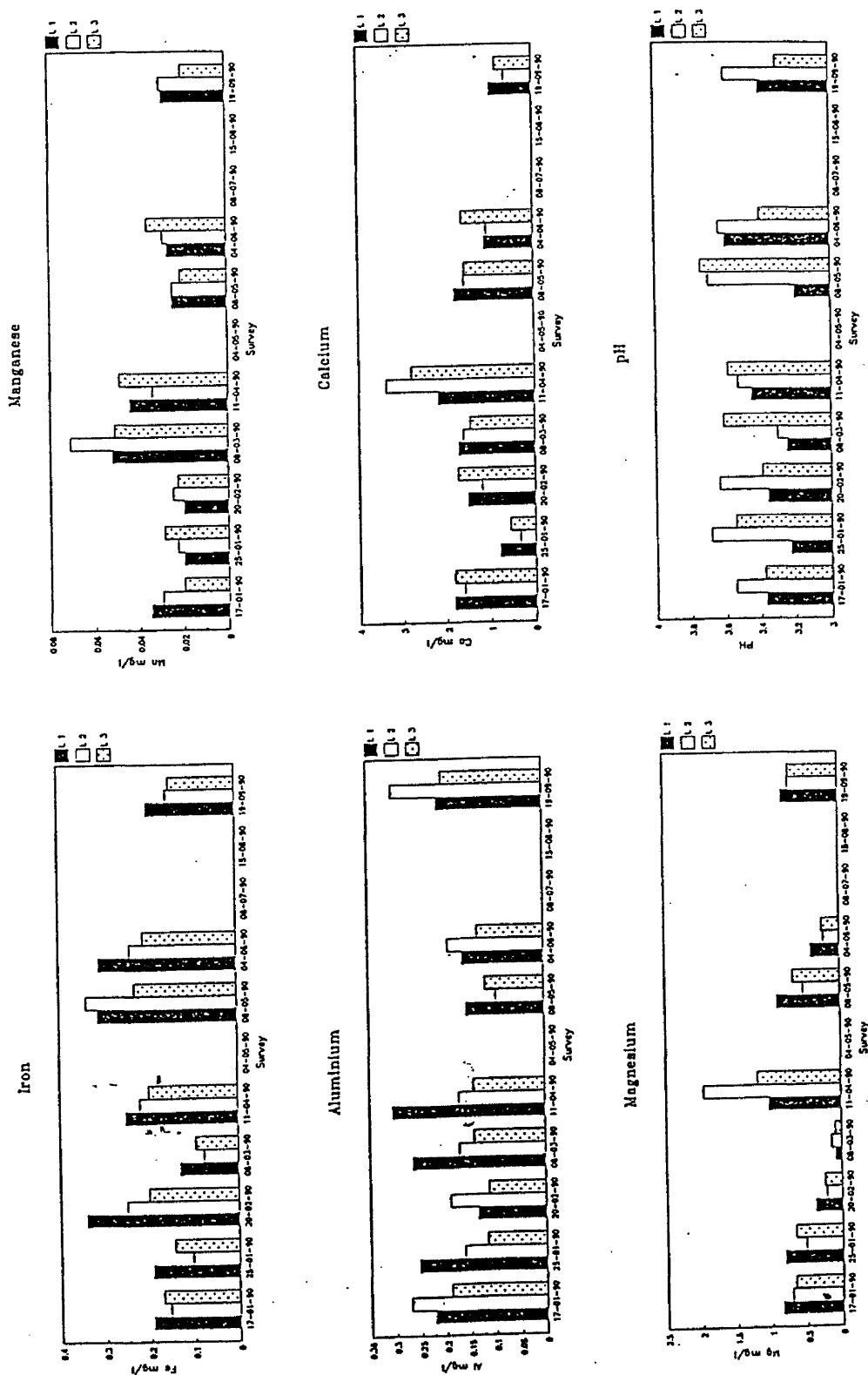


Figure 4.38 Spatial variation of metals and pH levels in North Wales lysimeters.

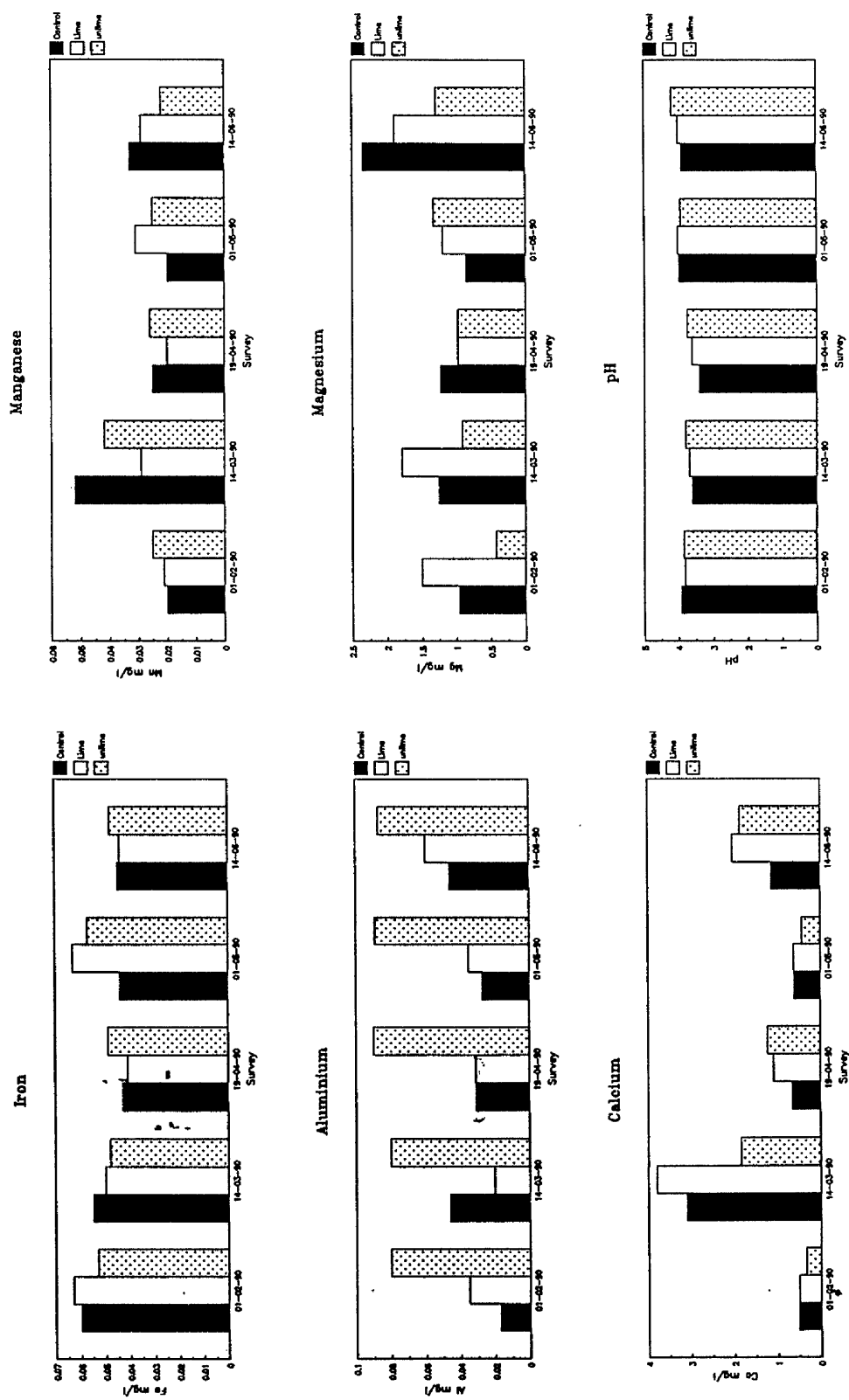


Figure 4.37 shows the levels of iron, manganese, aluminium, calcium, magnesium and pH in the Longdendale Valley lysimeter. In 8 out of 11 surveys there were sufficient samples to be measured. As the figures show, the water samples in the three lysimeters in all the surveys were extremely acidic, pH being in the range of 3 to 4 pH units. Iron concentration varied between 0.1 - >0.4 mg/l. The levels varied from one lysimeter to another, generally the levels of iron in lysimeter "L1" were higher than in the other two.

Manganese levels were high and varied over a narrow range from near the detection limit 0.02 to 0.07 mg/l. Aluminium levels were also low and varied from one lysimeter to another, generally the highest concentration was in L1. The concentration of aluminium varied within the range 0.1 to 0.3 mg/l.

The levels of calcium and magnesium were low, being in the range of 1 to 3.5 and 0.1 to 2 mg/l, and the concentrations varied from one lysimeter to another.

The spatial variation of iron, manganese and aluminium in the North Wales lysimeters were less distinct than in the Longdendale Valley (Figure 4.38), the levels being less than 0.07, 0.05 and 0.1 mg/l. It appears that there was no significant difference between the levels of these metals in the three lysimeters. Likewise, the concentration of calcium and magnesium was also low. It varied slightly from one area to another, but no clear difference was apparent between them. The water of all the lysimeters were

extremely acidic, pH being below 4 in most of the surveys.

#### **4.11.4 Temporal variation of some parameters in the lysimeters.**

Figure 4.39 illustrates the temporal variation of metals in the lysimeters at the Longdendale Valley. As the figure shows there is a drop in the levels of the metals and pH in the two surveys which had been carried out in May, July and August 1990, because there was no water leaching through the lysimeters during this period, even after a spell of rain. When there was a leaching of water through the soil into the lysimeter, the levels of metals and pH varied from survey to survey. There was no clear apparent pattern to temporal variation of metals and pH with the levels rising and falling erratically, varying over a fairly narrow range. The pH of the water varied between the range of 3 to 4 pH units. The levels of metals were always higher in lysimeter "L1" than in the other two L2 or L3.

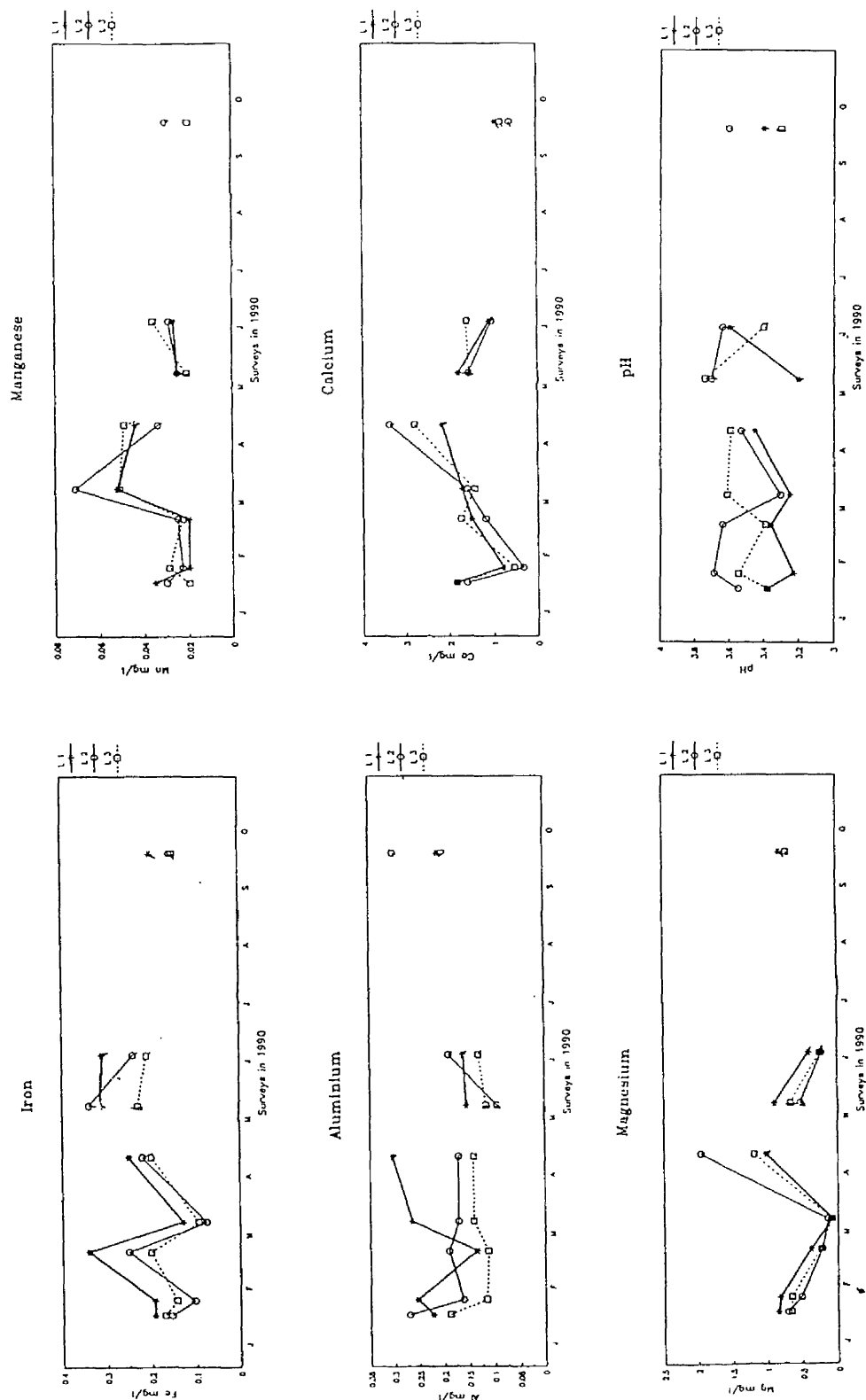
In general, the amount of metals leached through the lysimeter varied from survey to survey over a narrow range, when there was enough water to be leached.

### **4.12 The leaching experiment.**

#### **4.12.1 Spatial variation in colour levels in the monolith tins experiment.**

There are variations in colour levels in the water (water characteristics were given in table 3.2 and the site of the collection of the soil samples was shown in section 3.6) leaching through different types of soil and at

Figure 4.39 Temporal variation of some parameters in the lysimeters at Longdendale Valley.



different temperatures. Figure 4.40 illustrates that difference. As the figure shows the highest average colour levels were in the water samples which had been leached through the top two soil samples "Peat" while the lowest in peaty soil samples (lime and unlimed) then in the bottom samples (slightly peaty soil). Also the figure shows that the levels of colour in eluate when the water had been percolated through the top and bottom samples was higher at temperature 20 °C than at 10 °C. Also the figure shows that the colour level in the lime sample was slightly higher than in the unlimed one.

#### 4.12.2 Temporal variations of the colour in the monolith tins experiment.

Figure 4.41 illustrate the temporal variation of colour in the eluate which had been leached through different types of soils; at different temperatures.

As the figure shows, the levels of the colour in the eluate of the top samples differed when it was treated with different types of waters (natural (A), distilled (B), hard (C) and natural water (E & F)). The levels of colour remained just the same in the samples which had been kept at 20 °C, until it was treated with hard water; the levels of colour increased and then decreased to its original level, while the colour levels in the top samples which had been kept at 10 °C declined dramatically when it was treated, from around 800 Hazen unit until it reached its lowest level, around 100 Hazen unit.

As for the bottom samples, which had been kept at 10

**Figure 4.40** Spatial variation of colour in the eluted when treated with different types of water at 10 C and 20 C.

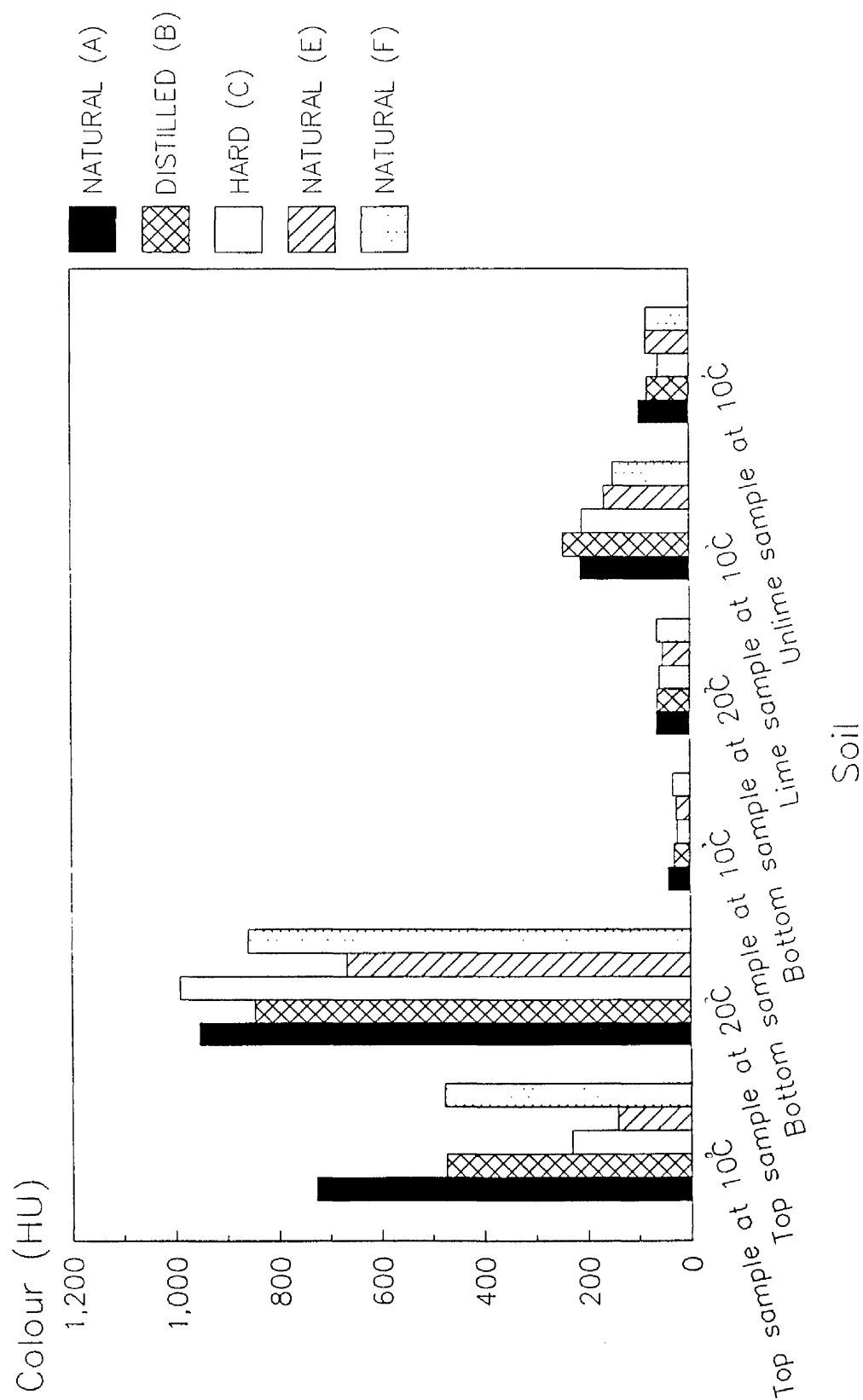
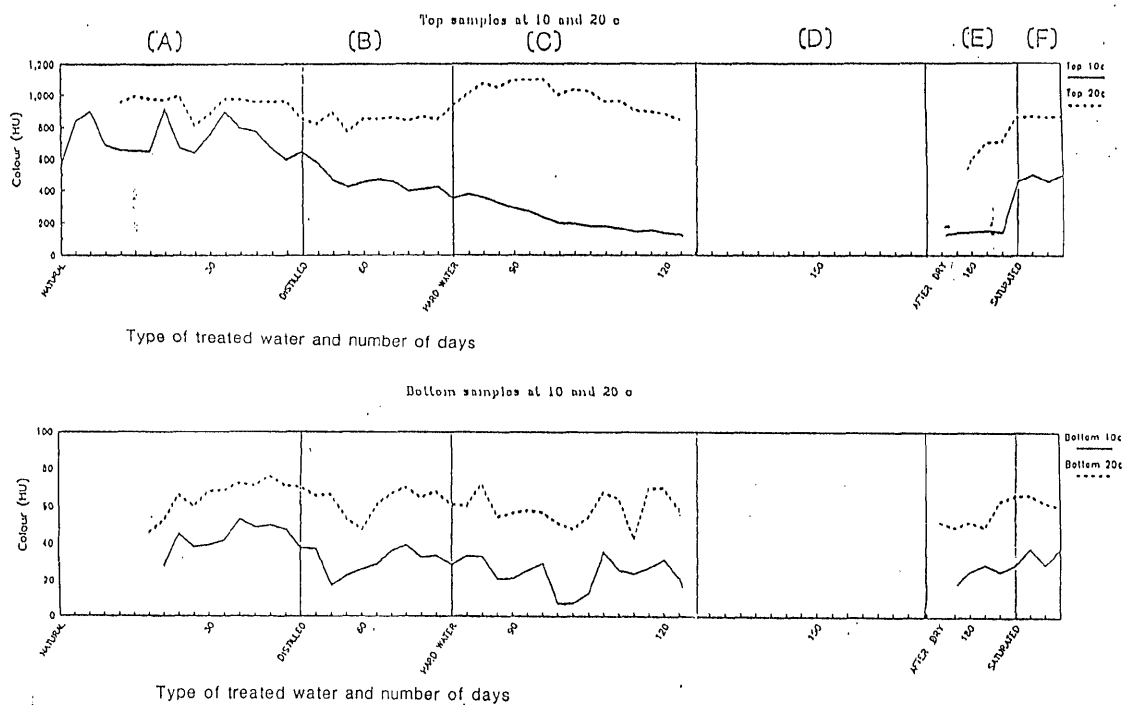


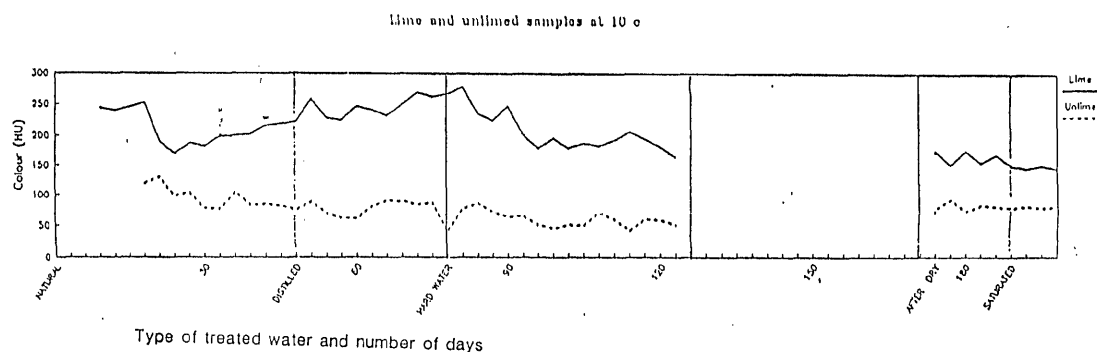


Figure 4.41 Leaching of colour from different types of soils by different waters as function of time and temperature.

Longdendale Valley soil samples.



North Wales soil samples.



Types of the treated water.

Natural water (A), colour = 11.9 HU  
 Distilled water (B), colour = 0.0 HU  
 Hard water (C), colour = 3.1 HU

No added water (D)  
 Natural water (E), colour = 5.2 HU  
 Saturated with natural water (F), colour = 5.2 HU

& 20 °C, when they were treated with natural water (A) the colour levels increased slightly. After they were treated with distilled water (B) the colour levels decreased and then increased, after they were treated with hard water (C), the colour levels started to increase, fluctuated, and then fell again to their original levels. In general the colour levels seemed not to follow a clear pattern, there were erratic patterns and the concentration rose and fell rapidly during the experiment; between 40-80 Hazen unit for the sample which had been kept at 20 °C and between 10-40 for the sample which had been kept at 10 °C. For both the top and bottom samples the colour levels of the samples kept at 20 °C were always higher than the levels of those kept at 10 °C.

The colour levels in the North Wales soil samples (lime and unlimed) which had been kept at 10 °C decreased initially after it was treated with the natural water (A), then the colour levels in the lime samples started to increase gradually until the sample was treated with hard water, at which point the levels declined dramatically to about 150 Hazen unit. The colour levels in the unlimed sample when treated with A, B and C water, showed a general decrease; it then varied between 50-100 Hazen unit while it was decreasing. After samples were left for 45 days without treatment (prolonged dry period), then were treated with natural water (E), the colour levels in the eluate in all the samples increased to the original levels before they were left to dry out. When the samples were saturated

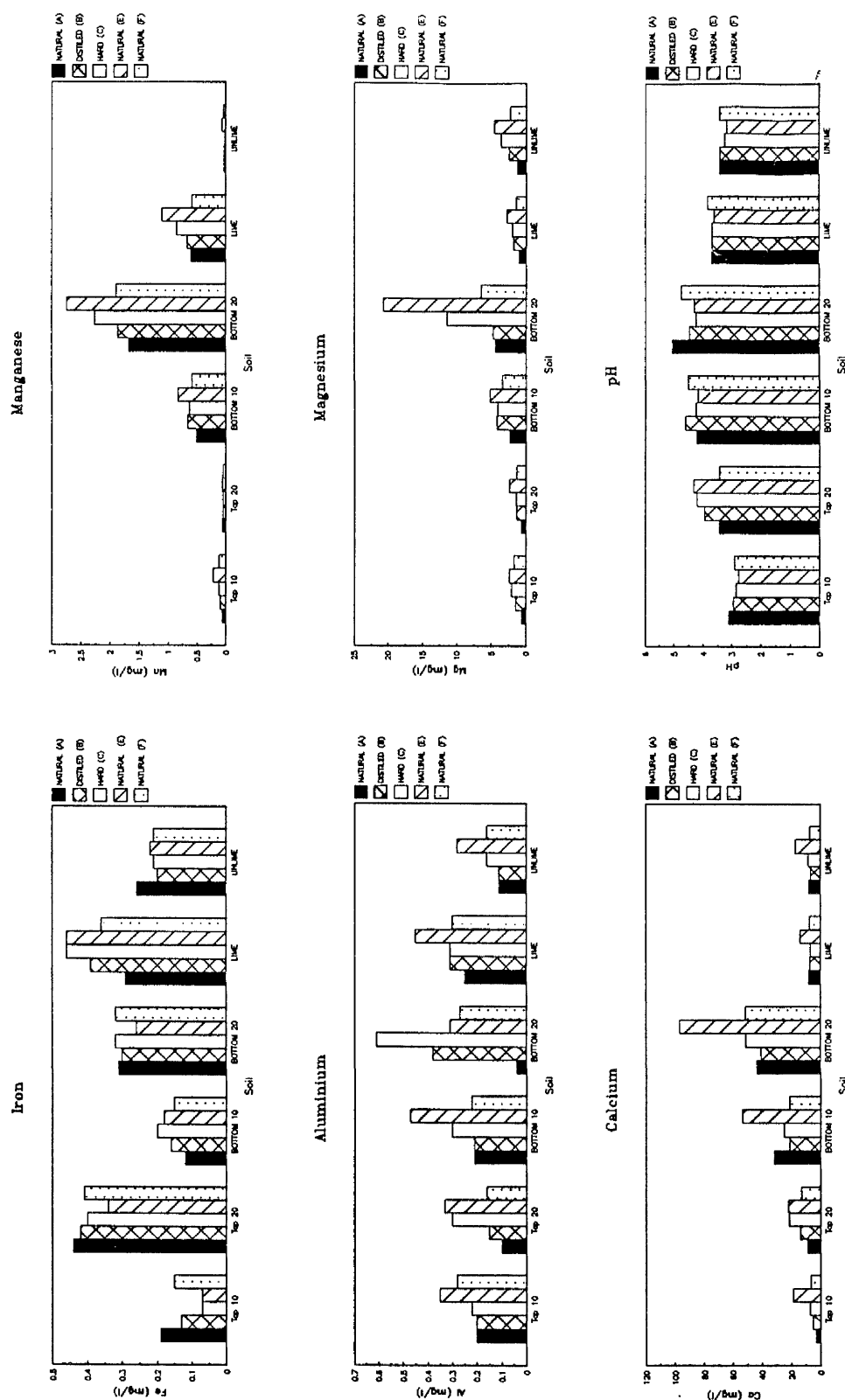
with natural water (F), the colour levels in the Longdendale samples showed a general increase but it was not clearly shown in the North Wales samples. After the dry period when the water was added to the samples the time it took for the water to leach through varied according to the type of soil. The top soil samples (peat) took a larger amount of water and a longer time before the leaching started than the bottom samples (peaty soil).

#### 4.12.3 Metals leaching experiment (monolith tins).

Figure 4.42 illustrates the average levels of some parameters in the eluates, which had been leached through different types of soils, at two temperatures "low" 8-10 °C and "high" at 18-20 °C. As the figure shows, the amount of metals leached from the different types of soil varied from one soil to another. For example, the amount of manganese, magnesium and calcium leached from the bottom soil sample (which had been taken from the peaty soil of the bottom of the hill at Longdendale Valley and kept at "low and "high" temperatures) were higher than the top sample (which had been taken from the peat at the top of the hill at Longdendale Valley), and also higher than the limed and unlimed samples (which had been taken from North Wales "peaty soil"). Also the above mentioned figure shows that the levels of iron, magnesium and aluminium were higher in the eluate of the lime soil than in the unlimed soil.

Although the figure shows, the average levels in the eluate increased with increase of temperature, especially

Figure 4.42 The average levels of some parameters in the eluate when different types of soil was treated with different temperatures of water and at different temperatures.



iron, manganese, magnesium and calcium this increase depended on the types of soil. Also the pH of the eluate seems to have increased with increase of temperature. In general the pH of the eluates varied between 2.88 - 5.8, the lowest was in top samples at 10 °C. The average aluminium levels in the eluates appear not to be affected by the temperature. There was no clear variations in the levels at either temperature the levels rising and falling at both temperatures.

#### 4.13 Arylsulphatase activity in different soils.

Arylsulphatase activities measured in different type of soil collected from the top of the hills at Longdendale Valley and from the monolith tins experiment are shown in table 4.1. Activities varied from one hill to another at the Longdendale Valley, the highest were at Coombes Clough, Torside Clough and Longside Clough, the lowest, were at Ogden Clough. In the monolith tins experiment the highest activities was in the top and bottom samples which were kept at 20 °C whilst the activity in the other samples (limed and unlimed) was quite the same.

**Table 4.1 Arylsulphatase activity in surface soil samples from the top of the hills at Longdendale Valley and from the monolith experiment, activities are the means of 5 replicates.**

Samples Locations	Date	Arylsulphatase activity umol p-NPh-1g-1 dry wt	
		MEAN	SDT
Coombes Clough (Top) SK 053996	29-7-90	2.082	0.337
Crowden Brook (Top) SE 074007		1.042	0.296
Woodhead Bridge (Top) SE 091039		1.268	0.317
Longside End (Top) SK 135700		1.793	0.427
Torside Clough (Top) SK 077968		1.881	0.149
Ogden Clough (top) SK 047969		0.339	0.117
TOP Crowden Brook	23-8-90	1.190	0.364
bottom Crowden Brook		0.553	0.206
Woodhead Bridge (top)		1.538	0.266
Top 10 °C (monolith)	22-2-90	0.417	0.170
Top 20 °C (monolith)		1.453	0.351
bottom 10 °C (monolith)		0.417	0.170
bottom 20 °C (monolith)		0.810	0.210
Lime 10 °C (monolith)		0.533	0.170
unlime 10 °C (monolith)		0.467	0.237

#### 4.14 Summary of the results.

No clear visible difference in the levels of colour or metals could be detected moving down stream; the negligible change will not have any significant impact on the treatment works. However, a clear significant difference was seen between one set of samples and another.

It can be seen quite clearly that colour levels varied from stream to stream and it also varied from survey to survey. The dry summer of 1990 produced clear waters and low colour levels, whereas the wet summer of 1988 produced dirty water and high colour levels.

The highest level of colour was recorded at Coombes and Torside; during the period between August-December 1988, between November-December 1989 and in mid-November 1990. The colour maybe attributed to seasonal changes; usually the highest colour occurs in the autumn and winter. The colour in some streams such as Longside Clough was almost constant, varying between 30-60 Hazen unit for most of the time.

Generally the lowest colour levels in the streams were as follows:

Ogden Clough > Woodhead Bridge > Crowden Brook > Longside Clough > Torside Clough > Coombes Clough

Usually during the autumn and winter there was a peak in the concentration but it varied from year to year.

Clear differences in the level of colour were seen between the lysimeter in Longdendale Valley and in North Wales, being high between the range of 100-400 Hazen unit

at Longdendale Valley and low between the range of 20-60 Hazen unit at the North Wales lysimeter. The colour varied from one lysimeter to another and from survey to survey. No leaching was recorded during the summer at Longdendale Valley.

There are variations in colour levels in the eluate which leached through different types of soil in the Monolith Tins experiment at different temperatures. The highest average colour levels was in the top two "Peat" soil samples while it was low in the peaty soil, "lime and unlimed" The lowest was observed in the bottom sample; "slightly peaty soil". Also the experiment showed that the colour levels increased with increase in temperature.

The pH of the raw water at Arnfield works range most of the time between 6-7 but during the autumn and winter it was lower being between 4-5 or lower, usually there were a drop in the levels of the pH especially in the winter of 1989/1990. At the streams the level of pH depend on the drainage area of the stream and other factors such as the rainfall. In general the pH of the water in all the streams varied over the range 3- to 7.5. Some of the streams were generally highly acidic such as Coombes Clough and Longside Clough while others were generally moderate such as Torside and Ogden Clough. In general the levels of pH in the winter were lower than in the summer, the levels of pH increased gradually through the spring and summer and remained low during the winter.

The water samples in the lysimeter experiment in all



surveys were extremely acidic, pH being in the range of 3 to 4 pH units. There was no apparent pattern to temporal variation of pH with the levels rising and falling erratically, varying over a fairly narrow range. Also the pH in the monolith tins experiment was also quite low, depending on the type of soils. In general the pH of the eluates varied between 2.88-5.8.

Clear year to year variations in the soil moisture deficit. Also it shows that the deficit in soil can happen at any time of year as long as there is not sufficient rain to replace the deficit which is mainly due to losses of water from the soil by evaporation and transpiration. The deficit in the last two years was higher than in 1987 and 1988. This is probably due to the global world changes in the weather.

The water temperature dropped during the autumn and winter months; and it increased during the summer time.

The levels of metals (iron, manganese and aluminium) in the raw water at Arnfield works were always high, above the E.E.C. standard, especially iron, increasing to double or more than double usually during autumn and winter. Likewise these metals showed extreme peaks in the concentration especially on two occasions (on 16 June and on 16 October 1987). In order of decreasing levels they were as follows:

Iron > Aluminium > Manganese

Iron levels varied from one stream to another; and from survey to survey in the same stream. The highest

concentration of iron was in Longside Clough, being greater than 400 PPb for most of the time; with the exception of two surveys in May 1990. Most of the streams displayed distinct peaks, especially at Coombes Clough and Torside. They showed a marked peak concentration, being between 500 to 1,200 PPb. In some streams, such as Coombes Clough, the levels increased during the autumn and winter months while it remained low during the rest of the year.

Iron concentration in the lysimeters was high especially in the ones at Longdendale Valley. Also there was a high concentration of iron leached through the soil in the Monolith tin experiment, depending on the types of soil. The concentration seems to increase with increase in the temperature.

The concentration of manganese varied from stream to stream, and from occasion to occasion, the highest concentration was also at Longside Clough, (most of the time varying) being between 100 - 450 PPb. Manganese in the other streams varied over a narrow range of 30 or close to the limit of detection. In general the levels were low.

In the lysimeters manganese levels were also low and varied over a narrow range from near the detection limit 0.02 to 0.07 mg/l and in the Monolith also the amount leached from different types of soil varied from one soil to another. The amount of manganese leached from the bottom soil sample was higher than the top, lime and unlime samples.

Spatial variations of aluminium in the streams,

showed that levels rise and fall erratically in each stream. The highest and lowest levels of aluminium recorded during the study were at Longside Clough. In general the levels were relatively high. Also levels were high in both the lysimeter and the monolith tins.

The levels of calcium and magnesium in the streams varied from one stream to another and from one survey to another. The lowest levels were mostly at Coombes Clough while the highest level at Torside Clough and Ogden Clough. The concentration was in general low in all of the stream. Also the levels were low in the lysimeters, being in the range of 1 to 3.5 and 0.1 to 2 mg/l, and the concentration varied from one lysimeter to another. The amounts of calcium and magnesium leached from the bottom soil sample in the monolith experiment were higher than those leached from the top, lime and unlime samples.

In general, the concentration of all these metals in the streams was low during the summer except at Longside Clough while the concentrations increased in autumn and winter. They appeared to follow a seasonal variation. Iron and manganese in Ogden Clough were generally low during the sampling period. The amount of metals leached through the lysimeter varied from survey to survey over a narrow range, when there was enough water to be leached to the lysimeters. Also the amount of metals leached from the different types of soils in the monolith experiment varied, depending on the types of soil and temperature.

The levels of the suspended solids in each stream

varied from survey to survey. It can be as low as 0.2 mg/l or as high as to exceed 2,800 mg/l in some streams such as Coombes Clough; Distinct peaks were seen, the highest peak recorded during this study was at Coombes Clough, Ogden Clough and Crowden Brook in 1988, In general the peaks of the suspended solids usually occurred in autumn and winter, but not in all the streams. In some streams the levels were generally low; with rapid increases and decreases between a narrow range of 0.2 to 5 mg/l such as in Ogden Clough.

Arylsulphatase activity varied from one hill to another; the highest being at Coombes Clough, Torside Clough and Longside Clough, the lowest being at Ogden Clough. The highest activity in the monolith tins samples were observed in the top and bottom portions, kept at 20°C.

#### 4.15 Field observations.

The remotely sensed data have the inherent properties of being able to provide brief observations with high observational density over relatively large areas. However, what is normally measured by in-situ devices used in hydrology, and what is observed by remote sensing devices, may not be exactly the same. Therefore, to evaluate remotely sensed data, field trips were carried out to identify the types of soil and vegetation cover, and also to determine the correlation between in-situ measurements and remotely sensed measurements and to attempt to classify the types of vegetation from the data available. The

observations made after studying the landsat image and visiting the field were:

The image shows five main colours which may be classified into five different vegetation types these are:

- 1) brown and dark purple areas.
- 2) light blue or light purple.
- 3) a red spot within the brown or dark purple area.
- 4) green or light green.
- 5) white or yellow.

On visiting the site it was found that the brown or dark purple areas show areas of thick peat (>60 cm in thickness "Type I") at high altitude where the land is flat or gently sloping (see figure 4.43). The light blue or light purple areas show area of thinner layers of peat (<60 cm in thickness "Type II") at a lower altitude where there are steep hills and slopes (see figure 4.44). This area had also been identified before by Bower (1960) and Johnson (1981 and 1989) as an area of extensive peat erosion. Bower (1960) studied the distribution of peat to the south of Longdendale Valley. He noted that peat has developed most extensively and was deepest at the highest altitude. The red spot in the brown or in the dark purple (Type I) was an area of high risk of peat erosion; the raw peat often exceeds 1.5 metres thickness (see figure 4.45). This area had also been identified before by Bower (1960) as an area of advanced and extensive peat erosion. In figure 2.5 the light green represent the trees or forest areas (see figure 4.46), while the white areas represent

Figure 4.43 A picture showing peat at the flat or gently sloping site at higher altitude at coombes Clough (Type I), see figure 2.5 for the location of the site.



Figure 4.44 A picture showing steep slopes at a lower altitude at Crowden Brook (Type II), see figure 2.5 for the location of the site.



Figure 4.45 A picture showing an area of extensive peat erosion at Torside Clough (the red spot) : an area of about 30m x 10m,  
see figure 2.5 for the location of the site.





Figure 4.46 A picture showing an area of forest at lower part of Coombes Clough, see figure 2.5 for the location of the site.



the bare rocks, with little or no vegetation present (see figure 4.47). Due to a lack of close-up landsat images to show the vegetation in detail, figure 4.48 gives a photographic example of the varied vegetation of the area, and table 2.5 gives details of the vegetation cover according to observations made in the field.

According to figure 2.5, the vegetation which overlays the Longdendale catchment areas differ; it shows clearly the difference between the types of vegetation and the types of peat. This difference could not be detected in the soil surveys maps (see figures 2.3 and 2.4). For example, the difference between bare rocks, slopes and different thickness of peat ... etc.

Figure 4.47 A picture showing an area of bare rocks or little vegetation cover at Crowden Brook, see figure 2.5 for the location of the site.



Figure 4.48 A picture showing an area of bracken surrounded by rough grassland at Crowden Clough, see figure 2.5 for the location of the site.



**Chapter 5**  
**Discussion.**

## **Part I.**

### **Colour.**

#### **5.1 The colour levels, origins and nature of organic substances.**

During the study colour levels at Woodhead Bridge, Crowden Brook and Ogden Clough were low compared with the other streams, except between August and November 1988. For the other streams peaks in colour levels usually occurred during the autumn and winter. In general the colour levels in the autumn and winter exceeded not only the guide levels, but also the maximum admissible concentration (M.A.C's) for water intended for human consumption, especially in Coombes Clough.

Data for the Arnfield Treatment Works showing water colour tend to indicate higher levels in the late autumn and considerably marked seasonal and year to year variations (see figure 4.4 and appendix III). Also the levels did sometime exceed not just the guide levels, but also the maximum admissible concentration (M.A.C's) for water intended for human consumption.

Larson (1978) suggested that the potential sources of dissolved organic matter (DOM) from rain fall, soil run-off, tree canopy leachates, sediments, ground water, algal excretions, and leaching and biological processing of detritus must be considered. As was mentioned in the introduction, the colour in the upland water is mainly due

to the presence of natural organic chemicals (humic and fulvic acids). They were formed by a multistage process that included: decomposition of all plant components including lignin into simpler monomers, metabolism of the monomers with an accompanying increase in the soil biomass, repeated recycling of the biomass carbon and nitrogen with synthesis of new cell and concurrent polymerization of reactive monomers into high-molecular-weight polymers (Flaig 1966, Kononova 1966).

## 5.2 Rain fall and colour.

Rain plays a very important role in the quality of the stream waters. When rain falls on the surface it can possibly play many roles depending on such things as:

- 1- The quality of the rain itself- Acid rain; increased acidity and leaching metals from soils.
- 2- The amount of rain
  - Refilling the water table, dilution factor, erosion; increasing the suspended solids.
- 3- Time
  - The time span of falling (1 or 24 hrs.); erosion, and winter or summer.
- 4- Type of soils
  - peat/ peaty/ sandy.
- 5- The status of the soil
  - low/high soil

moisture deficit.

6- Other

- low/high temperature,  
the thickness of the  
layers, slopes,  
altitude and others.

It is very difficult to predict the role rain can play, since it can be more than one. When sudden heavy rain falls on the surface it might cause surface run-off; this run-off dilutes the concentration of metals and colour in the streams, or it might cause erosion if it falls over a susceptible area; which in turn leads to increases in the suspended solids, metals and colour in the streams.

During this study the three highest recorded colour levels were at Coombes Clough (18th August, 6th October 1988 and 12th November 1990) with levels of colour reaching 199, 245 and 226 Hazen Units, the daily rain (50.90, 15.30 and 0.00 mm), the three day cumulative rain fall (65.3, 31.50 and 14.40 mm), the six day cumulative rain fall (76.50, 31.5 and 15.00 mm) respectively, the suspended solid (7600, 7 and 785 mg/l) and the soil moisture deficit on the three occasions was (0.00 mm) (see figures 4.2, 4.3 and appendix II). Hence the picture is very complex and the role played by rain may not be straightforward. On the first occasion the heavy rain caused dilutions in the streams and at the same time it caused erosion (as is indicated by the levels of suspended solids, which are the highest recorded 7600 mg/l). On the second and third occasions there was less rain but more colour. It seems



that the colour levels in the streams were affected not only by the daily rain fall but also by the cumulative rain fall. The cumulative rain fall may have a stronger influence on the colour of the stream; this is probably due to the longer contact time between the water body and the soil which might lead to the release of more organic matter, while the daily rain fall may dilute, wash off from the surface or if it is sudden and heavy may lead to erosion. This could explain why the increases in the colour levels at the streams during August 1988 were at a time when there was the heaviest rain fall to be recorded during this study (rain fall 50.9 mm). This might have caused peat erosion, landslides or mudslides. Also the total cumulative rain fall during that summer (1988) was high (413.9 mm, see appendix II). Also as shown in figures 5.1 and 5.2 the levels of colour were affected by the previous three and seven days cumulative rain fall. The cumulative rain may play an important role in flushing large quantities of dissolved organic matter from the soil after it had been decomposed.

Field experiments (the lysimeters at Longdendale Valley) have indicated the importance of the amount of rain and the status of the soil in the discolouration of the runoff. During the winter the amount of rain was high and also the level of colour was high; when the amount of rain fall decreased through the spring the levels also decreased. When there was a high deficit and no rain such as in survey 4-5-1990, there was no leaching of

Figure 5.1 The relationship between colour, cumulative seven days rainfall and SMD at the feeder streams.

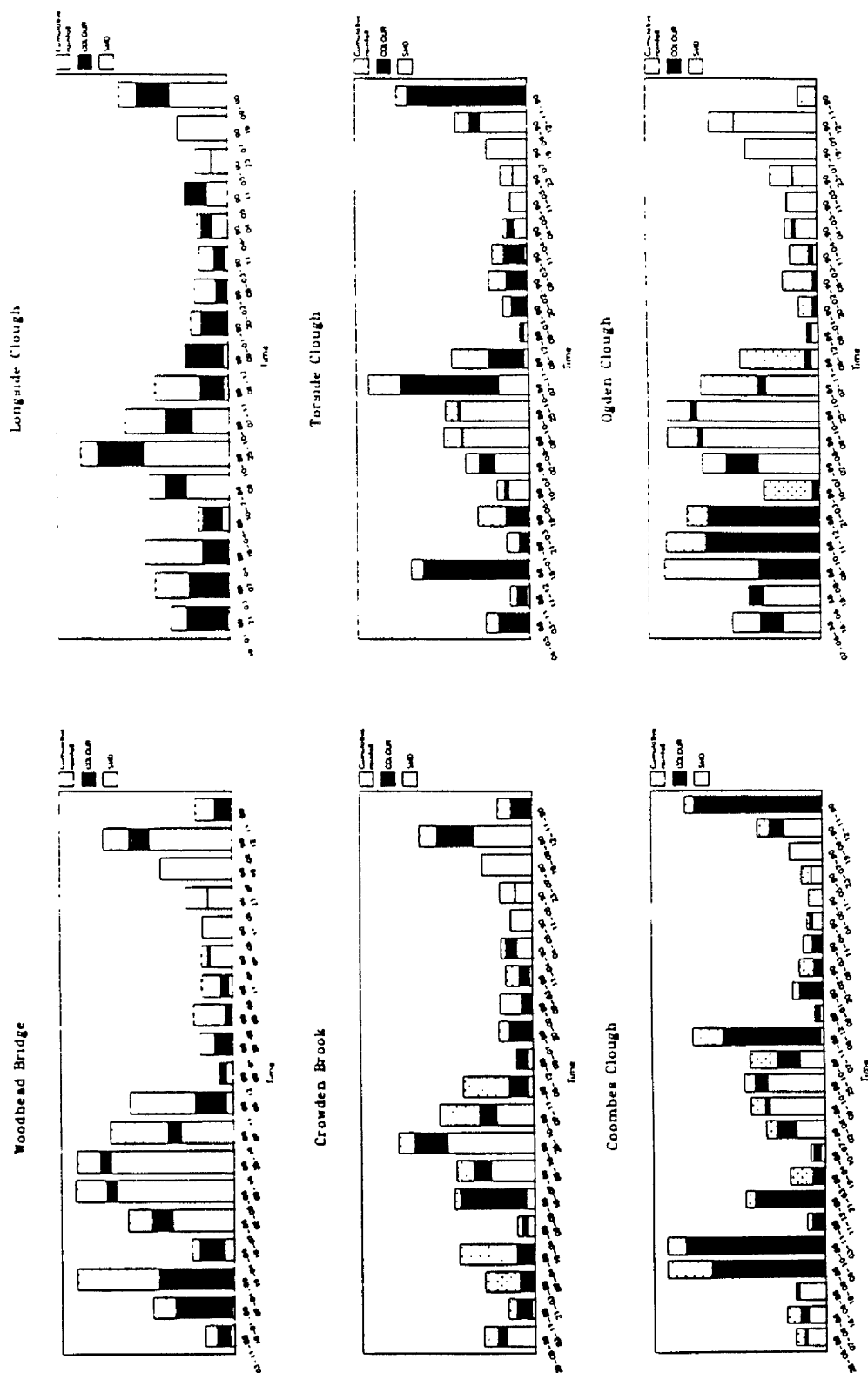
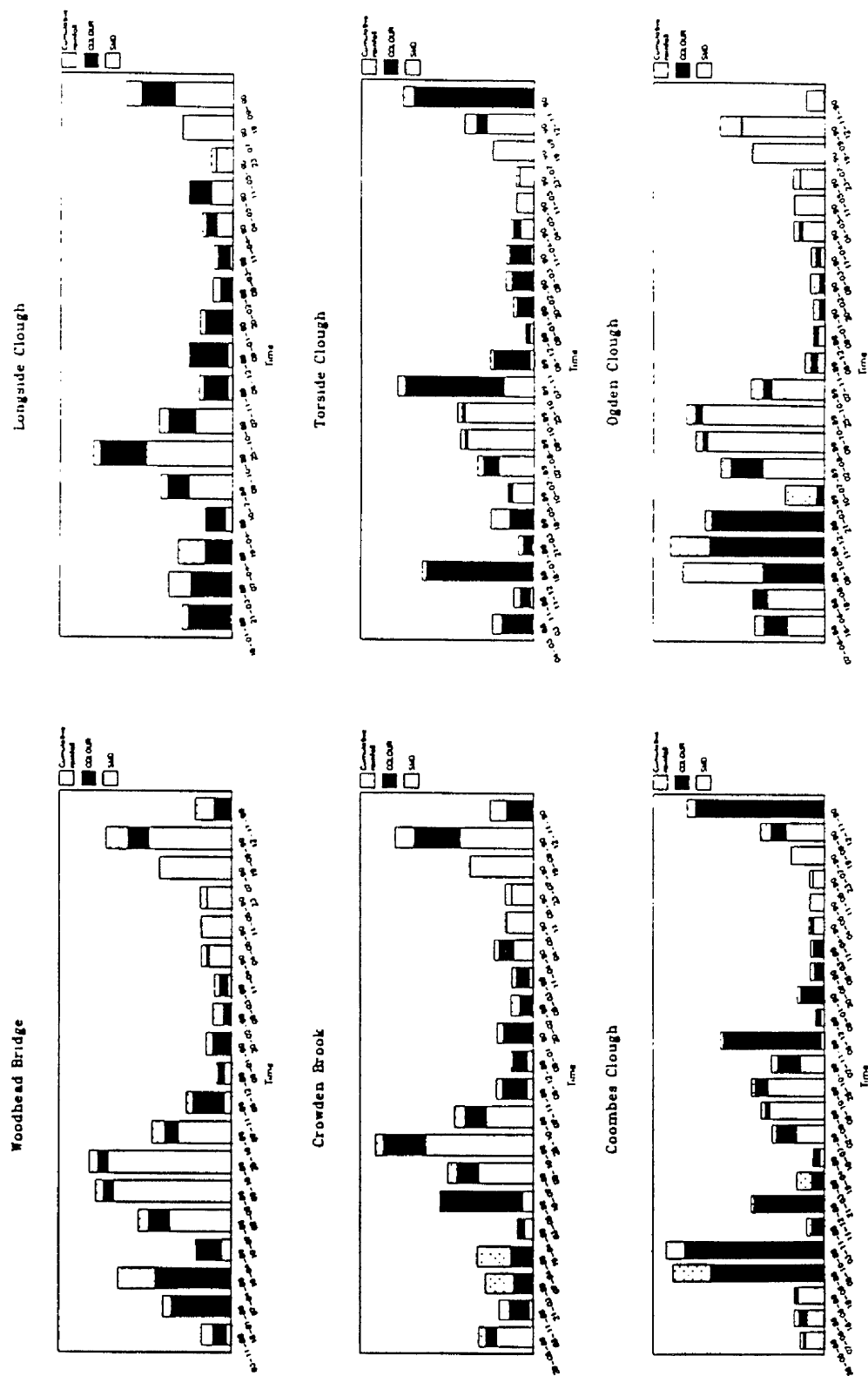


Figure 5.2 The relationship between colour, cumulative three days rainfall and SMD at the feeder streams.



water through to the lysimeters (see figure 4.36 and appendix IV).

Results of the laboratory rain fall simulation experiments have indicated that colour in the water (eluate) which had been leached out from different types of soil by different types of waters (soft, hard and distilled water), had increased in all the eluates. The increase in the levels of colour were more affected by the type of soil and other factors than by the type of water added. These results strongly suggest that after the decomposition of the organic matter, any type of added water will leach out these soluble organic acids., and the effect of this added water on the eluate will vary slightly from one type of water to another. The effect of the hard water on different types of soils varied from soil to soil. There was a decrease in the colour of almost all the eluates (except in the eluate of the peat sample which was kept at 20 °C; where there were slight increases in the levels at the beginning of the treatment with the hard water then the levels decreased to their original levels) but this was not significant (see figure 4.41). In the field also there were no significant differences in the levels of colour in the water leached through lysimeters which were placed in the lime and unlimed areas (see figure 4.36); probably because the limed area was treated nine months before the sample was taken and the lime had been washed out from the soil and repeated treatments were needed for a continued effect. It is quite difficult to

make conclusions on the effect of the type of water on colour; more investigations are required.

### 5.3 Acidity and colour.

It is well known that the Longdendale Valley receives acidic rain fall originating mainly from the nearby

industrial belt of the North West of England; the average pH of the rain fall in the Pennine region being between 4.2 and 4.5 (Edwards 1987, Spink 1988). This is believed to have had some notable impact on the local terrestrial and aquatic ecosystems. Anderson and Shimwell (1981) have attributed the gradual replacement of the indigenous bog mosses (Sphagnum spp.) by the hardier cotton grasses (Eriophorum spp.) over the last two centuries to the effect of acid rain fall. A reduction in the amount of Sphagnum moss has led to increased erosion on the catchment (Phillips et al., 1981). This may lead to extreme increases in the colour of the water in the streams due to the large amount of organic matter. McBride (1989) studied the factors influencing the distribution of humic substances and trace metals in the Longdendale catchment area. He discussed the causes of soil acidification from both natural and anthropogenic causes at Longdendale Valley. He suggested the following:

#### Natural causes:

- (I) Organic acids (particularly humic and fulvic acids) formed from the decomposition of vegetation.
- (II) Carbonic acid derived from microbiological and root

respiration.

(IV) Podzolization (part of the natural soil weathering and development processes, and occurring over a very long time span).

(V) Nitrification from natural sources of nitrogen



(VI) Sulphuric acid from the oxidation of mineral metal sulphides (especially iron) in rocks and soils.

**Anthropogenic causes:**

(I) Acid rain containing sulphuric and nitric acids formed from the oxidation of sulphur dioxide and nitrogen oxides respectively, which are by-products of fossil fuel combustion.

(II) Nitrification from soil utilisation, particularly nitrogenous fertilization of soil (most likely in the lower part of the valley).

(III) Forestry harvesting where cation nutrients taken up from the soil in the tree's lifetime and exchanged for hydrogen ions are not all returned to the soil.

It seems to be that the streams at Longdendale Valley were highly affected by both natural and anthropogenic causes because most of the catchment area is covered with peat and as already mentioned, the valley receives acidic rain fall originating mainly from the nearby industrial belt of the North West of England. This could explain the generally low levels of pH at the streams and at the treatment works as figures 4.5 and 4.14 show.

## **5.4 Soil and colour.**

### **5.4.1 Type of soil.**

The colour levels in some streams such as Coombes Clough and Ogden Clough seemed to be significantly affected by the type of soil which covered their catchment area. The drainage area of the former is covered with Winter Hill Associations (peat), Revidge and Belmont while the drainage area of the latter is covered with the same types of soil but without the peat. This could explain the generally high levels of colour at Coombes Clough (see figure 4.2) and the generally low levels of colour at Ogden Clough; the high colour is probably due to the presence of organic matter which had been leached from the peat because of waterlogging of the Winter Hill Associations, being of wetness Class V or VI, as classified by M.A.F.F. (see table 2.1). The colour levels at Longside Clough seemed to be significantly affected by Wilcock Soil Association (which is derived from carboniferous and lower palaeozoic rocks see table 2.1) rather than by the thinner layers of peat.

Field experiments have indicated the importance of the type of soil in generating the most colour. There was a significant variation in the levels of colour in the lysimeters. Colour levels were higher in the Longdendale Valley than in North Wales, as shown in figure 4.35. This was due to the location of the lysimeters, the former were located under peat while the latter were under peaty soil.

The monolith tin experiments also show clear differences in the colour level in the eluate which had

been leached through different types of soil. The highest colour was in the eluate of the peat sample then the peaty sample and the lowest at the slightly peaty soil (see figure 4.40). In general the soil whose parent material contains low concentrations of organic matter releases less organic matter (and has ultimately low colour) and the ones which contain high concentrations release more. All the above observations confirm that areas of peat are the major sources of colour within upland catchwater system.

#### 5.4.2 Thickness of the layers.

The thickness of the soil layers may play an important role in the quality of the stream waters. Schofield and Penman (1949) illustrated the drainage from three blocks of undisturbed soil, each 4 square metres in area and 0.5, 1 and 1.5 metres deep respectively. They illustrated that the amount of water and the time taken for water to move down from the surface sufficiently to produce the pressure head needed to cause drainage from these soils were different, depending mainly on the amount of rain fall, the time span of the falling rain and evaporation. The replacement of the deficit in the thinner soil (0.5 metres) was faster than in the thicker soil (1.5 metres). Also they observed that usually, when sudden heavy rain falls on a dry soil surface, drainage occurs before the deficit has been fully made good.

Drainage from thicker layers of peat may take a longer time and a larger volume of rain to occur than from thinner layers. When drainage does occur, however, there will be



more organic matter released from it than from the thinner soil due to its larger organic content and the contact time between the peat and water. The small amount of dissolved organic matter which might be released from the thinner layers of peat may be diluted, or absorbed by the vegetation before it reaches the streams. Even if it reaches the streams it will have relatively little effect on the colour of the streams waters, while the large amount of dissolved organic matter which might be released from the thicker layers of peat will have a significant effect on the colour of the streams waters. This could explain the peak in the colour at Coombes Clough and Torside Clough (see figure 4.2) where the drainage area is covered with thick layers of peat (see section 2.6 and figure 2.5) and the generally low colour in the streams where the catchment area is covered with thinner layers of peat such as Woodhead Bridge, Crowden Brook and the stream whose drainage area is not covered with peat (Ogden Clough).

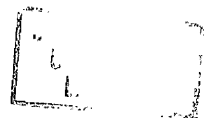
The results of microorganisms activities indicate the highest activities at the catchment area covered with thick layers of peat and flat or gently sloping sites (such as Coombes Clough, Torside Clough and Longside Clough) and the lowest being at Ogden Clough whose catchment area is not covered with peat (see table 4.2). This is probably due to the wetness of the layers or the nature of the organic matter present in the soil. Also these results could explain the variation of colour levels in the streams.

#### 5.4.3 Altitude and landforms of the catchment.

It seems to be not only the thickness of the layers of peat which has an effect on the levels of colour in the streams but also the altitude and the slope of the land. As mentioned in section 4.15, Bower (1960) studied the distribution of peat erosion in the Pennines. He suggested that peat erosion is most extensive at higher altitudes where it is common on flat ground as well as on the slopes. Peat becomes thinner and erosion less common as at lower elevations. This could explain why Ogden Clough drainage area is not covered with peat (see figure 2.8), possibly due to its lower altitude and the degree of slope of the catchment area (the absence of peat may be due to complete removal or because peat has never properly formed). Also he suggested that the development of extensive peat at higher altitudes is due to greater than average rain fall and low temperatures. Bower classified peat erosion into two areas, an area at risk of intense dendritic "Type 1" gulley erosion (deep peat on flat areas, on slopes of less than 5°) and areas of less intense, reticulate "Type 2" erosion (no limits to depth and the pattern of the gullying is much more open, on slopes exceeding 5°). Also he identified the contrast between the high plateaux (which exceed 2000 feet) and the lower moors (between about 1500-1700 feet) which are located to the south of the Longdendale Valley. On the former erosion is intensive, advanced (mainly type 1), in peat usually exceeding six feet in depth and on the flattest it is often deeper than

ten feet. As the altitude decreases away from the high plateaux, and the interfluves tend to become narrower, the peat depth decreases and erosion becomes less common. This could also explain the variation of colour levels at Torside Clough and Ogden Clough which are located to the south of the valley (see figure 2.8 and 4.2). The former (usually high colour) drains from the high plateaux and the latter (usually low colour) drains from the low moors. In general, these results suggest that those catchment areas which are located at lower altitudes may contribute minor sources of colour within upland catchwater systems, because of the thinner layers of peat or due to the absence of peat. Recently, Butcher et al. (1991), suggested that problems of peat erosion and water discolouration are linked; the link between water quality and erosion is not clear. They also show the annual loss in the capacity of some reservoirs at the southern Pennines. There was a wide variation in the figures for annual loss of capacity ranging from no loss to 15476 m<sup>3</sup>; also the percentage of loss of capacity per century varied between 0.0% to 93.5% in some reservoirs.

The size of the catchment area and the slopes of the streams may have an effect on the quality of the streams. Those streams (such as Crowden Brook, Woodhead Bridge and Ogden Clough) whose upper catchment areas were steep slopes, generally received a better quality of water than those whose upper catchment areas were flat or gently sloping such as Coombes Clough, Torside Clough and Longside



Clough (see figures 2.5, 2.8 and 4.2). Probably most of the rain falls on the former and drains down into the reservoirs (rapid run-off due to the slopes), while in the latter most of the water remained in the catchment (this may be due to flat or gently sloping sites); in these plateaux high rain fall, low temperatures and flat or gently sloping sites encourage poor drainage conditions and the build up of organic matter maybe due to the inhibition of the microorganisms responsible for mineralisation processes. This may lead ultimately to the formation of peat (and ultimately colour). The upper catchment areas of Crowden Brook, Woodhead Bridge and Ogden Clough were steep slopes but generally Crowden Brook received a better quality of water than Coombes Clough or Woodhead Bridge; this was probably because of the size of the catchment area. The former was larger (maybe more organic material was leached) than the latter. (see figures 2.8 and 4.2).

The sloping land was probably more prone to effects of sheep grazing, therefore over grazing (the density of sheep affects the regeneration of vegetation) in these slopes might lead to the encouragement of erosion (and ultimately poor quality water).

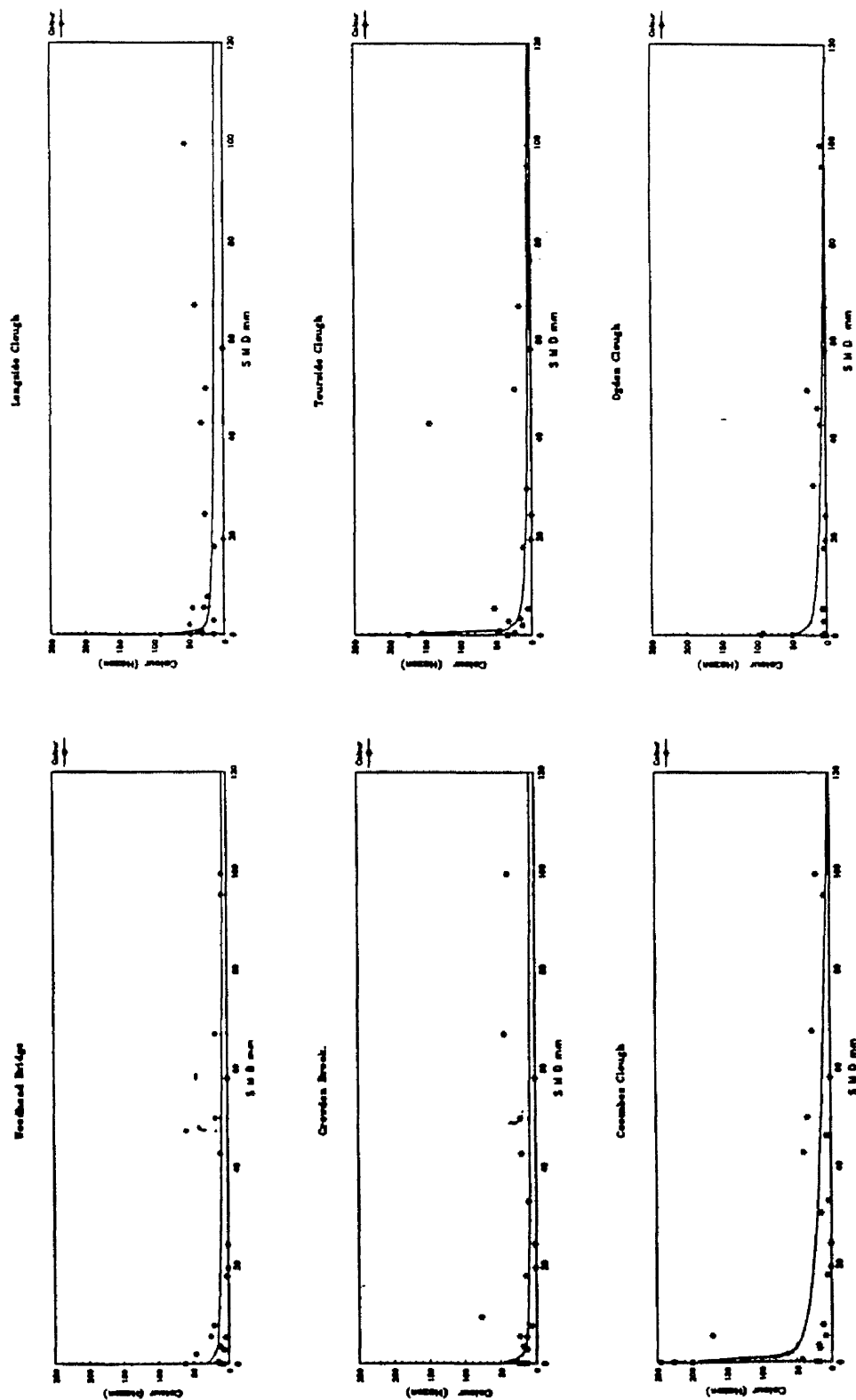
Also field observations have indicated the effect of slopes on colour levels in the lysimeters, the levels of colour in the leaching water from the first lysimeter (L1) at Longdendale Valley were higher than in the other two. The only visible difference between the location of this lysimeter and the other two was that it was in a sloping

area; the other two lysimeters were placed at almost the same depth, the vegetation cover was the same and the site was not eroding. This may be the reason for high levels of colour in general (gentle sloping may encourage more water to leach out from the soil before the deficit in soils is replaced or the decomposition of organic material (colour in water) takes less time to leach out in the gently sloping areas than in the flat areas). Runoff in steeply sloping areas might be too rapid to allow adequate leaching but could encourage erosion. Hence in such areas (i.e. those with steep slopes) extensive peat deposits are less likely. In general, these results suggested that those catchment areas with steep slopes and small catchment areas (not covered with peat) contribute only minor sources of colour within upland catchwater systems.

#### 5.4.4 Soil moisture deficit.

The status of the soil (low or high soil moisture deficit) when the rain falls probably plays an important role in the release of organic matter and metals. When the deficit is low more organic matter is released from the soil than when it is high following the replacement of any deficit, depending on many factors such as the type of soil and thickness ... etc, as already noted. Figure 5.3 and table 5.1 illustrate the correlation between soil moisture deficit and colour at the streams during the study. As the figure shows, most of the time the highest colour (the colour levels varied from stream to stream) in all the streams occurred when the soil moisture deficit was closer

Figure 5.3 Correlation between colour and SMD  
at the streams.



**Table 5.1 The average levels of some parameters at the streams and the treatment plant during high/low soil moisture deficit.**

		Colour Hazen	pH	Fe mg/l	Mn mg/l	Al mg/l	Mg mg/l	Ca mg/l
Coombes Clough	High-SMD*	23.60	4.44	0.10	0.05	0.19	2.57	3.37
	Low-SMD**	101.04	4.02	0.30	0.08	0.23	1.71	2.32
Crowden Brook	High-SMD	20.77	5.41	0.18	0.07	0.13	2.50	3.56
	Low-SMD	29.80	4.16	0.28	0.10	0.19	1.69	2.55
Woodhead Bridge	High-SMD	10.17	5.54	0.13	0.08	0.12	2.73	4.41
	Low-SMD	23.68	4.86	0.24	0.10	0.21	2.03	2.81
Longside Clough	High-SMD	26.67	5.65	0.87	0.27	0.23	4.29	9.10
	Low-SMD	40.60	4.44	0.95	0.18	0.30	1.77	3.98
Torside Clough	High-SMD	22.63	6.50	0.08	0.03	0.11	4.47	9.67
	Low-SMD	58.96	5.95	0.26	0.05	0.19	5.16	4.52
Ogden Clough	High-SMD	7.10	5.93	0.07	0.04	0.09	4.15	6.11
	Low-SMD	32.06	5.51	0.17	0.06	0.11	2.51	4.17
Arnfield Works.	High-SMD	78.97 <sup>T</sup>	6.37	0.57	0.08	0.18	-	-
	Low-SMD	104.0 <sup>T</sup>	6.02	0.54	0.09	0.19	-	-

\* High-SMD = The soil moisture deficit > 5 mm.

\*\* Low-SMD = The soil moisture deficit < 5 mm.

T True colour not included.

to zero (when the soil reaches its full capacity for holding water); as excess water was then available for run off (dissolved organic matter, erosion ... etc), depending on the status and type of soil. Assuming that soil moisture deficit for all the streams was the same (the data for soil moisture deficit represents the whole region not the individual stream, certainly each stream has different soil moisture deficit because each one is covered with a different type of soil, different thicknesses of layers and slopes ... etc). In the figures, if the dry weather line is extrapolated back to the colour axis, this represents the base line colour levels in that stream at a point other than heavy rain fall, at the end of a dry period to meet the soil moisture deficit. The colour levels at the streams when the soil moisture deficit is low, varied from stream to stream; the highest colour levels were expected to be at Coombes Clough and Torside Clough and the lowest colour levels were in the other streams, i.e. Ogden Clough, Woodhead Bridge, Crowden Brook and Longside Clough. It is difficult to specify the exact timing of the increase in the colour levels at each stream, because as mentioned previously that data for soil moisture deficit represents the whole region not just the individual stream. It seems to be that the increase happened just after the replacement of the soil moisture deficit in the soils layers which covered the catchment area (when there is a surface runoff).

Both extremely low and extremely high soil moisture



deficits can increase the colour in water. The records of the summer of 1989 are of special interest. At the end of that summer (25th September to 4th October) the highest soil moisture deficits (110.2-115.3 mm) for four years were recorded. (see figure 5.4 and appendix III). At this time the colour at the works increased to more than the normal average summer levels (< 80 to > 100 Hazen units). At the same time the levels of some metals, especially iron and manganese, increased to almost double the normal summer time level (i.e. iron from 350 to > 1500 PPb (see summer 1989, figure 4.34 and appendix III)). Colour at this time of year should be lower because there was no leaching of organic material from the soil due to the high deficit, and over three months of almost continuous drought. The colour in the waters could be due to one or more of the following factors:

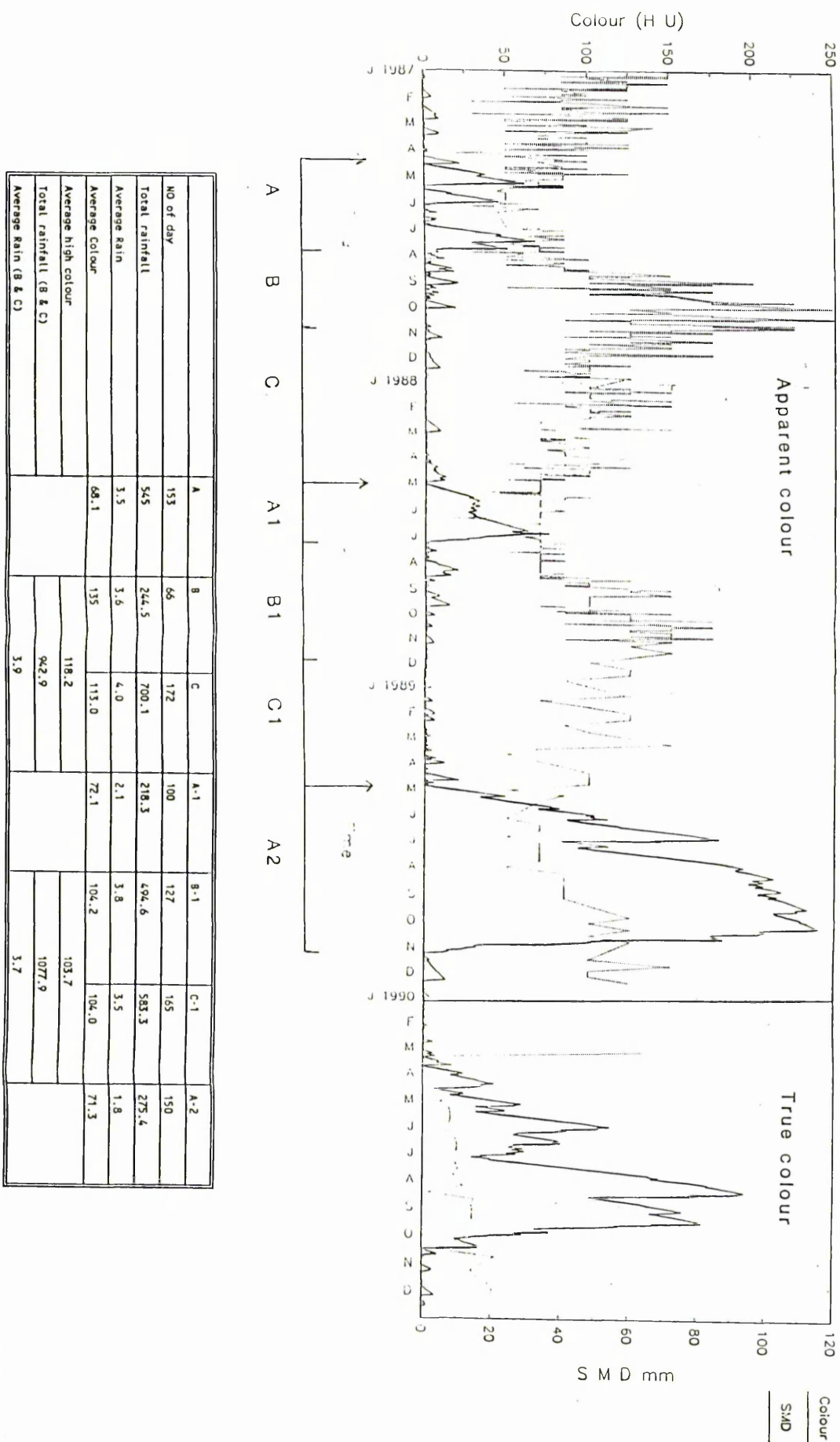
1- High temperatures may have increased the evaporation of water in the reservoirs; this could concentrate the metals increasing the colour, especially due to the formation of ferric hydroxide (see section 5.10).

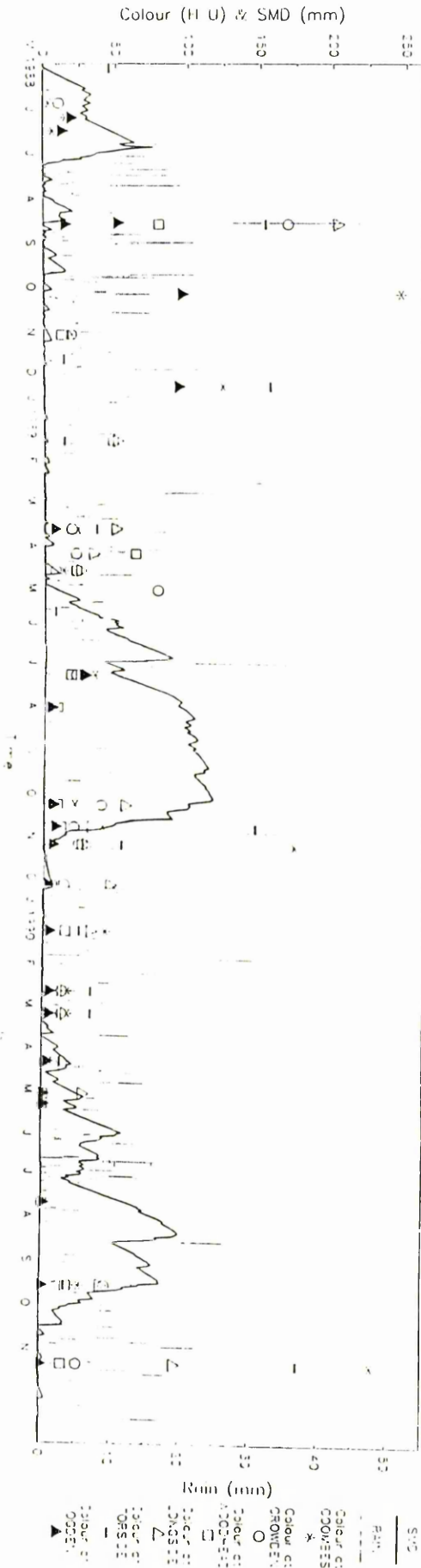
2- Colour may be due to increased aerobic decomposition of the organic matter in the sediment at the bottom of the reservoirs.

3- High water temperatures may have increased the leaching of metals from the rocks again increasing the colour. There is a tendency for the rate of chemical reactions to increase as the temperature increases.

Commonly a 10 °C increase in temperature doubles or trebles reaction rates, also the rate of biological activity is increased (Ollier 1979). Also Hornung and Adamson (1987) suggest that decomposition proceeds much more rapidly at higher temperatures but moisture is also necessary. In waterlogged, anaerobic conditions, however, decomposition proceeds very slowly. During that summer (1989) the levels of some metals such as iron also increased at some streams such as Longside Clough (On 9th and 25th October) and Torside Clough (On October 25th) (to 1.35 and 1.66 at Longside Clough, and to 0.22 mg/l at Torside Clough), when soil moisture deficit was 99.50 and 42.70 mm respectively (see figure 5.4 and appendix II). The colour and iron levels at Longside Clough increased on both occasions especially colour on the first. On the second occasion (on October 25th) the levels of colour and iron increased at Torside Clough when the soil moisture deficit was 42.70 mm; this was probably due to the large amount of accumulated rain during that week (was 46.10 mm) which, although not immediately meeting the soil moisture deficit did cause increased runoff. As can be seen, the colour can increase at both the Works and in some streams during the high soil moisture deficit. This increase can be due to the increase of iron. Summer increases were lower than the autumn and winter peaks (see figure 4.34 and 5.4). Some streams were more effected than other, the colour levels at Longside Clough were always at their highest when the soil moisture deficit was high (see figure 5.5). Also the soil moisture

Figure 5.4 The relationship between colour and SMD at Arnfield works.





deficit had some effect on the levels of colour in the raw water arriving at Arnfield Works (see figure 5.4). Most of the time the lowest colour levels occurred when the soil moisture deficit was high and the highest colour always occurred when the soil moisture deficit was low and after a period of high soil moisture deficit. The peaks in the colour usually occurred in the autumn. As shown in table 5.2 the start of the increase in colour was almost at the end of the time of low soil moisture deficit, and it varied from year to year. It is difficult to specify the exact timing of events because of the time lags built into the reservoirs storage, and the time it takes for the delivery of the water from the catchment to the reservoirs and then to the treatment plant is unknown.

**Table 5.2 Estimation of timing low/high colour and soil moisture deficit at Arnfield.**

Year	Colour		Soil moisture deficit.	
	Low	High	Low	High
1987	06-04-87 To 03-08-87	14-08-87 To 11-05-88	06-08-87 To 03-05-88	11-04-87 To 06-08-87
1988	11-05-88 To 16-08-88	16-08-88 To 01-05-89	09-07-88 To 27-04-88	03-05-88 To 09-07-88
1989	01-05-89 To 25-09-89	25-09-89 To 05-03-90	07-11-89 To 25-03-90	27-04-89 To 07-11-89
*1990	05-03-90 To 16-08-90	23-08-90 To 1991	08-11-89 To 04-03-90	04-03-90 To 16-10-90

\* True Colour.

Field observations have indicated the importance of soil moisture deficit in the discolouration of the runoff. At Longdendale Valley, lysimeter experiments showed that there was no leaching of water from the soil (ultimately colour) when the soil moisture deficit was high; even after a spell of rain (see appendix IV) although surface runoff could occur. The amount of dissolved organic matter which might be released from the soil during the high deficit periods may have been absorbed by the vegetation before it reached the stream and this would not have any impact on the quality of the stream water. When there is low deficit and high rain fall, the drainage from the soil could have a significant effect on the quality of the stream water and this depends on the type of soil and the amount of erosion.

#### 5.4.5 Temperature and biological activity.

The results in figures 4.40 and 4.41 indicate that the decomposition of organic material was highly affected by the temperature. The increase in the temperature from 10 °C to 20 °C, seems to have increased the colour levels in the water between not less than 20% to 50% as shown in figure 4.41. This was probably due to the aerobic conditions where the activity of microorganisms in the soil may increase (as indicated in table 4.1, the Arylsulphatase activity increases with an increase in temperature), which probably leads to the decomposition of more organic matter (oxidation of organic compound). Also it seems that the activity increased with the temperature, double the temperature (10 °C to 20 °C) increases the activity to

double or more depending on the type of soil (there is more activity in the peat than in peaty soil; see table 4.1). Due to the small number of samples, the fact that some microorganisms cannot survive under laboratory conditions and a shortage of time in the study, firm conclusions cannot be drawn; more investigations are required.

### 5.5 Colour and the geology of the area.

The colour level at Longside Clough seems to be more affected by inorganic substances, due to the presence of high levels of iron and manganese especially iron, rather than organic substances. The underlying rocks (Readycon Dean and Hyden Rocks) of the stream were important sources of their high levels of iron and manganese which could be responsible for the colour in this stream (see figures 2.8, 4.9 and 4.10).

### 5.6 Colour and vegetation.

Vegetation plays a significant role in the quality of the stream waters. For example, moss plants may reduce the erosion factor through acting as a physical barrier between the peat and the flowing water and it can act as a physical filter of suspended organic matter and, to a lesser extent, possibly even of dissolved organic matter. During the summer, such as in 1990 (see figure 4.3), the colour in the streams was low; this may be due to less organic matter reaching the streams from the soils, to the soil moisture



deficit or to the vegetation (growing season) which may absorb organic matter before it reaches the stream, especially at streams such as Coombes Clough, where the lower part of the stream is covered with quite a large forest (see figure 2.8). The underlying geology, soil and vegetation may play a very important role in the quality of the stream waters. Each of these factors may play an important role at a certain time, for example when it rains heavily and drainage occurs; probably soil plays a more important role in the quality of the streams water than the geology of the streams or the vegetation because there is not enough contact time for the geology or vegetation to play a significant role. In general vegetation may play a significant role in reducing colour in the streams during the high soil moisture deficit.

## 5.7 Colour and time.

It is known that peats are difficult to rewet when dried. As was described in section 1.2, Hayes (1987) and Hayes et al (1989) suggested when drying takes place it causes shrinking of the humic macromolecules, and it would appear that during the shrinking process the more hydrophobic structures are orientated towards the exterior. He also mentioned that drying will also affect the microbial population, and these will not metabolise below a certain moisture content. This stage (the dry period) seems to be the time when decomposition takes place assuming that enough moisture remains for the requirements

of the microorganism. When water is returned, wetting is slow. Eventually, however, the humic substances will swell to their dimensions prior to drying, and it may be, as had been suggested by Swift (1989), that macromolecules expand and the molecules go into solution (see section 1.2); this leads ultimately to colour. Birch (1958a, 1958b) has shown an explosion in biological activity after the rewetting of dry organic matter. Hayes (1987) suggested this activity could lead to oxidation of humic acids to fulvic acids, or the formation of fulvic acids during proliferation of organisms in the peat substrates, and if these fulvic acids and the lower molecular weight humic acids do not find sufficient hydrogen bonding sites to hold firmly on to the humic structures in the peat they will be removed in the drainage water. When it is wet, it might lead to extreme increases in the colour of the water in the streams due to the large amount of dissolved organic matter.

Sometimes, it is very difficult to distinguish between the colours caused by the organic matter or by the inorganic (such as iron compounds) especially during the autumn and winter, because at these times both the geology of the catchment area and the soil might be responsible for the levels of colour in the streams while in the summer it may be only from the underlying rocks (emerging through mineral springs).

Figure 5.5 illustrates the relationships between the rain fall, soil moisture deficit and colour in the streams. It is very difficult to find a straightforward relationship

between the three, because as mentioned before, rain can play more than one role (such as erosion, dilution ... etc) depending on the catchment area of the individual stream (geology, soil type, thickness of peat, slopes ... etc). It seems that usually the low colour in the streams occurred during the high soil moisture deficit, especially when it is a period of low cumulative rain fall, and the high colour usually occurred during the low soil moisture deficit, heavy rain fall or when there were large amounts of accumulative rain fall and after prolonged dry periods especially at the streams whose catchment area is covered with thick peat such as Coombes Clough or Torside Clough.

Field results have indicated the importance of soil moisture deficit on the time of high/low discoloration and may help to predict the date of onset of discoloration. As shown in figures 5.4 and 5.5, and table 5.1, the levels of colour (the average) were significantly affected by the soil moisture deficit, high colour occurring during the low soil moisture deficit while low colour occurs during the high soil moisture deficit at both the streams and Arnfield Works. It appears that there is year to year and season to season variation in the levels of colour depending on the amount of rain fall and the drainage area of the streams. The continuous wet period from July to May 1988/89 had a different effect on the streams; it seems that at the beginning of the period most of the organic matter washed out of the soil (which might have been decomposing during the dry period) and by the end of the period and the

initial flush of material had passed the colour decreased in the streams (probably due to the presence of less organic matter) especially at the streams whose drainage area is covered with thick layers of peat. The drought of 1989 and 1990 made the colour levels in the streams lower in some streams, in particular in those whose catchment area is not covered with peat or covered with thin layers of peat such as Ogden Clough and Woodhead Bridge. This drought does not as yet appear to have caused an increase in the colour except a sudden increase in the colour at the beginning of the low deficit after the drought. It might have a significant effect on the levels of colour in the coming years especially at some streams such as Coombes Clough and Torside Clough. In general, during the high soil moisture deficit the colour in the streams was low; As a rule there is no direct or obvious relationship between the colour, soil moisture deficit and the daily rain fall, but it is not denied that they almost certainly had some influence on the date of onset of colour, because the data for soil moisture deficit represent the whole region not the individual stream, also the rain might fall on one side of the valley and may not fall on the other. All these make the interpretation of the data difficult.

In an attempt to understand their relationship with the prolonged dry periods, the colour levels were divided into three periods represents different times; the time during the high soil moisture deficit (A), which may represent the time of composition of the organic matter in

the soil (usually low colour); the period after the dry period until the highest peaks (B), which may represent the releasing of organic matter from the soil (usually increased in colour); and the period after the peaks in the colour (C's), which may represent the settlement before the next prolonged dry period (usually decreases in colour levels), as shown in figure 5.4. As the table in the figure shows, the number of days in the dry period of 1987 to 1989 was 153, 100 and 150 days respectively. The average colour in the period after the dryness (B & C) was 135 and 113 Hazen units for the years 1987/88, 104.2 and 104 Hazen unit (B-1 & C-1) for the year 1988/89 and for the year 1989/90 the average level of colour was not clear due to a change in the method of its measurement. As the results indicate, the colour was affected by the length of the dry period; the longer the prolonged dry period the higher the subsequent levels of colour observed. Also as the results indicate, the release of colour was affected by the amount of rain fall (the higher the average of rain fall, the higher the colour). If this relation is true it means that in 1990 the colour levels would be high due to a longer prolonged dry period (150 days (A2)); if there was enough rain to release the previous accumulative colour. However, because of the drought of 1990, and the change in the method of measurement of colour we could not obtain the results for the prolonged dry period. Until the beginning of October 1991, there was not a significant increase in the colour levels of the raw water in reservoirs, even

after the wet spell in September 1991 (personal communication with the North West Water PLC on the 9th of October 1991). We have to wait for a wet year to see if that is true. However, no definite conclusion can be offered due to the shortage of details of the past and future long term records of colour, soil moisture deficit and rain fall.

In general the lowest levels in the raw waters were in the summer months and a marked increase was usually shown through the autumn and winter and the levels of colour at the streams and the works start to increase when the soil moisture deficit was close to zero. The colour levels in the last two years (1989 and 1990) were lower than in previous years; similar observations were noted in the other Pennine reservoirs at Thornton Moor (see Butcher et al. 1991).

## **Part II.**

### **Metals.**

#### **5.8 The metals levels, origin and nature of metals.**

The levels of iron, manganese and aluminium as shown in the results varied from stream to stream. The highest level of iron was in Longside Clough and the lowest was in Ogden Clough except during the summer of 1988 (see figure 4.9 and appendix II). The high levels of iron which had been recorded in this stream are in good agreement with the levels which had been reported by McBride (1989) at streams draining from the same catchment area. The levels of aluminium were lower at Ogden Clough than in the other streams. The levels of calcareous metals such as Ca and Mg were low in all the streams (below the E.E.C. guide levels) as shown in figures 4.12 and 4.13. Usually the level of one or more parameters at the streams exceed not just the guide levels, but also the maximum admissible concentration (M.A.C's) for water intended for human consumption. It should be noted that the E.E.C. standard refers to dissolved trace metal concentration in the treated drinking water. Whilst those values refer to the raw water, a comparison of the levels of trace metals recorded for the untreated, surface waters of Longdendale Valley with the E.E.C. standard, illustrates the degree of trace metal mobility present in the area.

Since the Industrial Revolution, efforts to reduce

pollution in the natural environment have not always been able to keep pace with the increasing amount of waste materials, and a growing population further aggravates the situation. The location of Longdendale Valley close to industrial areas makes the valley receive both dry and wet deposition. Sources of metals in the streams can be divided into soils and the underlying bedrocks. Metal from soil (both parent material and atmospheric deposition) can reach the streams if there is leaching. Metals from the underlying rocks can be leached out at any time as long as there is water running; and the levels of metals in both situations may depend on the types of rocks, type of soil, and other factors such as temperatures ... etc.

## 5.9 Rain fall and metals.

Sudden heavy rain falls cause surface run-off which might dilute the concentration of metals in some streams or it might do the opposite in others, depending on many factors, such as the amount of rain, type of soil ... etc. It is very difficult to predict what role rain is going to play because of its interaction with these other factors. Also, as with colour, it is likely that the cumulative rain fall may have a strong relationship with the concentration of metals; this might be due to the longer contact time (of ion exchange) between water and particles which may lead to the release of more metals depending on many factors such as pH.

As with the colour the results of the laboratory rain



fall simulation experiment have indicated that generally the average levels of metals (iron, manganese and aluminium) in all types of water (the input) which are used as leaching agents had increased after they percolated through the soil (see table 3.2 and figure 4.42). The level of some metals such as calcium and magnesium in the eluate varied from treatment to treatment. The level of both of them increased in all the eluates when the samples were treated with soft water and distilled water but when treated with hard water they decreased. It is very difficult to know what type of reaction takes place (ion exchange or redox). Some metals had been absorbed and some metals had been deabsorbed from the particles of the soil. It seems that most of the calcium and magnesium was absorbed from the hard water when it was used as a leaching agent. The levels of iron in the eluate of the lime sample were higher than in the unlimed sample. This could explain the increases of colour in the limed sample. Also as shown in table 3.1 the lime sample contained more iron than the unlimed sample; this could be due to contamination from the lime which was used to lime the site.

### 5.10 Acidity and metals.

As already mentioned, it is probable that acidity from both natural and anthropogenic sources is responsible for changing the chemistry of stream waters at Longdendale Valley. Anthropogenic causes of soil acidification can obviously aggravate the effects of the natural causal

processes by providing increased quantities of hydrogen ions and sulphate ions, the latter leading to mobility of metallic cations. A detailed review pertaining to the effects of acid deposition on the geochemical cycling of many trace elements is available (Campbell et al., 1985) and will not be repeated here. The authors also conclude that aluminium and manganese are mobilized from soils and that their concentration can be increased in acidified aquatic systems. Indeed E.R.L. (1983) notes that whilst relatively weak acids formed from natural acidification processes can cause quite high levels of acidity, their impact upon soil and water chemistry, especially in relation to mobilization of toxic aluminium and leaching of other trace metal ions, is less than that of comparatively strong inorganic acids arising from anthropogenic sources. Tyler (1981) suggested that under the normal course of podzolization, some metals such as Pb, Al and Fe formed complexes with organic matter. This could take place in the upper regions of Longdendale Valley where there is peat.

The buffering capacity of the streams is dependent upon the underlying geology, the type of soil and the vegetation cover. Bedrock influences soil buffering capacity according to its hardness and subsequent resistance to dissolution. At the Longdendale catchment area probably the most important mineral for neutralising acidity is calcium carbonate which is very low in the Kinderscout Grit and Shale Grit formations of the valley.

pH levels increased as the water flowed down the streams at Coombes Clough and Ogden Clough (see figure 4.7 and 4.8) during its dry period, because at the lower part of the streams there were layers of Shale Grit, from which some bases dissolved (see figure 2.8); the increase during the dry period may be due to the longer contact time between the water and the bedrocks while during the wet period there was less contact time. At Longdendale Valley the higher buffering capacity probably occurs more during the summer than in the autumn or winter. firstly, due to the increased contact time between the water in the streams and the bedrock, especially where there were layers of Shale Grit which contain more readily available bases. Secondly, less organic acid is leached from the soils due to the high soil moisture deficit. This increase in the pH may change the chemistry of the stream waters; it may encourage precipitation of any solubilized humic matter and some metals. The results demonstrate that the average concentration of the metals may have been affected by the pH. As the pH levels decreased the levels of some metals such as iron, manganese and aluminium increased and while the levels of some metals such as calcium and magnesium increased, the pH also increased (see table 5.1).

The exposure of water to air results in the oxidation of soluble ferrous bicarbonate to insoluble or colloidal ferric hydroxide. The water thus becomes opalescent and discoloured, and a deposit finally forms which undergoes further oxidation (Holden, 1970). In the oxidation of

ferrous bicarbonate, carbon dioxide is released and again becomes available for further dissolving more iron. This reaction can be represented as follows:



During the summer iron probably plays a more important role in the acidity and discolouration of the stream water than the organic matter because less organic acid is leached from the soil due to the high soil moisture deficit.

Vegetation plays significant roles, both positive and negative, in the quality of the stream waters. Moss plants may reduce the erosion and can act as a physical filter. Also vegetation can play a negative role. E.R.L. (1983) notes that coniferous forests contribute to greater levels of acidity in both soils and surface run-off than heathland or meadowland. This is due to a number of factors associated with coniferous trees in comparison with heathers and grasses. They have a much greater ability to scavenge anthropogenic acid inputs from the atmosphere, their higher humus decomposition rates and their relatively higher biomass growth (and subsequent increased ion uptake). This could explain the generally low levels of pH recorded in Coombes Clough (see figure 4.14), which drained from significant areas of coniferous forests (see figure 2.8).

The field investigation showed that the level of pH in the lysimeter experiment was low at both locations but it was extremely low at Longdendale Valley; this was

probably due to both natural and anthropogenic causes.

The laboratory study indicated that the pH in all the eluates shows a general decrease in the levels (see figure 4.42), even when the waters percolate through the lime sample (this is probably due to the previous leaching of calcium from the soil because the area was limed nine months before the sample was taken, therefore these may not have been enough remaining to effect on the pH). Also when the hard water was used as a leaching agent the level in the eluates was low (it seems likely that the pH was affected by organic matter rather than inorganic), and most of the calcium had been absorbed by the soil sample. Then after the dryness and when the natural water (E) which contained low calcium was applied, there were noticeable increases in the levels of calcium in the eluates (especially in the Bottom sample whose original parent material contained more calcium, see table 3.1); probably because they could not bind firmly on to the soil when hard water previous applied; the pH increased slightly also.

## 5.11 Soil and metals.

### 5.11.1 Type of soil.

The field results strongly suggest that the main source of iron in the streams and ultimately in the reservoirs appears to be related to the peat and Belmont Soil Association which covered almost all the streams as shown in figure 2.8. This is because the Belmont Association consists chiefly of ironpan stagnopodzols

which have iron enriched subsoil and, being almost permanently waterlogged, are particularly prone to trace metal mobilisation resulting from soil acidification processes. Also since Wilcocks are derived from carboniferous and lower palaeozoic rocks and they are not susceptible to summer drought due to their ability to hold a large capacity of water, also being of Wetness Class V or VI (see table 2.1). This may lead to rapid run-off; this might increase the leaching rate of iron and organic matters substantially.

Results of the laboratory experimentals and field studies indicate that the metals were highly affected by the type of soil. The leaching of metals from the soil into the lysimeters varied from location to location. For example, the levels of iron, aluminium and manganese were higher in the Longdendale Valley than in North Wales (see figures 4.37 and 4.38), This was probably due to the type of soil; the former peat and the latter peaty soil. The monolith tins experiment also indicates that the metals were highly affected by the parent material of the soil sample. For example the level of manganese in the eluate of the bottom sample was higher than in the top sample (see figure 4.42); and is probably due to the concentration of manganese in the original material (see table 3.1 and figure 4.42).

#### 5.11.2 Thickness of the layers.

As with colour, the thickness of the layers of soil may play an important role in the levels of metals. When

drainage occurs there might be more organic matter released from thicker layers of soil, especially peat, than from the thinner layers. Usually the organic material form complexes with metals, therefore when there are high levels of organic matter leaching from the soils there could also be high levels of metals.

#### 5.11.3 Altitude and landforms of the catchment.

The slopes, altitude and the size of the catchment area of the streams also seemed to play a role in the levels of metals in the streams. For example the levels of iron, manganese and aluminium were generally lower at Ogden Clough than in other streams (see figures 4.9-4.11). This could be due to its lower altitude (no peat, less erosion), the size of the catchment area (small) and the degree of the slope (high). All these may have either assisted the historic washing out of metals from the soils rapidly; it may decrease the amount of metals in the catchment area and ultimately in the stream or mean that the current drainage has too short a residence time for effective leaching of metals.

#### 5.11.4 Soil moisture deficit.

When the soil moisture deficit is low the level of metals (such as iron, manganese and aluminium) may increase; This may be because there are two sources of metals from both the rocks and soil. As shown in table 5.1, the average concentration of some metals such as iron, manganese and aluminium, increased during the low SMD (because of the surface runoff) and decreased during the

high SMD (no surface runoff) while the levels of other metals such as calcium and magnesium increased during the high SMD (longer contact time between the water body and rocks such as the Shale Grit) especially at the streams.

The effect of soil moisture deficit on metals levels in the raw water arriving at the treatment plant varied from year to year and from metal to metal. For example, during the years 1988-1990 the levels of iron increased during the high soil moisture deficit while in 1987 the levels increased after the high soil moisture deficit (see figure 4.34). This could be because during the last three years there was less rain fall (drought in the last two years) and as discussed before in section 5.4.4, the increase in the levels of metals during the summer may be due to evaporation, aerobic decomposition of organic matter in the bottom sediment and possibly the high temperature increased leaching of metals from the rocks. The year 1987 was a wet year. This might have diluted the concentration of metals. The increase in the levels of iron after the drought may be due to the organic matter which may have washed out of the soil after it had been decomposed; the increase in the levels of colour was similar to iron (see figure 4.34 and 5.4). The effect the soil moisture deficit had on metals is not clear. Aluminium levels seem to decrease during high soil moisture levels especially during less wet years.

In general, from the point of view of this study, the lysimeter experiments showed that leaching of metals from



the soils usually occurred when the soil moisture deficit was low; this may increase the level of metals in the streams if the leaching water reaches the stream. During the high soil moisture deficit there was less or no leaching from the soil and it might not have had a significant effect on the quality of the stream water; vegetation may absorb (during the growing season) both organic matters and metals before reaching the stream.

#### 5.11.5 Temperature and biological activity.

The most important microbiological effects on metals behaviour in soil often arose through the transformation of organic matter and oxidation reduction reactions (redox) of sulphur (Connell and Patrick 1968, Engler and Patrick 1975). There are two ways in which redox reactions can influence the behaviour of metals in soils: directly, through a change in the oxidation state of the metal itself, or indirectly, through a change in the oxidation state of a different element contained in a ligand that can form complexes with metals (Sposito and Page 1984).

Laboratory experiments in this study have demonstrated that colour and metals, especially iron, were affected by temperature; this was probably by forming complexes with the organic acid or it could have been influenced by the microorganisms ... etc. At higher temperatures there was more iron leached from the soil sample (see figure 4.42). This could be affected by the aerobic condition which leads to decomposition of organic material by the microorganisms (probably by forming complexes with the organic acid); as

indicated by the increase of Arylsulphatase activity in the soil (see table 4.2), which indicates that at higher temperatures the activity increased or as mentioned before that increases in the temperature may lead to increases in the reaction rate. As shown in figure 4.42, there is an indication that temperature has some effect on some metals but not on others; as mentioned before, due to the small number of samples and a shortage of time in the study, more investigations are required.

## 5.12 Metals and the geology of the area.

Spatial variation of iron levels in the streams appeared to be strongly related to the geology the catchment area of the individual streams. Longside Clough which drained from the underlying rock (Readycon Dean and Hyden Rocks; which contain a lot of iron (personal communication with North West Water PLC)) which might be important sources of iron and manganese (description of the rocks were given in section 2.6) and might be responsible for the colour in this stream as has been discussed before. Also the low levels of calcium in the streams appears to be strongly related to the geology of the valley. This is because the levels of calcium carbonate are very low in the Kinderscout Grit and Shale Grit formations of the Longdendale Valley (see section 2.6).

### 5.13 Metals and vegetation.

Vegetation can play a significant role in the levels of metals in the streams. As mentioned before in section 5.6 , moss plants may reduce the erosion factor through acting as a physical barrier between the peat and the flowing water. Also mosses are excellent scavengers of trace metals due to the ionic exchange properties of their surfaces. Probably not all types of vegetation play important roles in the levels of metals in the streams; some may help reduce the levels of metals at certain times. Therefore more investigations are required.

### 5.14 Metals and time.

The results of the streams study show that the levels of some metals such as iron increased during the autumn and winter (due to surface runoff) in some streams such as Coombes Clough (see figure 4.16) and in the same streams the levels of other metals such as calcium may increase during the summer (see figure 4.17); this could be due to the longer contact time between the water body and rocks. As already discussed in section 5.11.4, the soil moisture deficit may have a strong influence on the levels of metals at the works. In general the levels of some metals such as iron at the treatment plant can be high during the high soil moisture deficit, low during the low soil moisture deficit, after prolonged dry periods and after storms (see figure 4.34).

## 5.15 Relationship between colour, metals and other

parameters.

As mentioned before, it appears to be very difficult to distinguish between the colours caused by the organic and by the inorganic matter (such as iron compounds) especially during the autumn and winter, because at these time both the geology of the catchment area and the soil might be responsible for the levels of colour in the streams whilst in the summer it may be only from the underlaying rocks (springs). Also it appears to be very difficult to find out what level of metals (such as iron) will affect the colour in the water and when it will increase the levels of colour (the break point). For example, there is a marked contrast between colour levels and iron over the years at the treatment plant. The levels of iron in the drought years (1989 and 1990) were higher than in the wet years (1987 or 1988) but the colour levels was the opposite; they were higher in the wet years and lower in the dry years (see figures 4.34 and 5.4). The increase in the concentration of iron could be due to evaporation or something else as already discussed in section 5.4. It seems that there is definitely no simple straightforward relationship between the colour and the other parameters for the reasons which have already been discussed in section 5.4. such as rain fall, soil moisture deficit ... etc.

As can be seen, the large number of parameters makes the inter-relationships difficult to explain. Therefore auto-correlation matrices are used to indicate possible relationships. The linear correlation coefficients and their associated levels of significance (\*  $P = < 0.05$ ) for all possible bi-variant combinations of parameters for each stream and the treatment works are given in appendix VI. All statistical analyses were performed using the statistical package for social studies (SPSS). Table 5.3 summarizes the relationship between colour and pH with the other parameters.

As shown in table 5.3, at the treatment plant the turbidity demonstrated a significant positive correlation colour; within three out of four years (as the colour increased turbidity also increased; may caused by erosion). Also the colour strongly displayed a significant negative correlation with the soil moisture deficit at the works but not at the streams; this could be due to the types of soil, thickness of the layers and other factors as have already been mentioned before such as the soil moisture deficit representing the whole region not just the individual stream. The daily rain, the accumulative three and seven days (rain3c and rain7c) rain fall did not show any relationship with colour at the works; as mentioned before, rain probably played more than one role such as dilution, erosion ... etc. At some streams, rain showed a significant positive correlation with colour, especially after the accumulative three days.

Table 5.3 summarizes the number of significant relationship between colour and pH with the other parameters at the streams and the treatment plant.

Parameters	Colour		pH	
	Out/6 S*	Out/4 Y*	Out/6 S*	Out/4 Y*
Turbidity	---	+3 /4	---	-1 /4
SMD	-1 /6	-4 /4	0 /6	-2 & +1 /4
Rain1	+3 /6	0 /4	-5 /6	+1 /4
Rain3c	+3 /6	0 /4	-2 /6	0 /4
Rain7c	+2 /6	0 /4	-5 /6	0 /4
pH	-1 /6	0 /4		
Fe	+4 /6	+2 /4	-1 /6	+1 /4
Mn	+2 /6	-1 /4	-3 /6	0 /4
Al	+4 /6	+3 /4	-4 /6	-1 /4
Ca	-2 /6	---	+2 /6	---
Mg	-1 /6	---	+3 /6	---
W-temp.	0 /6	-2 /4	+1 /6	+3 /4
A-Temp.	0 /6	-3 /4	0 /6	+2 /4
S S	+2 /6	---	0 /6	---

S\* Number of the streams.

Y\* Numbers of the years.

Also the pH demonstrated no correlation with colour either at the works or at the streams with the exception of one out of six streams. A good positive correlation was shown between iron and aluminium with colour at the streams and works but not with manganese. Other parameters such as calcium, magnesium, suspended solid, air and water temperatures did not show a significant correlation with colour at the streams. A negative significant correlation was shown between colour, and air and water temperatures. In general the correlation between colour and turbidity, iron and aluminium was in good agreement with the finding of McDonald et al. (1987) and McBride (1989) who also obtained positive relationships between colour and each of iron, aluminium and manganese. In this study correlation between manganese and colour was not clear in either the streams or works. This is probably due to the levels of manganese in the underlaying rock where it is too low (see table 2.6). The vast majority of feeder streams demonstrated a significant negative correlation between aluminium and manganese with pH. It seems likely the acidity influences the leaching of manganese and aluminium but not iron; iron probably forms complexes with the organic matter but during the last two years there was less colour and ultimately less organic matter. Also pH showed a positive significant correlation with calcium and magnesium in some streams. The rain fall showed a negative significant correlation with pH in most the of streams; especially the daily and the seven days accumulative rain

fall.

There is no simple straightforward relationship between the parameters that can be observed. Some individual relationships are statistically significant but they are not necessarily large enough to explain the overall variation in colour. To look more closely at the association of colour with the parameters, stepwise multiple regression was used to give an indication of the relative importance of the parameters. The percentage of explained variation in colour levels at the streams and the treatment works is shown in table 5.4. Stepwise regression analysis of colour variation at the stream was first examined using all variables available; rain fall (the daily, and three and seven days of accumulative rain), soil moisture deficit, pH, iron, manganese, aluminium, calcium, magnesium, suspended solid, and water and air temperatures (step A). Secondly only the soil moisture deficit, daily rain fall and iron were used as independent variables (step B). Also at the treatment works the same examinations were carried out but using fewer variables (without calcium, magnesium, 3 and 7 days accumulative rain fall) because they are not available. As shown in the table the percentage of explaining the variation in the levels of colour were between 3% and 89% (step A). It varied from stream to stream and in the treatment plant it varied from year to year. Also the regression analyses indicated the colour variation in the streams and the works could largely be explained by the combination of soil moisture deficit,



the daily rain fall and iron. The poor the percentage (3%) explaining the variation in the levels of colour (both step A & B) at the streams in the Crowden Brook catchment, which had very large catchment area, can be explained by the fact that there was not much peat cover and the catchment had many steep slopes. Also being a large catchment area; the rain might fall on one side of the catchment and may not fall on the other. There was also more grazing by sheep and even evidence of over grazing which might lead to the encouragement of erosion. The higher percentage (89%) the variation were at Coombes Clough and Torside could be explained by the fact that those catchment areas were covered with thick layers of peat and flat or gently sloping sites. As shown in the table the percentage of explaining the variation in the levels of colour at the works were low; probably because the treatment works represents the integration of all the streams and reservoirs. It might be difficult to explain the variation in the parameters statistically, especially colour, probably due to the large number of factors which affect levels of colour and the difficulty of measuring each one precisely or attributing an appropriate weighting to each at this stage.

**Table 5.4 Stepwise multiple regressions of colour levels against all variables (A), and against soil moisture deficit, rain and iron (B). The table gives the variable entered at each step and the cumulative percent of explained variation ( $R^2$ ) in colour levels at the streams and the treatment works.**

		(A)	(B)		
			step 1 (SMD)	Step 2 (Rain)	Step 3 (iron)
<b>Streams</b>	<b>Coombes Clough</b>	71 %	16 %	36 %	70 %
	<b>Crowden Brook</b>	3 %	2 %	2 %	3 %
	<b>Woodhead Bridge</b>	76 %	8 %	33 %	33 %
	<b>Longside Clough</b>	46 %	None	None	46 %
	<b>Torside Clough</b>	89 %	8 %	15 %	62 %
	<b>Ogden Clough</b>	56 %	8 %	22 %	41 %
<b>Works</b>	<b>Arnfield 1987</b>	58 %	10 %	11 %	42 %
	<b>Arnfield 1988</b>	22 %	21 %	22 %	22 %
	<b>Arnfield 1989</b>	46 %	7 %	19 %	37 %
	<b>Arnfield 1990</b>	27 %	6 %	12 %	13 %

## **Chapter 6**

### **Conclusions and recommendations**

## 6.1 Conclusions.

It is clear that colour levels and metals varied from stream to stream and from survey to survey. Dry summer produced clear waters, whereas wet summers produced dirty water, and high levels of colour and metals usually occurred in the late autumn and winter in some streams such as Coombes Clough. Also the levels of colour and some metals in the raw water at Arnfield Treatment Works indicate that higher level occurs in the late autumn and there are considerably marked seasonal and year to year variations. In general the levels of one or more parameters at the streams or at the works exceeded not only the guide levels, but also the maximum admissible concentration (M.A.C's) for water intended for human consumption, especially in the autumn and winter. There were no clear visible differences in the levels of colour or metals detected moving down stream in some streams; the negligible change would not have any significant impact on the treatment works, but a clear significant difference was seen between one set of samples and another.

Longdendale Valley receives acidic rainfall originating mainly from the nearby industrial belt of the North West of England. This is believed to have had some notable impact on the local terrestrial and aquatic ecosystems. Probably the most important mineral for neutralising acidity in the valley is calcium carbonate which is very low in the Kinderscout Grit and Shale Grit formations of the valley, which therefore offer only a low

buffering capacity. Higher buffering capacity probably occurs more during the summer than in the autumn or winter.

There were considerable variations between the levels of colour and metals at the streams. The underlying geology, soil and vegetation of the individual stream seems to play a very important role in the quality of the stream waters. Each of these factors may play an important role at a certain time. Also the thickness of layers, slopes, altitude, size of the catchment area, temperature, rainfall, the soil moisture deficit and bacterial activity indicate to have a strong influence on the colour and metals levels in the streams. It seems that the colour levels in the streams were affected not only by the daily rainfall but also by the cumulative rainfall. The cumulative rainfall may have some influence on the colour of the stream, but in general it is very difficult to predict the role of rainfall, since it can play more than one role such as dilution, erosion ... etc. The status of the soil (low or high soil moisture deficit) when the rain falls probably plays an important role in the release of organic matter and metals. When the deficit is low more organic matter is released from the soil than when it is high, depending on many factors such as the type of soil and thickness ... etc. It seems that usually the low colour in the streams occurred during the high soil moisture deficit, especially when it is a period of no cumulative rainfall, and the high colour usually occurred during the low soil moisture deficit, heavy rainfall or when there

were large amounts of accumulative rainfall and after prolonged dry periods especially at the streams whose catchment area is covered with thick peat such as Coombes Clough or Torside Clough. At Longdendale Valley the levels of metals were probably affected by the acidification from both natural and anthropogenic sources. It seems more likely that the geology of Longside Clough (Readycon Dean and Hyden Rocks) and the soil (Winter Hill (peat) and Wilcocks Association) is an important source of its metals, also it might be that the Shale Grit (calcium carbonate in the shale; neutralising acidity) was responsible for the buffering of the streams, which may lead to an increase or decrease in the concentration of some metals (redissolving or precipitation). The colour level at some streams such as Longside Clough seems to be more affected by inorganic substances, due to the presence of high levels of iron and manganese especially iron, rather than organic substances, from the underlying geology and the cover soils.

As a rule, at a given moment in time, there is no direct or obvious relationship between the colour, soil moisture deficit and the daily rainfall, but it is not denied that they may have had some influence on the date of the onset of colour. There are always time lags in each catchment area and these differ from stream to stream making immediate relationships difficult to determine. The regression analyses indicated that the colour variation in the streams and the works could largely be explained by the combination of soil moisture deficit, the daily rainfall

and iron. It might be difficult to explain the variation in the parameters statistically especially colour, probably due to the large number of factors which affect levels of colour.

The experiment study (lysimeters and the monolith tins) shows that the levels of colour and metals in the water leached through them were highly affected by the type of soil. In general, the lysimeter experiments show that leaching of colour and metals usually occurs when it is a wet period and the soil moisture deficit is low, and during the high soil moisture deficit there is less or no leaching from the soil; and it might not have a significant effect on the quality of the stream water. The results of the monolith experiment indicate that the levels of colour and some metals such as iron were affected by temperature, and the level of colour in all the types of water which had been used as leaching agents (soft, hard and distilled water) increased. In general the soil whose parent material contains low concentrations of organic matter releases less organic matter (and has ultimately low colour) and the ones which contain high concentrations release more. It is quite difficult to draw conclusion on the effect of lime on colour and metals; the result does not show a significant effect on the colour of the water or even in the pH of the water indicating that very large application of lime are required to have any effect. The results of arylsulphatase activity indicate the activity of microorganisms at the catchment areas varied from hill to hill; the highest being

in the catchment area covered with thick layers of peat and flat or gently sloping sites and the lowest being in the catchment area which is not covered with peat, and the activity increased at high temperatures.

## **6.2 Recommendations for catchment management policy and future research work.**

1- The use of the remote sensing data is one approach which shows some promise in identifying the altitude, slope, aspect, area, proportion of deep and shallow peat, vegetation, erosion and extent of burning. McDonald et al. (1987), in their investigation of water quality, found that burning and grazing are the key variables related to colour. Therefore, using the remote sensing may lead to successful management of grazing land, to limiting erosion involving the minimizing of risk. This might include siting the heaviest grazing pressure in areas of least erosion risk by strategic location of fences and watering points. It might also include destocking the most vulnerable areas during certain periods such as droughts when erosion risk is high. In general remote sensing has become an extremely useful aid in the field work. Because of the relatively low cost, it can show the effect of seasonal changes in vegetation cover and other factors as already mentioned in section 2.4.

2- Improve the use of the by-pass watercourse, which skirts the northern shores of the reservoir chain, to



divert much of the artificial and feeder stream drainage and dilute with the feeder stream water before entering the reservoirs (buffering system; this existing system may have a little important implications for water quality in the reservoirs). This could be done by dividing the existing by-pass watercourse (or building a new divided by-pass watercourse at the south side) into two drainage lines, for example, red and green lines of drainage, and organise the collection of the streams water. The red line could be used to collect water which is not going to the reservoirs (passing all reservoirs and going into the river) while the green line could be used to collect water which is going to the reservoirs to be used for drinking water supplies. Avoiding collecting water from the streams which contain high levels of colour (organic matter) at certain times probably would have more significant implications (long and short term effects) for water quality in the reservoirs. It would be better than decreasing the colour the levels by diluting with water from the other feeder streams. As the results show, there were significant differences between colour levels in the streams during the low soil moisture deficit (when there is a surfaces water). The streams whose drainage area was flat or gently sloping, covered with a thick blanket of peat and which was at a high risk of erosion (such as Coombes Clough) contained more colour (let us say "type I") than the streams whose catchment area was not covered with peat (let us say "type II"); from catchment areas below 330 m O.D. because the

peat is usually found above this altitude, or the streams whose catchment area is covered with thin layers of peat (let us say "type III"); which are usually located in sloping areas. It would be better to avoid collecting waters from the streams which are "type I" during this period (low soil moisture deficit); especially during the heavy rainfall, by using the red line drainage and collecting water only from type II and III; by using the green line. This could possibly lead to:

- 1- Short term effect - Low levels of colour and metals in the water reaching the reservoirs which is used for drinking purposes; less treatment and ultimately less cost.
- 2- Long term effect - Prevent losses in the capacity of the reservoirs; less peat end up in the reservoirs (from the erosion), may increase the pH levels of the water; less organic matter, may reduce the effect from the peat, which might be deposited in the bottom of the reservoirs; due to less sediment (organic), and other such things; may repopulate the fish population and ... etc.

During the high soil moisture deficit a collection of water from the three types can be made by using the green line, because during this period there was less organic

matter leaching from the soil due to the drought (no surface water); possibly water from streams such as Longside Clough can be diverted into the red line because it might contain a lot of iron (see section 5.2.1). The red line can be used to divert the water from the streams during certain activities on its catchment area, such as during the agricultural spreading of farmyard manure or during forestry (pre-planting), and it can be used to divert water which contains large amounts of organic matter during the low/high soil moisture deficit, to be used for agricultural purposes. Finally avoiding collecting the first water washed off the surface (the first runoff from the soil when the soil moisture deficit is close to zero) from all the streams may also assist in getting good quality water for the treatment plant.

3- The wide variety of different methods of colour measurement used, both in the past and the present such as apparent colour, true colour and Hazen, make interpretation of past trends and comparisons from one local authority to another difficult. Therefore, adoption of one method of measurement, such as CIELAB, will be better for making comparisons.

#### **Future research work:**

- = Investigation of the effect of the reservoirs sediment on the colour and metals mobilization.
- = Further investigation of the relationship between vegetation cover and water quality using a closer

remote sensing image.

- = Further investigation on the effect (short/ long term) of lime on water quality.
- = Investigation of the effect of the depth of the soils, slopes, altitude, rainfall, soil moisture deficit, sun light, humidity, time and the type of vegetation ... etc; on microorganisms activity and relate them to the quality of the streams water.
- = Use of the remote sensing data to identify and monitor the changes in the catchment area.

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## **Appendix I**



### Key.

Colour	- Hazen Units (HU)
* Fe	- Dissolved iron (PPb)
* Mn	- Dissolved manganese (PPb)
* Al	- Dissolved aluminium (PPb)
Ca	- Dissolved calcium (mg/l)
Mg	- Dissolved magnesium (mg/l)
Temp-A	- Air temperature (°F)
Temp-W	- Water temperature (°C)
SS	- Suspended solid (mg/l)
Rain1c	- Daily rainfall at Swineshaw (mm)
Rain3c	- 3 day cumulative rainfall at Swineshaw (mm)
Rain7c	- 7 day cumulative rainfall at Swineshaw (mm)
SMD	- Soil moisture deficit at Buxton (mm)

\* Both PPb and mg/l have been used to enable comparisons between information obtained from this study and data from the Upper Nidd catchment (Naden and McDonald 1987) and Arnfield water treatment works. Most stream data is given as PPb, to compare with the large amount of information supplied from Arnfield works.

# Levels of some parameters within Coombes Clough.

Date	site	pH	Colour Hazen	Fe mg/l	Mn mg/l	Ca mg/l	Mg mg/l	SS mg/l
28-05-88	S-1	3.60	8.49	0.16	0.10	2.30	0.25	0.25
	S-2	3.60	8.46	0.15	0.08	1.88	1.90	6.70
	S-3	5.50	9.68	0.26	0.10	3.60	1.00	1.00
	S-4	6.26	3.62	0.11	0.12	3.80	3.50	0.98
	S-5	6.10	5.07	0.09	0.06	2.70	2.20	3.90
07-06-88	S-1	3.52	2.65	0.20	0.10	1.60	0.08	1.28
	S-2	3.76	3.32	0.10	0.12	1.80	1.50	1.50
	S-3	3.81	8.48	0.10	0.10	2.20	1.40	1.19
	S-4	4.66	20.19	0.06	0.04	1.70	2.70	2.00
	S-5	6.71	15.15	0.06	0.06	2.60	2.20	1.50
16-06-88	S-1	3.84	14.64	0.25	0.05	1.32	1.20	4.00
	S-2	4.10	19.08	0.16	0.07	2.80	1.80	0.49
	S-3	4.12	16.13	0.14	0.10	5.40	1.90	0.59
	S-4	4.79	10.62	0.15	0.02	5.00	3.20	2.38
	S-5	4.85	6.24	0.07	0.02	5.20	2.66	1.80
18-08-88	S-1	=	=	=	=	=	=	=
	S-2	3.66	218.46	0.62	0.02	1.10	0.40	68.80
	S-3	3.68	243.04	0.79	0.03	1.60	0.40	99.19
	S-4	3.72	233.04	0.78	0.05	1.70	0.50	109.60
	S-5	3.81	199.25	0.90	0.08	2.95	0.60	218.80
06-10-88	S-1	=	=	=	=	=	=	=
	S-2	3.20	233.50	0.47	0.03	0.40	0.05	28.10
	S-3	3.64	247.31	0.39	0.03	1.00	0.10	29.60
	S-4	0.36	235.60	0.35	0.03	1.10	0.10	24.50
	S-5	3.66	244.53	0.35	0.04	1.26	0.11	15.60
19-04-89	S-1	3.03	29.04	0.12	0.14	0.41	2.00	0.17
	S-2	3.72	2.67	0.09	0.10	0.81	2.60	0.50
	S-3	3.27	15.82	0.05	0.13	0.71	2.50	0.26
	S-4	3.36	14.88	0.04	0.13	0.91	2.35	0.30
	S-5	3.42	12.59	0.04	0.13	0.85	2.47	0.60
Grig reference			Coombes Clough sk 052992					
			Coombes Clough sk 053996					
			Coombes Clough sk 053991					
			Coombes Clough sk 053984					
			Coombes Clough sk 053981					

# Levels of some parameters within Ogden Clough.

Date	site	pH	Colour		Fe mg/l	Mn mg/l	Ca mg/l	Mg mg/l	SS mg/l
			Hazen						
07-06-88	S-1	4.46	19.02	0.05	0.07	3.10	1.80	0.50	
	S-2	6.70	18.31	0.03	0.03	10.50	4.00	2.39	
	S-3	6.70	18.85	0.04	0.02	10.60	4.30	0.49	
16-06-88	S-1	4.65	3.75	0.09	0.05	7.40	2.51	1.00	
	S-2	7.40	19.10	0.06	0.01	17.20	7.40	0.60	
	S-3	7.02	12.36	0.19	0.04	16.60	7.50	4.29	
18-08-88	S-1	3.97	53.48	0.61	0.05	0.04	0.40	1.19	
	S-2	4.04	61.18	0.59	0.06	0.10	1.00	2.40	
	S-3	4.16	50.37	0.46	0.08	0.26	0.08	7.60	
06-10-88	S-1	4.46	61.52	0.24	0.09	1.63	0.07	5.10	
	S-2	6.90	69.86	0.50	0.10	4.50	0.39	5.60	
	S-3	6.10	94.20	0.56	0.08	3.30	0.22	8.10	
Grid reference			Ogden Clough sk 047969	S-1					
			Ogden Clough sk 044971	S-2					
			Ogden Clough sk 042978	S-3					

## Appendix II

# Concentration of the parameters at Coombes Clough.

Date	Colour	pH	Fe	Mn	Cu	Mg	Al	TempA	TempD	S.S	Rain1c	Rain3c	Rain7c	SMD
28-05-88	3.62	6.26	110	21	3.8	3.5	160	46.0	12.0	980.0	0.00	6.20	15.50	33.10
	(3.55-3.69)	(6.0-6.68)	(105-115)	(19-23)	(3.63-3.95)	(3.2-3.9)	(156-166)			(977.3-997.6)				
07-06-88	15.15	6.71	60	60	2.6	2.2	190	54.0	12.0	1500.6	7.50	7.50	22.10	30.50
	(13.92-16.11)	(6.3-6.96)	(55-66)	(51-65)	(2.45-2.76)	(1.9-2.4)	(178-205)			(1391.4-1598.3)				
16-06-88	6.24	4.85	70	20	5.2	2.66	130	55.4	13.0	1800.0	0.00	0.00	0.00	46.10
	(5.97-6.43)	(4.77-4.95)	(61-76)	(18-23)	(4.9-5.5)	(2.3-2.93)	(126-133)			(1654.4-1978.3)				
18-08-88	199.25	3.81	1112	120	2.95	0.6	260	59.0	13.0	2821.8	50.90	65.30	76.50	0.00
	(185.61-206.3)	(3.78-3.9)	(1089-1128)	(111-126)	(2.71-3.1)	(0.54-0.66)	(249-266)			(2661.3-2924.7)				
06-10-88	244.53	3.66	350	110	1.26	0.11	250	49.0	11.5	7.20	15.30	31.50	31.50	0.00
	(221.3-259.1)	(3.59-3.75)	(339-359)	(102-115)	(1.1-1.4)	(0.09-0.14)	(239-267)			(6.8-7.5)				
03-11-88	18.92	5.50	120	59	3.1	2.5	160	34.0	9.0	1.55	0.00	9.00	9.00	3.50
	(17.9-20.5)	(5.41-5.63)	(109-126)	(52-66)	(2.89-3.4)	(2.25-2.74)	(154-175)			(1.23-1.92)				
11-12-88	122.38	5.22	116	79	3.5	2.58	233	45.0	5.0	1.24	0.60	4.90	16.40	0.50
	(120.12-125.3)	(5.09-5.36)	(106-123)	(75-83)	(3.35-3.7)	(2.33-2.8)	(224-243)			(0.8-1.5)				
21-03-89	22.44	3.4	56	41	0.83	2.62	100	35.0	5.5	0.63	6.00	25.40	39.20	0.00
	(22.1-23.2)	(3.33-3.48)	(51-59)	(36-47)	(0.77-0.9)	(2.5-2.79)	(91-111)			(0.34-0.98)				
19-04-89	12.59	3.42	40	30	0.85	2.46	234	36.0	6.0	0.57	0.00	0.00	5.40	7.70
	(10.39-14.3)	(3.32-3.55)	(38-43)	(27-35)	(0.79-0.95)	(2.31-2.43)	(225-241)			(0.26-0.99)				
10-07-89	33.75	6.56	118	56	0.73	0.91	167	50.0	14.0	0.9	0.60	7.80	18.90	49.80
	(33.1-34.56)	(6.43-6.66)	(106-129)	(54-63)	(0.67-0.77)	(0.87-0.95)	(155-175)			(0.6-1.1)				
02-08-89	8.79	3.33	46	53	3.85	2.19	152	54.0	16.5	0.40	1.80	6.20	24.90	95.20
	(7.6-9.7)	(3.29-3.39)	(41-55)	(48-56)	(3.4-4.2)	(1.98-2.36)	(143-161)			(0.31-0.49)				
09-10-89	20.93	3.85	59	79	2.8	2.86	180	49.0	12.5	1.33	0.00	7.10	18.70	99.50
	(18.36-23.31)	(3.59-3.99)	(55-66)	(71-86)	(2.54-3.1)	(2.67-3.1)	(169-193)			(0.91-1.55)				
25-10-89	39.73	3.02	241	67	3.07	2.25	363	49.0	11.0	1.6	5.60	9.90	46.10	42.70
	(35.69-42.5)	(2.95-3.15)	(235-245)	(62-71)	(2.78-3.6)	(2.11-2.4)	(351-372)			(1.45-1.76)				
07-11-89	171.05	2.81	361	49	1.27	1.63	238	48.0	10.0	5.17	2.00	4.80	52.60	5.50
	(161.36-178.48)	(2.79-2.89)	(355-371)	(41-55)	(1.11-1.36)	(1.55-1.75)	(219-254)			(4.78-5.53)				
06-12-89	8.60	3.49	40	66	2.63	3.26	213	42.0	5.5	2.03	0.00	1.40	1.40	5.40
	(8.1-8.9)	(3.22-3.70)	(36-43)	(58-79)	(2.33-2.81)	(3.12-3.41)	(205-222)			(1.87-2.22)				
09-01-90	42.11	3.12	138	73	2.4	0.83	289	46.0	4.5	1.20	0.00	5.00	11.40	0.50
	(39.56-45.1)	(2.99-3.31)	(129-145)	(71-75)	(2.1-2.6)	(0.75-0.95)	(273-298)			(0.8-1.5)				
20-02-90	17.04	3.98	128	56	2.2	1.60	233	42.0	5.5	1.3	5.00	7.50	24.30	0.00
	(15.9-18.9)	(3.8-4.15)	(125-130)	(51-59)	(1.9-2.5)	(1.53-1.66)	(218-241)			(0.9-1.6)				
80-03-90	17.0	4.11	62	79	3.03	3.01	117	40.0	4.0	0.80	0.70	3.60	15.20	2.90
	(14.1-21.33)	(3.89-4.5)	(59-66)	(67-99)	(2.8-3.4)	(2.91-3.1)	(111-122)			(0.45-1.1)				
11-04-90	5.60	4.49	59	52	4.37	3.10	90	46.0	7.0	0.23	0.00	3.90	5.00	17.80
	(5.12-6.23)	(4.23-4.78)	(50-67)	(47-59)	(4.1-4.77)	(2.89-3.39)	(87-93)			(0.19-0.3)				
04-05-90	0.63	4.19	43	62	5.53	3.0	197	62.0	10.0	0.57	0.00	0.00	0.00	24.30
	(0.5-0.76)	(3.9-4.5)	(41-46)	(56-67)	(4.9-5.9)	(2.5-3.6)	(189-203)			(0.34-0.76)				
11-05-90	0.63	4.49	47	50	4.80	2.97	176	45.0	10.0	0.47	0.00	5.50	18.10	19.40
	(0.58-0.7)	(4.31-4.7)	(41-57)	(44-55)	(4.21-5.31)	(2.8-3.1)	(171-182)			(0.2-0.67)				
23-07-90	0.5	4.8	50	50	5.0	3.0	190	57.0	15.0	0.60	0.00	0.00	0.00	58.00
	(0.46-0.55)	(4.75-5.1)	(46-55)	(45-56)	(4.8-5.33)	(2.77-3.3)	(179-201)			(0.34-0.77)				
19-09-90	26.28	4.4	100	50	4.1	2.5	210	52.0	14.5	1.02	0.30	17.20	20.30	67.40
	(24.1-30.1)	(4.29-4.55)	(97-105)	(41-56)	(3.66-4.6)	(2.39-2.73)	(204-214)			(0.7-1.3)				
12-11-90	225.63	3.4	630	60	1.56	1.5	460	52.0	8.0	785.0	0.00	14.40	15.00	0.00
	(214.9-245.61)	(3.3-3.5)	(619-638)	(55-68)	(1.2-1.8)	(1.32-1.75)	(454-469)			(712.9-831.3)				

# Concentration of the parameters at Crowden Brook.

Date	Colour	pH	Fe	Mn	Ca	Mg	Al	TempA	TempW	S S	Rain1c	Rain3c	Rain7c	SMD
28-05-88	10.68 (9.9-11.5)	4.4 (4.05-4.66)	80 (74-89)	20 (17-22)	2.5 (2.3-2.77)	3.4 (3.17-3.59)	190 (181-203)	46.0	12.0	5900.1 (5676-6109)	0.00	6.20	15.50	33.10
03-11-88	18.72 (16.8-19.9)	6.2 (5.9-6.7)	142 (133-151)	77 (65-89)	2.2 (1.9-2.4)	2.4 (2.16-2.57)	210 (199-220)	34.0	9.0	0.75 (0.34-0.99)	0.00	9.00	9.00	3.50
21-03-89	18.41 (17.3-20.1)	4.91 (4.81-4.99)	56 (51-59)	69 (61-75)	1.11 (1.05-1.23)	2.4 (2.26-2.53)	137 (128-143)	35.0	5.5	0.77 (0.43-0.98)	6.00	25.40	39.20	0.00
07-04-89	21.27 (17.23-78)	2.99 (2.82-3.15)	89 (75-98)	110 (101-120)	0.83 (0.77-0.94)	1.71 (1.61-1.82)	260 (253-268)	38.0	6.0	0.93 (0.77-1.05)	9.10	30.10	65.90	0.00
19-04-89	7.15 (6.9-7.5)	5.23 (5.03-5.6)	40 (37-44)	90 (84-99)	1.4 (1.11-1.64)	3 (2.89-3.13)	49 (43-53)	36.0	6.0	0.23 (0.15-0.31)	0.00	0.00	5.40	7.70
03-05-89	77.03 (74.34-78.9)	6.06 (5.57-6.4)	130 (122-135)	67 (59-73)	1.28 (1.09-1.43)	1.49 (1.28-1.77)	37 (32-40)	52.0	7.5	1.03 (0.75-1.35)	0.00	0.00	5.80	9.40
10-07-89	21.03 (19.89-22.37)	7.89 (7.78-7.99)	42 (33-47)	31 (23-38)	3.62 (3.21-3.82)	2.85 (2.75-2.95)	170 (155-181)	50.0	14.0	0.6 (0.45-0.76)	0.60	7.80	18.90	49.80
09-10-89	39.11 (36.3-42.1)	5.06 (4.85-5.23)	314 (306-323)	101 (92-108)	3.53 (3.41-3.69)	1.93 (1.87-2.01)	213 (201-222)	49.0	12.5	1.30 (0.98-1.5)	0.00	7.10	18.70	99.50
25-10-89	20.21 (19.39-21.36)	3.73 (3.65-3.82)	257 (243-266)	75 (66-82)	3.17 (2.96-3.39)	1.89 (1.75-1.99)	226 (212-237)	49.0	11.0	2.57 (2.23-2.87)	5.60	9.90	46.10	42.70
07-11-89	23.45 (20.1-25.8)	3.59 (3.45-3.68)	302 (289-315)	101 (93-110)	1.97 (1.9-2.02)	2.06 (1.89-2.19)	148 (134-159)	48.0	10.0	3.43 (3.1-3.9)	2.00	4.80	52.60	5.50
06-12-89	13.60 (10.5-16.2)	4.88 (4.59-5.1)	170 (161-184)	69 (61-74)	2.87 (2.77-2.94)	2.63 (2.52-2.75)	158 (146-171)	42.0	5.5	0.63 (0.57-0.7)	0.00	1.40	1.40	5.40
09-01-90	27.75 (23.23-31.1)	3.52 (3.44-3.61)	290 (275-301)	106 (99-115)	2.1 (1.85-2.33)	0.62 (0.51-0.72)	204 (193-211)	46.0	4.5	0.6 (0.34-0.86)	0.00	5.00	11.40	0.50
20-02-90	13.09 (10.39-15.1)	4.47 (4.21-4.75)	318 (309-333)	79 (71-83)	1.12 (2.57-2.8)	1.12 (1.01-1.25)	151 (146-155)	42.0	5.5	0.53 (0.31-0.69)	5.00	7.50	24.30	0.00
08-03-90	13.1 (9.9-17.3)	4.65 (4.55-4.73)	147 (132-155)	99 (89-106)	2.49 (2.32-2.61)	2.40 (2.29-2.51)	143 (133-150)	40.0	4.0	0.43 (0.34-0.59)	0.70	3.60	15.20	2.90
11-04-90	13.94 (12.9-14.5)	6.09 (5.89-6.3)	261 (249-275)	64 (55-71)	5.67 (5.51-5.83)	2.53 (2.33-2.69)	30 (27-33)	46.0	7.0	0.80 (0.64-1.1)	0.00	3.90	5.00	17.80
04-05-90	1.18 (0.9-1.5)	5.59 (5.46-5.84)	122 (115-129)	57 (51-61)	4.94 (4.88-5.09)	2.45 (2.36-2.55)	80 (73-90)	62.0	10.0	0.73 (0.6-0.86)	0.00	0.00	0.00	24.30
11-05-90	0.56 (0.42-0.66)	5.73 (5.5-5.89)	210 (202-219)	51 (44-55)	5.23 (5.13-5.33)	2.48 (2.37-2.61)	67 (61-73)	45.0	10.0	0.70 (0.6-0.86)	0.00	5.50	18.10	19.40
23-07-90	0.4 (0.33-0.44)	5.73 (5.55-5.99)	200 (183-213)	51 (44-56)	6.2 (6.08-6.32)	2.9 (2.74-3.12)	80 (74-88)	57.0	15.0	0.90 (0.7-1.12)	0.00	0.00	0.00	58.00
19-09-90	43.73 (39.31-46.45)	5.5 (5.42-5.6)	190 (184-201)	85 (77-93)	5.3 (5.12-5.55)	3.0 (2.89-3.17)	160 (151-167)	52.0	14.5	3.90 (3.54-4.12)	0.30	17.20	20.30	66.90
12-11-90	25.2 (21.9-27.3)	4.4 (4.33-4.52)	800 (789-807)	130 (124-135)	6.1 (5.91-6.43)	1.9 (1.81-2.01)	240 (227-251)	52.0	8.0	131 (111.11-149.11)	0.00	14.40	15.00	0.00

# Concentration of the parameters at Woodhead Bridge.

Date	Colour	pH	Fe	Mn	Ca	Mg	Al	TempA	TempW	S S	Rain1c	Rain3c	Rain7c	SHD
03-11-88	11.82 (9.85-14.14)	6.13 (5.85-6.54)	80 (73-89)	83 (76-89)	1.6 (1.45-1.71)	2.10 (1.83-2.35)	110 (102-115)	34.0	9.0	1.6 (1.42-1.78)	0.00	9.00	9.00	3.50
18-01-89	46.91 (39.89-51.2)	6.58 (6.24-6.93)	56 (49-63)	54 (48-59)	0.81 (0.74-0.9)	2 (1.81-2.21)	177 (161-188)	40.0	6.0	0.77 (0.59-0.94)	0.00	6.40	17.60	2.00
07-04-89	62.07 (58.39-65.86)	3.79 (3.61-3.97)	245 (232-268)	80 (76-85)	1.50 (1.39-1.61)	2 (1.78-2.29)	320 (305-333)	38.0	6.0	14.0 (12.98-14.9)	9.10	30.10	65.90	0.00
19-04-89	21.39 (19.32-23.33)	5.93 (5.81-6.12)	300 (286-309)	140 (132-145)	1.50 (1.45-1.55)	3.0 (2.85-3.16)	50 (47-53)	36.0	6.0	0.35 (0.23-0.46)	0.00	0.00	5.40	7.70
10-07-89	17.54 (15.91-19.19)	7.74 (7.59-7.91)	91 (83-97)	21 (19-23)	3.17 (3.04-3.33)	1.55 (1.39-1.67)	150 (139-160)	50.0	14.0	0.50 (0.41-0.63)	0.60	7.80	18.90	49.80
02-08-89	8.61 (7.68-9.38)	5.08 (4.81-5.32)	41 (34-46)	21 (18-23)	5.99 (5.55-6.25)	2.13 (1.89-2.36)	101 (96-109)	54.0	16.5	0.37 (0.23-0.46)	1.80	6.20	24.90	95.20
09-10-89	9.09 (7.94-11.11)	5.78 (5.61-5.89)	113 (104-119)	32 (27-36)	4.27 (3.98-4.5)	2.76 (2.61-2.94)	77 (65-89)	49.0	12.5	0.90 (0.67-1.1)	0.00	7.10	18.70	99.50
25-10-89	11.45 (9.56-13.19)	4.01 (3.99-4.09)	176 (168-181)	93 (84-99)	3.67 (3.45-3.86)	2.31 (2.22-2.46)	240 (233-245)	49.0	11.0	2.30 (2.1-2.5)	5.60	9.90	46.10	42.70
07-11-89	25.95 (21.69-29.88)	3.63 (3.55-3.71)	301 (288-315)	121 (118-125)	1.85 (1.72-1.95)	2.24 (2.12-2.39)	172 (165-180)	48.0	10.0	2.53 (2.22-2.86)	2.00	4.80	52.60	5.50
06-12-89	5.48 (5.02-5.91)	4.82 (4.56-5.06)	40 (34-49)	113 (106-118)	3.47 (3.32-3.55)	3.23 (3.12-3.36)	183 (177-190)	42.0	5.5	0.23 (0.15-0.3)	0.00	1.40	1.40	5.40
09-01-90	15.08 (13.67-16.12)	3.74 (3.61-3.89)	157 (148-168)	120 (114-124)	2.65 (2.51-2.79)	0.72 (0.66-0.75)	216 (206-222)	46.0	4.5	0.3 (0.21-0.4)	0.00	5.00	11.40	0.50
20-02-90	7.52 (6.66-8.86)	4.58 (4.41-4.76)	181 (168-198)	101 (98-104)	3.33 (3.2-3.45)	1.27 (1.18-1.37)	210 (205-219)	42.0	5.5	0.23 (0.18-0.31)	5.00	7.50	24.30	0.00
08-03-90	7.52 (6.51-8.9)	4.51 (4.32-4.69)	78 (71-83)	153 (149-156)	2.87 (2.75-3.02)	2.60 (2.55-2.69)	213 (201-222)	40.0	4.0	0.6 (0.45-0.77)	0.70	3.60	15.20	2.90
11-04-90	2.81 (2.71-2.9)	6.25 (6.12-6.39)	109 (97-119)	115 (106-122)	6.83 (6.65-6.99)	3.05 (2.89-3.29)	100.0 (89-109)	46.0	7.0	0.23 (0.19-0.29)	0.00	3.90	5.00	17.80
04-05-90	0.82 (0.77-0.89)	5.42 (5.31-5.55)	99 (87-113)	73 (66-81)	5.67 (5.55-5.85)	2.76 (2.67-2.9)	127 (122-130)	62.0	10.0	0.63 (0.55-0.76)	0.00	0.00	0.00	24.30
11-05-90	0.67 (0.59-0.76)	5.96 (5.77-6.15)	88 (75-98)	88 (78-96)	6.47 (6.32-6.65)	2.97 (2.81-3.09)	73 (69-78)	45.0	10.0	0.37 (0.24-0.48)	0.00	5.50	18.10	19.40
23-07-90	0.5 (0.39-0.65)	6.0 (5.77-6.34)	80 (71-85)	88 (74-99)	5.0 (4.89-5.1)	3.10 (2.94-3.31)	90 (88-99)	57.0	15.0	0.40 (0.33-0.45)	0.00	0.00	0.00	58.00
19-09-90	17.69 (15.06-19.98)	5.82 (5.59-6.05)	80 (73-86)	50 (44-55)	5.1 (4.87-5.29)	3.60 (3.48-3.75)	90 (86-99)	52.0	14.5	6.0 (5.69-6.23)	0.30	17.20	20.30	66.90
12-11-90	14.85 (12.11-16.96)	4.7 (4.51-4.97)	860 (845-875)	120 (112-125)	6.9 (6.63-7.15)	3.50 (3.38-3.65)	240 (234-244)	52.0	8.0	11.0 (9.1-13.14)	0.00	14.40	15.00	0.00

# Concentration of the parameters at Longside Clough.

Date	Colour	pH	Fe	Mn	Ca	Mg	Al	TempA	TempH	S S	Rain1c	Rain3c	Rain7c	SMD
18-01-89	49.61 (45.37-53.8)	5.80 (5.59-5.99)	887 (875-899)	219 (203-228)	1.10 (1.01-1.15)	1.76 (1.55-1.96)	223 (214-231)	40.0	6.0	1.10 (0.95-1.32)	0.00	6.40	17.60	2.00
21-03-89	48.22 (39.3-53.9)	4.78 (4.65-4.87)	600 (591-611)	116 (107-122)	1.64 (1.52-1.77)	2.73 (2.56-2.89)	233 (221-242)	35.0	5.5	1.27 (1.1-1.45)	6.00	25.40	39.20	0.00
07-04-89	32.72 (31.2-35.6)	3.30 (3.12-3.46)	576 (556-591)	133 (125-141)	1.11 (0.98-1.13)	1.40 (1.31-1.52)	330 (319-336)	38.0	6.0	1.60 (1.23-1.84)	9.10	30.10	65.90	0.00
19-04-89	23.92 (21.1-25.6)	5.73 (5.55-5.91)	800 (779-816)	300 (291-306)	1.90 (1.75-2.06)	4.0 (3.87-4.12)	340 (316-355)	36.0	6.0	4.90 (4.75-5.14)	0.00	0.00	5.40	7.70
10-07-89	25.6 (23.4-27.26)	5.10 (4.95-5.26)	750 (740-765)	320 (304-331)	3.50 (3.31-3.67)	5.1 (4.97-5.23)	290 (276-303)	50.0	14.0	5.10 (4.89-5.3)	0.60	7.80	18.90	49.80
09-10-89	54.86 (3.51-1.58.5)	6.12 (5.89-6.3)	1350 (1349-1365)	450 (437-458)	11.27 (10.87-11.71)	5.07 (4.87-5.21)	170 (161-183)	49.0	12.5	3.40 (3.12-3.56)	0.00	7.10	18.70	99.50
25-10-89	31.95 (28.9-33.66)	3.21 (3.12-3.31)	1657 (1641-1666)	258 (245-267)	4.13 (4.03-4.24)	1.87 (1.75-1.96)	763 (754-777)	49.0	11.0	7.20 (6.8-7.49)	5.60	9.90	46.10	42.70
07-11-89	28.57 (25.29-33.34)	3.86 (3.65-4.05)	968 (951-979)	204 (281-287)	4.98 (4.76-5.19)	3.20 (2.96-3.39)	225 (217-234)	48.0	10.0	2.73 (2.34-2.99)	2.00	4.80	52.60	5.50
06-12-89	44.86 (41.14-47.19)	5.52 (5.29-5.75)	850 (843-855)	330 (319-336)	8.63 (8.51-8.78)	4.61 (4.55-4.65)	317 (301-328)	42.0	5.5	1.97 (1.64-2.25)	0.00	1.40	1.40	5.40
09-01-90	31.97 (27.28-36.32)	4.18 (3.99-4.3)	930 (901-945)	230 (221-236)	405 (394-412)	0.78 (0.66-0.88)	229 (211-239)	46.0	4.5	2.40 (2.16-2.65)	0.00	5.00	11.40	0.50
20-02-90	15.41 (13.16-16.9)	4.71 (4.44-4.95)	740 (731-747)	199 (190-206)	4.0 (3.88-4.16)	1.23 (1.15-1.33)	257 (241-266)	42.0	5.5	1.38 (1.11-1.59)	5.00	7.50	24.30	0.00
08-03-90	15.44 (12.18-18.17)	4.53 (4.35-4.81)	601 (587-624)	231 (215-241)	5.03 (4.86-5.21)	2.99 (2.78-3.15)	300 (289-321)	40.0	4.0	1.13 (0.98-1.4)	0.70	3.60	15.20	2.90
11-04-90	14.0 (11.16-19.3)	6.76 (6.66-6.97)	1093 (1054-1118)	342 (337-346)	17.17 (16.9-17.46)	4.43 (4.21-4.58)	23 (19-26)	46.0	7.0	1.30 (1.1-1.5)	0.00	3.90	5.00	17.80
04-05-90	27.27 (23.39-33.3)	6.26 (6.05-6.43)	235 (224-243)	59 (48-65)	4.80 (4.67-4.89)	1.30 (1.21-1.42)	73 (64-81)	62.0	10.0	2.0 (1.8-2.2)	0.00	0.00	0.00	24.30
11-05-90	0.77 (0.69-0.9)	7.22 (6.99-7.39)	40 (37-44)	21 (19-23)	14.5 (14.21-14.95)	5.76 (5.51-5.94)	50 (43-55)	45.0	10.0	1.90 (1.53-2.2)	0.00	5.50	18.10	19.40
23-07-90	1.0 (0.87-1.11)	6.30 (6.15-6.4)	910 (899-924)	300 (287-309)	15.6 (15.43-15.8)	5.0 (4.87-5.12)	110 (107-113)	57.0	15.0	3.30 (2.9-3.68)	0.00	0.00	0.00	58.00
19-09-90	40.51 (36.9-42.45)	6.06 (5.89-6.22)	890 (876-898)	350 (341-358)	13.60 (11.15-15.12)	6.90 (6.75-7.14)	120 (106-131)	52.0	14.5	2.90 (2.64-3.3)	0.30	17.20	20.30	66.90
12-11-90	90.83 (87.81-93.3)	3.80 (3.71-3.89)	2300 (2281-2321)	145 (131-153)	10.9 (9.4-13.37)	1.50 (1.41-1.62)	550 (542-565)	52.0	8.0	8.90 (8.1-9.5)	0.00	14.40	15.00	0.00



# Concentration of the parameters at Torside Clough.

Date	Colour	pH	Fe	Mn	Ca	Mg	Al	TempA	TempW	S S	Rain1c	Rain3c	Rain7c	SMD
04-05-88	45.18 (37.3-49.44)	6.06 (5.84-6.21)	690 (677-701)	20 (18-23)	2.10 (1.91-2.34)	2.7 (2.1-3.1)	300 (289-312)	46.0	8.5	39.0 (35.1-42.3)	1.90	12.70	18.00	0.90
03-11-88	16.15 (15.14-17.16)	7.18 (6.98-7.42)	105 (91-115)	41 (34-47)	5.80 (5.74-5.87)	3.1 (2.88-3.36)	240 (231-245)	34.0	9.0	0.7 (0.55-0.99)	0.00	9.00	9.00	3.50
11-12-88	154.99 (143.31-165.12)	6.87 (6.77-6.99)	590 (575-602)	54 (43-61)	5.33 (5.12-5.46)	3.01 (2.87-3.19)	267 (251-277)	45.0	5.0	0.58 (0.43-0.67)	0.60	4.90	16.40	0.50
18-01-89	13.57 (12.13-14.51)	5.53 (5.41-5.67)	40 (35-46)	61 (55-67)	3.90 (3.78-4.01)	1.49 (1.32-1.68)	160 (148-177)	40.0	6.0	0.43 (0.32-0.55)	0.00	6.40	17.60	2.00
21-03-89	35.56 (32.33-38.87)	5.62 (5.57-5.69)	67 (59-74)	42 (34-47)	1.14 (1.03-1.25)	2.58 (2.34-2.84)	303 (296-313)	35.0	5.5	1.70 (1.23-2.1)	6.00	25.40	39.20	0.00
18-05-89	7.11 (6.97-7.23)	7.56 (7.45-7.65)	59 (49-67)	20 (17-23)	10.53 (9.99-10.89)	5.28 (5.11-5.47)	50 (42-55)	58.0	9.0	1.18 (0.9-1.4)	0.00	1.20	10.30	29.60
10-07-89	23.83 (21.17-26.24)	7.08 (6.98-7.15)	40 (37-43)	31 (28-35)	2.57 (2.45-2.67)	1.55 (1.33-1.76)	183 (177-189)	50.0	14.0	0.50 (0.34-0.67)	0.60	7.80	18.90	49.80
02-08-89	3.79 (3.66-3.96)	6.90 (6.75-7.1)	40 (33-45)	21 (19-24)	18.45 (16.16-21.98)	7.53 (7.35-7.81)	110 (99-119)	54.0	16.5	1.0 (0.8-1.29)	1.80	6.20	24.90	95.20
09-10-89	3.46 (3.11-3.71)	7.38 (7.29-7.49)	49 (41-56)	20 (17-25)	9.87 (9.77-9.99)	7.20 (6.98-7.41)	46 (39-51)	49.0	12.5	1.05 (0.7-1.26)	0.00	7.10	18.70	99.50
25-10-89	144.15 (124.25-155.14)	3.1 (3.05-3.19)	223 (219-229)	67 (58-81)	3.13 (2.98-3.33)	1.95 (1.75-2.25)	391 (377-402)	49.0	11.0	2.93 (2.75-3.21)	5.60	9.90	46.10	42.70
07-11-89	52.91 (49.11-55.53)	5.15 (4.98-5.31)	286 (271-306)	82 (74-89)	2.41 (2.22-2.63)	2.71 (2.61-2.87)	148 (133-157)	48.0	10.0	1.43 (1.21-1.6)	2.00	4.80	52.60	5.50
06-12-89	5.49 (5.14-5.77)	5.91 (5.75-6.1)	40 (29-49)	21 (16-24)	6.93 (6.72-7.15)	4.53 (4.11-4.89)	73 (66-78)	42.0	5.5	0.27 (0.22-0.33)	0.00	1.40	1.40	5.40
09-01-90	24.49 (22.13-27.27)	6.15 (6.02-6.26)	45 (37-51)	35 (25-44)	5.27 (5.13-5.45)	3.13 (2.95-3.33)	59 (48-61)	46.0	4.5	0.30 (0.12-0.45)	0.00	5.00	11.40	0.50
20-02-90	32.76 (27.29-35.98)	5.99 (5.87-6.1)	144 (131-152)	49 (41-57)	2.73 (2.51-2.91)	1.41 (1.22-1.57)	37 (32-45)	42.0	5.5	2.13 (1.98-2.29)	5.00	7.50	24.30	0.00
08-03-90	32.77 (24.26-37.33)	6.57 (6.43-6.77)	70 (59-85)	89 (77-98)	3.5 (3.33-3.68)	2.93 (2.74-3.16)	40 (35-42)	40.0	4.0	0.83 (0.55-1.09)	0.70	3.60	15.20	2.90
11-04-90	12.20 (10.06-13.47)	7.06 (6.89-7.18)	40 (34-44)	20 (18-22)	12.33 (11.24-14.19)	4.73 (4.55-4.93)	43 (37-49)	46.0	7.0	1.43 (1.12-1.75)	0.00	3.90	5.00	17.80
04-05-90	0.7 (0.59-0.82)	6.74 (6.67-6.81)	44 (36-49)	22 (19-26)	5.73 (5.51-5.94)	2.42 (2.34-2.56)	70 (65-79)	62.0	10.0	0.50 (0.34-0.66)	0.00	0.00	0.00	24.30
11-05-90	0.77 (0.65-0.93)	7.22 (7.01-7.39)	45 (42-47)	23 (19-26)	14.5 (12.12-16.15)	5.76 (5.55-5.93)	60 (54-65)	45.0	10.0	0.20 (0.19-0.23)	0.00	5.50	18.10	19.40
23-07-90	0.77 (0.55-0.94)	7.0 (6.88-7.15)	45 (37-51)	20 (17-22)	17 (16.15-18.23)	6.0 (5.77-6.24)	50 (42-61)	57.0	15.0	0.40 (0.23-0.55)	0.00	0.00	0.00	58.00
19-09-90	16.36 (15.15-17.19)	6.90 (6.75-7.12)	60 (53-64)	35 (28-41)	12.6 (10.45-14.12)	4.0 (3.79-4.35)	60 (51-65)	52.0	14.5	3.10 (2.89-3.4)	0.30	17.20	20.30	66.90
12-11-90	175.17 (166.65-187.38)	3.55 (3.33-3.7)	630 (612-645)	56 (45-61)	10.90 (9.97-11.61)	1.78 (1.66-1.87)	270 (263-277)	52.0	8.0	6.90 (6.2-7.3)	0.00	14.40	15.00	0.00

# Concentration of the parameters at Ogden Clough.

Date	Colour	pH	Fe	Mn	Ca	Mg	Al	TempA	TempW	S S	Rain1c	Rain2c	Rain7c	SMD
07-06-88	18.85	6.70	40	21	10.60	4.30	100	54.0	12.0	490.0	7.50	7.50	22.10	30.50
	(16.94-20.19)	(6.55-6.97)	(37-45)	(17-24)	(9.98-11.11)	(4.16-4.47)	(92-105)			(444.3-516.6)	0.00	0.00	0.00	46.10
16-06-88	12.36	7.02	340	40	16.60	7.5	120	55.4	13.0	632.0	0.00	0.00	0.00	0.00
	(10.97-13.14)	(6.87-7.11)	(327-355)	(33-45)	(15.15-17.63)	(7.34-7.66)	(111-129)			(591.8-676.76)	50.90	65.30	76.50	0.00
18-08-88	50.37	4.16	460	80	2.60	0.12	110	59.0	13.0	7600.0	15.30	31.50	31.50	0.00
	(42.36-54.63)	(3.98-4.33)	(445-477)	(76-88)	(2.45-2.86)	(0.08-0.19)	(101-119)			(7189.9-7819.5)	0.60	4.90	16.40	0.50
06-10-88	94.20	6.10	560	80	3.30	0.22	90	49.0	11.5	11.80	6.00	25.40	39.20	0.00
	(88.23-98.97)	(5.89-6.33)	(543-587)	(74-85)	(3.12-3.52)	(0.19-0.25)	(78-97)			(10.3-16.15)	0.00	4.90	16.40	0.50
11-12-88	91.88	6.77	40	41	5.17	4.08	250	45.0	5.0	0.5	0.60	4.90	16.40	0.50
	(78.14-104.95)	(6.57-6.91)	(37-45)	(34-45)	(4.95-5.34)	(3.97-4.23)	(237-264)			(0.34-0.66)	6.00	25.40	39.20	0.00
21-03-89	6.71	5.78	40	20	1.38	4.53	50	35.0	5.5	4.0	0.60	4.90	16.40	0.50
	(6.25-7.12)	(5.61-5.98)	(35-47)	(17-24)	(1.22-1.52)	(4.31-4.73)	(43-55)			(3.89-4.1)	0.60	4.90	16.40	0.50
10-07-89	26.92	5.01	85	40	0.67	0.85	170	50.0	14.0	0.40	0.60	7.80	18.90	49.80
	(23.23-29.25)	(4.86-5.12)	(76-91)	(36-45)	(0.55-0.77)	(0.74-0.95)	(158-177)			(0.26-0.55)	1.80	6.20	24.90	95.20
02-08-89	4.26	6.10	40	23	9.65	4.87	112	54.0	16.5	0.43	0.00	7.10	18.70	99.50
	(3.88-4.54)	(5.89-6.33)	(34-49)	(18-26)	(9.34-9.98)	(4.67-5.09)	(98-120)			(0.34-0.51)	0.00	7.10	18.70	99.50
09-10-89	6.35	6.17	65	22	2.93	5.20	60	49.0	12.5	4.70	0.00	7.10	18.70	99.50
	(5.94-6.76)	(5.89-6.44)	(52-78)	(19-24)	(2.78-3.1)	(4.93-5.4)	(51-65)			(4.53-4.9)	5.60	9.90	46.10	42.70
25-10-89	7.53	4.31	40	94	2.50	2.53	187	49.0	11.0	1.40	5.60	9.90	46.10	42.70
	(7.29-7.77)	(4.09-3.49)	(33-45)	(79-103)	(2.31-2.76)	(2.23-2.77)	(177-198)			(1.28-1.54)	2.00	4.80	52.60	5.50
07-11-89	5.97	5.53	40	30	3.60	4.37	58	48.0	10.0	0.57	0.00	1.40	1.40	5.40
	(5.81-6.17)	(5.26-5.76)	(35-43)	(26-33)	(3.45-3.74)	(4.1-4.63)	(48-63)			(0.44-0.67)	0.00	1.40	1.40	5.40
06-12-89	2.97	6.12	40	23	9.20	8.38	93	42.0	5.5	1.60	0.00	5.00	11.40	0.50
	(2.75-3.16)	(5.89-6.31)	(31-46)	(19-25)	(8.88-9.51)	(8.02-8.59)	(82-99)			(1.43-1.76)	0.00	5.00	11.40	0.50
09-01-90	4.05	5.20	40	60	3.53	2.20	50	46.0	4.5	1.67	5.00	7.50	24.30	0.00
	(3.79-4.24)	(4.89-5.37)	(37-42)	(51-66)	(3.32-3.66)	(1.94-2.35)	(42-57)			(1.46-1.87)	5.00	7.50	24.30	0.00
20-02-90	4.40	4.99	54	26	3.30	2.46	113	42.0	5.5	0.67	0.70	3.60	15.20	2.90
	(4.23-4.63)	(4.83-5.22)	(48-61)	(22-29)	(3.12-3.45)	(2.32-2.55)	(105-119)			(0.55-0.78)	0.00	3.90	5.00	17.80
08-03-90	4.38	6.25	43	82	3.17	3.80	40	40.0	4.0	0.90	0.00	3.90	5.00	17.80
	(4.16-4.59)	(5.97-6.54)	(34-51)	(71-91)	(3.01-3.33)	(3.66-3.97)	(33-53)			(0.75-1.05)	0.00	3.90	5.00	17.80
11-04-90	3.45	6.66	41	66	5.50	3.32	40	46.0	7.0	0.30	0.00	0.00	0.00	24.30
	(3.22-3.67)	(6.51-6.89)	(34-46)	(51-78)	(5.34-5.69)	(3.1-3.48)	(35-46)			(0.22-0.35)	0.00	0.00	0.00	24.30
04-05-90	0.87	5.44	40	20	0.99	0.95	72	62.0	10.0	0.50	0.00	0.00	0.00	24.30
	(0.68-1.04)	(5.24-5.75)	(34-44)	(17-23)	(0.75-1.24)	(0.73-1.14)	(64-76)			(0.41-0.64)	0.00	5.50	18.10	19.40
11-05-90	0.87	6.28	40	40	5.50	3.33	57	45.0	10.0	0.33	0.00	5.50	18.10	19.40
	(0.77-0.99)	(5.98-6.51)	(36-47)	(31-46)	(5.34-5.76)	(3.1-3.56)	(51-68)			(0.26-0.41)	0.00	5.50	18.10	19.40
23-07-90	0.87	6.30	40	40	5.80	4.10	40	57.0	15.0	0.40	0.00	0.00	0.00	58.00
	(0.75-0.98)	(6.19-6.44)	(29-49)	(35-48)	(5.34-6.1)	(3.89-4.29)	(32-47)			(0.31-0.54)	0.30	17.20	20.30	66.90
19-09-90	1.01	5.47	40	40	5.90	4.3	40	52.0	14.5	0.50	0.00	17.20	20.30	66.90
	(0.93-1.11)	(5.25-5.66)	(35-46)	(33-47)	(5.74-6.13)	(4.17-4.48)	(29-48)			(0.39-0.61)	0.00	14.40	15.00	0.00
12-11-90	0.5	4.80	100	70	10.90	2.70	190	52.0	8.0	0.70	0.00	14.40	15.00	0.00
	(0.44-0.55)	(4.66-4.96)	(93-109)	(63-76)	(9.97-11.6)	(2.55-2.87)	(179-197)			(0.55-0.81)				

### **Appendix III**

Levels of some parameters (soil moisture deficit, daily rain, pH, colour (apparent & true), turbidity, Mn, Fe, Al, and water & air temperature) in the raw water received at Arnfield works from 1987-1990.

Date	SMD mm	Rain mm	pH	Colour Hazen	Tur. ftu	Mn PPb	Fe PPb	Al PPb	Temp-A ° F	Temp-W ° C
01-01-87	0.0	4.7	...	...	...	...	...	...	...	...
02-01-87	0.1	0.0	5.6	85.0	2.8	90.0	387.0	160.0	...	...
03-01-87	0.0	0.7	...	...	...	...	...	...	...	...
04-01-87	0.0	20.4	...	...	...	...	...	...	...	...
05-01-87	0.0	7.2	5.5	125.0	2.2	95.0	380.0	120.0	...	...
06-01-87	0.2	0.0	5.3	150.0	3.0	83.0	401.0	160.0	...	...
07-01-87	0.3	0.0	5.2	85.0	2.8	81.0	227.0	120.0	...	...
08-01-87	0.5	0.0	5.6	150.0	3.0	83.0	323.0	105.0	...	...
09-01-87	0.6	0.0	5.3	100.0	2.0	79.0	328.0	136.0	...	...
10-01-87	0.6	0.0	...	...	...	...	...	...	...	...
11-01-87	0.3	0.0	...	...	...	...	...	...	...	...
12-01-87	0.0	0.0	5.3	125.0	2.6	79.0	359.0	130.0	...	...
13-01-87	0.0	0.0	5.5	85.0	2.0	101.0	91.0	110.0	...	...
14-01-87	0.0	0.0	5.6	85.0	2.5	85.0	333.0	120.0	...	...
15-01-87	0.0	0.0	5.6	150.0	3.0	84.0	396.0	130.0	...	...
16-01-87	0.2	0.0	5.4	125.0	3.7	830.0	2950.0	200.0	...	...
17-01-87	0.0	0.0	...	...	...	...	...	...	...	...
18-01-87	0.2	0.0	...	...	...	...	...	...	...	...
19-01-87	0.0	12.6	5.1	125.0	2.5	86.0	372.0	150.0	...	...
20-01-87	0.0	2.7	6.2	125.0	3.0	82.0	334.0	155.0	...	...
21-01-87	0.1	1.6	5.5	50.0	3.5	87.0	324.0	110.0	...	...
22-01-87	0.1	0.6	5.8	125.0	2.5	85.0	353.0	130.0	...	...
23-01-87	0.4	0.0	5.4	85.0	2.5	79.0	364.0	140.0	...	...
24-01-87	0.6	0.0	...	...	...	...	...	...	...	...
25-01-87	0.8	0.0	...	...	...	...	...	...	...	...
26-01-87	1.1	0.0	5.4	100.0	2.5	77.0	327.0	100.0	...	...
27-01-87	1.4	0.0	5.7	85.0	2.5	72.0	364.0	140.0	...	...
28-01-87	1.6	0.0	5.4	100.0	2.5	79.0	323.0	150.0	...	...
29-01-87	1.9	0.0	5.5	100.0	2.5	77.0	312.0	160.0	...	...
30-01-87	2.2	0.0	5.5	50.0	2.2	77.0	361.0	110.0	...	...
31-01-87	2.5	0.0	...	...	...	...	...	...	...	...
01-02-87	1.1	1.6	...	...	...	...	...	...	...	...
02-02-87	0.0	6.7	5.5	125.0	2.5	74.0	309.0	135.0	...	...
03-02-87	0.3	0.4	5.7	85.0	2.5	75.0	333.0	100.0	...	...
04-02-87	0.5	0.0	5.4	85.0	2.5	80.0	328.0	115.0	...	...
05-02-87	0.0	3.6	5.5	30.0	2.5	89.0	340.0	120.0	...	...
06-02-87	0.3	0.0	5.6	100.0	2.0	90.0	326.0	95.0	...	...
07-02-87	0.0	11.6	...	...	...	...	...	...	...	...
08-02-87	0.0	6.9	...	...	...	...	...	...	...	...
09-02-87	0.0	14.4	5.4	125.0	2.3	83.0	305.0	160.0	...	...
10-02-87	0.0	0.6	5.6	150.0	2.5	83.0	297.0	130.0	...	...
11-02-87	0.4	0.0	5.6	85.0	2.5	79.0	325.0	135.0	...	...
12-02-87	0.7	0.0	5.3	100.0	2.5	89.0	305.0	100.0	...	...
13-02-87	1.1	0.0	5.9	85.0	2.0	78.0	329.0	100.0	...	...
14-02-87	1.5	1.0	...	...	...	...	...	...	...	...
15-02-87	1.9	0.0	...	...	...	...	...	...	...	...
16-02-87	2.2	0.0	5.3	100.0	2.5	82.0	327.0	236.0	...	...
17-02-87	2.7	0.0	5.3	150.0	2.5	81.0	318.0	225.0	...	...
18-02-87	3.1	0.0	5.6	125.0	2.6	84.0	309.0	373.0	...	...
19-02-87	3.6	0.0	5.6	30.0	3.0	77.0	308.0	195.0	...	...
20-02-87	4.0	0.0	5.5	85.0	2.5	79.0	334.0	255.0	...	...
21-02-87	3.2	0.2	...	...	...	...	...	...	...	...
22-02-87	3.5	0.6	...	...	...	...	...	...	...	...
23-02-87	3.6	0.0	5.8	125.0	2.5	73.0	333.0	240.0	...	...
24-02-87	4.1	0.0	5.7	125.0	2.8	76.0	273.0	183.0	...	...
25-02-87	4.5	0.0	6.1	50.0	2.5	79.0	315.0	215.0	...	...
26-02-87	0.0	7.5	5.4	125.0	2.8	84.0	282.0	260.0	...	...
27-02-87	0.0	4.3	5.9	50.0	2.5	83.0	276.0	280.0	...	...
28-02-87	0.0	4.2	...	...	...	...	...	...	...	...
01-03-87	0.0	12.4	...	...	...	...	...	...	...	...
02-03-87	0.6	0.0	5.9	85.0	2.7	80.0	324.0	210.0	...	...
03-03-87	0.0	0.6	6.2	100.0	2.7	77.0	312.0	255.0	...	...

Con.

Date	SMD	Rain	pH	Colour	Tur.	Mn	Fe	Al	Temp-A	Temp-W
04-03-87	0.6	0.0	6.0	50.0	2.5	78.0	324.0	225.0	...	...
05-03-87	0.0	5.4	5.9	100.0	3.0	82.0	377.0	250.0	...	...
06-03-87	0.0	6.7	5.4	140.0	1.4	89.0	317.0	230.0	...	...
07-03-87	0.0	0.8	...	...	...	...	...	...	...	...
08-03-87	0.7	0.0	...	...	...	...	...	...	...	...
09-03-87	1.3	0.0	5.9	125.0	3.4	77.0	315.0	220.0	...	...
10-03-87	2.0	0.0	5.8	100.0	2.8	97.0	346.0	225.0	...	...
11-03-87	2.7	0.0	5.9	50.0	2.5	78.0	302.0	280.0	...	...
12-03-87	3.5	0.0	5.9	125.0	3.1	86.0	343.0	190.0	...	...
13-03-87	4.2	0.0	5.9	85.0	2.3	84.0	312.0	237.0	...	...
14-03-87	4.6	0.0	...	...	...	...	...	...	...	...
15-03-87	4.1	0.0	...	...	...	...	...	...	...	...
16-03-87	1.0	3.7	5.6	70.0	2.4	73.0	316.0	224.0	...	...
17-03-87	0.0	8.6	6.0	85.0	2.5	77.0	316.0	250.0	...	...
18-03-87	0.0	4.8	5.9	100.0	2.7	71.0	310.0	224.0	...	...
19-03-87	0.4	0.6	6.0	70.0	2.7	76.0	316.0	180.0	...	...
20-03-87	0.0	0.4	6.6	70.0	2.6	76.0	318.0	130.0	...	...
21-03-87	0.8	0.0	...	...	...	...	...	...	...	...
22-03-87	0.0	3.6	...	...	...	...	...	...	...	...
23-03-87	0.0	6.8	7.2	100.0	2.9	71.0	295.0	240.0	...	...
24-03-87	0.0	10.4	6.0	100.0	2.8	74.0	282.0	150.0	...	...
25-03-87	0.0	0.6	6.1	50.0	2.5	84.0	309.0	87.0	...	...
26-03-87	0.0	5.7	6.7	125.0	3.0	75.0	305.0	261.0	...	...
27-03-87	0.0	16.6	6.7	50.0	2.0	68.0	282.0	323.0	...	...
28-03-87	0.0	0.6	...	...	...	...	...	...	...	...
29-03-87	0.0	1.4	...	...	...	...	...	...	...	...
30-03-87	0.3	0.5	6.1	125.0	2.7	73.0	324.0	...	46.0	4.0
31-03-87	0.0	5.9	5.9	85.0	2.8	101.0	297.0	172.0	40.0	4.0
01-04-87	0.0	10.8	5.9	50.0	2.5	78.0	305.0	218.0	52.0	4.0
02-04-87	1.2	0.0	5.4	100.0	3.5	76.0	324.0	200.0	42.0	4.0
03-04-87	1.2	2.0	5.7	45.0	2.0	74.0	359.0	137.0	42.0	4.0
04-04-87	0.0	6.0	...	...	...	...	...	...	45.0	4.0
05-04-87	1.3	0.3	...	...	...	...	...	...	42.0	4.0
06-04-87	0.0	0.0	6.6	20.0	3.5	74.0	313.0	201.0	42.0	4.5
07-04-87	0.0	14.2	6.1	70.0	2.7	78.0	258.0	75.0	42.0	4.5
08-04-87	0.0	6.6	5.3	100.0	2.6	75.0	292.0	248.0	49.0	5.5
09-04-87	0.0	8.6	6.3	50.0	2.5	74.0	299.0	266.0	49.0	5.5
10-04-87	0.0	11.1	5.9	50.0	2.0	73.0	316.0	239.0	49.0	5.5
11-04-87	1.4	0.0	...	...	...	...	...	...	48.0	5.5
12-04-87	2.9	0.0	...	...	...	...	...	...	45.0	5.5
13-04-87	3.4	1.2	6.9	85.0	3.1	89.0	271.0	256.0	49.0	5.5
14-04-87	4.9	0.0	6.7	80.0	2.9	81.0	298.0	121.0	50.0	6.0
15-04-87	6.5	0.0	6.0	100.0	3.2	17.0	293.0	152.0	54.0	6.5
16-04-87	8.0	0.0	5.8	70.0	2.1	70.0	310.0	123.0	52.0	7.0
17-04-87	9.6	0.0	...	...	...	...	...	...	54.0	7.0
18-04-87	10.5	0.0	...	...	...	...	...	...	54.0	7.0
19-04-87	0.0	9.1	...	...	...	...	...	...	57.0	7.5
20-04-87	1.3	1.6	...	...	...	...	...	...	55.0	7.5
21-04-87	2.9	0.0	5.8	85.0	3.3	84.0	274.0	260.0	54.0	7.5
22-04-87	4.6	0.0	6.7	50.0	2.8	76.0	284.0	215.0	58.0	7.5
23-04-87	6.4	0.0	6.4	100.0	2.9	92.0	263.0	247.0	54.0	7.5
24-04-87	8.1	0.0	5.8	50.0	2.0	77.0	318.0	211.0	56.0	7.5
25-04-87	9.9	0.0	...	...	...	...	...	...	50.0	8.0
26-04-87	11.7	0.0	...	...	...	...	...	...	56.0	8.0
27-04-87	13.6	0.0	6.0	85.0	2.3	74.0	259.0	266.0	56.0	9.5
28-04-87	15.4	0.0	6.5	45.0	3.5	79.0	319.0	269.0	58.0	9.5
29-04-87	16.6	0.0	6.7	125.0	2.7	79.0	324.0	324.0	63.0	10.0
30-04-87	18.1	1.2	6.9	70.0	2.3	74.0	290.0	273.0	61.0	10.5
01-05-87	16.7	1.9	5.7	85.0	2.1	76.0	297.0	220.0	51.0	9.5
02-05-87	15.6	3.2	...	...	...	...	...	...	46.0	10.0
03-05-87	17.2	0.4	...	...	...	...	...	...	42.0	9.5
04-05-87	19.0	0.0	...	...	...	...	...	...	43.0	9.0
05-05-87	20.8	0.0	6.0	85.0	2.5	72.0	277.0	270.0	45.0	9.0
06-05-87	22.7	0.0	6.7	50.0	2.3	71.0	314.0	250.0	56.0	9.0
07-05-87	24.5	0.0	6.2	50.0	2.2	70.0	270.0	220.0	52.0	9.0
08-05-87	26.4	0.0	6.5	70.0	1.9	67.0	265.0	215.0	50.0	10.0
09-05-87	28.3	0.0	...	...	...	...	...	...	56.0	10.0
10-05-87	29.3	1.5	...	...	...	...	...	...	50.0	10.0
11-05-87	14.8	21.0	6.4	70.0	1.9	66.0	269.0	210.0	50.0	10.0
12-05-87	6.7	6.1	6.0	85.0	2.0	67.0	280.0	191.0	49.0	9.5
13-05-87	0.0	10.1	6.2	50.0	2.0	70.0	246.0	210.0	46.0	9.5
14-05-87	0.0	5.2	6.1	85.0	2.0	76.0	263.0	250.0	50.0	10.0

Con.

Date	SMD	Rain	pH	Colour	Tur.	Mn	Fe	Al	Temp-A	Temp-W
15-05-87	0.0	4.2	6.3	50.0	2.3	73.0	282.0	190.0	44.0	10.0
16-05-87	0.4	2.2	...	...	...	...	...	...	47.0	10.0
17-05-87	0.0	5.2	...	...	...	...	...	...	50.0	10.0
18-05-87	2.1	0.0	6.0	45.0	2.0	80.0	262.0	190.0	50.0	10.0
19-05-87	4.2	0.0	6.3	45.0	2.0	73.0	365.0	220.0	50.0	10.0
20-05-87	6.3	0.0	6.5	50.0	2.0	65.0	231.0	235.0	48.0	10.0
21-05-87	8.0	0.6	6.6	50.0	1.7	73.0	247.0	215.0	53.0	10.0
22-05-87	6.6	8.9	6.9	50.0	1.4	73.0	251.0	210.0	44.0	10.0
23-05-87	8.8	0.0	...	...	...	...	...	...	48.0	10.0
24-05-87	11.0	0.0	...	...	...	...	...	...	45.0	10.0
25-05-87	13.2	0.0	...	...	...	...	...	...	46.0	10.0
26-05-87	15.4	0.0	6.3	50.0	2.8	76.0	254.0	210.0	54.0	11.0
27-05-87	16.1	1.0	6.2	50.0	1.9	69.0	262.0	235.0	48.0	11.0
28-05-87	18.2	1.8	6.1	50.0	1.7	69.0	260.0	230.0	54.0	11.0
29-05-87	20.4	0.0	6.2	50.0	1.7	71.0	260.0	185.0	52.0	11.5
30-05-87	21.5	3.5	...	...	...	...	...	...	56.0	11.5
31-05-87	21.5	0.8	...	...	...	...	...	...	55.0	11.5
01-06-87	13.6	7.1	6.4	45.0	2.0	68.0	274.0	210.0	57.0	11.5
02-06-87	5.9	8.5	6.4	60.0	1.9	66.0	262.0	210.0	56.0	11.5
03-06-87	0.0	40.9	6.8	45.0	1.6	63.0	282.0	215.0	55.0	12.0
04-06-87	1.7	0.0	6.3	40.0	2.0	68.0	270.0	185.0	52.0	12.0
05-06-87	0.0	6.0	6.3	30.0	1.6	66.0	286.0	200.0	55.0	12.0
06-06-87	0.0	25.8	...	...	...	...	...	...	55.0	12.0
07-06-87	0.0	5.1	...	...	...	...	...	...	54.0	12.0
08-06-87	0.0	7.9	5.8	70.0	2.2	69.0	289.0	205.0	54.0	12.0
09-06-87	0.0	7.2	6.0	60.0	2.4	68.0	295.0	180.0	54.0	12.0
10-06-87	1.2	2.9	6.1	60.0	2.2	69.0	293.0	240.0	53.0	12.0
11-06-87	0.0	4.0	6.4	50.0	2.5	69.0	273.0	210.0	54.0	12.0
12-06-87	1.8	0.8	5.2	45.0	1.7	75.0	319.0	230.0	54.0	12.0
13-06-87	3.6	0.0	...	...	...	...	...	...	55.0	12.0
14-06-87	0.0	0.9	...	...	...	...	...	...	54.0	12.0
15-06-87	0.0	2.1	...	...	...	...	...	...	48.0	11.5
16-06-87	0.0	2.6	...	...	...	...	...	...	49.0	11.5
17-06-87	0.0	0.0	...	...	...	...	...	...	53.0	11.5
18-06-87	0.0	15.8	...	...	...	...	...	...	55.0	12.0
19-06-87	1.8	0.0	...	...	...	...	...	...	59.0	12.0
20-06-87	3.6	0.0	...	...	...	...	...	...	54.0	12.0
21-06-87	2.1	2.7	...	...	...	...	...	...	54.0	11.5
22-06-87	3.1	0.0	...	...	...	...	...	...	55.0	11.5
23-06-87	0.0	10.2	...	...	...	...	...	...	59.0	11.5
24-06-87	0.0	1.7	...	...	...	...	...	...	54.0	11.5
25-06-87	0.0	35.7	...	...	...	...	...	...	54.0	12.0
26-06-87	0.0	3.1	...	...	...	...	...	...	54.0	11.5
27-06-87	1.6	0.7	...	...	...	...	...	...	57.0	12.0
28-06-87	0.8	0.7	...	...	...	...	...	...	65.0	12.0
29-06-87	2.4	5.2	5.8	50.0	2.5	72.0	334.0	220.0	68.0	12.5
30-06-87	4.3	0.0	6.3	70.0	2.4	55.0	325.0	205.0	58.0	11.5
01-07-87	6.5	0.0	5.6	70.0	2.3	73.0	308.0	210.0	60.0	11.5
02-07-87	8.7	0.0	6.1	60.0	2.1	77.0	387.0	225.0	56.0	13.0
03-07-87	11.0	0.0	6.0	85.0	2.0	68.0	304.0	240.0	60.0	11.0
04-07-87	13.2	0.0	...	...	...	...	...	...	64.0	14.0
05-07-87	15.4	0.0	...	...	...	...	...	...	68.0	14.0
06-07-87	17.6	0.0	5.8	60.0	2.3	65.0	334.0	235.0	72.0	14.0
07-07-87	19.9	0.0	6.0	25.0	2.4	68.0	327.0	230.0	66.0	14.0
08-07-87	22.1	0.0	6.6	50.0	2.2	76.0	354.0	225.0	61.0	15.0
09-07-87	22.5	5.8	6.1	85.0	1.7	80.0	357.0	220.0	59.0	15.0
10-07-87	20.7	7.5	6.5	60.0	1.4	72.0	299.0	240.0	62.0	15.0
11-07-87	22.6	1.0	...	...	...	...	...	...	68.0	15.0
12-07-87	24.8	0.0	...	...	...	...	...	...	62.0	15.0
13-07-87	27.0	0.0	6.7	85.0	1.5	63.0	305.0	210.0	62.0	15.5
14-07-87	29.1	1.1	6.3	85.0	1.9	69.0	325.0	205.0	66.0	15.5
15-07-87	30.0	7.5	6.8	70.0	1.9	63.0	308.0	250.0	64.0	15.5
16-07-87	32.2	0.0	6.0	50.0	1.4	70.0	320.0	200.0	60.0	15.5
17-07-87	27.7	9.0	6.1	60.0	1.1	68.0	314.0	210.0	61.0	15.5
18-07-87	14.4	20.5	...	...	...	...	...	...	57.0	15.5
19-07-87	13.9	2.9	...	...	...	...	...	...	55.0	15.5
20-07-87	16.0	0.5	5.9	50.0	1.7	72.0	311.0	205.0	58.0	14.5
21-07-87	17.9	0.0	5.8	70.0	1.6	72.0	300.0	225.0	59.0	14.5
22-07-87	20.0	0.0	5.7	60.0	2.0	69.0	276.0	110.0	59.0	14.5
23-07-87	21.1	0.6	6.6	85.0	1.6	70.0	314.0	180.0	54.0	14.5
24-07-87	22.5	1.4	6.3	70.0	1.3	68.0	307.0	185.0	62.0	14.5
25-07-87	24.4	0.0	...	...	...	...	...	...	56.0	14.5

Con.

Date	SMD	Rain	pH	Colour	Tur.	Mn	Fe	Al	Temp-A	Temp-W
26-07-87	3.4	27.9	...	...	...	...	...	...	54.0	14.5
27-07-87	5.4	0.0	6.2	70.0	1.7	81.0	361.0	260.0	58.0	14.0
28-07-87	2.9	10.2	6.3	85.0	1.5	81.0	355.0	230.0	58.0	14.0
29-07-87	3.8	2.4	6.3	30.0	1.5	72.0	358.0	275.0	60.0	14.0
30-07-87	4.1	4.2	6.0	60.0	1.6	73.0	365.0	200.0	60.0	14.0
31-07-87	0.6	4.5	6.1	60.0	1.3	72.0	380.0	220.0	60.0	14.0
01-08-87	1.0	1.2	...	...	...	...	...	...	60.0	14.0
02-08-87	3.0	0.0	...	...	...	...	...	...	60.0	14.0
03-08-87	1.6	8.3	6.8	50.0	2.0	72.0	750.0	245.0	60.0	14.0
04-08-87	3.5	0.0	6.1	85.0	1.8	72.0	388.0	230.0	56.0	14.0
05-08-87	3.8	0.0	5.9	85.0	1.6	72.0	424.0	190.0	52.0	14.5
06-08-87	5.7	0.6	6.6	100.0	1.6	65.0	410.0	215.0	52.0	14.5
07-08-87	0.0	9.0	6.5	50.0	1.6	66.0	384.0	245.0	53.0	14.5
08-08-87	0.3	4.0	...	...	...	...	...	...	54.0	14.5
09-08-87	0.0	8.9	...	...	...	...	...	...	55.0	14.5
10-08-87	1.9	0.0	5.9	85.0	2.0	67.0	429.0	255.0	52.0	14.5
11-08-87	1.6	4.4	6.2	85.0	2.0	67.0	490.0	265.0	52.0	14.5
12-08-87	0.0	10.6	5.9	70.0	2.0	67.0	444.0	205.0	53.0	14.5
13-08-87	1.8	0.0	6.2	50.0	1.5	64.0	454.0	245.0	54.0	14.5
14-08-87	3.6	0.0	6.0	85.0	1.6	62.0	475.0	255.0	55.0	14.5
15-08-87	5.3	0.0	...	...	...	...	...	...	54.0	14.5
16-08-87	6.5	1.5	...	...	...	...	...	...	55.0	14.5
17-08-87	8.0	2.7	5.7	85.0	2.4	80.0	525.0	225.0	60.0	15.5
18-08-87	4.1	2.6	5.8	100.0	2.8	61.0	552.0	240.0	61.0	15.5
19-08-87	5.8	0.0	5.7	85.0	2.4	64.0	595.0	230.0	62.0	15.5
20-08-87	6.8	0.6	6.2	100.0	2.4	62.0	654.0	280.0	59.0	15.5
21-08-87	8.5	0.4	5.6	125.0	2.8	67.0	682.0	255.0	56.0	15.5
22-08-87	0.0	7.0	...	...	...	...	...	...	57.0	15.5
23-08-87	0.0	8.4	...	...	...	...	...	...	60.0	15.0
24-08-87	1.6	0.0	6.4	150.0	4.0	70.0	751.0	220.0	56.0	15.0
25-08-87	2.0	1.1	6.1	100.0	3.0	66.0	706.0	200.0	56.0	15.0
26-08-87	0.0	19.1	6.0	125.0	3.7	65.0	715.0	215.0	56.0	15.0
27-08-87	1.5	0.0	6.1	100.0	3.0	69.0	739.0	250.0	52.0	15.0
28-08-87	0.8	4.2	5.9	100.0	2.9	70.0	770.0	210.0	57.0	15.0
29-08-87	2.3	0.0	...	...	...	...	...	...	60.0	15.0
30-08-87	3.7	0.0	...	...	...	...	...	...	61.0	15.0
31-08-87	4.9	0.0	...	...	...	...	...	...	56.0	14.5
01-09-87	6.8	1.4	6.0	200.0	4.0	65.0	748.0	200.0	56.0	14.5
02-09-87	8.0	0.0	6.6	100.0	3.6	75.0	844.0	215.0	58.0	14.5
03-09-87	9.7	1.2	5.0	175.0	3.8	69.0	871.0	225.0	53.0	14.5
04-09-87	8.9	1.4	5.9	125.0	3.2	70.0	830.0	230.0	64.0	15.0
05-09-87	6.6	11.7	...	...	...	...	...	...	58.0	15.0
06-09-87	0.0	8.9	...	...	...	...	...	...	58.0	15.0
07-09-87	0.8	2.7	6.0	150.0	4.4	66.0	1015.0	215.0	54.0	15.0
08-09-87	2.5	0.0	6.2	50.0	4.0	69.0	909.0	230.0	56.0	14.5
09-09-87	1.6	3.6	5.8	150.0	4.3	84.0	974.0	230.0	56.0	14.5
10-09-87	3.3	0.0	5.9	100.0	4.9	70.0	858.0	215.0	54.0	14.5
11-09-87	0.0	5.6	6.6	175.0	4.0	73.0	972.0	205.0	56.0	14.5
12-09-87	0.4	0.6	...	...	...	...	...	...	54.0	14.5
13-09-87	1.9	0.0	...	...	...	...	...	...	62.0	14.5
14-09-87	2.3	0.0	5.9	125.0	3.7	71.0	938.0	210.0	59.0	14.5
15-09-87	3.8	0.0	5.8	100.0	3.5	70.0	928.0	145.0	58.0	14.5
16-09-87	0.0	21.9	5.9	150.0	4.0	69.0	899.0	225.0	58.0	14.5
17-09-87	1.2	0.5	...	...	...	...	...	...	58.0	14.5
18-09-87	2.6	0.0	...	...	...	...	...	...	56.0	14.5
19-09-87	0.0	20.2	...	...	...	...	...	...	56.0	14.5
20-09-87	1.3	0.0	...	...	...	...	...	...	56.0	14.0
21-09-87	0.6	2.2	...	...	...	...	...	...	55.0	14.0
22-09-87	1.6	0.0	5.9	175.0	5.0	70.0	848.0	225.0	62.0	14.0
23-09-87	0.0	14.2	6.8	225.0	4.3	66.0	896.0	195.0	58.0	14.0
24-09-87	0.0	7.0	7.0	175.0	3.8	69.0	806.0	225.0	58.0	14.0
25-09-87	1.2	0.0	...	...	...	...	...	...	54.0	14.0
26-09-87	2.3	0.0	...	...	...	...	...	...	50.0	14.0
27-09-87	3.4	0.0	...	...	...	...	...	...	42.0	14.0
28-09-87	4.5	0.0	6.2	225.0	4.9	77.0	840.0	230.0	42.0	14.0
29-09-87	5.5	0.0	6.7	250.0	6.1	75.0	959.0	229.0	39.0	12.0
30-09-87	6.5	0.0	6.5	250.0	5.9	74.0	919.0	220.0	40.0	12.0
01-10-87	7.7	0.0	5.4	150.0	4.6	71.0	943.0	216.0	40.0	12.0
02-10-87	8.8	0.0	5.9	125.0	4.3	72.0	869.0	200.0	39.0	12.0
03-10-87	0.0	6.5	...	...	...	...	...	...	42.0	12.0
04-10-87	0.0	0.7	...	...	...	...	...	...	41.0	12.0
05-10-87	0.0	2.8	7.2	150.0	4.6	63.0	976.0	180.0	54.0	12.0

Con.

Date	SMD	Rain	pH	Colour	Tur.	Mn	Fe	Al	Temp-A	Temp-W
06-10-87	0.0	4.1	7.3	150.0	4.7	72.0	972.0	210.0	58.0	12.0
07-10-87	0.0	10.4	6.9	100.0	4.0	73.0	939.0	262.0	52.0	13.0
08-10-87	0.0	14.9	7.2	175.0	6.4	66.0	960.0	204.0	52.0	12.0
09-10-87	0.0	15.0	6.7	175.0	4.0	70.0	931.0	259.0	52.0	12.0
10-10-87	0.0	0.8	...	...	...	...	...	...	49.0	11.5
11-10-87	0.5	0.0	...	...	...	...	...	...	46.0	11.0
12-10-87	0.0	1.7	6.3	250.0	5.7	66.0	967.0	260.0	50.0	12.0
13-10-87	0.0	1.1	6.3	125.0	5.7	67.0	820.0	185.0	48.0	11.0
14-10-87	0.0	8.3	6.3	200.0	5.4	71.0	899.0	210.0	47.0	11.0
15-10-87	0.0	11.3	6.3	85.0	4.0	82.0	926.0	210.0	50.0	11.0
16-10-87	0.0	28.1	6.3	125.0	3.5	2012.0	2990.0	128.0	48.0	11.0
17-10-87	0.1	0.0	...	...	...	...	...	...	50.0	10.0
18-10-87	0.0	1.7	...	...	...	...	...	...	56.0	10.0
19-10-87	0.2	0.0	6.7	125.0	3.9	70.0	858.0	197.0	58.0	10.0
20-10-87	0.0	11.1	6.3	225.0	5.7	65.0	844.0	240.0	56.0	10.0
21-10-87	0.0	1.2	6.4	175.0	5.7	66.0	799.0	201.0	57.0	10.0
22-10-87	0.0	0.0	6.4	200.0	5.5	70.0	854.0	552.0	48.0	10.0
23-10-87	0.6	0.0	5.8	225.0	4.9	71.0	817.0	207.0	42.0	10.0
24-10-87	1.1	0.0	...	...	...	...	...	...	42.0	10.0
25-10-87	1.7	0.0	...	...	...	...	...	...	44.0	10.0
26-10-87	0.0	1.9	6.5	150.0	5.2	79.0	861.0	256.0	48.0	9.5
27-10-87	0.0	11.4	5.8	150.0	6.5	70.0	814.0	200.0	53.0	9.5
28-10-87	0.5	0.0	6.1	100.0	6.5	72.0	800.0	186.0	49.0	9.5
29-10-87	1.0	0.0	6.1	175.0	6.2	68.0	834.0	155.0	44.0	9.5
30-10-87	0.9	0.0	6.5	125.0	4.7	79.0	744.0	156.0	47.0	9.0
31-10-87	0.7	0.0	...	...	...	...	...	...	52.0	9.5
01-11-87	1.3	0.7	...	...	...	...	...	...	54.0	9.5
02-11-87	2.0	0.0	6.1	125.0	5.3	71.0	812.0	174.0	52.0	9.5
03-11-87	2.6	0.0	6.1	150.0	5.0	78.0	729.0	156.0	52.0	9.5
04-11-87	3.2	0.0	5.8	85.0	5.8	80.0	733.0	352.0	50.0	9.5
05-11-87	3.8	0.0	6.5	125.0	5.3	72.0	737.0	186.0	50.0	9.5
06-11-87	4.3	0.0	6.0	125.0	5.1	75.0	771.0	290.0	40.0	9.0
07-11-87	4.9	0.0	...	...	...	...	...	...	40.0	9.5
08-11-87	1.0	4.2	...	...	...	...	...	...	41.0	9.5
09-11-87	1.5	0.9	6.0	175.0	4.6	79.0	649.0	210.0	44.0	8.5
10-11-87	0.0	5.4	6.0	125.0	4.7	75.0	720.0	252.0	46.0	8.5
11-11-87	0.0	5.5	5.8	150.0	4.7	70.0	737.0	215.0	44.0	8.0
12-11-87	0.0	14.2	6.3	150.0	4.4	73.0	956.0	215.0	45.0	8.0
13-11-87	0.0	0.4	6.1	100.0	3.7	75.0	709.0	196.0	46.0	8.0
14-11-87	0.0	7.4	...	...	...	...	...	...	45.0	8.0
15-11-87	0.0	7.4	...	...	...	...	...	...	44.0	8.0
16-11-87	0.0	5.3	6.0	150.0	4.1	75.0	717.0	200.0	44.0	9.0
17-11-87	0.4	0.0	5.9	150.0	4.1	75.0	790.0	319.0	45.0	9.0
18-11-87	0.0	13.9	6.2	100.0	3.9	75.0	706.0	140.0	44.0	9.0
19-11-87	0.0	14.1	6.5	85.0	4.1	77.0	750.0	210.0	44.0	9.0
20-11-87	0.3	0.2	6.1	100.0	3.6	71.0	693.0	254.0	46.0	9.0
21-11-87	0.0	2.0	...	...	...	...	...	...	46.0	8.0
22-11-87	0.0	1.6	...	...	...	...	...	...	46.0	8.0
23-11-87	0.0	19.7	6.3	85.0	3.7	79.0	722.0	130.0	40.0	8.0
24-11-87	0.3	2.5	6.2	100.0	3.8	74.0	706.0	...	44.0	6.5
25-11-87	0.6	0.0	5.8	175.0	4.1	69.0	776.0	...	42.0	7.5
26-11-87	0.8	0.0	6.2	175.0	4.8	67.0	678.0	198.0	42.0	7.5
27-11-87	1.1	0.0	6.2	100.0	3.1	64.0	617.0	250.0	36.0	5.5
28-11-87	1.4	0.0	...	...	...	...	...	...	34.0	5.5
29-11-87	1.1	0.9	...	...	...	...	...	...	43.0	6.0
30-11-87	1.3	1.7	...	...	...	...	...	...	45.0	6.0
01-12-87	1.3	0.6	6.2	85.0	3.7	79.0	831.0	175.0	44.0	6.0
02-12-87	1.4	0.7	5.8	100.0	3.2	77.0	647.0	189.0	42.0	5.5
03-12-87	1.8	0.0	6.4	100.0	3.5	76.0	707.0	171.0	40.0	5.0
04-12-87	2.1	0.0	6.5	100.0	2.9	72.0	513.0	202.0	48.0	5.0
05-12-87	1.9	0.0	...	...	...	...	...	...	40.0	5.0
06-12-87	2.0	0.8	...	...	...	...	...	...	40.0	5.0
07-12-87	2.3	0.0	6.1	85.0	3.5	69.0	618.0	172.0	39.0	5.0
08-12-87	2.6	0.0	6.7	100.0	3.7	92.0	605.0	181.0	36.0	4.5
09-12-87	2.9	0.0	6.0	125.0	3.6	72.0	615.0	200.0	34.0	4.5
10-12-87	3.2	0.0	6.1	85.0	4.5	76.0	662.0	135.0	38.0	4.5
11-12-87	3.4	0.0	6.2	100.0	3.6	74.0	602.0	140.0	42.0	4.5
12-12-87	3.7	0.0	...	...	...	...	...	...	45.0	4.5
13-12-87	4.0	0.0	...	...	...	...	...	...	44.0	4.5
14-12-87	4.3	0.0	6.3	100.0	4.0	73.0	467.0	180.0	39.0	4.5
15-12-87	0.0	6.9	6.3	100.0	4.6	80.0	600.0	131.0	33.0	3.5
16-12-87	0.0	6.8	6.6	60.0	2.6	73.0	569.0	150.0	47.0	3.5

Con.



Date	SMD	Rain	pH	Colour	Tur.	Mn	Fe	Al	Temp-A	Temp-W
17-12-87	0.0	23.3	...	...	2.5	...	...	...	52.0	3.5
18-12-87	0.0	0.0	6.0	100.0	2.5	75.0	814.0	198.0	53.0	4.0
19-12-87	0.0	1.8	...	...	...	...	...	...	49.0	4.0
20-12-87	0.0	0.0	...	...	...	...	...	...	53.0	4.5
21-12-87	0.1	1.5	6.0	85.0	3.4	83.0	585.0	140.0	40.0	4.5
22-12-87	0.4	0.0	6.3	100.0	4.9	79.0	457.0	133.0	54.0	5.5
23-12-87	0.7	0.0	6.0	70.0	4.2	56.0	505.0	146.0	50.0	5.0
24-12-87	0.0	0.6	6.1	125.0	4.4	72.0	563.0	164.0	50.0	5.0
25-12-87	0.3	0.0	...	...	...	...	...	...	48.0	5.0
26-12-87	0.0	10.0	...	...	...	...	...	...	48.0	5.0
27-12-87	0.0	0.8	...	...	...	...	...	...	47.0	5.0
28-12-87	0.0	3.3	6.1	125.0	3.0	69.0	568.0	173.0	55.0	6.0
29-12-87	0.0	2.8	6.1	125.0	3.4	73.0	575.0	183.0	57.0	6.0
30-12-87	0.0	3.2	6.5	125.0	3.1	71.0	586.0	184.0	51.0	6.0
31-12-87	0.0	4.2	7.2	125.0	3.5	78.0	589.0	161.0	51.0	6.5
01-01-88	0.0	31.4	...	...	...	...	...	...	48.0	6.5
02-01-88	0.0	10.5	...	...	...	...	...	...	52.0	6.5
03-01-88	0.0	8.1	...	...	...	...	...	...	46.0	6.5
04-01-88	0.0	8.2	6.0	100.0	4.5	76.0	613.0	194.0	46.0	6.0
05-01-88	0.0	13.1	5.9	100.0	3.5	76.0	606.0	158.0	42.0	6.0
06-01-88	0.0	1.6	6.0	100.0	4.1	79.0	468.0	191.0	45.0	6.0
07-01-88	0.3	1.1	6.0	125.0	4.3	...	...	...	40.0	5.0
08-01-88	0.0	4.4	5.6	100.0	3.4	74.0	547.0	180.0	39.0	5.0
09-01-88	0.0	2.4	...	...	...	...	...	...	46.0	5.5
10-01-88	0.0	3.8	...	...	...	...	...	...	37.0	5.5
11-01-88	0.3	1.8	5.6	150.0	5.1	77.0	561.0	186.0	36.0	5.0
12-01-88	0.0	1.5	5.9	85.0	4.2	78.0	592.0	156.0	42.0	4.5
13-01-88	0.3	0.0	6.5	125.0	3.8	74.0	576.0	180.0	40.0	4.5
14-01-88	0.4	0.7	5.6	100.0	3.6	86.0	584.0	163.0	36.0	4.5
15-01-88	0.8	0.0	5.7	100.0	4.4	78.0	590.0	139.0	40.0	4.5
16-01-88	1.2	0.0	...	...	...	...	...	...	38.0	4.5
17-01-88	0.0	10.2	...	...	...	...	...	...	39.0	4.5
18-01-88	0.0	1.5	5.8	100.0	3.3	74.0	592.0	188.0	40.0	5.5
19-01-88	0.0	0.0	5.6	100.0	4.5	79.0	575.0	191.0	44.0	5.5
20-01-88	0.0	3.0	5.8	125.0	3.3	82.0	620.0	174.0	40.0	5.5
21-01-88	0.0	3.4	6.6	150.0	7.2	97.0	600.0	175.0	38.0	5.5
22-01-88	0.0	6.8	6.0	100.0	3.0	86.0	520.0	175.0	30.0	5.0
23-01-88	0.0	27.4	...	...	...	...	...	...	33.0	5.0
24-01-88	0.0	0.0	...	...	...	...	...	...	42.0	5.0
25-01-88	0.5	2.0	5.5	125.0	3.2	78.0	565.0	185.0	38.0	5.0
26-01-88	0.9	0.0	5.2	50.0	3.3	80.0	571.0	167.0	38.0	5.0
27-01-88	0.0	0.0	5.4	150.0	2.9	84.0	598.0	164.0	34.0	5.0
28-01-88	0.0	2.4	6.1	100.0	3.4	86.0	586.0	154.0	32.0	5.0
29-01-88	0.0	8.0	5.2	85.0	2.4	79.0	538.0	190.0	36.0	5.0
30-01-88	0.0	8.4	...	...	...	...	...	...	36.0	5.0
31-01-88	0.0	6.1	...	...	...	...	...	...	34.0	5.0
01-02-88	0.0	8.3	5.9	100.0	3.3	83.0	740.0	208.0	38.0	4.5
02-02-88	0.0	4.4	6.3	100.0	3.4	84.0	544.0	197.0	40.0	4.5
03-02-88	0.0	7.4	5.2	125.0	3.6	75.0	528.0	228.0	36.0	4.0
04-02-88	0.0	5.7	5.5	100.0	4.6	79.0	524.0	237.0	38.0	4.0
05-02-88	0.0	0.0	5.1	100.0	3.5	83.0	491.0	178.0	36.0	4.0
06-02-88	0.0	1.1	...	...	...	...	...	...	32.0	4.0
07-02-88	0.0	9.5	...	...	...	...	...	...	30.0	4.0
08-02-88	0.0	1.6	5.6	125.0	2.9	72.0	515.0	187.0	32.0	4.0
09-02-88	0.0	21.0	5.0	125.0	3.6	75.0	514.0	163.0	32.0	4.0
10-02-88	0.0	4.0	5.3	100.0	3.3	77.0	427.0	159.0	35.0	4.0
11-02-88	0.0	7.8	5.2	100.0	3.4	68.0	515.0	180.0	34.0	4.0
12-02-88	0.0	4.0	5.4	100.0	1.0	77.0	477.0	104.0	32.0	3.5
13-02-88	0.0	2.0	...	...	...	...	...	...	34.0	3.5
14-02-88	0.6	0.0	...	...	...	...	...	...	33.0	3.5
15-02-88	0.0	8.6	5.4	85.0	1.0	85.0	448.0	300.0	38.0	3.5
16-02-88	0.6	0.0	5.6	85.0	3.3	80.0	454.0	202.0	38.0	3.5
17-02-88	1.2	0.0	5.2	70.0	3.5	78.0	479.0	240.0	37.0	3.5
18-02-88	1.8	0.0	5.2	70.0	3.3	70.0	370.0	192.0	38.0	3.5
19-02-88	2.4	0.0	6.0	70.0	2.7	86.0	510.0	223.0	40.0	3.5
20-02-88	3.1	0.0	...	...	...	...	...	...	40.0	3.5
21-02-88	3.8	0.7	...	...	...	...	...	...	40.0	3.5
22-02-88	4.5	0.8	5.3	85.0	3.4	83.0	462.0	194.0	50.0	3.5
23-02-88	5.3	0.0	5.0	100.0	4.2	83.0	454.0	210.0	40.0	3.5
24-02-88	6.0	0.7	5.9	150.0	5.8	83.0	469.0	130.0	30.0	3.5
25-02-88	6.8	0.0	4.2	100.0	3.3	78.0	453.0	191.0	30.0	3.0
26-02-88	7.1	0.8	6.0	70.0	2.6	93.0	360.0	251.0	29.0	3.0

Con.

Date	SMD	Rain	pH	Colour	Tur.	Mn	Fe	Al	Temp-A	Temp-W
27-02-88	7.6	0.0	...	...	...	...	...	...	38.0	3.0
28-02-88	8.0	0.0	...	...	...	...	...	...	38.0	3.0
29-02-88	8.9	0.0	5.5	85.0	3.5	87.0	433.0	194.0	27.0	3.0
01-03-88	9.5	0.0	...	...	...	...	...	...	28.0	3.0
02-03-88	3.1	5.5	...	...	...	...	...	...	27.0	3.0
03-03-88	0.0	0.5	...	...	...	...	...	...	24.0	3.0
04-03-88	0.7	0.0	5.0	85.0	3.1	116.0	486.0	202.0	28.0	3.0
05-03-88	0.0	8.9	...	...	...	...	...	...	24.0	3.0
06-03-88	0.0	4.4	...	...	...	...	...	...	36.0	3.0
07-03-88	0.3	0.5	5.7	100.0	2.7	104.0	490.0	180.0	38.0	4.0
08-03-88	0.9	0.7	5.3	70.0	3.2	88.0	480.0	...	39.0	4.0
09-03-88	0.0	17.6	5.8	85.0	2.7	81.0	427.0	205.0	42.0	4.0
10-03-88	0.8	0.6	5.8	85.0	3.2	84.0	452.0	167.0	42.0	4.0
11-03-88	0.0	18.1	5.7	70.0	3.1	96.0	424.0	...	40.0	4.0
12-03-88	0.0	16.0	...	...	...	...	...	...	40.0	4.0
13-03-88	0.0	12.6	...	...	...	...	...	...	39.0	4.0
14-03-88	0.0	12.8	5.9	85.0	2.7	87.0	496.0	224.0	28.0	2.5
15-03-88	0.0	11.2	...	...	...	...	...	...	23.0	2.5
16-03-88	0.9	0.6	...	...	...	...	...	...	28.0	2.5
17-03-88	1.7	0.0	...	...	...	...	...	...	23.0	2.5
18-03-88	0.0	10.1	5.3	100.0	2.4	89.0	388.0	320.0	34.0	2.5
19-03-88	0.0	10.8	...	...	...	...	...	...	40.0	2.5
20-03-88	0.0	8.2	...	...	...	...	...	...	42.0	2.5
21-03-88	1.0	0.5	5.4	85.0	3.3	79.0	385.0	238.0	46.0	5.5
22-03-88	0.0	17.0	4.6	74.0	1.0	79.0	366.0	236.0	41.0	5.5
23-03-88	0.0	2.0	...	...	...	...	...	...	44.0	5.5
24-03-88	0.0	6.2	5.3	85.0	3.1	77.0	399.0	272.0	43.0	4.5
25-03-88	0.0	4.2	...	...	...	...	...	...	39.0	4.5
26-03-88	0.0	4.8	...	...	...	...	...	...	38.0	4.5
27-03-88	0.0	3.1	...	...	...	...	...	...	38.0	4.5
28-03-88	0.0	6.2	...	...	...	...	...	...	42.0	4.5
29-03-88	1.2	0.0	5.8	85.0	3.5	86.0	443.0	231.0	40.0	4.0
30-03-88	1.4	2.8	...	...	...	...	...	...	36.0	5.5
31-03-88	2.7	0.0	7.0	125.0	5.1	79.0	345.0	...	40.0	5.5
01-04-88	0.0	4.9	...	...	...	...	...	...	38.0	5.5
02-04-88	1.0	0.0	...	...	...	...	...	...	39.0	5.5
03-04-88	0.0	3.3	...	...	...	...	...	...	39.0	5.5
04-04-88	1.0	0.0	...	...	...	...	...	...	38.0	6.5
05-04-88	2.0	0.0	...	...	...	...	...	...	35.0	6.5
06-04-88	3.1	0.0	5.4	100.0	4.0	83.0	380.0	190.0	39.0	6.5
07-04-88	3.4	0.8	5.6	125.0	4.0	76.0	345.0	200.0	40.0	6.5
08-04-88	1.3	6.2	5.5	50.0	2.8	78.0	370.0	237.0	42.0	6.5
09-04-88	2.2	0.0	...	...	...	...	...	...	33.0	6.0
10-04-88	3.3	0.0	...	...	...	...	...	...	33.0	6.0
11-04-88	4.5	0.0	5.4	125.0	5.0	81.0	357.0	200.0	42.8	6.0
12-04-88	5.7	0.0	5.8	100.0	3.5	85.0	416.0	177.0	39.2	6.0
13-04-88	6.9	0.0	6.1	60.0	3.6	85.0	376.0	197.0	39.2	5.0
14-04-88	8.1	0.0	5.4	100.0	4.0	75.0	332.0	200.0	39.2	5.0
15-04-88	4.8	2.8	5.5	100.0	2.3	83.0	342.0	228.0	39.0	5.0
16-04-88	5.2	1.8	...	...	...	...	...	...	50.0	5.0
17-04-88	6.5	0.6	...	...	...	...	...	...	50.0	5.0
18-04-88	4.6	2.2	6.4	100.0	2.9	80.0	354.0	214.0	50.0	8.0
19-04-88	5.9	0.7	5.7	70.0	2.6	83.0	327.0	188.0	52.0	8.0
20-04-88	7.0	0.0	6.4	70.0	3.4	85.0	338.0	205.0	48.0	8.0
21-04-88	7.2	2.6	6.0	100.0	3.5	87.0	312.0	189.0	49.0	8.0
22-04-88	8.3	0.0	6.3	70.0	2.4	79.0	348.0	170.0	37.0	8.0
23-04-88	9.7	0.0	...	...	...	...	...	...	34.0	8.0
24-04-88	11.1	0.0	...	...	...	...	...	...	34.0	8.0
25-04-88	12.6	0.4	5.8	70.0	2.6	83.0	345.0	209.0	38.0	8.0
26-04-88	8.4	9.8	5.6	85.0	2.5	79.0	319.0	215.0	46.0	8.0
27-04-88	8.8	4.2	5.8	50.0	2.4	85.0	372.0	220.0	39.0	8.0
28-04-88	10.4	0.0	6.9	70.0	2.5	76.0	340.0	214.0	34.0	8.0
29-04-88	11.8	1.0	...	...	...	...	...	...	36.0	8.0
30-04-88	7.2	2.3	...	...	...	...	...	...	36.0	8.0
01-05-88	0.1	2.0	...	...	...	...	...	...	44.0	8.5
02-05-88	0.0	1.7	...	...	...	...	...	...	42.0	8.0
03-05-88	0.0	9.1	5.6	70.0	1.9	124.0	383.0	252.0	44.0	8.5
04-05-88	0.9	1.9	...	...	...	...	...	...	46.0	8.5
05-05-88	2.8	0.0	5.8	70.0	2.6	77.0	438.0	210.0	47.0	8.5
06-05-88	4.8	0.0	5.9	70.0	2.0	69.0	509.0	219.0	44.0	9.5
07-05-88	6.7	0.0	...	...	...	...	...	...	46.0	10.5
08-05-88	8.7	0.0	...	...	...	...	...	...	46.0	10.5

Con.

Date	SMD	Rain	pH	Colour	Tur.	Mn	Fe	Al	Temp-A	Temp-W
09-05-88	10.7	0.0	6.6	70.0	2.3	82.0	488.0	204.0	48.0	10.0
10-05-88	12.7	0.0	6.6	70.0	2.5	80.0	461.0	235.0	43.0	10.0
11-05-88	14.8	1.6	6.3	40.0	2.4	77.0	450.0	213.0	43.0	10.0
12-05-88	16.7	0.0	6.0	70.0	2.5	77.0	446.0	287.0	46.0	10.0
13-05-88	18.8	0.0	6.1	45.0	2.1	82.0	507.0	166.0	48.0	10.0
14-05-88	20.9	0.0	...	...	...	...	...	...	46.0	11.0
15-05-88	23.0	0.0	...	...	...	...	...	...	48.0	11.0
16-05-88	25.2	0.0	5.8	100.0	2.3	84.0	518.0	212.0	50.0	11.0
17-05-88	27.4	0.0	6.4	85.0	2.5	73.0	443.0	...	48.0	11.0
18-05-88	29.6	0.0	6.4	85.0	2.5	72.0	493.0	190.0	39.0	11.0
19-05-88	26.8	1.0	6.2	85.0	3.7	74.0	600.0	210.0	42.0	11.0
20-05-88	29.1	0.0	6.4	70.0	2.2	91.0	489.0	238.0	40.0	11.0
21-05-88	31.3	0.0	...	...	...	...	...	...	60.0	11.0
22-05-88	33.4	0.0	...	...	...	...	...	...	70.0	11.0
23-05-88	32.2	4.8	6.6	70.0	2.3	81.0	650.0	180.0	47.0	12.0
24-05-88	30.3	3.7	5.9	70.0	2.2	76.0	500.0	194.0	49.0	12.0
25-05-88	29.4	0.8	6.0	70.0	2.1	128.0	856.0	200.0	48.0	12.0
26-05-88	28.3	6.2	6.7	70.0	2.8	69.0	536.0	188.0	47.0	12.0
27-05-88	30.7	0.0	6.4	70.0	2.0	76.0	550.0	184.0	48.0	12.0
28-05-88	33.1	0.0	...	...	...	...	...	...	46.0	12.0
29-05-88	30.1	3.9	...	...	...	...	...	...	50.0	12.0
30-05-88	27.5	12.6	...	...	...	...	...	...	50.0	12.0
31-05-88	28.6	0.0	...	...	...	...	...	...	48.0	12.0
01-06-88	30.5	0.0	6.1	85.0	2.3	77.0	575.0	226.0	50.0	12.0
02-06-88	31.3	1.6	6.1	70.0	2.7	75.0	918.0	140.0	51.8	12.0
03-06-88	28.1	10.6	6.0	70.0	3.9	86.0	590.0	181.0	50.0	12.0
04-06-88	25.9	2.4	...	...	...	...	...	...	49.0	12.0
05-06-88	27.9	0.0	...	...	...	...	...	...	48.0	12.0
06-06-88	30.0	0.0	6.2	70.0	2.7	71.0	746.0	232.0	46.0	12.0
07-06-88	30.5	7.5	7.0	70.0	2.8	99.0	697.0	170.0	54.0	12.0
08-06-88	29.4	7.4	6.8	70.0	2.5	74.0	490.0	168.0	52.0	12.0
09-06-88	31.4	0.5	6.4	70.0	1.9	76.0	656.0	136.0	48.0	12.0
10-06-88	33.5	0.0	6.2	17.0	0.5	77.0	582.0	168.0	44.0	12.0
11-06-88	35.6	0.0	...	...	...	...	...	...	46.0	12.0
12-06-88	37.7	0.0	...	...	...	...	...	...	47.0	12.0
13-06-88	39.8	0.0	6.1	50.0	1.6	77.0	642.0	148.0	54.0	12.0
14-06-88	41.9	0.0	...	...	...	...	...	...	58.0	13.0
15-06-88	44.0	0.0	7.3	70.0	1.6	67.0	545.0	126.0	59.0	13.0
16-06-88	46.1	0.0	6.9	70.0	1.9	66.0	544.0	121.0	55.4	13.0
17-06-88	48.2	0.0	7.0	50.0	1.1	71.0	538.0	170.0	52.0	14.0
18-06-88	50.3	0.0	...	...	...	...	...	...	50.0	13.0
19-06-88	52.5	0.0	...	...	...	...	...	...	52.0	13.0
20-06-88	54.6	0.0	6.2	50.0	1.8	78.0	636.0	183.0	58.0	13.5
21-06-88	56.4	0.0	6.8	70.0	1.7	75.0	659.0	168.0	56.0	13.5
22-06-88	58.5	0.0	6.2	50.0	1.9	65.0	578.0	135.0	55.0	13.5
23-06-88	60.7	0.0	6.1	40.0	1.8	77.0	638.0	182.0	52.0	13.5
24-06-88	62.8	0.0	6.6	70.0	1.9	73.0	680.0	170.0	52.0	14.0
25-06-88	52.8	16.6	...	...	...	...	...	...	52.0	14.0
26-06-88	55.0	0.0	...	...	...	...	...	...	50.0	14.0
27-06-88	75.1	0.0	6.4	70.0	2.0	84.0	662.0	136.0	50.0	14.0
28-06-88	59.2	0.0	6.1	70.0	1.9	80.0	650.0	165.0	52.0	14.0
29-06-88	52.4	5.7	6.5	70.0	2.3	117.0	673.0	153.0	57.0	14.5
30-06-88	46.1	5.9	7.0	70.0	1.9	72.0	492.0	138.0	58.0	15.0
01-07-88	37.2	4.0	6.0	60.0	1.3	79.0	476.0	130.0	58.0	15.5
02-07-88	35.7	2.3	...	...	...	...	...	...	50.0	14.5
03-07-88	32.6	17.6	...	...	...	...	...	...	52.0	14.0
04-07-88	25.7	6.6	6.7	70.0	2.1	93.0	760.0	120.0	52.0	14.0
05-07-88	26.4	2.5	7.3	70.0	2.1	19.0	504.0	144.0	52.0	15.0
06-07-88	14.1	8.4	6.3	70.0	2.7	72.0	656.0	122.0	56.0	15.0
07-07-88	11.4	8.1	6.2	70.0	3.5	82.0	1028.0	127.0	51.0	15.0
08-07-88	3.4	13.4	6.2	85.0	1.5	74.0	720.0	154.0	52.0	15.0
09-07-88	1.7	3.5	...	...	...	...	...	...	52.0	14.0
10-07-88	0.0	0.8	...	...	...	...	...	...	50.0	14.0
11-07-88	1.9	3.1	6.5	70.0	2.4	94.0	667.0	143.0	53.0	14.0
12-07-88	0.0	20.0	6.1	70.0	2.1	72.0	625.0	149.0	54.0	14.0
13-07-88	0.0	2.2	6.2	70.0	2.2	75.0	648.0	132.0	50.0	14.0
14-07-88	0.0	4.9	6.0	85.0	2.3	72.0	561.0	145.0	52.0	14.0
15-07-88	2.1	0.0	6.1	70.0	1.6	77.0	964.0	124.0	52.0	14.0
16-07-88	0.0	20.5	...	...	...	...	...	...	51.0	14.0
17-07-88	2.2	1.0	...	...	...	...	...	...	52.0	14.0
18-07-88	4.4	0.0	6.3	70.0	1.5	83.0	671.0	110.0	52.0	14.0
19-07-88	6.6	0.6	6.5	50.0	1.7	81.0	660.0	118.0	54.0	14.0

Con.

Date	SMD	Rain	pH	Colour	Tur.	Mn	Fe	Al	Temp-A	Temp-W
20-07-88	3.2	4.3	6.4	85.0	1.6	89.0	579.0	101.0	54.0	14.0
21-07-88	1.1	4.5	6.0	70.0	1.6	83.0	545.0	97.0	58.0	14.0
22-07-88	1.7	0.9	6.2	70.0	1.7	88.0	566.0	112.0	60.0	14.0
23-07-88	0.0	20.0	...	...	...	...	...	...	60.0	15.0
24-07-88	0.0	3.6	...	...	...	...	...	...	54.0	15.0
25-07-88	1.6	0.5	6.2	70.0	1.5	79.0	594.0	154.0	54.0	15.0
26-07-88	0.5	2.4	6.6	70.0	1.7	81.0	620.0	153.0	53.0	15.0
27-07-88	2.5	0.5	6.2	70.0	1.7	71.0	602.0	144.0	52.0	15.0
28-07-88	0.0	4.5	6.2	85.0	2.0	88.0	506.0	145.0	51.0	15.0
29-07-88	0.9	4.0	6.6	70.0	1.1	80.0	484.0	132.0	49.0	15.0
30-07-88	0.0	5.4	...	...	...	...	...	...	48.0	15.0
31-07-88	2.0	0.0	...	...	...	...	...	...	50.0	15.0
01-08-88	4.4	0.0	6.6	70.0	1.4	161.0	678.0	140.0	52.0	15.0
02-08-88	6.9	0.0	6.5	70.0	1.3	75.0	548.0	160.0	51.0	15.0
03-08-88	7.3	3.6	6.6	70.0	1.6	81.0	538.0	124.0	53.0	15.0
04-08-88	8.4	2.0	6.7	70.0	1.3	94.0	494.0	143.0	54.0	15.0
05-08-88	10.8	0.0	6.1	70.0	1.1	97.0	622.0	158.0	57.0	15.0
06-08-88	13.1	0.0	...	...	...	...	...	...	52.0	15.0
07-08-88	15.4	0.0	...	...	...	...	...	...	59.0	15.0
08-08-88	16.4	2.8	6.4	70.0	2.0	80.0	477.0	135.0	64.0	15.0
09-08-88	18.7	0.0	6.0	70.0	2.0	82.0	465.0	129.0	60.0	15.0
10-08-88	19.9	1.9	7.5	70.0	1.4	82.0	489.0	125.0	58.0	16.0
11-08-88	11.6	11.3	6.6	70.0	1.4	85.0	509.0	118.0	55.0	16.0
12-08-88	11.6	5.3	7.8	85.0	1.0	108.0	511.0	114.0	55.0	16.0
13-08-88	10.6	3.5	...	...	...	...	...	...	52.0	16.0
14-08-88	11.3	2.4	...	...	...	...	...	...	52.0	16.0
15-08-88	13.4	0.0	6.3	70.0	1.7	88.0	424.0	148.0	51.8	12.0
16-08-88	15.5	0.0	7.0	100.0	1.2	67.0	429.0	116.0	53.6	13.0
17-08-88	10.7	14.4	7.3	70.0	1.1	64.0	455.0	155.0	57.2	13.0
18-08-88	0.0	50.9	6.2	70.0	1.5	70.0	427.0	122.0	59.0	13.0
19-08-88	0.0	16.0	7.0	125.0	1.6	89.0	464.0	169.0	58.1	13.0
20-08-88	0.0	16.4	...	...	...	...	...	...	52.0	14.5
21-08-88	2.0	0.5	...	...	...	...	...	...	50.0	14.5
22-08-88	3.9	0.0	6.6	85.0	2.2	76.0	439.0	125.0	55.4	13.0
23-08-88	5.7	0.0	6.2	100.0	2.0	66.0	477.0	145.0	50.0	13.0
24-08-88	0.0	5.0	5.8	100.0	2.2	66.0	486.0	159.0	54.0	13.0
25-08-88	1.8	1.1	5.9	100.0	2.3	85.0	527.0	156.0	50.0	13.0
26-08-88	0.0	14.6	6.1	85.0	1.5	93.0	638.0	81.0	48.0	13.0
27-08-88	0.0	7.6	...	...	...	...	...	...	48.0	13.0
28-08-88	1.8	0.5	...	...	...	...	...	...	48.0	13.0
29-08-88	1.4	10.6	...	...	...	...	...	...	49.0	13.0
30-08-88	1.5	3.8	6.9	150.0	2.7	83.0	506.0	160.0	50.0	13.5
31-08-88	0.0	2.1	7.0	125.0	4.9	87.0	594.0	150.0	51.0	13.5
01-09-88	0.0	22.8	7.4	125.0	3.0	81.0	516.0	143.0	53.0	13.5
02-09-88	0.0	10.6	...	...	...	...	...	...	50.0	13.5
03-09-88	0.1	0.0	...	...	...	...	...	...	46.0	13.0
04-09-88	0.0	0.0	...	...	...	...	...	...	48.0	13.5
05-09-88	1.8	0.0	6.1	150.0	4.2	80.0	522.0	213.0	50.0	12.0
06-09-88	3.5	0.0	6.5	125.0	3.6	93.0	550.0	195.0	50.0	11.0
07-09-88	5.2	0.0	6.2	100.0	3.2	81.0	533.0	225.0	57.2	12.0
08-09-88	6.9	0.0	5.7	100.0	3.7	81.0	548.0	183.0	59.9	13.0
09-09-88	8.5	0.0	...	...	...	...	...	...	50.0	14.0
10-09-88	8.7	4.2	...	...	...	...	...	...	57.0	14.0
11-09-88	6.0	0.0	...	...	...	...	...	...	40.0	14.0
12-09-88	3.6	1.7	...	...	...	...	...	...	48.0	14.0
13-09-88	5.2	0.0	...	...	...	...	...	...	46.0	14.0
14-09-88	6.6	0.0	...	...	...	...	...	...	46.0	14.0
15-09-88	8.1	0.0	...	...	...	...	...	...	48.0	14.0
16-09-88	9.5	0.0	...	...	...	...	...	...	52.0	14.0
17-09-88	10.9	0.0	...	...	...	...	...	...	48.0	14.0
18-09-88	12.2	0.0	...	...	...	...	...	...	48.0	14.0
19-09-88	13.6	0.0	5.5	100.0	1.5	94.0	576.0	202.0	49.0	14.0
20-09-88	14.9	0.0	6.1	70.0	2.5	92.0	544.0	189.0	50.0	14.0
21-09-88	14.4	0.8	7.0	85.0	2.5	98.0	595.0	198.0	50.0	13.0
22-09-88	5.0	8.5	7.4	85.0	2.2	93.0	550.0	101.0	50.0	13.0
23-09-88	0.0	22.1	6.1	125.0	2.3	88.0	530.0	208.0	49.0	13.0
24-09-88	1.0	0.0	...	...	...	...	...	...	52.0	12.5
25-09-88	0.0	16.5	...	...	...	...	...	...	48.0	13.0
26-09-88	1.1	0.3	6.0	80.0	3.9	89.0	569.0	187.0	52.0	12.5
27-09-88	0.0	4.4	5.4	150.0	3.1	78.0	594.0	175.0	52.0	12.5
28-09-88	0.0	8.5	6.4	85.0	2.5	83.0	575.0	90.0	50.0	12.5
29-09-88	1.0	0.6	5.5	125.0	4.0	75.0	582.0	192.0	44.0	12.5

Con.

Date	SMD	Rain	pH	Colour	Tur.	Mn	Fe	Al	Temp-A	Temp-W
30-09-88	2.0	0.0	5.5	125.0	2.0	86.0	631.0	168.0	36.0	12.0
01-10-88	3.3	0.0	...	...	...	...	...	...	36.0	12.0
02-10-88	4.4	0.0	...	...	...	...	...	...	36.0	12.0
03-10-88	5.6	0.0	6.6	125.0	2.9	82.0	567.0	179.0	41.0	11.5
04-10-88	1.1	9.1	6.4	125.0	2.6	79.0	597.0	190.0	44.0	11.5
05-10-88	0.0	7.1	6.5	175.0	3.3	85.0	607.0	206.0	48.0	11.5
06-10-88	0.0	15.3	7.9	100.0	3.3	85.0	566.0	197.0	49.0	11.5
07-10-88	0.0	8.9	5.6	125.0	1.9	97.0	659.0	191.0	46.0	11.0
08-10-88	0.0	0.7	...	...	...	...	...	...	48.0	11.0
09-10-88	0.0	2.2	...	...	...	...	...	...	43.0	11.0
10-10-88	0.8	0.0	7.1	150.0	2.5	74.0	528.0	200.0	48.0	11.0
11-10-88	0.0	4.3	6.6	85.0	2.2	78.0	586.0	208.0	45.0	11.0
12-10-88	0.0	4.3	5.5	175.0	2.3	77.0	524.0	182.0	43.0	11.0
13-10-88	0.8	0.0	6.3	175.0	2.4	79.0	440.0	193.0	45.0	11.0
14-10-88	1.7	0.0	6.3	150.0	1.7	75.0	583.0	204.0	44.0	11.0
15-10-88	2.4	0.0	...	...	...	...	...	...	48.0	11.0
16-10-88	3.2	0.0	...	...	...	...	...	...	50.0	11.0
17-10-88	3.9	0.0	7.4	150.0	2.5	89.0	566.0	194.0	48.0	11.0
18-10-88	0.0	9.4	6.7	125.0	3.1	82.0	537.0	194.0	50.0	11.0
19-10-88	0.0	15.3	5.6	125.0	3.0	78.0	557.0	195.0	55.0	11.0
20-10-88	0.0	2.3	6.5	125.0	2.1	71.0	563.0	186.0	53.0	10.5
21-10-88	0.7	0.0	7.2	150.0	2.0	80.0	572.0	180.0	46.0	10.5
22-10-88	1.1	0.0	...	...	...	...	...	...	50.0	10.0
23-10-88	0.0	3.2	...	...	...	...	...	...	49.0	10.5
24-10-88	0.0	2.5	5.4	150.0	2.5	76.0	570.0	201.0	49.0	10.0
25-10-88	0.0	2.4	5.4	150.0	2.7	84.0	600.0	200.0	50.0	10.0
26-10-88	0.0	5.0	5.3	125.0	2.5	85.0	540.0	190.0	51.8	10.0
27-10-88	0.0	3.8	6.6	175.0	2.7	80.0	551.0	198.0	50.0	10.0
28-10-88	0.5	0.0	5.9	150.0	3.2	76.0	550.0	181.0	46.4	9.0
29-10-88	1.0	0.0	...	...	...	...	...	...	28.0	9.0
30-10-88	1.5	0.0	...	...	...	...	...	...	40.0	9.0
31-10-88	2.0	0.0	5.4	85.0	2.8	76.0	525.0	180.0	34.0	9.0
01-11-88	2.5	9.0	5.4	150.0	3.1	85.0	520.0	...	28.0	9.0
02-11-88	3.0	0.0	...	...	...	...	...	...	40.0	9.0
03-11-88	3.5	0.0	...	...	...	...	...	...	34.0	9.0
04-11-88	4.0	0.0	...	...	...	...	...	...	34.0	9.0
05-11-88	4.4	0.0	...	...	...	...	...	...	37.0	9.0
06-11-88	4.8	0.0	...	...	...	...	...	...	40.0	9.0
07-11-88	5.3	0.0	7.5	125.0	2.7	81.0	884.0	239.0	44.0	9.0
08-11-88	0.1	5.6	...	...	...	...	...	...	41.0	8.0
09-11-88	0.0	1.2	...	...	...	...	...	...	50.0	8.0
10-11-88	0.0	1.0	...	...	...	...	...	...	52.0	8.0
11-11-88	0.4	0.0	...	...	...	...	...	...	42.0	8.0
12-11-88	0.0	0.0	...	...	...	...	...	...	39.0	8.0
13-11-88	0.3	1.0	...	...	...	...	...	...	38.0	8.0
14-11-88	0.7	0.0	7.5	150.0	2.5	87.0	553.0	192.0	36.0	8.0
15-11-88	1.0	0.0	...	...	...	...	...	...	39.0	8.0
16-11-88	1.1	0.6	...	...	...	...	...	...	40.0	7.5
17-11-88	0.0	9.9	...	...	...	...	...	...	44.0	7.5
18-11-88	0.3	0.0	...	...	...	...	...	...	44.0	7.5
19-11-88	0.0	9.1	...	...	...	...	...	...	42.0	7.5
20-11-88	0.3	0.0	...	...	...	...	...	...	40.0	6.0
21-11-88	0.5	0.0	6.0	125.0	2.3	108.0	504.0	184.0	29.0	7.5
22-11-88	0.8	0.0	...	...	...	...	...	...	24.0	6.0
23-11-88	1.0	1.2	...	...	...	...	...	...	26.0	6.0
24-11-88	1.2	0.0	...	...	...	...	...	...	34.0	6.0
25-11-88	1.4	0.0	...	...	...	...	...	...	36.0	6.0
26-11-88	1.7	0.0	...	...	...	...	...	...	37.0	6.0
27-11-88	0.0	5.6	...	...	...	...	...	...	28.0	6.0
28-11-88	0.0	2.7	5.8	100.0	2.2	91.0	525.0	182.0	40.0	6.0
29-11-88	0.0	25.0	...	...	...	...	...	...	41.0	8.0
30-11-88	0.0	4.0	...	...	...	...	...	...	41.0	8.0
01-12-88	0.0	7.3	...	...	...	...	...	...	40.0	6.0
02-12-88	0.2	1.6	...	...	...	...	...	...	34.0	6.0
03-12-88	0.0	4.2	...	...	...	...	...	...	30.0	6.0
04-12-88	0.0	6.6	...	...	...	...	...	...	33.0	6.0
05-12-88	0.0	2.4	6.3	25.0	2.5	81.0	558.0	180.0	40.0	6.0
06-12-88	0.4	0.0	...	...	...	...	...	...	38.0	5.0
07-12-88	0.6	1.5	...	...	...	...	...	...	33.0	5.0
08-12-88	0.0	7.6	...	...	...	...	...	...	43.0	5.0
09-12-88	0.0	3.8	...	...	...	...	...	...	44.0	5.0
10-12-88	0.4	0.5	...	...	...	...	...	...	46.0	5.0

Con.

Date	SMD	Rain	pH	Colour	Tur.	Mn	Fe	Al	Temp-A	Temp-W
11-12-88	0.5	0.6	...	...	...	...	...	...	45.0	5.0
12-12-88	0.8	0.9	6.8	125.0	2.0	82.0	547.0	178.0	31.0	5.0
13-12-88	0.8	0.0	...	...	...	...	...	...	34.0	5.0
14-12-88	1.1	0.6	...	...	...	...	...	...	28.0	5.0
15-12-88	0.7	0.8	...	...	...	...	...	...	30.0	5.0
16-12-88	0.9	0.2	...	...	...	...	...	...	33.0	5.0
17-12-88	1.1	1.4	...	...	...	...	...	...	38.0	5.0
18-12-88	0.0	13.2	...	...	...	...	...	...	42.0	5.0
19-12-88	0.0	7.4	5.6	85.0	1.6	79.0	554.0	186.0	46.0	3.0
20-12-88	0.0	6.6	...	...	...	...	...	...	36.0	3.0
21-12-88	0.0	7.6	...	...	...	...	...	...	46.0	3.0
22-12-88	0.0	10.7	...	...	...	...	...	...	49.0	3.0
23-12-88	0.0	5.0	...	...	...	...	...	...	48.0	3.5
24-12-88	0.0	2.8	...	...	...	...	...	...	46.0	3.5
25-12-88	0.4	0.0	...	...	...	...	...	...	42.0	3.5
26-12-88	0.0	8.7	...	...	...	...	...	...	50.0	6.5
27-12-88	0.4	0.0	...	...	...	...	...	...	45.0	6.5
28-12-88	0.8	0.0	...	...	...	...	...	...	50.0	6.5
29-12-88	0.5	0.0	...	...	...	...	...	...	46.0	7.0
30-12-88	0.9	0.0	...	...	...	...	...	...	46.0	7.0
31-12-88	1.4	0.0	...	...	...	...	...	...	41.0	6.5
01-01-89	1.6	0.0	...	...	...	...	...	...	40.0	6.5
02-01-89	1.9	0.0	...	...	...	...	...	...	42.0	6.5
03-01-89	1.9	0.0	...	...	...	...	...	...	44.0	6.5
04-01-89	0.0	4.4	...	...	...	...	...	...	40.0	6.0
05-01-89	0.0	9.4	...	...	...	...	...	...	44.0	6.0
06-01-89	0.1	0.4	...	...	...	...	...	...	43.0	6.0
07-01-89	0.0	6.0	...	...	...	...	...	...	47.0	6.0
08-01-89	0.2	0.0	...	...	...	...	...	...	47.0	6.0
09-01-89	0.0	2.0	6.1	125.0	2.9	83.0	427.0	180.0	47.0	6.0
10-01-89	0.3	0.0	...	...	...	...	...	...	41.0	6.0
11-01-89	0.0	3.1	...	...	...	...	...	...	38.0	6.0
12-01-89	0.4	0.6	...	...	...	...	...	...	44.0	6.0
13-01-89	0.0	10.6	...	...	...	...	...	...	37.0	6.0
14-01-89	0.4	0.0	...	...	...	...	...	...	42.0	6.0
15-01-89	0.8	0.0	...	...	...	...	...	...	46.0	6.0
16-01-89	1.2	6.4	5.5	70.0	2.4	77.0	476.0	207.0	40.0	6.0
17-01-89	1.6	0.0	...	...	...	...	...	...	40.0	6.0
18-01-89	2.0	0.0	...	...	...	...	...	...	40.0	6.0
19-01-89	2.4	0.0	...	...	...	...	...	...	40.0	6.0
20-01-89	0.0	4.2	...	...	...	...	...	...	38.0	6.0
21-01-89	0.0	3.2	...	...	...	...	...	...	40.0	6.0
22-01-89	0.2	0.0	...	...	...	...	...	...	42.0	5.0
23-01-89	0.0	0.0	5.8	100.0	2.8	83.0	433.0	194.0	44.0	5.5
24-01-89	0.5	0.0	...	...	...	...	...	...	46.0	5.5
25-01-89	0.0	0.0	...	...	...	...	...	...	38.0	5.5
26-01-89	0.0	0.8	...	...	...	...	...	...	42.0	5.5
27-01-89	0.0	5.4	...	...	...	...	...	...	46.0	5.5
28-01-89	0.5	0.0	...	...	...	...	...	...	40.0	5.5
29-01-89	1.1	0.0	...	...	...	...	...	...	36.0	5.5
30-01-89	1.7	0.0	5.8	125.0	1.8	77.0	435.0	193.0	41.0	4.0
31-01-89	2.3	0.0	...	...	...	...	...	...	42.0	5.0
01-02-89	2.7	0.0	...	...	...	...	...	...	41.0	5.0
02-02-89	2.9	0.0	...	...	...	...	...	...	40.0	5.0
03-02-89	3.1	0.4	...	...	...	...	...	...	42.0	5.0
04-02-89	0.0	8.1	...	...	...	...	...	...	46.0	5.0
05-02-89	0.5	0.0	...	...	...	...	...	...	42.0	5.0
06-02-89	1.0	0.0	6.6	125.0	2.9	80.0	503.0	220.0	49.0	5.0
07-02-89	1.5	0.0	...	...	...	...	...	...	49.0	5.0
08-02-89	2.0	0.0	...	...	...	...	...	...	48.0	5.0
09-02-89	2.5	0.0	...	...	...	...	...	...	42.0	5.0
10-02-89	3.0	0.0	...	...	...	...	...	...	42.0	5.0
11-02-89	0.0	4.8	...	...	...	...	...	...	36.0	5.5
12-02-89	0.0	0.0	...	...	...	...	...	...	41.0	5.5
13-02-89	0.0	6.7	5.8	85.0	2.2	179.0	820.0	194.0	40.0	6.0
14-02-89	0.0	1.8	...	...	...	...	...	...	38.0	6.0
15-02-89	0.0	10.2	...	...	...	...	...	...	44.0	6.0
16-02-89	0.0	0.0	...	...	...	...	...	...	36.0	6.0
17-02-89	0.0	31.5	...	...	...	...	...	...	34.0	5.5
18-02-89	0.0	3.2	...	...	...	...	...	...	46.0	5.5
19-02-89	0.0	0.0	...	...	...	...	...	...	44.0	5.5
20-02-89	0.8	0.0	...	...	...	...	...	...	42.0	5.5

Con.

Date	SMD	Rain	pH	Colour	Tur.	Mn	Fe	Al	Temp-A	Temp-W
21-02-89	0.0	2.4	5.9	100.0	4.0	74.0	402.0	284.0	34.0	5.0
22-02-89	0.8	0.0	...	...	...	...	...	...	39.0	5.5
23-02-89	0.0	4.0	...	...	...	...	...	...	34.0	5.0
24-02-89	0.0	24.4	...	...	...	...	...	...	38.0	5.0
25-02-89	0.9	0.0	...	...	...	...	...	...	32.0	5.0
26-02-89	0.0	2.5	...	...	...	...	...	...	30.0	5.0
27-02-89	0.8	7.0	5.9	125.0	2.9	71.0	615.0	196.0	36.0	5.0
28-02-89	1.7	16.0	...	...	...	...	...	...	38.0	5.0
01-03-89	0.9	2.4	...	...	...	...	...	...	39.0	5.0
02-03-89	0.0	6.0	...	...	...	...	...	...	38.0	5.0
03-03-89	0.6	0.0	...	...	...	...	...	...	40.0	5.0
04-03-89	0.0	9.2	...	...	...	...	...	...	44.0	5.0
05-03-89	0.8	0.0	...	...	...	...	...	...	46.0	5.0
06-03-89	0.0	3.6	5.4	150.0	5.5	73.0	347.0	194.0	40.0	5.0
07-03-89	0.8	0.0	...	...	...	...	...	...	45.0	5.0
08-03-89	0.0	2.6	...	...	...	...	...	...	40.0	5.0
09-03-89	0.0	5.2	...	...	...	...	...	...	42.0	5.0
10-03-89	0.3	0.4	...	...	...	...	...	...	42.0	5.0
11-03-89	1.2	0.0	...	...	...	...	...	...	40.0	5.0
12-03-89	0.0	10.2	...	...	...	...	...	...	40.0	5.0
13-03-89	0.0	0.5	5.7	70.0	4.0	85.0	381.0	226.0	38.0	5.0
14-03-89	0.0	10.7	...	...	...	...	...	...	40.0	5.5
15-03-89	0.6	0.8	...	...	...	...	...	...	40.0	5.5
16-03-89	1.2	1.8	...	...	...	...	...	...	36.0	5.5
17-03-89	2.2	0.0	...	...	...	...	...	...	28.0	5.5
18-03-89	0.0	11.2	...	...	...	...	...	...	32.0	5.5
19-03-89	0.0	5.4	...	...	...	...	...	...	44.0	5.0
20-03-89	0.0	14.0	6.1	50.0	2.7	74.0	355.0	188.0	40.0	5.5
21-03-89	0.0	6.0	...	...	...	...	...	...	35.0	5.5
22-03-89	0.0	9.0	...	...	...	...	...	...	44.0	5.5
23-03-89	0.0	26.4	...	...	...	...	...	...	34.0	5.5
24-03-89	1.2	0.0	...	...	...	...	...	...	40.0	5.5
25-03-89	2.2	1.0	...	...	...	...	...	...	38.0	5.5
26-03-89	3.5	0.0	...	...	...	...	...	...	43.0	5.5
27-03-89	0.4	3.6	...	...	...	...	...	...	48.0	5.5
28-03-89	1.7	0.0	3.2	70.0	4.5	63.0	334.0	202.0	50.0	5.5
29-03-89	3.1	0.0	...	...	...	...	...	...	36.0	5.5
30-03-89	4.4	5.5	...	...	...	...	...	...	46.0	5.5
31-03-89	5.8	0.0	...	...	...	...	...	...	46.0	5.5
01-04-89	5.5	3.4	...	...	...	...	...	...	46.0	5.5
02-04-89	0.0	13.6	...	...	...	...	...	...	38.0	5.5
03-04-89	0.0	1.4	6.9	85.0	5.8	77.0	335.0	218.0	31.0	5.0
04-04-89	0.0	17.4	...	...	...	...	...	...	28.0	5.0
05-04-89	0.0	8.8	...	...	...	...	...	...	31.0	5.0
06-04-89	0.0	12.2	...	...	...	...	...	...	35.0	5.0
07-04-89	0.0	9.1	...	...	...	...	...	...	38.0	6.0
08-04-89	1.1	0.0	...	...	...	...	...	...	39.0	6.0
09-04-89	0.0	9.0	...	...	...	...	...	...	36.0	5.0
10-04-89	0.0	3.0	7.2	100.0	5.3	69.0	317.0	208.0	44.0	5.5
11-04-89	0.0	5.0	...	...	...	...	...	...	44.0	5.5
12-04-89	0.0	3.2	...	...	...	...	...	...	42.0	5.5
13-04-89	0.0	5.4	...	...	...	...	...	...	42.0	5.5
14-04-89	1.2	0.0	...	...	...	...	...	...	42.0	5.5
15-04-89	2.5	0.0	...	...	...	...	...	...	42.0	5.5
16-04-89	3.7	0.0	...	...	...	...	...	...	40.0	5.5
17-04-89	5.0	0.0	6.0	100.0	5.4	82.0	325.0	...	40.0	6.0
18-04-89	6.3	0.0	...	...	...	...	...	...	36.0	6.0
19-04-89	7.7	0.0	...	...	...	...	...	...	36.0	6.0
20-04-89	8.8	0.0	...	...	...	...	...	...	41.0	6.0
21-04-89	10.1	0.0	...	...	...	...	...	...	39.0	6.0
22-04-89	0.0	12.5	...	...	...	...	...	...	40.0	6.0
23-04-89	0.0	2.0	...	...	...	...	...	...	39.0	6.0
24-04-89	1.4	0.0	6.4	100.0	3.6	72.0	421.0	...	33.0	6.5
25-04-89	2.9	0.0	...	...	...	...	...	...	35.0	6.5
26-04-89	0.0	2.2	...	...	...	...	...	...	32.0	6.0
27-04-89	0.9	0.0	...	...	...	...	...	...	33.0	6.0
28-04-89	0.0	0.0	...	...	...	...	...	...	35.0	6.0
29-04-89	1.6	5.8	...	...	...	...	...	...	40.0	6.0
30-04-89	3.1	0.0	...	...	...	...	...	...	42.0	6.0
01-05-89	5.2	0.0	...	...	...	...	...	...	51.0	7.0
02-05-89	7.3	0.0	5.6	50.0	4.6	74.0	326.0	208.0	48.0	7.5
03-05-89	9.4	0.0	...	...	...	...	...	...	52.0	7.5

Con.

Date	SMD	Rain	pH	Colour	Tur.	Mn	Fe	Al	Temp-A	Temp-W
04-05-89	11.6	0.0	...	...	...	...	...	...	55.0	8.0
05-05-89	13.8	0.0	...	...	...	...	...	...	54.0	8.5
06-05-89	16.0	0.0	...	...	...	...	...	...	46.0	7.5
07-05-89	18.2	0.0	...	...	...	...	...	...	48.0	7.5
08-05-89	20.5	0.0	7.1	85.0	3.7	81.0	306.0	-1.0	48.0	8.0
09-05-89	22.8	0.0	...	...	...	...	...	...	48.0	8.0
10-05-89	23.6	0.0	...	...	...	...	...	...	44.0	8.0
11-05-89	16.4	8.4	...	...	...	...	...	...	49.0	8.0
12-05-89	16.8	5.4	...	...	...	...	...	...	40.0	8.0
13-05-89	19.2	0.2	...	...	...	...	...	...	43.0	9.0
14-05-89	21.7	0.0	...	...	...	...	...	...	49.0	9.0
15-05-89	22.7	3.5	7.2	70.0	3.3	82.0	428.0	187.0	50.0	9.0
16-05-89	25.1	0.0	...	...	...	...	...	...	46.0	9.0
17-05-89	27.2	1.2	...	...	...	...	...	...	48.0	9.0
18-05-89	29.6	0.0	...	...	...	...	...	...	58.0	9.0
19-05-89	31.6	0.0	...	...	...	...	...	...	54.0	9.5
20-05-89	34.2	0.0	...	...	...	...	...	...	52.0	10.0
21-05-89	36.8	0.0	...	...	...	...	...	...	50.0	11.0
22-05-89	36.7	0.0	...	...	...	...	...	176.0	53.0	12.0
23-05-89	39.3	0.0	...	...	...	...	...	...	56.0	12.0
24-05-89	33.3	21.2	...	...	...	...	...	...	63.0	12.0
25-05-89	35.9	0.0	...	...	...	...	...	...	50.0	12.0
26-05-89	38.6	0.0	...	...	...	...	...	...	47.0	12.0
27-05-89	41.3	0.0	...	...	...	...	...	...	48.0	12.5
28-05-89	44.0	0.0	...	...	...	...	...	...	48.0	12.0
29-05-89	46.8	0.0	...	...	...	...	...	...	50.0	12.0
30-05-89	49.5	0.7	...	...	...	...	...	169.0	42.0	13.0
31-05-89	47.1	7.4	...	...	...	...	...	...	44.0	13.0
01-06-89	49.7	0.0	...	...	...	...	...	...	40.0	12.5
02-06-89	48.3	3.4	...	...	...	...	...	...	42.0	12.5
03-06-89	50.8	0.0	...	...	...	...	...	...	42.0	12.5
04-06-89	53.4	0.0	...	...	...	...	...	...	42.0	12.5
05-06-89	41.7	4.8	5.5	50.0	2.6	206.0	198.2	30.0	49.0	12.5
06-06-89	42.1	1.9	...	...	...	...	...	...	46.0	12.5
07-06-89	44.1	5.1	...	...	...	...	...	...	46.0	12.5
08-06-89	46.6	1.4	...	...	...	...	...	...	46.0	12.5
09-06-89	48.5	0.7	...	...	...	...	...	...	48.0	12.5
10-06-89	51.2	0.0	...	...	...	...	...	...	50.0	12.5
11-06-89	53.9	0.6	...	...	...	...	...	...	54.0	12.5
12-06-89	56.5	0.0	7.3	70.0	2.7	67.0	350.0	123.0	52.0	12.5
13-06-89	57.2	8.0	...	...	...	...	...	...	57.0	12.5
14-06-89	59.8	0.0	...	...	...	...	...	...	58.0	12.5
15-06-89	62.5	0.0	...	...	...	...	...	...	58.0	12.5
16-06-89	65.3	0.0	...	...	...	...	...	...	60.0	12.5
17-06-89	68.0	0.0	...	...	...	...	...	...	64.0	12.5
18-06-89	70.7	0.0	...	...	...	...	...	...	67.0	12.5
19-06-89	73.4	0.0	7.5	70.0	2.5	77.0	513.0	133.0	60.0	14.5
20-06-89	76.2	0.0	...	...	...	...	...	...	66.0	14.5
21-06-89	78.4	0.0	...	...	...	...	...	...	58.0	14.5
22-06-89	80.5	0.0	...	...	...	...	...	...	53.0	14.5
23-06-89	82.4	0.0	...	...	...	...	...	...	59.0	14.5
24-06-89	84.3	0.0	...	...	...	...	...	...	54.0	14.0
25-06-89	86.1	0.0	...	...	...	...	...	...	56.0	14.5
26-06-89	82.1	8.8	6.7	50.0	2.0	73.0	473.0	136.0	60.0	15.0
27-06-89	74.0	9.6	...	...	...	...	...	...	67.0	15.0
28-06-89	66.2	11.5	...	...	...	...	...	...	60.0	15.0
29-06-89	68.9	0.0	...	...	...	...	...	...	67.0	15.0
30-06-89	40.1	34.8	...	...	...	...	...	...	49.0	15.0
01-07-89	41.1	2.8	...	...	...	...	...	...	60.0	15.0
02-07-89	44.1	0.0	...	...	...	...	...	...	57.0	15.0
03-07-89	47.0	0.0	6.3	70.0	2.1	92.0	634.0	148.0	54.0	15.0
04-07-89	49.9	0.0	...	...	...	...	...	...	50.0	15.0
05-07-89	52.8	0.0	...	...	...	...	...	...	49.0	14.0
06-07-89	53.9	2.9	...	...	...	...	...	...	52.0	14.0
07-07-89	45.9	8.2	...	...	...	...	...	...	58.0	14.0
08-07-89	44.8	7.2	...	...	...	...	...	...	56.0	14.0
09-07-89	47.7	0.0	...	...	...	...	...	...	54.0	14.0
10-07-89	49.8	0.6	7.4	70.0	5.0	88.0	652.0	129.0	50.0	14.0
11-07-89	52.7	0.0	...	...	...	...	...	...	54.0	14.0
12-07-89	55.5	0.0	...	...	...	...	...	...	57.0	14.0
13-07-89	58.4	0.0	...	...	...	...	...	...	56.0	15.0
14-07-89	61.2	0.0	...	...	...	...	...	...	50.0	15.0

Con.



Date	SMD	Rain	pH	Colour	Tur.	Mn	Fe	Al	Temp-A	Temp-W
15-07-89	64.0	0.0	...	...	...	...	...	...	56.0	15.5
16-07-89	66.8	0.0	...	...	...	...	...	...	60.0	15.5
17-07-89	69.6	0.0	7.0	70.0	2.5	68.0	888.0	147.0	60.0	17.0
18-07-89	72.4	0.0	...	...	...	...	...	...	60.0	17.0
19-07-89	75.1	0.0	...	...	...	...	...	...	63.0	17.0
20-07-89	77.9	0.0	...	...	...	...	...	...	64.0	17.0
21-07-89	80.6	0.0	...	...	...	...	...	...	69.0	17.0
22-07-89	83.1	0.0	...	...	...	...	...	...	68.0	17.0
23-07-89	85.8	0.0	...	...	...	...	...	...	66.0	17.0
24-07-89	87.6	0.0	5.9	70.0	2.2	82.0	638.0	142.0	64.0	17.0
25-07-89	89.0	2.4	...	...	...	...	...	...	66.0	17.0
26-07-89	90.6	0.0	...	...	...	...	...	...	62.0	17.0
27-07-89	92.1	0.0	...	...	...	...	...	...	60.0	17.0
28-07-89	93.5	1.2	...	...	...	...	...	...	60.0	17.0
29-07-89	91.8	16.5	...	...	...	...	...	...	55.0	17.0
30-07-89	90.9	1.0	...	...	...	...	...	...	58.0	17.0
31-07-89	91.5	4.4	5.8	50.0	2.6	87.0	909.0	136.0	50.0	17.0
01-08-89	93.9	0.0	...	...	...	...	...	...	48.0	16.5
02-08-89	95.2	1.8	...	...	...	...	...	...	54.0	16.5
03-08-89	96.6	0.0	...	...	...	...	...	...	58.0	16.5
04-08-89	97.9	0.0	...	...	...	...	...	...	50.0	16.5
05-08-89	99.0	0.0	...	...	...	...	...	...	54.0	16.0
06-08-89	100.2	0.0	...	...	...	...	...	...	63.0	17.0
07-08-89	101.2	0.0	7.8	85.0	2.4	58.0	645.0	162.0	60.0	16.0
08-08-89	102.2	0.0	...	...	...	...	...	...	56.0	16.5
09-08-89	99.9	3.9	...	...	...	...	...	...	62.0	16.5
10-08-89	95.9	8.3	...	...	...	...	...	...	55.0	16.5
11-08-89	96.6	2.1	...	...	...	...	...	...	57.0	17.0
12-08-89	99.0	0.0	...	...	...	...	...	...	56.0	16.5
13-08-89	99.3	2.2	...	...	...	...	...	...	54.0	16.5
14-08-89	95.0	4.6	7.3	...	...	66.0	746.0	...	56.0	16.0
15-08-89	96.8	3.6	...	...	...	...	...	...	56.0	16.0
16-08-89	98.0	0.8	...	...	...	...	...	...	52.0	16.0
17-08-89	99.2	0.0	...	...	...	...	...	...	56.0	16.0
18-08-89	96.9	0.0	...	...	...	...	...	...	56.0	16.0
19-08-89	99.3	0.0	...	...	...	...	...	...	54.0	16.0
20-08-89	101.2	0.0	...	...	...	...	...	...	54.0	16.0
21-08-89	102.8	0.9	...	...	...	...	...	...	54.0	16.0
22-08-89	103.6	0.8	...	...	...	...	...	...	59.0	16.0
23-08-89	104.5	0.0	...	...	...	...	...	...	59.0	16.0
24-08-89	103.2	2.6	...	...	...	...	...	...	54.0	16.0
25-08-89	99.9	7.3	...	...	...	...	...	...	54.0	16.0
26-08-89	97.7	7.0	...	...	...	...	...	...	54.0	16.0
27-08-89	99.7	0.2	...	...	...	...	...	...	54.0	16.0
28-08-89	101.6	0.7	...	...	...	...	...	...	54.0	16.0
29-08-89	103.3	0.5	...	...	...	...	...	...	59.0	15.0
30-08-89	100.7	9.0	...	...	...	...	...	...	59.0	15.0
31-08-89	102.5	0.0	...	...	...	...	...	...	48.0	15.0
01-09-89	103.6	0.9	...	...	...	...	...	...	50.0	15.0
02-09-89	104.9	0.0	...	...	...	...	...	...	48.0	15.0
03-09-89	105.7	0.0	...	...	...	...	...	...	48.0	13.0
04-09-89	106.4	0.0	6.5	85.0	3.8	69.0	976.0	123.0	54.0	14.5
05-09-89	107.2	0.0	...	...	...	...	...	...	54.0	14.5
06-09-89	107.9	0.0	...	...	...	...	...	...	52.0	14.5
07-09-89	108.7	0.0	...	...	...	...	...	...	52.0	14.5
08-09-89	109.4	0.0	...	...	...	...	...	...	52.0	14.5
09-09-89	110.1	0.0	...	...	...	...	...	...	52.0	14.0
10-09-89	110.7	2.8	...	...	...	...	...	...	52.0	14.0
11-09-89	111.4	1.7	...	...	...	...	...	...	49.0	13.5
12-09-89	112.0	0.0	...	...	...	...	...	...	52.0	14.0
13-09-89	108.7	4.0	...	...	...	...	...	...	52.0	14.0
14-09-89	109.2	0.5	...	...	...	...	...	...	49.0	13.5
15-09-89	109.0	1.7	...	...	...	...	...	...	48.0	13.5
16-09-89	102.3	10.6	...	...	...	...	...	...	49.0	13.5
17-09-89	102.6	0.0	...	...	...	...	...	...	48.0	13.5
18-09-89	102.9	0.0	...	...	...	...	...	...	49.0	13.5
19-09-89	104.2	0.0	...	...	...	...	...	...	52.0	13.5
20-09-89	105.4	0.0	...	...	...	...	...	...	53.0	13.5
21-09-89	106.0	0.0	...	...	...	...	...	...	48.0	13.5
22-09-89	107.2	5.3	...	...	...	...	...	...	53.0	13.5
23-09-89	108.4	0.0	...	...	...	...	...	...	49.0	13.5
24-09-89	109.6	0.0	...	...	...	...	...	...	48.0	13.5

Con.

Date	SMD	Rain	pH	Colour	Tur.	Mn	Fe	Al	Temp-A	Temp-W
25-09-89	110.2	0.0	6.2	125.0	3.3	75.0	1275.0	158.0	52.0	14.0
26-09-89	110.0	0.8	...	...	...	...	...	...	59.0	14.0
27-09-89	111.1	0.0	...	...	...	...	...	...	54.0	14.0
28-09-89	112.1	0.0	...	...	...	...	...	...	47.0	14.0
29-09-89	112.5	0.0	...	...	...	...	...	...	46.0	14.0
30-09-89	112.9	0.0	...	...	...	...	...	...	44.0	14.0
01-10-89	113.6	0.0	...	...	...	...	...	...	50.0	14.0
02-10-89	114.1	0.0	6.9	100.0	2.6	78.0	1450.0	30.0	49.0	13.0
03-10-89	114.7	0.0	...	...	...	...	...	...	43.0	13.0
04-10-89	115.3	0.0	...	...	...	...	...	...	50.0	15.0
05-10-89	113.0	3.2	...	...	...	...	...	...	50.0	13.0
06-10-89	104.9	8.4	...	...	...	...	...	...	47.0	13.0
07-10-89	98.2	6.3	...	...	...	...	...	...	48.0	13.0
08-10-89	98.4	0.8	...	...	...	...	...	...	44.0	13.0
09-10-89	99.5	0.0	8.0	125.0	3.6	80.0	1680.0	...	49.0	12.5
10-10-89	98.3	1.3	...	...	...	...	...	...	46.0	12.5
11-10-89	97.6	0.6	...	...	...	...	...	...	49.0	12.5
12-10-89	88.7	10.8	...	...	...	...	...	...	52.0	12.5
13-10-89	83.7	9.6	...	...	...	...	...	...	48.0	12.5
14-10-89	83.6	0.6	...	...	...	...	...	...	50.0	12.0
15-10-89	84.3	0.8	...	...	...	...	...	...	49.0	12.0
16-10-89	85.3	0.0	7.3	100.0	6.3	90.0	1760.0	164.0	50.0	12.0
17-10-89	86.2	0.0	...	...	...	...	...	...	52.0	12.0
18-10-89	87.0	0.0	...	...	...	...	...	...	45.0	12.0
19-10-89	69.7	19.0	...	...	...	...	...	...	48.0	12.0
20-10-89	60.1	5.8	...	...	...	...	...	...	50.0	12.0
21-10-89	55.3	5.0	...	...	...	...	...	...	50.0	12.0
22-10-89	49.3	6.4	...	...	...	...	...	...	49.0	12.0
23-10-89	48.6	0.0	6.3	125.0	6.3	107.0	1410.0	170.0	48.0	12.0
24-10-89	46.9	4.3	...	...	...	...	...	...	44.0	11.0
25-10-89	42.7	5.6	...	...	...	...	...	...	49.0	11.0
26-10-89	39.6	4.0	...	...	...	...	...	...	48.0	11.0
27-10-89	35.4	2.5	...	...	...	...	...	...	52.0	11.0
28-10-89	18.5	34.3	...	...	...	...	...	...	52.0	11.0
29-10-89	15.3	14.2	...	...	...	...	...	...	49.0	10.5
30-10-89	14.8	1.0	6.8	...	...	107.0	1375.0	181.0	49.0	10.5
31-10-89	15.1	0.0	...	...	...	...	...	...	49.0	10.5
01-11-89	12.8	3.0	...	...	...	...	...	...	46.0	10.5
02-11-89	11.8	2.6	...	...	...	...	...	...	48.0	10.0
03-11-89	10.6	17.2	...	...	...	...	...	...	44.0	10.0
04-11-89	6.8	25.0	...	...	...	...	...	...	42.0	10.0
05-11-89	7.3	0.0	...	...	...	...	...	...	45.0	10.0
06-11-89	6.4	2.8	...	...	...	...	...	...	45.0	10.0
07-11-89	5.5	2.0	...	...	...	...	...	...	48.0	10.0
08-11-89	0.0	18.2	...	...	...	...	...	...	45.0	10.0
09-11-89	0.0	4.8	...	...	...	...	...	...	42.0	10.0
10-11-89	0.0	10.8	...	...	...	...	...	...	46.0	10.0
11-11-89	0.0	1.4	...	...	...	...	...	...	47.0	10.0
12-11-89	0.4	0.0	...	...	...	...	...	...	50.0	9.0
13-11-89	0.7	0.0	8.0	100.0	7.6	117.0	1390.0	222.0	44.0	8.5
14-11-89	1.1	0.0	...	...	...	...	...	...	45.0	8.5
15-11-89	1.4	0.0	...	...	...	...	...	...	42.0	8.5
16-11-89	1.8	0.0	...	...	...	...	...	...	40.0	8.5
17-11-89	1.0	0.0	...	...	...	...	...	...	39.0	8.5
18-11-89	1.3	0.0	...	...	...	...	...	...	42.0	8.5
19-11-89	1.6	0.0	...	...	...	...	...	...	42.0	8.5
20-11-89	1.8	0.0	7.1	150.0	7.1	121.0	1010.0	252.0	42.0	8.5
21-11-89	2.1	0.0	...	...	...	...	...	...	46.0	8.5
22-11-89	2.0	0.0	...	...	...	...	...	...	38.0	8.0
23-11-89	2.2	0.0	...	...	...	...	...	...	31.0	8.0
24-11-89	2.5	0.0	...	...	...	...	...	...	28.0	8.0
25-11-89	2.7	0.0	...	...	...	...	...	...	32.0	7.0
26-11-89	3.0	0.0	...	...	...	...	...	...	34.0	7.0
27-11-89	3.2	0.0	6.9	100.0	6.3	115.0	840.0	262.0	29.0	7.0
28-11-89	3.4	0.0	...	...	...	...	...	...	34.0	7.0
29-11-89	3.6	0.0	...	...	...	...	...	...	34.0	7.0
30-11-89	3.8	0.0	...	...	...	...	...	...	36.0	7.0
01-12-89	4.2	0.0	...	...	...	...	...	...	37.0	7.0
02-12-89	4.5	0.0	...	...	...	...	...	...	30.0	7.0
03-12-89	4.8	0.0	...	...	...	...	...	...	26.0	6.0
04-12-89	5.0	0.9	5.4	100.0	6.2	131.0	1310.0	264.0	34.0	5.5
05-12-89	5.2	0.5	...	...	...	...	...	...	42.0	5.5

Con.

Date	SMD	Rain	pH	Colour	Tur.	Mn	Fe	Al	Temp-A	Temp-W
06-12-89	5.4	0.0	...	...	...	...	...	...	42.0	5.5
07-12-89	5.7	0.0	...	...	...	...	...	...	40.0	5.5
08-12-89	5.9	0.0	...	...	...	...	...	...	37.0	5.5
09-12-89	6.2	0.0	...	...	...	...	...	...	36.0	5.0
10-12-89	6.5	0.0	...	...	...	...	...	...	38.0	5.0
11-12-89	2.8	2.8	4.5	125.0	6.3	246.0	1340.0	259.0	40.0	5.0
12-12-89	0.0	0.9	...	...	...	...	...	...	34.0	5.0
13-12-89	0.0	16.6	...	...	...	...	...	...	34.0	5.0
14-12-89	0.0	30.0	...	...	...	...	...	...	32.0	5.0
15-12-89	0.0	4.1	...	...	...	...	...	...	34.0	4.5
16-12-89	0.0	1.0	...	...	...	...	...	...	35.0	4.5
17-12-89	0.0	1.9	...	...	...	...	...	...	40.0	4.5
18-12-89	0.0	10.2	6.5	...	6.8	119.0	720.0	297.0	40.0	4.5
19-12-89	0.0	3.8	...	...	...	...	...	...	35.0	4.5
20-12-89	0.0	17.2	...	...	...	...	...	...	41.0	4.5
21-12-89	0.0	22.7	...	...	...	...	...	...	44.0	4.5
22-12-89	0.3	0.0	...	...	...	...	...	...	42.0	4.5
23-12-89	0.0	3.8	...	...	...	...	...	...	40.0	4.5
24-12-89	0.0	6.3	...	...	...	...	...	...	44.0	4.5
25-12-89	0.0	0.0	...	...	...	...	...	...	45.0	4.5
26-12-89	0.3	0.0	...	...	...	...	...	...	44.0	4.5
27-12-89	0.6	0.0	...	...	...	...	...	...	42.0	4.5
28-12-89	0.9	0.0	...	...	...	...	...	...	40.0	4.5
29-12-89	1.2	0.0	...	...	...	...	...	...	38.0	4.5
30-12-89	1.5	0.0	...	...	...	...	...	...	34.0	4.5
31-12-89	1.8	0.0	...	...	...	...	...	...	34.0	4.5

In 1990 the method of colour measurement was changed from apparent to true. ( T ) = True Colour.

Date	SMD	Rain	pH	T-Colour	Tur.	Mn	Fe	Al	Temp-A	Temp-W
01-01-90	0.0	5.2	...	...	...	...	...	...	38.0	4.5
02-01-90	0.0	4.4	...	...	5.6	113.0	632.0	227.0	42.0	4.5
03-01-90	0.3	0.0	...	...	...	...	...	...	38.0	4.5
04-01-90	0.7	0.0	...	...	...	...	...	...	43.0	4.5
05-01-90	0.0	1.4	...	...	...	...	...	...	48.0	4.5
06-01-90	0.0	5.0	...	...	...	...	...	...	34.0	4.5
07-01-90	0.0	5.0	...	...	...	...	...	...	40.0	4.5
08-01-90	0.1	0.0	...	...	4.3	107.0	765.0	280.0	44.0	4.5
09-01-90	0.5	0.0	...	...	...	...	...	...	46.0	4.5
10-01-90	0.0	7.8	...	...	...	...	...	...	45.0	4.5
11-01-90	0.4	0.0	...	...	...	...	...	...	44.0	4.5
12-01-90	0.0	2.6	...	...	...	...	...	...	40.0	5.0
13-01-90	0.0	4.0	...	...	...	...	...	...	40.0	5.0
14-01-90	0.0	8.2	...	...	...	...	...	...	48.0	5.0
15-01-90	0.0	4.6	...	...	3.7	124.0	480.0	240.0	50.0	5.0
16-01-90	0.0	8.6	...	...	...	...	...	...	42.0	4.5
17-01-90	0.5	0.0	...	...	...	...	...	...	40.0	4.5
18-01-90	0.0	0.5	...	...	...	...	...	...	42.0	4.5
19-01-90	0.0	2.2	...	...	...	...	...	...	40.0	4.5
20-01-90	0.0	3.1	...	...	...	...	...	...	43.0	4.5
21-01-90	0.0	4.6	...	...	2.4	100.0	389.0	343.0	47.0	6.0
22-01-90	0.0	9.0	...	...	...	...	...	...	46.0	6.0
23-01-90	0.0	1.6	...	...	...	...	...	...	39.0	6.0
24-01-90	0.0	16.2	...	...	...	...	...	...	46.0	6.0
25-01-90	0.0	13.5	...	...	...	...	...	...	37.0	6.0
26-01-90	0.6	0.0	...	...	...	...	...	...	34.0	6.0
27-01-90	0.0	30.4	...	...	...	...	...	...	33.0	5.0
28-01-90	0.0	4.6	...	...	...	...	...	...	38.0	6.0
29-01-90	0.0	1.3	...	...	4.7	110.0	403.0	325.0	42.0	6.0
30-01-90	0.0	3.8	...	...	...	...	...	...	42.0	6.0
31-01-90	0.0	0.0	...	...	...	...	...	...	40.0	6.0
01-02-90	0.0	3.2	...	...	...	...	...	...	40.0	6.0
02-02-90	0.0	1.2	...	...	...	...	...	...	40.0	5.5
03-02-90	0.0	0.0	...	...	...	...	...	...	42.0	5.5
04-02-90	0.5	0.0	...	...	...	...	...	...	48.0	5.0
05-02-90	1.1	0.0	...	...	...	97.0	373.0	269.0	49.0	5.0
06-02-90	0.0	7.9	...	...	...	...	...	...	48.0	5.0
07-02-90	0.0	23.8	...	...	...	...	...	...	40.0	5.0
08-02-90	0.4	0.6	...	...	...	...	...	...	41.0	5.0
09-02-90	0.0	1.0	...	...	...	...	...	...	40.0	5.5
10-02-90	0.0	4.1	...	...	...	...	...	...	38.0	5.5
11-02-90	0.0	4.0	...	...	...	...	...	...	38.0	5.5
12-02-90	0.0	2.2	...	...	4.8	102.0	397.0	626.0	38.0	5.5
13-02-90	0.0	6.4	...	...	...	...	...	...	30.0	5.5
14-02-90	0.0	9.6	...	...	...	...	...	...	34.0	5.5
15-02-90	0.0	1.0	...	...	...	...	...	...	32.0	5.5
16-02-90	0.1	2.0	...	...	...	...	...	...	39.0	5.5
17-02-90	0.0	4.2	...	...	...	...	...	...	40.0	5.5
18-02-90	0.8	0.5	...	...	...	...	...	...	46.0	5.0
19-02-90	0.0	2.0	...	...	4.1	92.0	336.0	23.0	50.0	5.0
20-02-90	0.0	5.0	...	...	...	...	...	...	42.0	5.5
21-02-90	0.9	0.0	...	...	...	...	...	...	46.0	5.5
22-02-90	1.9	0.0	...	...	...	...	...	...	49.0	6.0
23-02-90	2.8	0.0	...	...	...	...	...	...	52.0	6.0
24-02-90	1.4	2.7	...	...	...	...	...	...	42.0	6.0
25-02-90	0.0	8.3	...	...	...	...	...	...	46.0	6.0
26-02-90	0.0	4.2	...	...	...	...	...	...	33.0	6.0
27-02-90	0.0	3.4	...	...	...	...	...	...	36.0	6.0
28-02-90	0.0	10.0	...	...	...	...	...	...	33.0	6.0
01-03-90	0.0	4.9	...	...	...	...	...	...	36.0	6.0
02-03-90	0.0	0.6	...	...	...	...	...	...	36.0	5.0
03-03-90	0.0	3.2	...	...	...	...	...	...	40.0	5.0
04-03-90	0.0	3.8	...	...	...	...	...	...	43.0	5.0
05-03-90	0.8	4.0	...	133.0	...	95.0	387.0	235.0	46.0	5.0
06-03-90	1.2	2.9	...	...	...	...	...	...	46.0	4.5
07-03-90	2.2	0.0	...	...	...	...	...	...	39.0	4.5
08-03-90	2.9	0.7	...	...	...	...	...	...	40.0	4.0
09-03-90	1.2	4.0	...	...	...	...	...	...	42.0	4.0
10-03-90	2.3	0.0	...	...	...	...	...	...	46.0	4.5
11-03-90	3.4	0.0	...	...	...	...	...	...	42.0	6.0
12-03-90	1.7	1.6	...	1.2	1.0	121.0	421.0	198.0	43.0	6.0

Con.

Date	SMD	Rain	pH	T-Colour	Tur.	Mn	Fe	Al	Temp-A	Temp-W
13-03-90	0.0	3.2	...	...	...	...	...	...	44.0	6.0
14-03-90	1.2	0.0	...	...	...	...	...	...	46.0	6.0
15-03-90	2.4	0.0	...	...	...	...	...	...	47.0	6.5
16-03-90	3.6	0.0	...	...	...	...	...	...	50.0	6.5
17-03-90	4.8	0.0	...	...	...	...	...	...	54.0	6.5
18-03-90	4.2	0.0	...	...	...	...	...	...	44.0	6.5
19-03-90	4.4	0.0	...	...	...	...	...	...	42.0	6.5
20-03-90	5.7	0.0	...	...	...	...	...	...	42.0	6.5
21-03-90	7.1	0.0	...	...	...	...	...	...	44.0	6.5
22-03-90	8.5	0.0	...	...	...	...	...	...	43.0	6.5
23-03-90	0.0	12.6	...	...	...	...	...	...	42.0	6.5
24-03-90	0.0	2.2	...	...	...	...	...	...	41.0	6.5
25-03-90	1.5	0.0	...	...	...	...	...	...	30.0	7.0
26-03-90	3.0	0.0	...	...	...	...	...	...	34.0	7.0
27-03-90	4.6	0.8	...	...	...	...	...	...	39.0	7.0
28-03-90	6.2	0.0	...	...	...	...	...	...	40.0	7.0
29-03-90	7.7	0.8	...	...	...	...	...	...	44.0	7.0
30-03-90	9.4	0.0	...	...	...	...	...	...	48.0	7.0
31-03-90	11.1	0.0	...	...	...	...	...	...	46.0	7.5
01-04-90	11.7	1.3	...	...	...	...	...	...	52.0	7.5
02-04-90	9.9	3.5	...	...	...	...	...	...	38.0	7.5
03-04-90	8.2	2.5	...	...	...	...	...	...	42.0	7.5
04-04-90	9.5	0.0	...	...	...	...	...	...	32.0	7.5
05-04-90	10.8	1.1	6.7	23.4	1.5	94.0	334.0	236.0	36.0	7.5
06-04-90	12.2	0.0	...	...	...	...	...	...	40.0	7.5
07-04-90	13.6	0.0	...	...	...	...	...	...	34.0	7.5
08-04-90	15.1	0.0	...	...	...	...	...	...	32.0	7.0
09-04-90	16.1	2.1	...	...	...	...	...	...	44.0	7.0
10-04-90	16.6	1.8	...	...	...	...	...	...	41.0	7.0
11-04-90	17.8	0.0	...	...	...	...	...	...	46.0	7.0
12-04-90	19.1	0.0	...	...	...	...	...	...	42.0	7.0
13-04-90	20.7	1.1	...	...	...	...	...	...	38.0	7.0
14-04-90	17.3	11.1	...	...	...	...	...	...	38.0	7.0
15-04-90	17.3	3.4	...	...	...	...	...	...	40.0	7.0
16-04-90	17.1	6.6	...	...	...	...	...	...	38.0	7.0
17-04-90	15.0	9.4	...	...	...	...	...	...	37.0	7.0
18-04-90	11.0	8.1	...	...	...	...	...	...	40.0	7.0
19-04-90	3.4	17.2	7.2	25.2	5.3	86.0	706.0	221.0	48.0	7.0
20-04-90	4.3	3.8	...	...	...	...	...	...	40.0	7.0
21-04-90	6.1	0.1	...	...	...	...	...	...	40.0	7.0
22-04-90	7.9	0.0	...	...	...	...	...	...	40.0	7.0
23-04-90	9.8	0.0	...	...	...	...	...	...	48.0	7.5
24-04-90	11.7	0.0	...	...	...	...	...	...	46.0	7.5
25-04-90	11.9	2.1	...	...	...	...	...	...	52.0	7.5
26-04-90	8.0	14.6	7.3	22.7	2.4	95.0	602.0	237.0	40.0	7.0
27-04-90	10.0	0.0	...	...	...	...	...	...	38.0	7.0
28-04-90	12.0	0.0	...	...	...	...	...	...	51.0	7.0
29-04-90	14.0	0.0	...	...	...	...	...	...	51.0	10.0
30-04-90	16.1	0.0	...	...	...	...	...	...	56.0	10.0
01-05-90	18.1	0.0	...	...	...	...	...	...	49.0	10.0
02-05-90	20.2	0.0	...	...	...	...	...	...	54.0	10.0
03-05-90	22.2	0.0	6.4	10.6	2.8	84.0	340.0	157.0	60.0	10.0
04-05-90	24.3	0.0	...	...	...	...	...	...	62.0	10.0
05-05-90	26.5	0.0	...	...	...	...	...	...	52.0	10.0
06-05-90	28.6	0.0	...	...	...	...	...	...	49.0	10.0
07-05-90	27.3	7.8	...	...	...	...	...	...	48.0	10.0
08-05-90	26.3	4.8	...	...	...	...	...	...	48.0	10.0
09-05-90	15.6	4.5	...	...	...	...	...	...	48.0	10.0
10-05-90	17.2	1.0	6.8	16.2	2.1	88.0	364.0	228.0	46.0	10.0
11-05-90	19.4	0.0	...	...	...	...	...	...	45.0	10.0
12-05-90	21.7	0.0	...	...	...	...	...	...	45.0	10.0
13-05-90	24.1	0.0	...	...	...	...	...	...	48.0	11.0
14-05-90	23.7	4.0	...	...	...	...	...	...	50.0	11.0
15-05-90	15.8	8.4	...	...	...	...	...	...	52.0	11.0
16-05-90	17.9	0.7	...	...	...	...	...	...	54.0	11.0
17-05-90	20.3	0.0	6.3	17.0	2.0	91.0	815.0	...	44.0	11.0
18-05-90	22.8	0.0	...	...	...	...	...	...	49.0	11.0
19-05-90	25.3	0.0	...	...	...	...	...	...	43.0	11.0
20-05-90	27.7	0.0	...	...	...	...	...	...	45.0	11.0
21-05-90	30.3	0.0	...	...	...	...	...	...	48.0	11.0
22-05-90	32.8	0.0	...	...	...	...	...	...	48.0	11.0
23-05-90	35.3	0.0	...	...	...	...	...	...	47.0	11.0
24-05-90	37.9	0.0	6.0	17.0	1.8	93.0	1910.0	160.0	45.0	11.0

Con.

Date	SMD	Rain	pH	T-Colour	Tur.	Mn	Fe	Al	Temp-A	Temp-W
25-05-90	40.5	0.0	...	...	...	...	...	...	47.0	11.0
26-05-90	43.1	0.0	...	...	...	...	...	...	50.0	11.0
27-05-90	45.8	0.0	...	...	...	...	...	...	57.0	12.0
28-05-90	48.3	0.0	...	...	...	...	...	...	56.0	12.0
29-05-90	49.7	3.5	...	...	...	...	...	...	59.0	12.0
30-05-90	51.8	0.0	...	...	...	...	...	...	56.0	13.0
31-05-90	54.5	0.0	...	...	...	...	...	...	60.0	13.0
01-06-90	51.4	8.6	...	...	...	...	...	...	52.0	13.0
02-06-90	50.9	6.2	...	...	...	...	...	...	52.0	13.0
03-06-90	40.7	10.5	...	...	...	...	...	...	48.0	13.0
04-06-90	42.0	1.1	...	...	...	...	...	...	52.0	13.0
05-06-90	40.7	3.1	...	...	...	...	...	...	42.0	13.0
06-06-90	38.0	1.2	5.9	14.2	3.1	76.0	1558.0	165.0	49.0	13.0
07-06-90	31.9	9.8	...	...	...	...	...	...	49.0	13.0
08-06-90	27.8	13.4	...	...	...	...	...	...	50.0	13.0
09-06-90	27.4	3.7	...	...	...	...	...	...	50.0	13.0
10-06-90	26.7	0.8	...	...	...	...	...	...	49.0	13.0
11-06-90	28.7	0.0	...	...	...	...	...	...	47.0	13.0
12-06-90	30.7	0.0	...	...	...	...	...	...	49.0	13.0
13-06-90	32.8	0.0	...	...	...	...	...	...	52.0	13.0
14-06-90	34.8	0.0	6.1	20.0	2.2	82.0	1650.0	166.0	54.0	13.0
15-06-90	36.8	0.0	...	...	...	...	...	...	54.0	13.0
16-06-90	38.9	0.0	...	...	...	...	...	...	60.0	13.0
17-06-90	39.7	1.0	...	...	...	...	...	...	58.0	13.0
18-06-90	38.2	5.7	...	...	...	...	...	...	58.0	13.0
19-06-90	40.2	0.0	...	...	...	...	...	...	57.0	13.0
20-06-90	37.7	7.8	...	...	...	...	...	...	56.0	13.0
21-06-90	26.6	17.4	7.7	21.3	2.6	96.0	736.0	131.0	53.0	13.0
22-06-90	27.4	5.3	...	...	...	...	...	...	54.0	13.0
23-06-90	26.1	0.3	...	...	...	...	...	...	56.0	13.0
24-06-90	25.2	6.8	...	...	...	...	...	...	54.0	13.0
25-06-90	27.3	0.0	...	...	...	...	...	...	58.0	13.0
26-06-90	29.2	0.0	...	...	...	...	...	...	62.0	13.5
27-06-90	26.1	3.0	...	...	...	...	...	...	56.0	13.5
28-06-90	28.2	0.0	7.1	21.0	2.9	83.0	868.0	121.0	54.0	13.5
29-06-90	29.6	1.5	...	...	...	...	...	...	56.0	13.5
30-06-90	27.7	10.6	...	...	...	...	...	...	54.0	13.5
01-07-90	24.6	2.2	...	...	...	...	...	...	52.0	13.5
02-07-90	27.4	0.0	...	...	...	...	...	...	52.0	13.5
03-07-90	26.6	1.3	...	...	...	...	...	...	52.0	13.5
04-07-90	17.1	13.3	6.3	18.4	3.0	81.0	718.0	143.0	53.0	13.5
05-07-90	18.9	1.0	...	...	...	...	...	...	54.0	13.5
06-07-90	14.4	9.6	...	...	...	...	...	...	50.0	13.5
07-07-90	17.2	1.0	...	...	...	...	...	...	55.0	13.5
08-07-90	19.9	0.0	...	...	...	...	...	...	59.0	13.5
09-07-90	19.6	5.7	...	...	...	...	...	...	55.0	13.5
10-07-90	22.5	0.0	...	...	...	...	...	...	52.0	13.5
11-07-90	25.3	0.0	...	...	...	...	...	...	55.0	13.5
12-07-90	28.1	0.0	...	...	...	...	...	...	60.0	13.5
13-07-90	30.9	0.0	...	...	...	...	...	...	62.0	13.5
14-07-90	33.7	0.0	...	...	...	...	...	...	58.0	14.0
15-07-90	36.2	1.1	...	...	...	...	...	...	61.0	14.0
16-07-90	39.0	0.0	...	...	...	...	...	...	62.0	14.0
17-07-90	41.8	0.0	...	...	...	...	...	...	59.0	15.0
18-07-90	44.5	0.0	...	...	...	...	...	...	66.0	15.0
19-07-90	47.2	0.0	5.4	21.9	3.9	103.0	1400.0	170.0	69.0	15.0
20-07-90	49.9	0.0	...	...	...	...	...	...	68.0	15.0
21-07-90	52.6	0.0	...	...	...	...	...	...	59.0	15.0
22-07-90	55.3	0.0	...	...	...	...	...	...	56.0	15.0
23-07-90	58.0	0.0	...	...	...	...	...	...	57.0	15.0
24-07-90	60.6	0.0	...	...	...	...	...	...	57.0	15.0
25-07-90	63.3	0.0	...	...	...	...	...	...	63.0	15.0
26-07-90	65.9	0.0	6.0	18.9	2.1	83.0	652.0	128.0	62.0	15.0
27-07-90	66.4	2.6	...	...	...	...	...	...	55.0	15.0
28-07-90	69.0	0.0	...	...	...	...	...	...	60.0	15.0
29-07-90	66.9	7.5	...	...	...	...	...	...	60.0	15.0
30-07-90	69.5	0.0	...	...	...	...	...	...	62.0	15.0
31-07-90	72.0	0.0	...	...	...	...	...	...	56.0	15.0
01-08-90	74.9	0.0	...	...	...	...	...	...	62.0	15.0
02-08-90	77.5	0.0	7.5	21.9	2.7	81.0	675.0	125.0	70.0	15.0
03-08-90	79.6	0.0	...	...	...	...	...	...	70.0	15.0
04-08-90	81.6	0.0	...	...	...	...	...	...	68.0	15.0
05-08-90	83.4	0.0	...	...	...	...	...	...	60.0	15.0

Con.

Date	SMD	Rain	pH	T-Colour	Tur.	Mn	Fe	Al	Temp-A	Temp-W
06-08-90	83.0	1.5	...	...	...	...	...	...	56.0	16.0
07-08-90	85.0	0.0	...	...	...	...	...	...	56.0	16.0
08-08-90	86.7	0.0	6.1	25.1	1.9	58.0	1162.0	103.0	58.0	16.0
09-08-90	88.4	0.0	...	...	...	...	...	...	58.0	16.0
10-08-90	89.9	0.0	...	...	...	...	...	...	61.0	16.0
11-08-90	91.4	0.0	...	...	...	...	...	...	60.0	16.0
12-08-90	92.8	0.8	...	...	...	...	...	...	59.0	16.0
13-08-90	93.9	2.6	...	...	...	...	...	...	58.0	16.0
14-08-90	92.4	4.4	...	...	...	...	...	...	58.0	16.0
15-08-90	90.1	5.3	...	...	...	...	...	...	58.0	16.0
16-08-90	78.3	18.9	7.9	3.6	1.0	55.0	574.0	105.0	52.0	16.0
17-08-90	79.2	3.2	...	...	...	...	...	...	52.0	16.0
18-08-90	71.4	9.6	...	...	...	...	...	...	50.0	16.0
19-08-90	51.9	26.3	...	...	...	...	...	...	56.0	16.0
20-08-90	48.9	7.6	...	...	...	...	...	...	53.0	16.0
21-08-90	50.8	0.0	...	...	...	...	...	...	50.0	15.0
22-08-90	53.0	0.0	...	...	...	...	...	...	57.0	15.0
23-08-90	55.2	0.0	7.7	31.8	4.4	69.0	1720.0	...	58.0	15.0
24-08-90	57.4	0.0	...	...	...	...	...	...	68.0	15.0
25-08-90	59.6	0.0	...	...	...	...	...	...	64.0	15.0
26-08-90	61.7	0.0	...	...	...	...	...	...	62.0	15.0
27-08-90	63.8	0.0	...	...	...	...	...	...	64.0	15.0
28-08-90	65.1	1.5	...	...	...	...	...	...	62.0	15.0
29-08-90	65.9	6.4	...	...	...	...	...	...	62.0	15.0
30-08-90	67.9	0.0	7.8	30.1	1.8	65.0	1580.0	128.0	58.0	15.0
31-08-90	69.7	0.0	...	...	...	...	...	...	57.0	15.0
01-09-90	71.2	0.0	...	...	...	...	...	...	56.0	15.0
02-09-90	73.4	0.7	...	...	...	...	...	...	59.0	15.0
03-09-90	74.0	4.7	...	...	...	...	...	...	59.0	15.0
04-09-90	75.8	0.5	...	...	...	...	...	...	59.0	15.0
05-09-90	73.9	4.3	6.8	30.7	1.7	78.0	1016.0	111.0	52.0	15.0
06-09-90	66.6	5.2	...	...	...	...	...	...	52.0	15.0
07-09-90	68.3	0.0	...	...	...	...	...	...	50.0	15.0
08-09-90	70.0	0.0	...	...	...	...	...	...	50.0	15.0
09-09-90	71.6	0.0	...	...	...	...	...	...	48.0	15.0
10-09-90	73.3	0.0	...	...	...	...	...	...	48.0	15.0
11-09-90	74.8	0.0	...	...	...	...	...	...	55.0	15.0
12-09-90	76.4	0.0	...	...	...	...	...	...	52.0	15.0
13-09-90	77.9	0.0	5.8	30.3	2.1	70.0	730.0	81.0	53.0	15.0
14-09-90	79.4	0.0	...	...	...	...	...	...	52.0	15.0
15-09-90	80.8	0.0	...	...	...	...	...	...	52.0	15.0
16-09-90	80.9	3.1	...	...	...	...	...	...	49.0	15.0
17-09-90	81.6	1.6	...	...	...	...	...	...	51.0	15.0
18-09-90	67.4	15.3	...	...	...	...	...	...	54.0	15.0
19-09-90	66.9	0.3	...	...	...	...	...	...	52.0	14.5
20-09-90	56.5	13.4	...	...	...	...	...	...	50.0	14.5
21-09-90	57.2	1.4	...	...	...	...	...	...	48.0	14.0
22-09-90	52.2	9.1	...	...	...	...	...	...	42.0	13.5
23-09-90	40.3	1.7	...	...	...	...	...	...	46.0	13.5
24-09-90	32.9	6.1	...	...	...	...	...	...	48.0	12.5
25-09-90	34.0	0.0	...	...	...	...	...	...	47.0	12.0
26-09-90	35.1	0.0	...	...	...	...	...	...	45.0	12.0
27-09-90	35.9	0.0	7.4	33.9	3.5	110.0	866.0	90.0	46.0	12.0
28-09-90	37.0	0.0	...	...	...	...	...	...	45.0	12.0
29-09-90	27.0	7.2	...	...	...	...	...	...	49.0	12.0
30-09-90	27.6	0.0	...	...	...	...	...	...	49.0	12.0
01-10-90	29.1	0.0	...	...	...	...	...	...	52.0	12.0
02-10-90	20.2	10.7	...	...	...	...	...	...	46.0	12.0
03-10-90	19.1	5.3	6.4	...	...	92.0	1160.0	126.0	52.0	11.5
04-10-90	14.1	7.0	...	...	...	...	...	...	55.0	11.5
05-10-90	14.4	5.7	...	...	...	...	...	...	48.0	11.5
06-10-90	9.6	10.6	...	...	...	...	...	...	53.0	11.5
07-10-90	9.9	0.0	...	...	...	...	...	...	52.0	11.5
08-10-90	11.1	0.0	...	...	...	...	...	...	48.0	11.5
09-10-90	11.8	7.5	...	...	...	...	...	...	39.0	11.0
10-10-90	12.3	6.3	6.4	...	...	79.0	773.0	176.0	42.0	11.0
11-10-90	13.5	0.5	...	...	...	...	...	...	50.0	11.0
12-10-90	14.6	0.0	...	...	...	...	...	...	50.0	11.0
13-10-90	15.5	0.0	...	...	...	...	...	...	51.0	11.0
14-10-90	16.4	0.0	...	...	...	...	...	...	58.0	11.0
15-10-90	15.2	3.4	...	...	...	...	...	...	54.0	11.0
16-10-90	16.2	0.0	...	...	...	...	...	...	52.0	11.0
17-10-90	0.6	14.2	...	...	...	...	...	...	52.0	11.0

Con.

Date	SMD	Rain	pH	T-Colour	Tur.	Mn	Fe	Al	Temp-A	Temp-W
18-10-90	0.4	6.4	6.8	9.6	3.0	84.0	941.0	114.0	52.0	11.0
19-10-90	1.1	1.2	...	...	...	...	...	...	50.0	11.0
20-10-90	1.9	0.0	...	...	...	...	...	...	52.0	11.0
21-10-90	2.8	0.0	...	...	...	...	...	...	52.0	11.0
22-10-90	3.6	0.0	...	...	...	...	...	...	46.0	11.5
23-10-90	4.4	0.0	...	...	...	...	...	...	46.0	11.5
24-10-90	1.0	5.4	...	...	...	...	...	...	50.0	11.5
25-10-90	0.0	13.0	7.1	44.5	3.0	86.0	1311.0	142.0	48.0	11.0
26-10-90	0.7	0.0	...	...	...	...	...	...	49.0	11.0
27-10-90	0.0	9.5	...	...	...	...	...	...	44.0	11.0
28-10-90	0.0	18.4	...	...	...	...	...	...	46.0	11.0
29-10-90	0.0	1.6	...	...	...	...	...	...	42.0	10.5
30-10-90	0.0	3.7	...	...	...	...	...	...	42.0	11.0
31-10-90	0.0	22.4	...	...	...	...	...	...	43.0	10.0
01-11-90	0.0	1.3	6.2	...	...	88.0	750.0	165.0	46.0	10.0
02-11-90	0.0	1.2	...	...	...	...	...	...	38.0	10.0
03-11-90	0.0	0.0	...	...	...	...	...	...	34.0	9.5
04-11-90	0.7	0.0	...	...	...	...	...	...	39.0	9.0
05-11-90	1.2	0.0	...	...	...	...	...	...	40.0	9.5
06-11-90	1.8	0.0	...	...	...	...	...	...	42.0	9.5
07-11-90	2.3	0.0	...	...	...	...	...	...	42.0	9.5
08-11-90	2.9	0.0	6.2	29.7	2.6	95.0	760.0	191.0	40.0	9.0
09-11-90	2.3	0.6	...	...	...	...	...	...	40.0	9.0
10-11-90	1.1	6.7	...	...	...	...	...	...	48.0	8.0
11-11-90	0.0	7.7	...	...	...	...	...	...	51.0	8.0
12-11-90	0.0	0.0	...	...	...	...	...	...	52.0	8.0
13-11-90	0.0	6.6	...	...	...	...	...	...	56.0	8.0
14-11-90	0.0	5.5	...	...	...	...	...	...	51.0	8.0
15-11-90	0.0	3.7	6.3	33.4	3.0	106.0	760.0	533.0	49.0	8.0
16-11-90	0.0	15.3	...	...	...	...	...	...	53.0	8.0
17-11-90	0.0	4.2	...	...	...	...	...	...	46.0	8.0
18-11-90	0.0	4.7	...	...	...	...	...	...	42.0	8.0
19-11-90	0.0	20.0	...	...	...	...	...	...	40.0	8.0
20-11-90	0.3	0.0	...	...	...	...	...	...	42.0	8.0
21-11-90	0.5	0.0	...	...	...	...	...	...	40.0	8.0
22-11-90	0.8	0.0	5.7	40.1	5.0	108.0	640.0	766.0	38.0	7.5
23-11-90	0.0	4.3	...	...	...	...	...	...	37.0	7.5
24-11-90	0.0	5.0	...	...	...	...	...	...	34.0	7.5
25-11-90	0.3	1.1	...	...	...	...	...	...	38.0	7.5
26-11-90	0.4	2.7	...	...	...	...	...	...	42.0	6.5
27-11-90	0.6	0.0	...	...	...	...	...	...	39.0	6.5
28-11-90	0.9	0.0	...	...	...	...	...	...	42.0	6.5
29-11-90	1.2	0.0	5.6	43.0	2.9	145.0	863.0	269.0	34.0	6.0
30-11-90	1.4	0.0	...	...	...	...	...	...	40.0	6.0
01-12-90	1.8	0.0	...	...	...	...	...	...	40.0	6.0
02-12-90	2.2	1.2	...	...	...	...	...	...	42.0	6.0
03-12-90	2.6	0.6	...	...	...	...	...	...	...	6.0
04-12-90	3.0	0.0	...	...	...	...	...	...	...	6.0
05-12-90	3.4	0.0	...	...	...	...	...	...	...	6.0
06-12-90	3.7	0.0	6.7	42.0	2.7	111.0	716.0	275.0	...	6.0
07-12-90	0.0	17.2	...	...	...	...	...	...	...	6.0
08-12-90	0.0	20.2	...	...	...	...	...	...	29.0	5.0
09-12-90	0.0	6.5	...	...	...	...	...	...	40.0	5.0
10-12-90	0.0	1.4	...	...	...	...	...	...	36.0	5.0
11-12-90	0.0	6.9	...	...	...	...	...	...	34.0	4.5
12-12-90	0.3	0.0	...	...	...	...	...	...	37.0	4.0
13-12-90	0.7	0.0	...	...	...	...	...	...	34.0	4.0
14-12-90	1.0	0.0	...	...	...	...	...	...	33.0	4.0
15-12-90	0.8	1.3	...	...	...	...	...	...	30.0	4.0
16-12-90	1.1	0.0	...	...	...	...	...	...	40.0	5.0
17-12-90	1.3	0.0	...	...	...	...	...	...	37.0	4.0
18-12-90	1.1	1.3	...	...	...	...	...	...	34.0	4.0
19-12-90	0.0	4.2	...	...	...	...	...	...	36.0	4.0
20-12-90	0.0	17.4	...	...	...	...	...	...	38.0	4.0
21-12-90	0.0	1.3	...	...	...	...	...	...	42.0	4.0
22-12-90	0.0	0.0	...	...	...	...	...	...	48.0	4.0
23-12-90	0.0	2.3	...	...	...	...	...	...	48.0	4.0
24-12-90	0.0	4.1	...	...	...	...	...	...	44.0	4.0
25-12-90	0.0	14.2	...	...	...	...	...	...	44.0	4.0
26-12-90	0.0	13.9	...	...	...	...	...	...	41.0	4.0
27-12-90	0.0	1.9	...	...	...	...	...	...	39.0	4.0
28-12-90	0.0	24.2	...	...	...	...	...	...	39.0	4.0
29-12-90	0.0	0.0	...	...	...	...	...	...	40.0	4.0
30-12-90	0.0	0.0	...	...	...	...	...	...	38.0	4.0



**Levels of colour in the raw waters at Arnfield (1987-1990), rain and soil moisture deficit at Longendale Valley.**

Year	Parameters	Mean	Std Dev	Min	Max	NO. Samples	Total Rainfall
1987	Colour (Hazen)	99.24	44.78	20	250	238	1171.1
	Rain mm	3.21	5.72	0	40.9	365	
	SMD mm	4.11	6.77	0	32.2	365	
1988	Colour	92.22	30.54	17	175	197	1314.3
	Rain	3.59	5.8	0	50.9	366	
	SMD	7.89	13.76	0	75.1	366	
1989	Colour	91.89	27.73	50	150	40	1054.4
	Rain	2.89	5.57	0	34.8	365	
	SMD	37.58	42.12	0	11.5	365	
1990	Colour *	27.47	22.33	1.2	133	31	1134
	Rain	3.12	5.01	0	30.4	364	
	SMD	22.33	26.61	0	93.9	364	

\* True colour

Levels of some water quality levels in the raw waters at Arnfield (1987-1990).

Year	Parameters	Mean	Std Dev	Min	Max	No. Samples
1987	pH units	6.07	0.43	5	7.3	238
	Turbidity ftu	3.03	1.18	1.1	6.5	238
	Mn ppb	85.4	134.89	17	2012	238
	Fe ppb	509.29	326.94	91	2990	238
	Al ppb	203.75	54	75	552	235
	Air °F	51.75	7.05	33	72	277
	Water °C	10.59	3.56	3.5	15.5	277
	pH	6.11	0.62	4.2	7.9	197
	Turbidity	2.65	0.99	0.5	7.2	197
	Mn	81.86	11.91	19	161	196
1988	Fe	533.73	112.7	312	1028	196
	Al	178.28	38.98	81	320	191
	Air	44.23	8.27	23	70	366
	Water	9.03	4.08	2.5	16	366
	pH	6.4	0.93	3.2	8	43
	Turbidity	3.98	1.67	1.8	7.6	41
	Mn	92.44	37.41	58	246	43
	Fe	724.84	427.57	198.2	1760	43
	Al	182.8	56.67	30	297	40
	Air	46.35	8.44	26	69	365
1989	Water	9.76	4.24	4	17	365
	pH	6.61	0.69	5.4	7.9	32
	Turbidity	2.96	1.18	1.0	5.6	37
	Mn	92.29	17.66	55	145	42
	Fe	815.07	415.52	334.0	1910	42
	Al	213.23	144.10	23	766	40
	Air	47.61	8.32	29	70	359
	Water	9.67	3.91	4	16	364
1990						

The seasonal average of some water quality levels in the raw waters at Arnfield (1987-1990).

Year	Season	SMD	Rain	Total Rain	pH	Colour	Turbidity	Mn	Fe	Al	A-Temp	W-Temp
1987	Winter	1.1	1.9	140.0	5.6	100.1	2.6	96.8	375.5	172.7	-	-
	Spring	6.6	3.7	339.7	6.2	67.0	2.4	73.0	289.1	210.1	50.8	8.9
	Summer	7.5	3.4	317.1	6.1	87.0	2.4	69.6	525.9	221.6	57.9	14.1
	Autumn	1.4	3.5	316.0	6.3	142.0	4.6	105.2	819.3	211.1	46.5	9.4
1988	Winter	1.0	4.7	423.9	5.7	100.6	3.5	80.5	528.7	183.4	39.2	4.4
	Spring	14.1	2.2	199.4	6.1	76.9	2.7	81.2	471.7	204.6	43.9	8.5
	Summer	14.5	4.5	413.9	6.5	79.2	2.0	81.1	577.2	143.5	52.7	14.1
	Autumn	1.8	3.0	271.8	6.3	127.0	2.6	83.7	569.1	186.9	42.1	9.2
1989	Winter	0.6	3.3	294.7	5.8	105.5	3.0	87.4	490.3	206.7	41.5	5.3
	Spring	18.4	3.0	271.8	6.2	75.5	4.0	86.1	335.9	170.9	43.9	8.1
	Summer	86.0	2.0	179.8	6.8	68.9	2.8	76.0	707.4	139.6	56.3	15.4
	Autumn	44.5	3.3	294.2	6.7	115.0	5.6	115.2	1349.1	196.2	44.2	10.2
1990	Winter	0.4	3.9	350.7	6.5	* 67.1	4.2	107.3	482.1	278.5	41.3	5.1
	Spring	20.8	2.2	199.3	5.9	* 18.5	2.6	87.7	919.9	196.3	46.3	9.3
	Summer	56.2	2.3	211.3	6.8	* 22.9	2.5	76.8	985.9	122.4	57.3	14.6
	Autumn	10.4	3.9	354.8	6.4	* 34.5	3.2	100.4	867.3	258.8	44.9	9.4

\* True Colour

## **Appendix IV**

**Concentration of some parameters in the lysimeter experiment**

Longdendale Valley lysimeters

Date	Lysimeters	pH	Colour Hazen	Fe mg/l	Mn mg/l	Ca mg/l	Hg mg/l	Al mg/l	Rain mm	Rain3c mm	Rain7c mm	SMD mm
17-01-90	L-1	3.38	344.56	0.19	0.04	1.84	0.84	0.22	0.00	21.40	35.80	0.50
	L-2	3.54	253.57	0.16	0.03	1.60	0.71	0.27				
	L-3	3.38	268.57	0.17	0.02	1.83	0.66	0.19				
25-01-90	L-1	3.23	337.84	0.19	0.02	0.80	0.81	0.25	13.50	26.80	37.20	0.00
	L-2	3.69	144.94	0.10	0.02	0.34	0.51	0.16				
	L-3	3.54	191.58	0.15	0.03	0.56	0.65	0.12				
20-02-90	L-1	3.36	183.16	0.34	0.02	1.50	0.37	0.13	5.00	6.70	25.70	0.00
	L-2	3.64	156.40	0.25	0.03	1.18	0.21	0.19				
	L-3	3.39	133.20	0.20	0.02	1.73	0.23	0.11				
08-03-90	L-1	3.25	120.00	0.13	0.05	1.72	0.08	0.27	0.70	6.90	19.40	2.90
	L-2	3.30	96.20	0.08	0.07	1.60	0.14	0.17				
	L-3	3.61	80.11	0.10	0.05	1.43	0.08	0.14				
11-04-90	L-1	3.45	177.08	0.25	0.04	2.17	1.01	0.31	0.00	3.90	5.00	17.80
	L-2	3.53	103.64	0.22	0.03	3.38	1.96	0.17				
	L-3	3.59	107.44	0.20	0.05	2.80	1.18	0.14				
04-05-90	L-1	No leaching							0.00	0.00	0.00	24.30
	L-2	No leaching										
	L-3	No leaching										
08-05-90	L-1	3.20	210.00	0.31	0.03	1.79	0.89	0.15	4.80	7.80	7.80	26.30
	L-2	3.70	150.10	0.34	0.03	1.56	0.52	0.10				
	L-3	3.74	142.65	0.23	0.02	1.55	0.66	0.12				
04-06-90	L-1	3.60	188.00	0.31	0.03	1.10	0.40	0.16	1.10	25.30	28.80	42.00
	L-2	3.64	156.10	0.24	0.03	1.05	0.22	0.19				
	L-3	3.40	139.00	0.21	0.04	1.60	0.24	0.13				
08-07-90	L-1	No leaching							0.00	11.60	28.40	19.90
	L-2	No leaching										
	L-3	No leaching										
15-08-90	L-1	No leaching							5.30	7.80	7.80	90.10
	L-2	No leaching										
	L-3	No leaching										
19-09-90	L-1	3.40	285.00	0.20	0.03	0.94	0.80	0.21	0.30	20.00	20.00	66.90
	L-2	3.60	251.30	0.16	0.03	0.61	0.71	0.30				
	L-3	3.30	241.30	0.15	0.02	0.82	0.70	0.20				

# North Wales lysimeters

Date	lysimeters	pH	Colour Hazen	Fe mg/l	Mn mg/l	Ca mg/l	Mg mg/l	Al mg/l
01-02-90	Control	3.92	21.61	0.060	0.020	0.510	0.965	0.017
	Lime	3.82	23.56	0.063	0.021	0.503	1.500	0.035
	After Lime	3.84	29.07	0.053	0.025	0.337	0.428	0.080
14-03-90	Control	3.61	34.27	0.055	0.052	3.100	1.250	0.046
	Lime	3.69	34.44	0.050	0.029	3.790	1.787	0.020
	After Lime	3.79	32.95	0.048	0.042	1.833	0.910	0.080
19-04-90	Control	3.41	45.25	0.043	0.025	0.657	1.230	0.031
	Lime	3.60	51.20	0.041	0.020	1.077	0.973	0.031
	After Lime	3.75	46.45	0.049	0.026	1.227	0.973	0.090
01-05-90	Control	3.99	21.11	0.044	0.020	0.610	0.860	0.027
	Lime	4.02	23.56	0.063	0.031	0.620	1.200	0.035
	After Lime	3.94	21.07	0.057	0.025	0.420	1.330	0.089
14-06-90	Control	3.91	39.10	0.045	0.033	1.133	2.350	0.046
	Lime	4.01	34.60	0.044	0.029	2.030	1.890	0.060
	After Lime	4.19	31.90	0.048	0.022	1.850	1.290	0.087

Levels of some parameters in the monolith tin experiment.  
( Longendale Valley samples )

Top the hill samples at 10 °C

Date	Out mm	pH	Colour Hazen	Fe mg/l	Mn mg/l	Ca mg/l	Mg mg/l	Al mg/l
<b>Natural water (A)</b>								
30-01-90	178	3.37	554.40	0.14	0.06	3.00	1.03	0.12
04-02-90	128	3.37	837.89	0.30	0.03	3.20	0.80	0.31
07-02-90	107	3.20	901.79	0.24	0.04	5.00	0.85	0.17
10-02-90	112	3.18	690.30	0.30	0.07	3.40	0.60	0.11
13-02-90	108	3.22	656.79	0.14	0.05	1.65	0.52	0.16
16-02-90	104	3.16	654.22	0.19	0.06	3.80	0.33	0.15
19-02-90	109	3.23	650.00	0.17	0.06	1.60	0.30	0.20
22-02-90	110	3.16	915.40	0.15	0.05	1.80	0.29	0.10
25-02-90	122	2.90	674.68	0.19	0.05	1.60	0.24	0.27
28-02-90	108	2.75	640.34	0.16	0.06	2.40	0.57	0.18
03-03-90	110	3.14	752.78	0.19	0.05	2.40	0.58	0.11
06-03-90	90	3.14	897.82	0.21	0.05	6.20	0.76	0.22
09-03-90	106	3.06	794.85	0.18	0.07	2.60	0.59	0.28
12-03-90	110	2.98	774.23	0.14	0.06	2.40	0.58	0.24
15-03-90	118	2.97	671.34	0.15	0.09	6.10	1.05	0.22
18-03-90	107	3.01	594.06	0.19	0.09	4.90	1.22	0.29
<b>Distilled water (B)</b>								
23-03-90	110	3.01	643.57	0.20	0.10	4.40	1.21	0.28
26-03-90	100	2.93	577.78	0.16	0.10	4.90	1.30	0.29
29-03-90	122	3.04	466.59	0.16	0.09	5.00	1.45	0.23
01-04-90	118	2.92	424.50	0.13	0.11	4.90	1.36	0.17
04-04-90	101	2.95	456.65	0.14	0.11	5.50	1.55	0.18
07-04-90	122	2.98	469.46	0.15	0.09	5.30	1.66	0.18
10-04-90	107	2.91	459.69	0.11	0.12	4.80	1.65	0.17
13-04-90	110	2.96	397.33	0.08	0.08	5.50	1.76	0.15
16-04-90	114	2.85	409.05	0.09	0.09	5.70	1.68	0.16
19-04-90	120	2.98	424.22	0.10	0.08	5.70	1.70	0.16
<b>Hard water (C)</b>								
24-04-90	115	2.88	353.06	0.10	0.08	6.60	1.79	0.17
27-04-90	123	2.84	379.65	0.08	0.10	6.40	1.69	0.20
30-04-90	104	2.84	358.62	0.06	0.12	6.50	1.89	0.22
02-05-90	130	2.93	324.62	0.07	0.10	6.50	1.80	0.22
05-05-90	120	2.95	290.81	0.07	0.08	5.50	1.20	0.26
08-05-90	110	2.93	271.51	0.08	0.12	6.90	1.90	0.21
11-05-90	115	2.87	236.05	0.06	0.11	6.60	1.90	0.19
14-05-90	134	2.88	200.24	0.07	0.12	7.60	1.86	0.18
17-05-90	118	2.88	192.92	0.09	0.12	7.00	1.90	0.20
20-05-90	130	2.85	179.92	0.10	0.12	7.50	2.10	0.22
23-05-90	120	2.80	181.48	0.10	0.11	7.80	2.12	0.22
26-05-90	122	2.79	165.28	0.06	0.13	7.30	2.29	0.21
29-05-90	101	2.80	144.73	0.07	0.14	8.90	2.30	0.26
01-06-90	120	2.72	154.10	0.06	0.14	8.20	2.30	0.26
04-06-90	110	2.86	138.39	0.06	0.15	7.70	2.40	0.29
07-04-90	118	2.85	128.32	0.06	0.14	8.12	2.60	0.26
<b>Natural water (E)</b>								
29-07-90	90.00	2.89	129.29	0.09	0.25	20.40	4.10	0.44
01-08-90	90.00	2.64	140.93	0.05	0.22	18.00	1.98	0.32
04-08-90	104.00	2.81	145.36	0.07	0.22	19.80	1.85	0.33
07-08-90	90.00	2.72	152.30	0.08	0.22	18.80	1.78	0.34
10-08-90	100.00	2.80	141.33	0.05	0.19	16.40	1.95	0.32
<b>Natural water (F)</b>								
13-08-90	107.00	2.80	454.36	0.13	0.14	7.60	2.20	0.26
16-08-90	110.00	3.01	498.67	0.17	0.09	5.60	1.22	0.29
13-08-90	119.00	2.80	454.36	0.13	0.14	7.60	2.20	0.26
16-08-90	111.00	3.01	498.67	0.17	0.09	5.60	1.22	0.29

Top of the hill samples at 20 °C

<b>Natural water (A)</b>								
30-01-90	=	=	=	=	=	=	=	=
04-02-90	=	=	=	=	=	=	=	=
07-02-90	=	=	=	=	=	=	=	=
10-02-90	=	=	=	=	=	=	=	=
13-02-90	98.00	3.30	956.80	0.54	0.05	11.00	0.87	0.11
16-02-90	99.00	3.36	994.88	0.57	0.04	10.00	0.50	0.10
Con.								

Date	Out	pH	Colour	Fe	Mn	Ca	Mg	Al
19-02-90	110.00	3.48	979.12	0.35	0.04	7.42	0.40	0.09
22-02-90	96.00	3.40	972.00	0.42	0.04	7.70	0.50	0.06
25-02-90	98.00	2.90	996.80	0.37	0.04	6.30	0.42	0.09
28-02-90	100.00	2.97	810.49	0.41	0.06	7.30	0.64	0.08
03-03-90	105.00	3.66	883.11	0.47	0.07	8.30	0.65	0.09
06-03-90	117.00	3.70	977.08	0.47	0.07	11.40	0.71	0.11
09-03-90	98.00	3.69	975.79	0.41	0.07	7.10	0.69	0.10
12-03-90	110.00	4.01	961.70	0.39	0.06	8.30	0.68	0.12
15-03-90	90.00	3.84	962.13	0.43	0.06	15.00	1.20	0.09
18-03-90	110.00	3.90	964.00	0.50	0.04	14.80	1.29	0.09
<b>Distilled water (B)</b>								
23-03-90	100.00	3.61	852.86	0.45	0.05	11.20	1.30	0.09
26-03-90	125.00	3.60	819.50	0.45	0.06	10.00	1.32	0.16
29-03-90	116.00	4.30	894.40	0.46	0.05	15.80	1.30	0.18
01-04-90	114.00	3.86	770.95	0.40	0.05	14.00	1.33	0.16
04-04-90	117.00	4.18	851.96	0.40	0.06	15.60	1.29	0.15
07-04-90	118.00	4.01	851.47	0.45	0.06	15.40	1.35	0.14
10-04-90	112.00	3.85	861.47	0.44	0.05	14.40	1.32	0.15
13-04-90	130.00	4.36	841.93	0.35	0.04	16.10	1.36	0.13
16-04-90	105.00	3.75	865.60	0.37	0.05	15.60	1.39	0.15
19-04-90	118.00	3.99	849.20	0.39	0.04	11.40	1.33	0.14
<b>Hard water (C)</b>								
24-04-90	90.00	3.82	927.52	0.35	0.04	16.60	1.51	0.29
27-04-90	120.00	4.27	1007.51		0.40	0.05	20.80	1.35
30-04-90	90.00	4.63	1072.82		0.43	0.05	24.40	1.44
02-05-90	120.00	3.85	1051.13		0.39	0.06	16.00	1.35
05-05-90	120.00	4.10	1094.69		0.36	0.06	14.00	1.20
08-05-90	105.00	4.30	1094.95		0.40	0.05	19.00	1.35
11-05-90	114.00	4.28	1098.25		0.46	0.06	20.00	1.37
14-05-90	117.00	4.30	1001.10		0.42	0.06	21.00	1.36
17-05-90	112.00	4.24	1033.02		0.45	0.06	23.00	1.37
20-05-90	112.00	4.16	1023.24		0.50	0.07	20.30	1.40
23-05-90	118.00	4.25	958.71	0.43	0.05	18.90	1.35	0.29
26-05-90	115.00	4.40	961.71	0.37	0.04	24.00	1.40	0.28
29-05-90	114.00	4.09	903.63	0.38	0.03	26.90	1.50	0.32
01-06-90	70.00	4.30	897.17	0.36	0.04	25.40	1.51	0.28
04-06-90	110.00	4.25	880.68	0.38	0.05	27.30	1.49	0.27
07-04-90	118.00	4.24	843.04	0.37	0.05	26.15	1.50	0.26
<b>Natural water (E)</b>								
29-07-90	=	=	=	=	=	=	=	=
01-08-90	=	=	=	=	=	=	=	=
04-08-90	121.00	4.20	592.89	0.35	0.06	23.60	2.60	0.32
07-08-90	80.00	4.57	701.46	0.32	0.07	20.60	2.30	0.32
10-08-90	90.00	4.23	703.96	0.35	0.06	20.80	2.20	0.34
<b>Natural water (F)</b>								
13-08-90	102.00	3.30	857.30	0.31	0.05	12.50	1.36	0.22
16-08-90	110.00	3.60	861.90	0.50	0.04	13.90	1.29	0.09
13-08-90	109.00	3.30	857.30	0.31	0.05	12.50	1.36	0.22
16-08-90	110.00	3.60	861.90	0.50	0.04	13.90	1.29	0.09

#### Bottom of the hill sample at 10 °C

<b>Natural water (A)</b>								
30-01-90	=	=	=	=	=	=	=	=
04-02-90	=	=	=	=	=	=	=	=
07-02-90	=	=	=	=	=	=	=	=
10-02-90	=	=	=	=	=	=	=	=
13-02-90	=	=	=	=	=	=	=	=
16-02-90	=	=	=	=	=	=	=	=
19-02-90	70.00	=	=	=	=	=	=	=
22-02-90	140.00	3.64	28.70	=	0.70	44.00	1.35	0.26
25-02-90	115.00	3.44	45.10	0.16	0.45	42.00	1.10	0.13
28-02-90	97.00	3.70	38.48	0.10	0.55	37.50	2.60	0.25
03-03-90	100.00	4.31	39.44	0.10	0.45	28.00	2.45	0.16
06-03-90	87.00	4.69	41.76	0.11	0.53	30.00	2.60	0.17
09-03-90	95.00	4.40	53.56	0.13	0.48	21.35	2.15	0.26
12-03-90	107.00	4.22	49.06	0.11	0.50	17.90	2.05	0.28
15-03-90	117.00	4.86	50.11	0.14	0.45	37.50	3.25	0.16
18-03-90	100.00	4.80	47.84	0.14	0.53	28.00	3.60	0.14
<b>Distilled water (B)</b>								
23-03-90	105.00	5.00	37.70	0.14	0.59	21.00	3.70	0.14
26-03-90	90.00	4.63	37.55	0.15	0.65	24.00	4.00	0.21
29-03-90	110.00	4.80	17.28	0.18	0.56	22.30	3.90	0.21
<b>Con.</b>								



Date	Out	pH	Colour	Fe	Mn	Ca	Mg	Al
01-04-90	110.00	4.66	23.08	0.17	0.68	23.00	3.90	0.19
04-04-90	108.00	4.62	26.74	0.15	0.66	20.60	4.00	0.25
07-04-90	105.00	4.52	29.32	0.15	0.65	20.90	4.10	0.20
10-04-90	98.00	4.35	36.55	0.17	0.69	20.90	4.00	0.26
13-04-90	117.00	4.59	39.51	0.18	0.78	19.60	4.60	0.22
16-04-90	95.00	4.36	33.24	0.18	0.73	20.10	4.78	0.22
19-04-90	98.00	4.60	34.14	0.17	0.69	20.50	4.60	0.23
<b>Hard water (C)</b>								
24-04-90	98.00	3.94	29.07	0.17	0.70	20.00	4.60	0.31
27-04-90	125.00	4.43	33.99	0.19	0.72	22.10	3.97	0.21
30-04-90	97.00	4.66	33.79	0.18	0.76	27.80	5.36	0.21
02-05-90	128.00	4.35	21.18	0.19	0.70	25.00	4.20	0.28
05-05-90	110.00	4.40	21.52	0.19	0.59	20.60	3.39	0.29
08-05-90	112.00	4.40	26.01	0.19	0.66	24.60	3.81	0.34
11-05-90	120.00	4.19	29.82	0.18	0.63	25.90	4.14	0.38
14-05-90	120.00	4.23	7.45	0.20	0.69	26.00	4.22	0.34
17-05-90	118.00	4.33	7.45	0.23	0.68	25.80	4.20	0.33
20-05-90	112.00	4.30	12.76	0.26	0.65	21.50	4.13	0.35
23-05-90	118.00	4.10	36.07	0.27	0.64	19.90	4.01	0.29
26-05-90	118.00	4.15	26.20	0.21	0.55	26.50	3.89	0.28
29-05-90	100.00	4.13	24.01	0.19	0.56	27.00	3.80	0.28
01-06-90	118.00	4.11	27.55	0.18	0.56	26.35	4.11	0.30
04-06-90	118.00	4.12	32.07	0.17	0.59	28.00	3.90	0.31
07-04-90	116.00	4.18	21.46	0.19	0.53	29.00	4.10	0.35
<b>Natural water (E)</b>								
29-07-90	100.00	4.20	24.10	0.16	0.90	55.50	5.45	0.46
01-08-90	110.00	4.19	23.60	0.18	0.90	52.50	5.20	0.46
04-08-90	98.00	4.17	25.60	0.18	0.84	58.00	6.00	0.45
07-08-90	107.00	4.09	29.30	0.19	0.80	50.00	4.80	0.48
10-08-90	91.00	4.25	25.60	0.18	0.75	51.00	4.60	0.48
<b>Natural water (F)</b>								
13-08-90	93.00	4.31	29.30	0.16	0.65	20.90	3.10	0.29
16-08-90	100.00	4.70	38.33	0.14	0.53	21.30	3.60	0.14
13-08-90	92.00	4.31	29.30	0.16	0.65	20.90	3.10	0.29
16-08-90	102.00	4.70	38.33	0.14	0.53	21.30	3.60	0.14

#### Bottom of the hill sample at 20 °C

<b>Natural water (A)</b>								
30-01-90	=	=	=	=	=	=	=	=
04-02-90	=	=	=	=	=	=	=	=
07-02-90	=	=	=	=	=	=	=	=
10-02-90	=	=	=	=	=	=	=	=
13-02-90	=	=	=	=	=	=	=	=
16-02-90	=	=	=	=	=	=	=	=
19-02-90	=	=	=	=	=	=	=	=
22-02-90	20.00	=	52.99	0.41	1.40	=	3.00	0.00
25-02-90	60.00	4.65	66.50	0.39	1.60	=	3.80	0.00
28-02-90	60.00	4.90	60.34	0.28	1.62	40.00	4.70	0.01
03-03-90	90.00	5.06	68.21	0.30	1.50	33.00	3.90	0.03
06-03-90	80.00	5.26	68.75	0.31	1.60	36.00	4.80	0.04
09-03-90	66.00	5.49	72.76	0.26	1.60	44.00	4.30	0.07
12-03-90	70.00	5.11	71.44	0.24	1.80	49.00	4.60	0.06
15-03-90	65.00	5.03	76.36	0.33	2.30	50.00	5.90	0.06
18-03-90	70.00	5.08	71.34	0.30	1.70	52.80	4.74	0.07
<b>Distilled water (B)</b>								
23-03-90	88.00	4.70	70.84	0.28	1.77	38.20	4.65	0.25
26-03-90	100.00	4.30	66.09	0.32	1.80	39.20	4.70	0.35
29-03-90	90.00	4.46	66.60	0.32	1.80	56.00	4.68	0.36
01-04-90	85.00	4.40	53.80	0.29	1.90	40.00	4.65	0.40
04-04-90	90.00	4.30	47.74	0.31	1.80	37.60	4.62	0.46
07-04-90	90.00	4.70	60.96	0.32	1.81	38.00	4.68	0.29
10-04-90	90.00	4.50	67.29	0.33	1.85	39.20	4.69	0.39
13-04-90	100.00	4.64	70.44	0.27	2.11	37.60	5.00	0.38
16-04-90	89.00	4.40	65.17	0.26	1.90	39.40	4.60	0.45
19-04-90	105.00	4.49	68.41	0.28	1.95	39.80	4.90	0.47
<b>Hard water (C)</b>								
24-04-90	70.00	4.20	61.41	0.28	2.16	38.00	10.15	0.48
27-04-90	100.00	4.35	60.74	0.29	2.10	52.00	11.15	0.44
30-04-90	90.00	4.40	72.34	0.27	2.20	52.00	10.85	0.42
02-05-90	118.00	4.38	54.81	0.29	2.19	50.00	11.00	0.46
05-05-90	110.00	4.40	56.76	0.26	1.89	46.50	9.90	0.49
08-05-90	100.00	4.40	58.12	0.30	1.90	49.35	12.50	0.43
<b>Con.</b>								

Date	Out	pH	Colour	Fe	Mn	Ca	Mg	Al
11-05-90	110.00	4.42	57.01	0.29	2.20	47.60	11.50	0.48
14-05-90	118.00	4.33	51.44	0.30	2.20	49.50	12.00	0.32
17-05-90	110.00	4.12	48.11	0.31	2.30	55.00	10.00	0.50
20-05-90	120.00	4.04	54.72	0.35	2.55	39.50	11.50	0.56
23-05-90	117.00	4.24	67.88	0.36	2.50	39.50	12.00	0.80
26-05-90	112.00	4.06	64.76	0.34	2.60	50.00	13.00	0.78
29-05-90	100.00	4.09	42.62	0.38	2.60	45.00	12.30	0.86
01-06-90	50.00	4.30	69.78	0.39	2.55	55.00	12.01	0.90
04-06-90	105.00	4.25	70.24	0.35	2.10	75.00	12.20	0.92
07-04-90	110.00	4.22	58.39	0.36	2.20	70.00	11.40	0.91
Natural water (E)								
29-07-90	=	=	=	=	=	=	=	=
01-08-90	=	=	=	=	=	=	=	=
04-08-90	66.00	4.39	52.10	0.26	3.15	102.00	21.50	0.42
07-08-90	65.00	4.24	49.30	0.29	2.83	95.00	20.30	0.35
10-08-90	70.00	4.30	63.22	0.26	2.28	93.00	20.45	0.15
Natural water (F)								
13-08-90	68.00	4.44	66.16	0.34	2.10	49.90	7.80	0.46
16-08-90	70.00	5.08	66.70	0.30	1.70	52.60	5.10	0.07
13-08-90	69.00	4.44	62.46	0.34	2.10	49.90	7.80	0.46
16-08-90	70.00	5.08	60.10	0.30	1.70	52.60	5.10	0.07

## ( North Wales samples ).

Lime sample at 10 °C

Date	Out mm	pH	Colour Hazen	Fe mg/l	Mn mg/l	Ca mg/l	Mg mg/l	Al mg/l
<b>Natural water (A)</b>								
30-01-90	=	=	=	=	=	=	=	=
04-02-90	=	=	=	=	=	=	=	=
07-02-90	=	=	=	=	=	=	=	=
10-02-90	128.00	3.73	244.6	0.30	=	8.80	1.40	0.25
13-02-90	110.00	3.76	240.0	0.28	=	9.80	1.28	0.19
16-02-90	113.00	3.80	246.0	0.30	0.66	10.10	0.70	0.17
19-02-90	114.00	3.88	252.9	0.29	0.61	7.40	0.67	0.23
22-02-90	110.00	3.93	190.2	0.37	0.60	7.10	0.83	0.22
25-02-90	122.00	3.15	169.8	0.32	0.64	6.60	0.78	0.14
28-02-90	110.00	3.23	188.0	0.25	0.60	6.50	1.03	0.28
03-03-90	122.00	3.83	182.8	0.20	0.58	5.00	0.92	0.22
06-03-90	119.00	3.86	199.4	0.25	0.62	12.60	1.06	0.27
09-03-90	110.00	3.90	200.4	0.31	0.56	6.03	0.80	0.36
12-03-90	118.00	3.77	202.9	0.30	0.60	6.30	0.86	0.32
15-03-90	122.00	3.70	216.7	0.31	0.61	10.60	1.55	0.26
18-03-90	110.00	3.90	220.4	0.33	0.59	8.60	1.63	0.29
<b>Distilled water (B)</b>								
23-03-90	118.00	3.81	223.12	0.38	0.60	7.60	1.59	0.31
26-03-90	105.00	3.75	258.84	0.37	0.65	8.20	1.80	0.37
29-03-90	120.00	3.77	229.63	0.39	0.70	9.00	1.79	0.31
01-04-90	122.00	3.74	226.17	0.40	0.65	8.50	1.68	0.27
04-04-90	104.00	3.40	247.72	0.36	0.62	7.20	1.80	0.32
07-04-90	130.00	3.65	241.94	0.35	0.62	6.60	1.75	0.26
10-04-90	97.00	3.63	233.44	0.40	0.68	6.80	1.90	0.27
13-04-90	118.00	3.78	250.82	0.44	0.80	6.20	2.02	0.27
16-04-90	97.00	3.60	269.60	0.43	0.75	6.23	1.96	0.37
19-04-90	120.00	3.85	263.30	0.40	0.76	6.20	1.89	0.30
<b>Hard water (C)</b>								
24-04-90	90.00	3.74	267.60	0.53	0.80	6.40	1.91	0.31
27-04-90	110.00	3.74	278.03	0.51	0.79	7.00	1.88	0.37
30-04-90	145.00	3.70	236.63	0.44	0.82	7.00	1.89	0.35
02-05-90	130.00	3.80	226.07	0.45	0.79	6.80	1.78	0.37
05-05-90	120.00	3.74	248.40	0.46	0.82	6.90	1.82	0.24
08-05-90	130.00	3.80	202.31	0.45	0.82	6.70	1.80	0.23
11-05-90	112.00	3.66	179.40	0.45	0.82	6.90	1.81	0.21
14-05-90	128.00	3.74	197.16	0.48	0.82	6.50	1.81	0.19
17-05-90	108.00	3.72	179.40	0.49	0.85	7.00	1.90	0.23
20-05-90	140.00	3.65	188.20	0.51	0.89	6.30	1.97	0.30
23-05-90	118.00	3.70	182.85	0.47	0.91	6.80	2.01	0.25
26-05-90	117.00	3.60	193.35	0.41	0.92	7.50	2.00	0.38
29-05-90	90.00	3.59	207.05	0.42	0.94	7.00	2.20	0.40
01-06-90	130.00	3.65	195.73	0.36	0.91	6.90	2.10	0.38
04-06-90	112.00	3.65	181.21	0.42	0.90	7.20	2.23	0.33
07-04-90	107.00	3.64	164.88	0.45	0.91	7.35	2.08	0.36
<b>Natural water (E)</b>								
29-07-90	50.00	3.69	175.61	0.50	1.14	14.60	3.00	0.46
01-08-90	110.00	3.63	152.27	0.45	1.06	13.80	2.85	0.46
04-08-90	100.00	3.64	175.98	0.43	1.04	13.80	2.45	0.41
07-08-90	112.00	3.57	154.57	0.48	1.14	12.40	2.55	0.47
10-08-90	100.00	3.61	169.48	0.42	1.18	15.40	2.95	0.47
<b>Natural water (F)</b>								
13-08-90	99.00	3.80	150.90	0.39	0.60	7.90	1.50	0.31
16-08-90	110.00	3.91	145.30	0.33	0.59	6.90	1.40	0.29
13-08-90	91.00	3.80	150.90	0.39	0.60	7.90	1.50	0.31
16-08-90	110.00	3.91	145.30	0.33	0.59	6.90	1.40	0.29

Unlime sample at 10 °C

Date	Out mm	pH	Colour Hazen	Fe mg/l	Mn mg/l	Ca mg/l	Mg mg/l	Al mg/l
<b>Natural water (A)</b>								
30-01-90	=	=	=	=	=	=	=	=
04-02-90	=	=	=	=	=	=	=	=
07-02-90	=	=	=	=	=	=	=	=
10-02-90	38.00	3.44	=	0.30	0.06	10.00	1.60	0.16
13-02-90	98.00	3.50	=	0.28	0.06	8.90	1.26	0.13
Con.								

Date	Out	pH	Colour	Fe	Mn	Ca	Mg	Al
16-02-90	110.00	3.48	123.00	0.29	0.02	8.00	1.32	0.11
19-02-90	107.00	3.49	120.00	0.27	0.02	8.03	0.96	0.09
22-02-90	120.00	3.58	130.10	0.37	0.03	7.70	0.80	0.11
25-02-90	138.00	2.91	98.66	0.29	0.02	7.40	0.82	0.07
28-02-90	109.00	3.01	104.17	0.20	0.02	8.00	1.30	0.09
03-03-90	110.00	3.60	79.20	0.19	0.03	6.70	1.05	0.07
06-03-90	118.00	3.66	77.97	0.18	0.03	12.70	1.15	0.13
09-03-90	105.00	3.63	105.17	0.21	0.03	8.40	1.10	0.16
12-03-90	124.00	3.49	84.63	0.30	0.02	5.90	1.13	0.14
15-03-90	123.00	3.40	86.90	0.29	0.05	11.10	1.60	0.12
18-03-90	120.00	3.55	83.60	0.20	0.03	6.80	1.80	0.11
Distilled water (B)								
23-03-90	105.00	3.51	76.77	0.21	0.03	7.10	2.30	0.15
26-03-90	107.00	3.43	90.03	0.20	0.02	7.60	2.30	0.13
29-03-90	108.00	3.53	70.71	0.21	0.04	7.10	2.10	0.12
01-04-90	122.00	3.45	63.38	0.21	0.03	7.70	2.10	0.12
04-04-90	125.00	3.42	62.27	0.19	0.03	6.90	2.40	0.10
07-04-90	108.00	3.36	82.83	0.21	0.02	6.40	2.50	0.11
10-04-90	90.00	3.28	92.59	0.20	0.03	6.00	2.70	0.10
13-04-90	123.00	3.47	91.71	0.19	0.02	5.90	2.92	0.09
16-04-90	105.00	3.30	86.29	0.19	0.03	6.50	2.97	0.08
19-04-90	118.00	3.49	88.72	0.18	0.03	5.20	2.50	0.09
Hard water (C)								
24-04-90	110.00	2.80	41.02	0.25	0.03	13.40	3.24	0.30
27-04-90	121.00	2.97	78.72	0.18	0.02	8.00	2.98	0.19
30-04-90	120.00	3.25	88.25	0.15	0.02	7.60	3.21	0.12
02-05-90	125.00	3.37	73.06	0.17	0.02	7.20	3.00	0.14
05-05-90	122.00	3.35	65.88	0.19	0.02	7.70	3.20	0.11
08-05-90	110.00	3.36	66.70	0.16	0.03	7.60	3.80	0.12
11-05-90	115.00	3.26	51.96	0.15	0.02	8.10	3.70	0.10
14-05-90	122.00	3.34	45.59	0.16	0.02	7.70	3.80	0.17
17-05-90	120.00	3.35	51.96	0.15	0.02	8.10	3.80	0.22
20-05-90	120.00	3.35	51.06	0.21	0.03	6.10	3.80	0.20
23-05-90	118.00	3.35	72.06	0.29	0.03	6.20	3.88	0.18
26-05-90	138.00	3.30	61.24	0.23	0.02	8.90	3.90	0.19
29-05-90	90.00	3.29	41.93	0.26	0.03	9.50	4.10	0.20
01-06-90	100.00	3.27	61.36	0.25	0.02	9.10	4.00	0.13
04-06-90	122.00	3.35	59.96	0.29	0.03	9.16	3.80	0.12
07-06-90	125.00	3.38	51.94	0.26	0.02	9.30	3.70	0.12
Natural water (E)								
29-07-90	60.00	3.00	80.50	0.25	0.06	20.20	4.25	0.38
01-08-90	88.00	3.33	95.00	0.20	0.07	18.20	4.55	0.28
04-08-90	75.00	3.25	75.00	0.21	0.08	14.60	5.00	0.24
07-08-90	85.00	3.33	86.00	0.21	0.08	14.60	4.30	0.24
10-08-90	80.00	3.10	83.00	0.23	0.08	17.00	4.65	0.27
Natural water (F)								
13-08-90	110.00	3.35	81.60	0.22	0.04	7.50	2.76	0.20
16-08-90	120.00	3.55	83.60	0.20	0.03	7.10	1.78	0.12
13-08-90	99.00	3.35	81.60	0.22	0.04	7.50	2.76	0.20
16-08-90	120.00	3.55	83.60	0.20	0.03	7.10	1.78	0.12

\* 50 ml of the treated water was added every day with exception during the dry period.  
 \* Out = The amount of the eluate.

## **Appendix VI**

Correlation matrix analysis of water chemistry data for Coombes Clough.

	SWD	Rein	SS	pH	Fe	Mn	Al	Ca	Mg	Tem-V	Rain3c	Rain7c
Colour	-0.40	0.52	0.28	-0.31	0.79	0.59	0.61	-0.43	-0.70	-0.01	0.61	0.55
	*	*	N.S	N.S	*	*	*	*	*	N.S	*	*
SWD		-0.24	-0.08	0.15	-0.32	-0.23	-0.23	0.36	0.26	0.75	-0.23	0.14
		N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	*	N.S	X
		Rain	0.69	-0.12	0.83	0.65	0.17	-0.14	-0.54	0.19	0.92	0.76
			*	N.S	*	*	N.S	N.S	*	N.S	*	*
			SS	0.24	0.63	0.14	0.10	0.13	-0.22	0.30	0.6	0.37
				N.S	*	N.S	N.S	N.S	N.S	N.S	*	N.S
					-0.25	-0.22	-0.39	0.22	0.20	0.28	-0.16	-0.30
				pH	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S
					Fe	0.57	0.55	-0.25	-0.62	0.13	0.82	0.70
						*	*	N.S	*	N.S	*	*
						Mn	0.32	-0.21	-0.56	-0.06	0.62	0.48
							N.S	N.S	*	N.S	*	*
							Al	-0.30	-0.48	0.10	0.20	0.26
								N.S	*	N.S	N.S	N.S
								Ca	0.56	0.31	-0.26	-0.38
									*	N.S	N.S	N.S
									Mg	-0.10	-0.58	-0.53
										N.S	*	*
										Tem-V	0.81	0.17
											N.S	N.S
											Rain3c	0.77
												*

S.N = Not significant  
\* =  $p < 0.05$

Correlation matrix analysis of water chemistry data for Crowden Brook.

	SMO	Rain	SS	pH	Fe	Mn	Al	Ce	Mg	Tem-U	Rain3c	Rain7c
Colour	0.15	-0.04	-0.13	0.04	0.10	0.29	0.09	-0.27	-0.38	0.03	0.12	0.08
	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S
SMO		-0.25	0.09	0.32	-0.06	-0.27	0.06	0.43	0.33	0.82	-0.09	-0.11
		N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	*	N.S	N.S
Rain			-0.13	-0.53	-0.13	0.19	0.41	-0.46	-0.33	-0.27	0.73	0.84
			N.S	*	N.S	N.S	N.S	*	N.S	N.S	*	*
SS				-0.13	-0.16	-0.47	0.15	-0.10	0.39	0.12	-0.05	-0.05
				N.S	N.S	*	N.S	N.S	N.S	N.S	N.S	N.S
pH					-0.30	-0.57	-0.50	0.36	0.47	0.41	-0.34	-0.58
					N.S	*	*	N.S	*	N.S	N.S	*
Fe						0.55	0.32	0.47	-0.40	-0.04	0.04	-0.01
						*	N.S	*	N.S	N.S	N.S	N.S
Mn							0.40	-0.17	-0.57	0.45	0.31	0.29
							N.S	N.S	*	*	N.S	N.S
Al								-0.21	-0.28	0.04	0.58	0.53
								N.S	N.S	N.S	*	*
Ce									0.30	0.52	-0.28	-0.42
									N.S	*	N.S	N.S
Mg										0.49	-0.20	-0.20
										*	N.S	N.S
Tem-U											-0.08	-0.06
											N.S	N.S
Rain3c												0.71
												*

Correlation matrix analysis of water chemistry data for Woodhead Bridge.

	SMO	Rain	SS	pH	Fe	Mn	Al	Ca	Mg	Tem-W	Rain3c	Rain7c
Colour	-0.29	0.52	0.61	-0.17	0.17	-0.12	0.52	-0.64	-0.28	-0.26	0.66	0.63
	N.S	*	*	N.S	N.S	N.S	*	*	N.S	N.S	*	*
		-0.13	-0.18	0.31	-0.33	-0.72	-0.09	0.41	0.20	0.86	-0.04	-0.03
SMO		N.S	N.S	N.S	N.S	*	*	N.S	N.S	*	N.S	N.S
			0.53	-0.54	0.08	-0.02	0.67	-0.28	-0.36	-0.13	0.66	0.82
			*	*	N.S	N.S	*	N.S	N.S	N.S	*	*
				-0.36	0.61	0.02	0.57	0.00	0.18	-0.07	0.88	0.56
				N.S	*	N.S	*	N.S	N.S	N.S	*	*
					-0.32	-0.48	-0.65	0.14	0.21	0.37	-0.26	-0.53
					N.S	*	*	N.S	N.S	*	N.S	*
						0.38	0.36	0.17	0.21	-0.20	0.30	0.17
						*	N.S	N.S	N.S	N.S	N.S	N.S
							0.24	-0.11	-0.14	-0.71	-0.29	-0.10
							N.S	N.S	N.S	*	N.S	N.S
								-0.32	-0.41	-0.49	0.55	0.57
								N.S	*	*	*	*
									0.52	0.43	-0.11	-0.32
									*	*	N.S	N.S
									Mg	0.23	-0.07	-0.30
										N.S	N.S	N.S
										Tem-W	0.01	0.02
											N.S	N.S
											Rain3c	0.69
												*



Correlation matrix analysis of water chemistry data for Longside Clough.

	SHD	Rain	SS	pH	Fe	Mn	Al	Ca	Mg	Tem-W	Rain3c	Rain7c
Colour	-0.04	0.00	0.46	-0.36	0.67	0.06	0.44	-0.16	-0.26	-0.11	0.39	0.11
	N.S	N.S	*	N.S	*	N.S	N.S	N.S	N.S	N.S	N.S	N.S
SHD		-0.26	0.23	0.37	0.16	0.58	-0.16	0.47	0.62	0.84	-0.11	-0.15
		N.S	N.S	N.S	N.S	*	N.S	*	*	*	N.S	N.S
			-0.09	-0.63	-0.06	-0.30	0.39	-0.49	-0.43	-0.23	0.74	0.83
			N.S	*	N.S	N.S	N.S	*	N.S	N.S	*	*
				-0.36	0.76	0.12	0.71	0.06	-0.04	0.36	-0.01	0.02
				N.S	*	N.S	*	N.S	N.S	N.S	N.S	N.S
					-0.43	0.11	-0.77	0.59	0.64	0.30	-0.46	-0.68
					N.S	N.S	*	*	*	N.S	*	*
							0.63	0.16	-0.17	0.11	0.09	0.05
							*	N.S	N.S	N.S	N.S	N.S
							0.01	0.25	0.48	0.33	-0.27	-0.18
							N.S	N.S	*	N.S	N.S	N.S
								-0.42	0.42	-0.19	0.23	0.39
							Al	N.S	N.S	N.S	N.S	N.S
								N.S	N.S	N.S	N.S	N.S
								Ca	0.64	0.48	-0.25	-0.44
									*	*	N.S	N.S
									Mg	0.60	-0.17	-0.28
										*	N.S	N.S
										Tem-W	-0.08	0.06
											N.S	N.S
											Rain3c	0.71
												*

Correlation matrix analysis of water chemistry data for Torside Clough.

	SMD	Rein	SS	pH	Fe	Mn	Al	Ca	Mg	Temp-W	Rein3c	Rein7c
Colour	-0.29	0.28	0.15	-0.70	0.76	0.53	0.71	-0.26	-0.13	-0.23	0.29	0.36
	N.S	N.S	N.S	*	*	*	*	N.S	N.S	N.S	N.S	N.S
SMD		-0.11	-0.18	0.32	-0.37	-0.40	-0.26	0.59	0.06	0.86	-0.07	0.01
		N.S	N.S	N.S	N.S	N.S	N.S	*	N.S	*	N.S	N.S
Rein			0.12	-0.50	0.10	-0.40	0.49	-0.45	-0.03	-0.11	0.53	0.72
			N.S	*	N.S	N.S	*	*	N.S	N.S	*	*
SS				-0.15	0.66	-0.14	0.39	-0.22	0.91	-0.03	0.29	0.04
				N.S	*	N.S	N.S	N.S	*	N.S	N.S	N.S
pH					-0.44	-0.59	-0.62	0.37	0.15	0.22	-0.36	-0.52
					*	*	*	N.S	N.S	N.S	N.S	*
Fe						0.24	0.63	-0.24	0.45	0.20	0.26	0.18
						N.S	*	N.S	*	N.S	N.S	N.S
Mn							0.31	-0.51	-0.40	-0.37	0.16	0.55
							N.S	*	N.S	N.S	N.S	*
Al								-0.45	0.16	-0.08	0.56	0.50
								*	N.S	N.S	*	*
Ca									0.04	0.57	-0.25	-0.38
									N.S	*	N.S	N.S
Mg										0.13	0.09	0.09
										N.S	N.S	N.S
Temp-W											-0.01	-0.07
											N.S	N.S
Rein3c												0.49
												*

Correlation matrix analysis of water chemistry data for Ogden Clough.

	SHD	Rain	SS	pH	Fe	Mn	Al	Ca	Mg	Temp-U	Rain3c	Rain7c
Colour	-0.29	0.43	0.28	0.10	0.62	0.28	0.47	-0.14	-0.36	0.01	0.45	0.29
	N.S	*	N.S	N.S	*	N.S	*	N.S	N.S	N.S	*	N.S
SHD		-0.26	-0.18	0.17	-0.19	0.35	-0.10	0.18	0.28	0.75	-0.26	-0.19
		N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	*	N.S	N.S
		Rain	0.94	-0.44	0.68	0.38	0.07	-0.21	-0.47	0.75	0.92	0.75
			*	*	*	N.S	N.S	N.S	*	*	*	*
			SS	-0.41	0.57	0.31	0.06	-0.09	-0.33	0.21	0.82	0.63
				N.S	*	N.S	N.S	N.S	N.S	N.S	*	*
				pH	-0.09	-0.37	-0.22	0.47	0.59	-0.04	-0.49	-0.58
					N.S	N.S	N.S	*	*	N.S	*	*
					Fe	0.44	0.09	0.10	-0.33	0.27	0.67	0.36
						*	N.S	N.S	N.S	N.S	*	N.S
						Mn	0.18	-0.16	-0.50	-0.14	0.40	0.30
							N.S	N.S	*	N.S	N.S	N.S
							Al	0.16	-0.13	-0.01	0.05	0.13
								N.S	N.S	N.S	N.S	N.S
								Ca	0.64	0.20	-0.26	-0.37
									*	N.S	N.S	N.S
									Mg	-0.07	-0.49	-0.39
										N.S	*	N.S
										Temp-U	0.16	0.14
											N.S	N.S
											Rain3c	0.77
												*

Correlation matrix analysis of water chemistry data for 1987 at Arnfield works.

	SMD	Reln	pH	Fe	Mn	Al	Temp-W	Temp-A	Turbidity	Reln3c	Rain7c
Colour	-0.32	0.01	0.07	0.63	0.04	0.10	0.04	-0.23	0.76	-0.12	-0.01
	*	N.S	N.S	*	N.S	N.S	N.S	*	*	N.S	N.S
SMD		-0.22	0.03	-0.40	-0.06	0.12	0.34	0.41	-0.46	-0.34	-0.35
		*	N.S	*	N.S	N.S	*	*	*	*	*
		Reln	0.19	0.22	0.32	-0.10	0.05	-0.01	-0.02	0.15	0.11
			*	*	*	N.S	N.S	N.S	N.S	*	N.S
			pH	0.07	0.02	0.02	0.02	0.03	0.07	-0.05	-0.09
				N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S
				Fe	0.60	-0.05	0.08	-0.20	0.64	-0.01	-0.02
				*	*	N.S	N.S	*	*	N.S	N.S
				Mn		-0.14	-0.01	-0.05	0.02	0.07	0.05
						N.S	N.S	N.S	N.S	N.S	N.S
						Al	0.29	0.22	-0.02	0.08	-0.04
							*	*	N.S	N.S	N.S
							Temp-W	0.66	-0.27	0.10	0.10
								*	*	N.S	N.S
								Temp-A	0.41	0.06	0.07
									*	N.S	N.S
									Turbidity	-0.16	-0.06
									*	*	N.S
										Reln3c	0.62
										*	*

Correlation matrix analysis of water chemistry data for 1988 at Arnfield works.

	SHD	Colour	pH	Fe	Mn	Al	Temp-U	Temp-A	Turbidity	Rain3c	Rain7c
	-0.46	0.03	-0.05	0.00	0.02	0.15	-0.22	-0.24	0.42	0.07	0.13
	*	N.S	N.S	N.S	N.S	*	*	*	*	N.S	N.S
SHD		-0.20	-0.29	0.23	-0.11	-0.16	0.42	0.37	-0.30	-0.25	-0.36
		*	*	*	N.S	*	*	*	*	*	*
		Rain	0.02	-0.02	-0.04	-0.08	0.06	0.13	-0.10	0.21	0.16
			N.S	N.S	N.S	N.S	N.S	N.S	N.S	*	*
				0.24	-0.01	-0.35	0.60	0.49	-0.30	-0.05	-0.12
				*	N.S	*	*	*	*	N.S	N.S
				Fe	0.10	-0.34	0.39	0.27	-0.01	0.15	0.10
					N.S	*	*	*	N.S	*	N.S
						0.05	-0.01	-0.07	-0.02	-0.09	-0.14
					Mn	N.S	N.S	N.S	N.S	N.S	*
						Al	-0.52	-0.45	0.28	-0.10	-0.14
							*	*	*	N.S	*
							Temp-U	0.84	-0.09	-0.05	-0.05
								*	N.S	N.S	N.S
							Temp-A		-0.06	-0.01	-0.03
									N.S	N.S	N.S
									Turbidity	0.01	-0.05
										N.S	N.S
										Rain3c	0.35
											*

Correlation matrix analysis of water chemistry data for 1989 at Arnfield works.

	SMO	Rain	pH	Fe	Mn	Al	Temp-W	Temp-A	Turbidity	Rain3c	Rein7c
Colour	-0.27	-0.28	-0.01	0.35	0.12	0.40	-0.41	-0.37	0.42	-0.03	-0.02
	N.S	N.S	N.S	*	N.S	*	*	*	*	N.S	N.S
	SMO	-0.22	0.35	0.39	-0.23	-0.72	0.90	0.75	-0.32	-0.20	-0.29
		N.S	*	*	N.S	*	*	*	*	N.S	N.S
		Rain	-0.19	-0.29	0.12	-0.01	-0.20	0.01	-0.28	0.22	0.09
			N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S
			pH	0.19	-0.28	-0.21	0.41	0.26	0.08	0.01	-0.01
				N.S	N.S	N.S	*	N.S	N.S	N.S	N.S
				Fe	0.30	-0.02	0.27	0.04	0.45	-0.09	-0.21
					N.S	N.S	N.S	N.S	*	N.S	N.S
					Mn	0.09	-0.16	-0.26	0.45	-0.16	-0.23
						N.S	N.S	N.S	*	N.S	N.S
						Al	-0.70	-0.65	0.51	0.02	0.15
							*	*	*	N.S	N.S
							Temp-W	0.82	-0.31	-0.09	-0.22
								*	N.S	N.S	N.S
								Temp-A	-0.46	-0.19	-0.18
									*	N.S	N.S
									Turbidity	0.07	0.17
										N.S	N.S
										Rain3c	0.74
											*

Correlation matrix analysis of water chemistry data for 1990 at Arnfield works.

	SHO	Colour	pH	Fe	Mn	Al	Temp-W	Temp-A	Turbidity	Rain3c	Rain7c
	-0.25	-0.18	-0.18	0.09	0.52	0.41	-0.43	-0.38	0.33	-0.05	0.15
	N.S	N.S	N.S	N.S	*	*	N.S	N.S	N.S	N.S	N.S
		-0.20	0.11	0.21	-0.64	-0.50	0.87	0.63	-0.51	-0.36	-0.37
		N.S	N.S	N.S	*	*	*	*	*	N.S	*
			0.46	-0.22	-0.18	-0.10	-0.08	-0.11	0.08	0.40	0.19
			*	N.S	N.S	N.S	N.S	N.S	N.S	*	N.S
				-0.21	-0.33	-0.32	0.14	0.09	-0.20	0.26	0.13
			pH	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S
				N.S	-0.12	-0.21	0.32	0.18	-0.06	-0.20	-0.15
				Fe	*	*	*	*	N.S	N.S	N.S
					Mn	0.48	-0.69	-0.51	0.44	0.01	0.22
						*	*	*	*	N.S	N.S
						Al	-0.60	-0.44	0.48	0.42	0.53
							*	*	*	*	*
							Temp-W	0.77	-0.41	-0.32	-0.41
								*	*	N.S	*
							Temp-A	-0.07	-0.07	-0.30	-0.32
								N.S	N.S	N.S	N.S
								Turbidity	0.49	0.65	0.61
									*	*	*
									Rain3c	0.61	*