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Natural Environment Research Council

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Executive summary

This report is based on extensive records collected by the Tweed River Purification Board and details results from a regional analysis of water quality in the Tweed river catchment. The work is part of the rivers component of the NERC Land Ocean Interaction Study which seeks to understand and quantify the movement of chemicals from the rivers to the sea. The report emphasises the research value of routine water quality data as collected by the River Purification Boards and the National Rivers Authority. These data are a national resource, far more extensive than specific research programmes can provide. However, making good use of such vast information resources is not easy. There are very few publications describing broad water quality characteristics at the regional scale: this report attempts to redress this imbalance. Simple analytical and graphical tools have been developed to aid regional description and here they are used to provide a regional overview for the Tweed river basin.

The Tweed is a rural river system in the eastern Scottish Borders south of Edinburgh. The area is agricultural, ranging from upland areas of moorland and rough pasture used for hill sheep farming, to arable regions in the lowlands where cereal crops are grown. The population is about 100,000 and industry is limited to a few small towns such as Hawick, Galashiels, Selkirk and Jedburgh. The Tweed and its tributaries are clean and unpolluted with only minor stretches below Class 1 status. Eutrophication can occur in some small lowland watercourses, and diatom growth on the lower Tweed can be significant. Accidental pollution, often related to agricultural or industrial practices, occasionally causes fish kills. The Tweed river is a highly managed system and legislative and economic policies play an important role in determining the water quality.

Extensive water quality records have been collected by the Tweed River Purification Board (Tweed RPB). Samples from rivers and discharges from sewage works, landfill sites and industry have been analysed for a wide range of determinands. The report is based on data from 1985 to 1994. Particular emphasis is placed on providing a regional perspective using a graphical approach. The river water quality has been interpreted in relation to catchment geography and to the observed point source inputs to the catchment.

For many determinands, both diffuse and point sources contribute to the overall riverine load, but to varying degrees. The importance of diffuse and point sources can be established by analysing the data. Point inputs are important sources of many determinands (e.g. phosphate, most metals and many micro-organics) and, in some cases, make a significant contribution to the overall riverine load (e.g. copper and lead). Diffuse agricultural sources are particularly important in lowland arable areas (e.g. for nitrate, phosphate and micro-organics). In addition, widespread geological sources contribute to loads of metals such as iron and zinc. Regional regression analysis suggests that spatial variations can be formally linked to land use and other factors.

Sewage effluent is the most significant source of many pollutant chemicals in the Tweed river basin. The quality of sewage effluent is regulated by consent conditions. Around 87% of sewage treatment works currently meet consent conditions and this figure is rising. Biochemical oxygen demand, nitrate, total ammonia, chloride and phosphate are high in sewage effluent relative to background river concentrations. This is due to the biodegradable load from faecal matter in domestic effluent plus trade efflent from industries such as food processing and textiles. Wastes from the electronics industry cause heavy metal pollution at some sites especially Selkirk and Galashiels. Changes in metal discharges have occurred over time as a result of changes in legislation, improved facilities (either at the sewage treatment works or as part of industrial processing) and a changing industrial base. An example is Selkirk where copper and chromium have declined whilst iron and lead have increased. In sewage effluent, organic chemicals, e.g. a mothproofing agent and some pesticide residues, have a mainly industrial source. Micro-organics in sewage effluent are site specific and, as with metals, there have been changes over time for some species.

Direct industrial discharges are very limited as a result of the Tweed RPB's active policy of encouraging, where possible, the connection of industrial wastes to the local authority sewers. Landfill sites have relatively little impact on water quality. Fish farms cause depletion of dissolved oxygen levels and increases in suspended solids and total ammonia but these have little impact on water quality.

The results from the Tweed provide important background information against which better interpretation of more industrially based river systems can be made. This is important for issues such as the reduction of chemical loads to the North Sea. The analysis of data sets such as these provides important insights into the dominant factors affecting water quality and the relative importance of point and diffuse inputs.

Foreword

Since its formation in 1953 the Tweed River Purification Board has achieved very significant improvements in the quality of the Tweed and its tributaries, whilst always maintaining the focus on the changing demographical, agricultural, industrial and legislative pressures. At the present time 99.7% of the rivers within the Board's area are now of the highest quality (Class 1) with only minor stretches of fairly good quality (Class 2); there are no rivers of Class 3 or 4 quality. The Board's long standing culture has been pollution prevention and a key element of its Mission Statement refers specifically to prevention. The Board's strategy has been largely based on the quantification of pollution sources so that any improvements required have been on the basis of sound water quality and hydrological data derived from and supported by its comprehensive sampling, monitoring and measurement programme.

This report brings together the wealth of chemical, hydrological and water management information collected by the Board. It presents the detailed scientific examination of that data within the context of a major UK community wide research initiative, LOIS (Land Ocean Interaction Study). In this respect, the process of examining such a major record and relating this to the accumulated knowledge of the Board's technical officers has been a major achievement and of credit to all concerned. Such is the advance in computing power, database development and software packages that the data analysis within the report would not have been possible even five years ago. As a consequence of all this, the study provides the most comprehensive analysis of water quality of the Tweed ever undertaken. It endorses the monitoring strategy of the Board and strengthens the case for programmes such as LOIS. One of the purposes of looking at the Tweed was to examine a catchment which was in relatively pristine condition and the influence of those issues which impinge upon it - I believe the range of data presented, its background and its significance, fully justifies that purpose. Most importantly the report points the way to future monitoring and research goals which hopefully will strengthen the link between the newly forming Environment Protection Agencies and the Natural Environment Research Council.

J C Currie
Director and River Inspector
Tweed River Purification Board

***Front cover**: photograph shows the Tweed above Galafoot (A J Robson).*

Contents

1 Introduction

This report describes the water quality of the Tweed river and its tributaries. There are two main objectives. The first is to present and interpret regional variations in water quality for the Tweed. For this a comprehensive analysis of contemporary conditions is included. The second objective is to describe the exploration and development of methods that are effective for investigating extensive water quality data sets.

The study is set against a background of general recognition that regional water quality data resources are largely under-used (e.g. Royal Commission, 1992). Very few UK publications address water quality at the regional level, yet such information is required for planning and research. The development of powerful modern computer resources make such analyses realistic, but new approaches must be developed to allow large quantities of data to be rapidly and effectively assimilated. The graphical techniques developed and used here show some examples of how data can be studied and presented. They have wide applicability and would provide new and valuable information if applied to other water quality records.

The Tweed catchment is part of the study area of the Land Ocean Interaction Study (LOIS). Within the LOIS programme the transport of chemicals by rivers in the North East UK is being studied at a regional level. The Tweed is an important component of LOIS because it is one of the major UK rivers entering the North Sea. The Tweed drains a rural, sparsely populated region: a stark contrast to the other main study area, the Humber system, where high population and levels of industrial activity give rise to much greater pollutant loads. For the LOIS region, water quality changes over time will be modelled in relation to the impacts of land use, urban development and industrial renewal/decay. For such modelling to be undertaken, it is necessary to have a sound appreciation of the current situation. An essential starting point is to bring together and assess existing data on a regional scale. Such an analysis enables modelling work to focus in on key processes and main concerns. In addition, it provides scope for adapting sampling programmes to collect data that address gaps in knowledge and that assist the modelling programme as fully as possible.

Extensive water quality data collected and analysed by the Tweed River Purification Board (Tweed RPB) form the base of this report. The document provides a summary of relevant background information about the catchment and the determinands that have been measured. It summarises regional patterns of water quality for a comprehensive range of determinands, examines the causes of the observed patterns, and assesses the relative importance of diffuse background inputs and point discharges. It is intended that the report will provide an important reference document for use in future hydrochemical studies.

2 *Background description of the Tweed catchment*

2.1 Landscape, climate and population

The River Tweed drains the eastern slopes of the Scottish Southern Uplands. It rises on the slopes of Broad Law and Hart Fell and flows over 160 km to reach the Tweed estuary at Berwick upon Tweed (Figure 2.1). The Tweed has a large catchment area (approximately 4400 km² at Norham). Elevations range from over 800 m in the hills down to sea-level at the coast (Figure 2.2). There is a high proportion of upland ground in the catchment: it is bounded to the North by the Moorfoot, Pentland and Lammermuir hills, and to the South by The Cheviot. The catchment contains two Environmentally Sensitive Areas (Central Southern Uplands and Central Borders), and numerous Sites of Special Scientific Interest (SSSI); the River Tweed and parts of some tributaries are a notified SSSI. Most of the Tweed catchment area lies in Scotland, but the River Till, which joins the Tweed upstream of Norham, flows from Northern England, draining the Cheviot and its foothills.

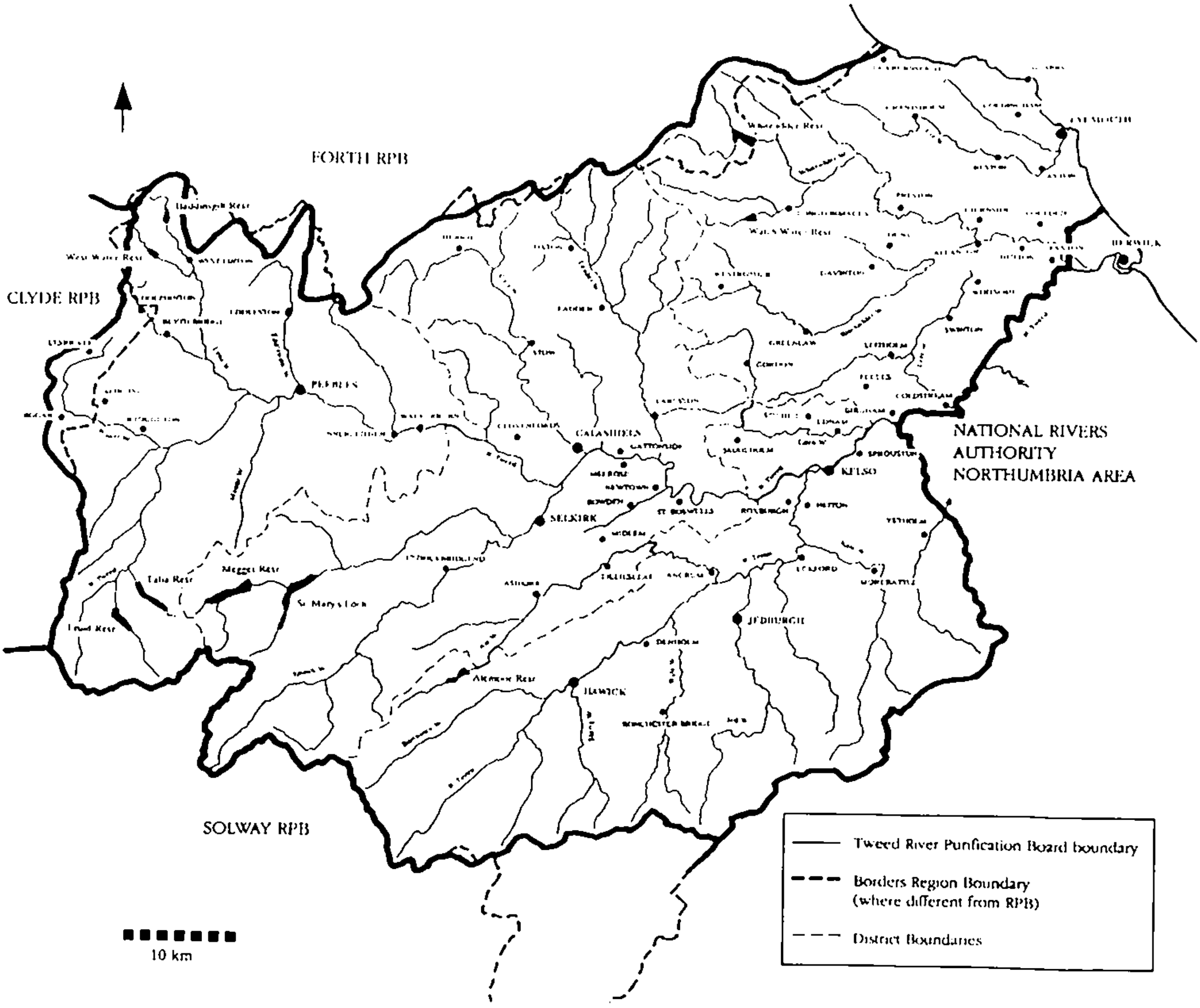


Figure 2.1 Map of the Tweed River Purification Board area.

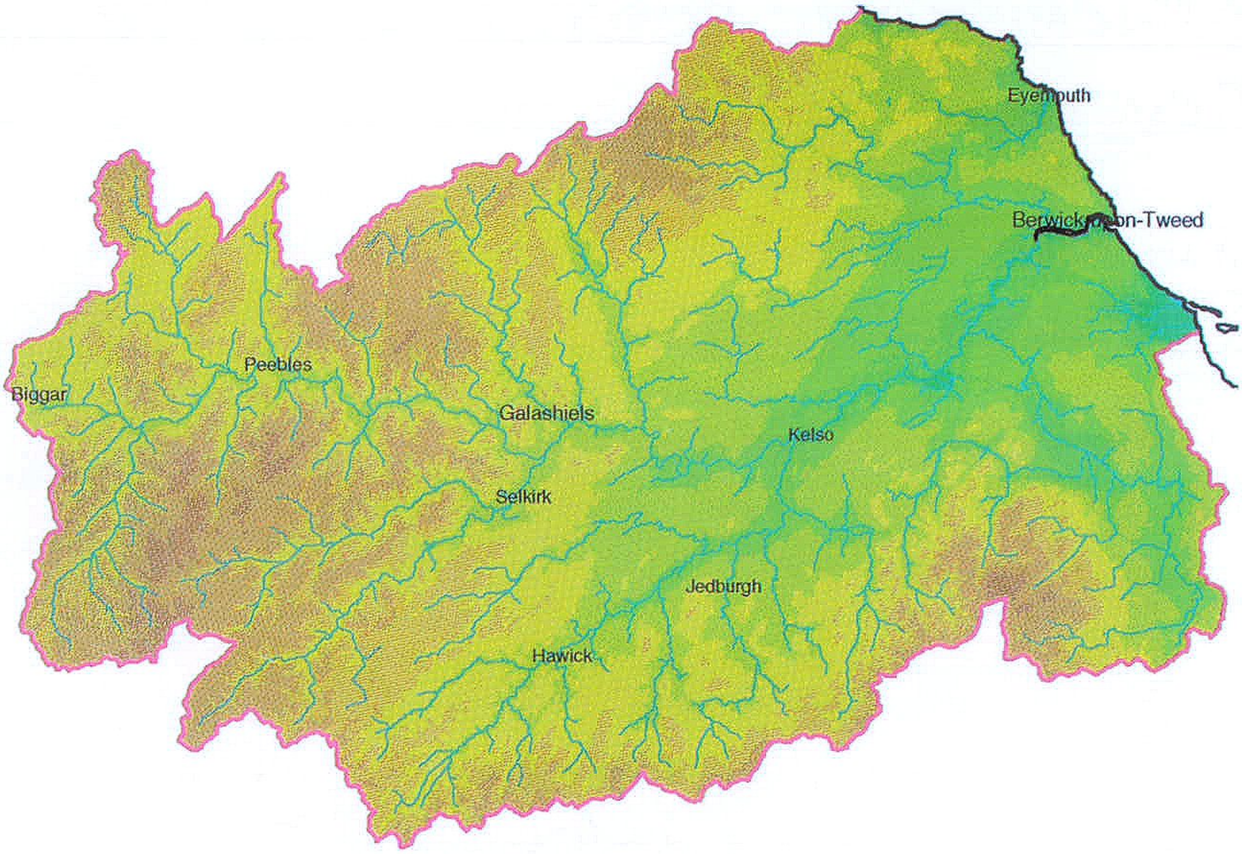


Figure 2.2 *The topography of the Tweed river basin.*

The climate is cool and temperate. Average MORECS monthly temperatures range from around 1°C in January to 13°C in August. Average rainfall over the whole catchment is 969 mm yr^{-1} (1961– 90; Tweed RPB, 1992) but there is a substantial variation within the region (Table 2.1). The highest average rainfalls are in the uplands and the lowest are in the low-lying eastern catchments (Figure 2.3). Because of the extent and topographic variation of the Tweed catchment, substantial year to year variations in annual rainfall occur across the area. For example, in 1991 upper Tweeddale received 120% of the 1941 – 1970 average, whilst Eastern Berwickshire and the foothills of the Cheviot received less than 80% of the average. Mean annual flow for the Tweed is 73 cumecs at Norham, which equates to an average annual runoff of 555 mm yr^{-1} (Institute of Hydrology, 1993; see Fox, 1989 for further hydrological details). As with rainfall, annual runoff varies widely across the catchment, highest and lowest values coinciding with high and low rainfall inputs. This in turn results in variable evapotranspiration losses (Table 2.1; Figure 2.4).

Table 2.1 *Variations in long period average rainfall and runoff across the Tweed catchment. Data: Institute of Hydrology, 1993.*

	Wettest gauged catchment (Ettrick Water)	**Driest gauged catchment (Leet Water)**	**Average for whole Tweed (Norham)**
Rainfall (mm)	1891	652	969
Runoff (mm)	1537	236	555
Percentage loss (%)	19	64	44

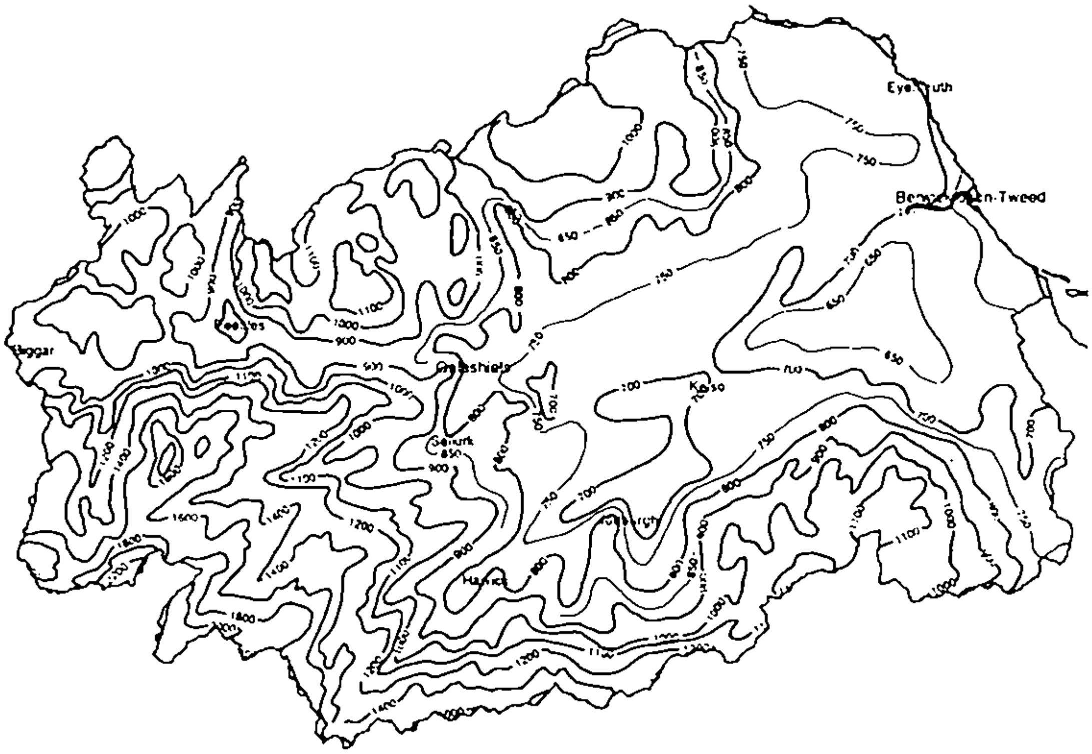


Figure 2.3 *Standard annual average rainfall (mm), 1941-1970, for the Tweed catchment.*

The geology of the area includes a large proportion of Ordovician and Silurian greywackes, shales and mudstones (Figure 2.5). These rocks form the hills to the North and West as well as a low plateau in the upper part of the Teviot basin. In the lowlands there are Old Red Sandstones and, nearer the coast and in northern England, Carboniferous sedimentary rocks. The Cheviot hills to the south are of volcanic origin. Soils are well drained brown earths in the lowlands with podzols on the higher land (peaty podzols and humus-iron podzols). On the hill tops there are peats and, on the southern slopes, gleyed soils are common. Soil properties have been characterised using a hydrologically based classification system HOST (Hydrology of Soil Types; Boorman *et al.*, 1995).

The land cover of the Tweed catchment is diverse (Figure 2.6), ranging from heather moorlands on the hills, through improved pastures on lower slopes, to rich agricultural lands in the warmer dryer lowlands (Fuller, 1993; Figure 2.7, Tables 2.2 and 2.3). Conifer plantations now occupy 16% of the land, an increase from 11% in 1983 and from 3% in 1945 (Borders Regional Council, 1991, 1994). Plantations are predominantly located on the hills to the south and west of the region and include Wauchope forest, Craik forest and sites generally west of Innerleithen. In 1993, around 180 thousand hectares of land were used for crops and grass (a high proportion for Scotland; MLURI, 1988), and 204 thousand hectares for rough grazing (Borders Regional Council, 1994).

Table 2.2 *Land cover types (Scottish Office, 1992, 1994)*

Land cover types (%)	
Arable	18
Improved grassland	26
Rough grassland	16
Heather/peatland	10
Woodland (mostly coniferous)	16
Urban/rural development	1
Mosaic (i.e. mixtures)	11

Figure 2.4 *Average annual evaporation in the Tweed catchment (mm) (Natural Environment Research Council).*

The main arable crops are barley, wheat, oats, oilseed rape and potatoes though relative proportions are variable and agricultural practices are constantly changing in the catchment (see Table 2.4). The 1970's saw increased cereal production, with a move to winter cereals in the 1980's and some development of fields higher up in the catchments; this trend has now been reversed with fields returning to grassland. Over the last decade the area used for growing wheat has increased, whilst barley acreage has dropped. Numbers of sheep, the largest livestock group, have increased and there has been substantial growth in poultry farming.

Table 2.3 *Agricultural capabilities (MLURI, 1988; Bown and Shipley, 1992).*

MLURI agricultural capabilities (%)		
Class 2	(Wide crop range)	<4
Class 3	(Moderate crop range)	20
Class 4	(Narrow crop range)	17
Class 5	(Improved grassland)	30
Class 6	(Rough grazing)	30

Table 2.4 *Agricultural usage in the Tweed (Borders Regional Council, 1994).*

	1983	**1993**	**Percentage change since 1983**
Crop areas (ha x1000)			
Wheat	10.5	20.9	99
Barley	53.8	29.1	-46
Oats	1.9	2.9	51
Rape	1.2	6.8	428
Potatoes	2.4	1.8	-24
Livestock numbers (x1000)			
Cattle	160	148	-8
Sheep	1263	1474	17
Pigs	23	21	-7
Poultry	631	1113	76

The Tweed is a sparsely populated, rural catchment. The largest centres of population are small towns such as Hawick, Galashiels and Selkirk (populations 16 000, 14 000 and 6000, respectively: data from the 1991 census). There are also numerous villages and hamlets scattered across the area. The total population of the Borders area is around 100 000, with an average population density of 22 heads km^{-2} which is less than a tenth of the UK average, 232 heads km^{-2}. The total urban area of the Borders region is 49 km^{2} (the Borders region covers a similar but not identical geographical area to the Tweed catchment).

Around 30 water treatment plants together supply 36 Ml day^{-1} to the public and a further 5 Ml day^{-1} (1992) to large industrial users (a decline from 8 Ml day^{-1} in 1990). Private boreholes extract substantial quantities of water for industrial use (in excess of 10 Ml day^{-1}). A few direct abstractions are made from the main rivers for both industrial use and for agricultural irrigation. The largest industrial abstraction is for a non-woven cellulose fibre mill: Dexter Nonwovens (9 Ml day^{-1}). The Tweed itself is not used for direct abstraction for public drinking water; supplies are taken from reservoirs and some boreholes. There are a number of direct supply reservoirs in the area. Conservation water releases to the rivers from these reservoirs (including a system of discrestionary freshets/block-grants) are invaluable in maintaining the quality of the river system. The freshets etc. are generally released in dry weather when flows are very low and water temperatures and algal activity are high, or when particular pollution problems occur (e.g. historical fibre accumulation below Dexter Nonwovens) on Whiteadder Water.

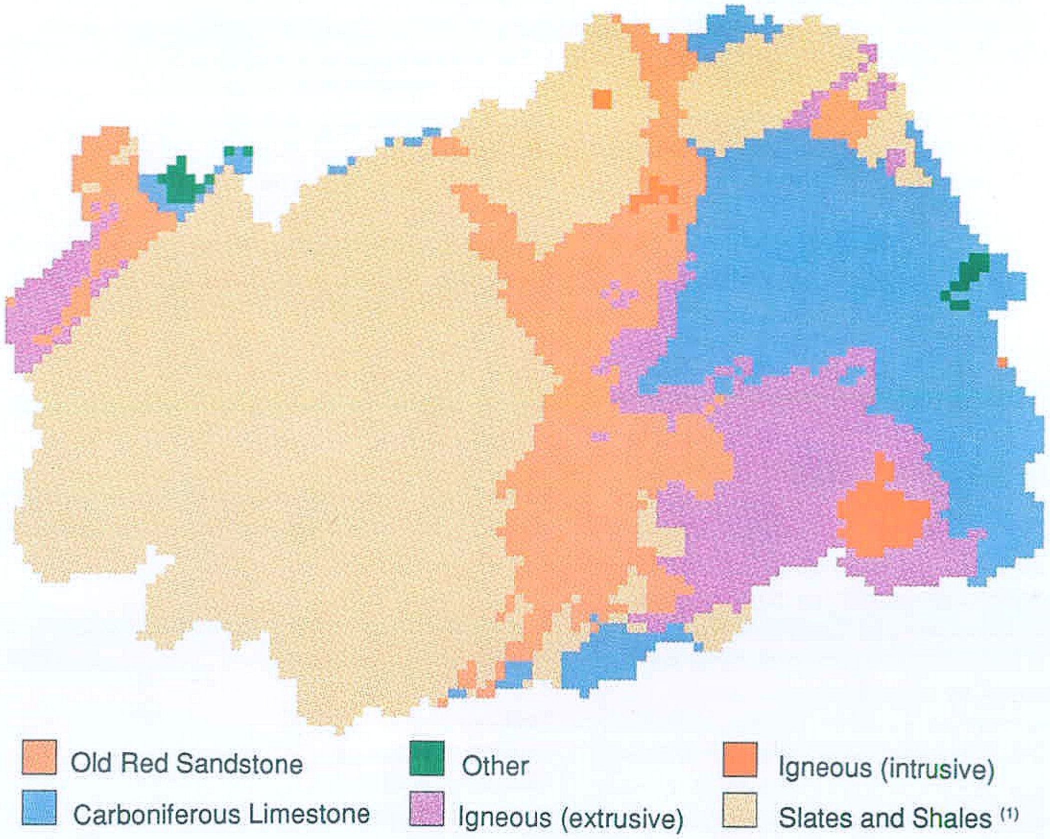


Figure 2.5 *Geology of the Tweed Catchment. (1)Silurian and Ordovician. Data are taken from the 1 km British Geological Survey map of the geology of the UK, 1990.*

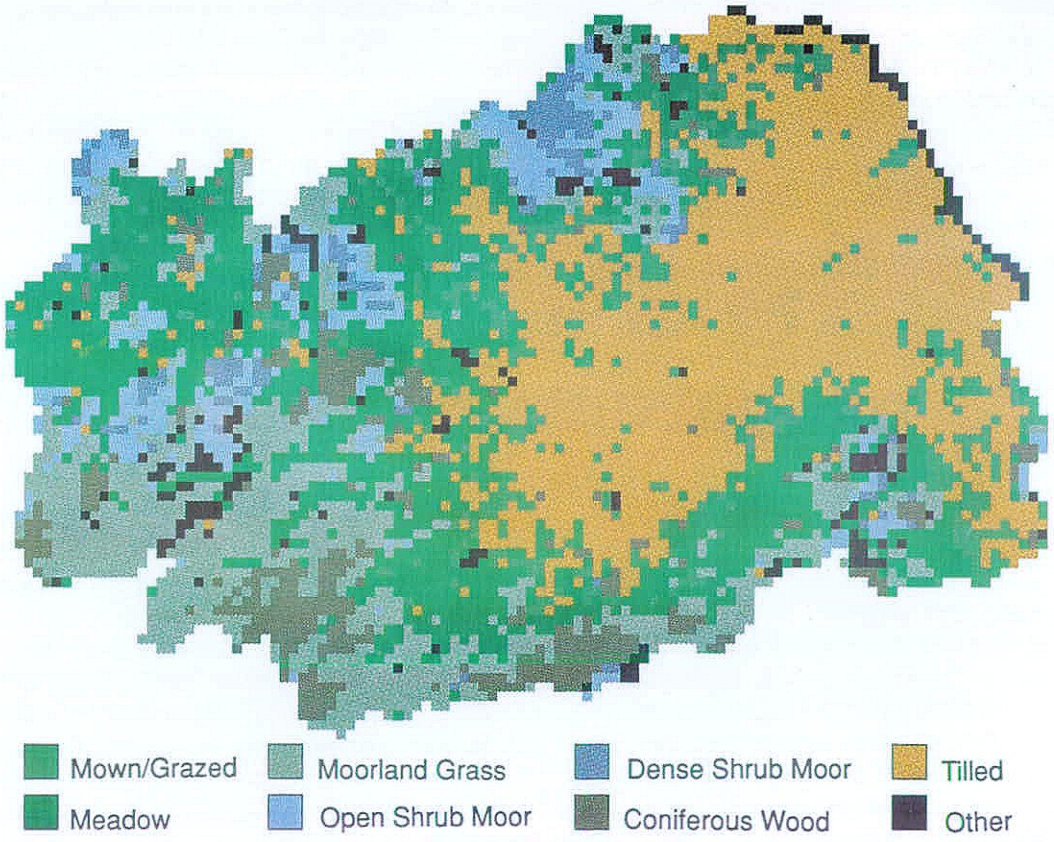


Figure 2.6 *Dominant land cover for the Tweed catchment. Data from the Land Cover Map of Great Britain (Fuller, 1993), provided by the Institute of Terrestrial Ecology.*

2.2 General water quality

The Tweed is a relatively clean river system supporting a diverse biology and an important fishing resource. Over 99% of the waters in the Tweed catchment area are Class 1, i.e. unpolluted (Scottish chemical classification system; Scottish Office, 1990, 1985). Overall, there are very few serious water quality problems. Only minor stretches of the rivers are of Class 2 (fairly good quality), and these usually result either from sewage discharges or from natural causes (Scottish Office, 1990). The main Class 2 stretches in 1994 were the Ettrick Water downstream of Selkirk (copper discharges), Biggar Water downstream of Biggar sewage treatment works (high nutrient load), Leet Water (diffuse nutrient inputs) and, until very recently, Jed Water downstream of Jedburgh sewage treatment works (high industrial load). In earlier years there were additional problems with the Langton Burn downstream of Duns sewage treatment works. The Jed Water and Langton Burn stretches have now moved into class 1 as a result of relocation of outfalls to downstream locations where dilution is greater. Eutrophication can occur in some of the eastern rivers in the arable areas, usually as a result of excessive phosphorus inputs, although nitrate concentrations can also be high. The problems on Leet Water have been the result of excessive growth and decomposition of weed in the eutrophic conditions. Diatom growth has been an occasional problem on the lower Tweed. Such growth commonly occurs in the spring and, in some years, this has led to high pH. Algal growth is more common and occurs on the lower Tweed, Teviot and Whiteadder Water where it can exert a significant effect on pH and dissolved oxygen.

The overall trend, as measured by the Scottish classification system, is one of steady improvement. The water quality of the Tweed area is controlled at a very local level with improvements being made as problems arise (Currie, 1989). Prevention, by persuasion and education, plays a large role in the Tweed RPB's work particularly with regard to potential inputs from agriculture.

2.3 Inputs to the Tweed

Sewage treatment works

In the Tweed RPB area there are 84 local authority consented sewage discharges serving a population of 80 000 (Tweed RPB, 1992). Sewage treatment ranges from moderate sized works serving the domestic and industrial effluents of towns, down to sedimentation tanks and settlement tanks in rural areas. Fifteen of the sewage treatment works receive industrial effluent, which can be a significant part of the load to sewage treatment works. For example, at Jedburgh, effluent from a fellmonger (sheepskin processing) almost doubles the population equivalent load to the works (Wallis, 1989) and at Galashiels the industrial load produces a population equivalent of 23 000 i.e. nearly twice the domestic load. At Hawick, industrial effluent from an abattoir (closed in 1993) and from woollen-finishing processes have had a substantial effect on the total load (Wallis, 1989) and this has historically created special problems for sewage treatment. The numbers of industrial discharges to sewers for 1988 are as shown in Table 2.5. Main industries are textiles, electronics and agriculturally related activities. Sludge from sewage treatment works is almost entirely utilised by spreading onto agricultural land.

Table 2.5 *Numbers of sewage treatment works receiving industrial effluent, by type in 1988 (Scottish Office, 1994).*

Industry	Number
Engineering	2
Food processing	4
Laundering/dry cleaning	1
Plating and metal finishing	3
Wool manufacture	5
General farming	5
Other	3

Sewage treatment works are continually being upgraded or improved either to cope with increased inputs or to meet consent requirements. In 1994, 87% of sewage treatment works met their consents, and each year consent compliance increases. Plans for sewage work improvements generally centre on those sewage treatment works which are most detrimental to river water quality. For example, a long history of problems downstream of Jedburgh works has led to the recent relocation of the outfall to Teviot Water, a larger river which can better assimilate the effluent. At Selkirk, electronics industries have led to high metal concentrations (especially copper) in Ettrick Water and a chemical treatment plant is now in operation here, while at Galashiels sewage treatment works, which serves one of the larger industrial towns, there is now tertiary treatment (Tweed RPB, 1993). A number of improvements and upgrades for smaller sewage treatment works are carried out each year. There are plans to improve the water quality of Biggar Water where, at minimum flows, effluent dilution may be as low as 1:1. In future, effluent may be diverted to the River Clyde, where there is significantly greater dilution.

Industry

Industrial activity in the Tweed catchment is low compared with the rest of the UK. Traditionally, the Tweed has been known for its woollen industry including tweed and hosiery mills. This industry remains, although in a much reduced form, being replaced by a growing electronics sector. One of Europe's largest electronics units is located at Selkirk. Other industrial activities include food processing e.g. fish smoking at Duns.

There are now only a few direct industrial discharges to the Tweed rivers and tributaries: industrial effluent is usually discharged to sewage treatment works for treatment, or diverted to a land based soakaway. There has been a trend away from direct discharges. In a number of cases, trade effluents also undergo some on-site treatment before they are discharged. There are currently 48 consented direct trade discharges, including six fish farms (discussed below). Most consents are for very small discharges and are deemed satisfactory with only a few being routinely sampled. For 1993/4, 92% of discharges were satisfactory. The main industrial discharges that are still monitored are Dexter Nonwovens, which had a new effluent treatment plant installed in 1991, and a potato packaging station (at Winfield, now relocated to Craigswalls). Previously, effluent data from Border Sheepskins, Moffat potatoes and the Chemical Spraying Company in Coldstream have been analysed. The Border Sheepskins' discharge was connected to public sewer in the 1980's and Moffat potatoes has discharged to soakaway since 1993. The Coldstream based Chemical Spraying Company, which stored rather than manufactured chemicals, was diverted to sewer in 1992.

Landfill sites

Management of the District Council landfill sites has improved in recent years. Leachate collection has been provided, sometimes with lagoons used to collect effluent, with new interceptor drains, or with surface water control. In some cases, such as at Easter Langlee refuse disposal site, a leachate interceptor drain with pumped connection to the public sewer has been installed. The last ten years have seen some changes in the active tips in the area e.g. Fawside tip has been closed and Cleugh tip in Berwickshire has been opened.

Fish farms

Six fish farms operate in the Tweed area. These are on the Yarrow, Ettrick, Gala, Manor and Whiteadder Waters at points where water quality is especially good. The Tweed RPB cannot directly control abstractions made for fish farming, unlike in England, but it can set consents and exerts some control over abstraction via these consents (e.g. by consenting on the volume and rate of discharge).

Pollution incidents

Pollution incidents are potentially harmful to the sensitive aquatic wildlife (Figure 2.8) that resides in the very clean rivers in the Tweed area. The Tweed RPB invests considerable time trying to prevent incidents occurring and in minimising damage when they arise. Most common incidents involve sewage (often due to equipment failure), oil and agricultural effluent or chemicals.

The Tweed RPB has worked hard to make farmers aware of the importance of proper practices and well maintained storage facilities. Historically, inadequate storage facilities for silage effluent have led to overflows during wet weather conditions. Silage effluent is highly polluting (200 times as polluting as raw domestic sewage; Royal Commission, 1992) so can seriously damage water quality. There has been increased inspection of agricultural activities and buildings (silos, slurry stores, sheep dippers) since 1985 (Tweed RPB, 1985, 1988, 1992) and remedial action or improvements have been required where problems were identified. This programme of education and persuasion has meant that farmers are more vigilant and few incidents of this type now occur.

A further programme of investigation, persuasion and education has been directed at sheep dipping (the region has the greatest sheep density of any Scottish region; Figure 2.8). A survey of sheep dippers by the Tweed RPB revealed problems with poor siting, inadequate disposal and bad management of dippers (Virtue, 1995). Farmers have now been encouraged to adopt better practise and to dispose of waste dip by diluting and spreading such contaminants on the land, away from water courses. This is now recommended in preference to use of soakaways. As a result, there have been marked reductions in organophosphate concentrations in local water courses.

The outcome of the RPB's proactive approach is a continuing downward trend in the number of pollution incidents; in 1993/4, there were approximately 205 reported incidents, 30% fewer than in 1989 (Tweed RPB, 1994).

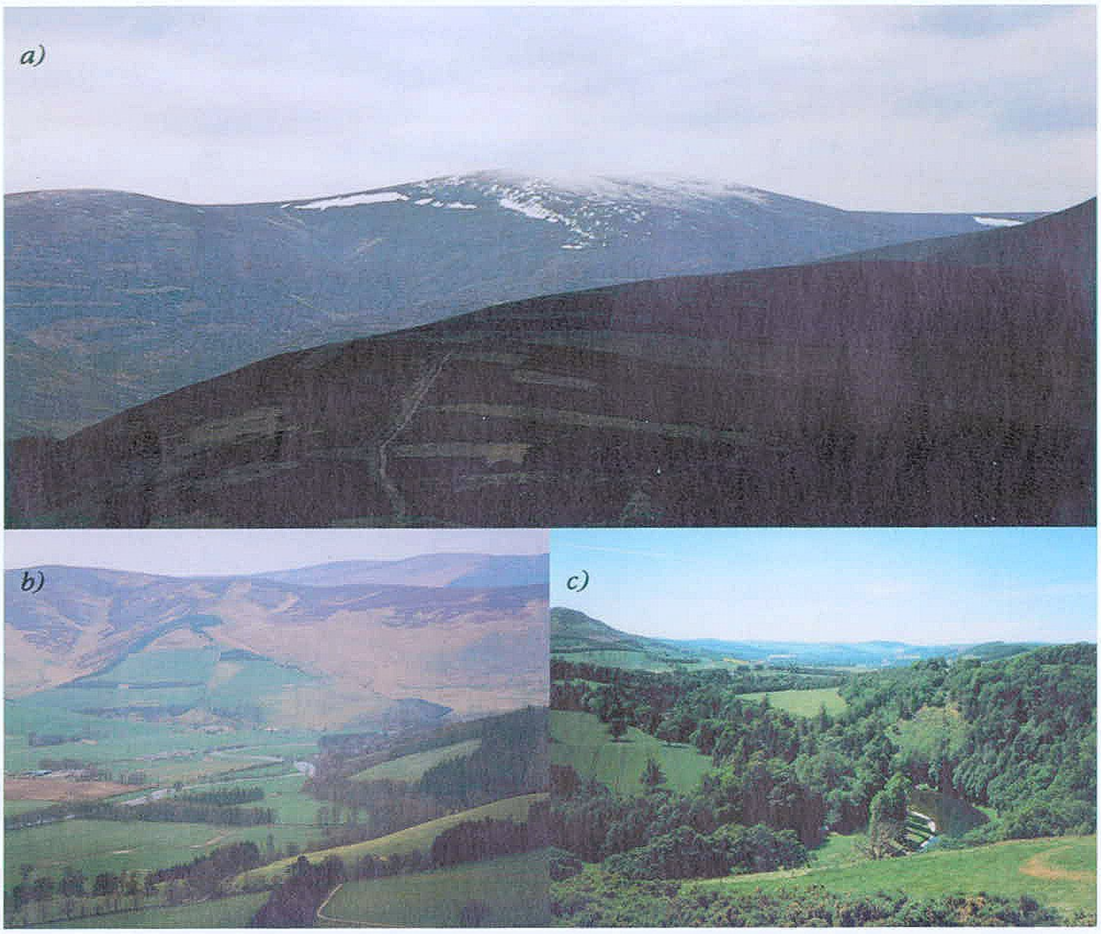


Figure 2.7 *Landscapes of the Tweed river basin a) upland moors near Peebles (R J Gibbens); b) upland and lowland scenery near Peebles (R J Gibbens); c) Scott's view (A J Robson).*

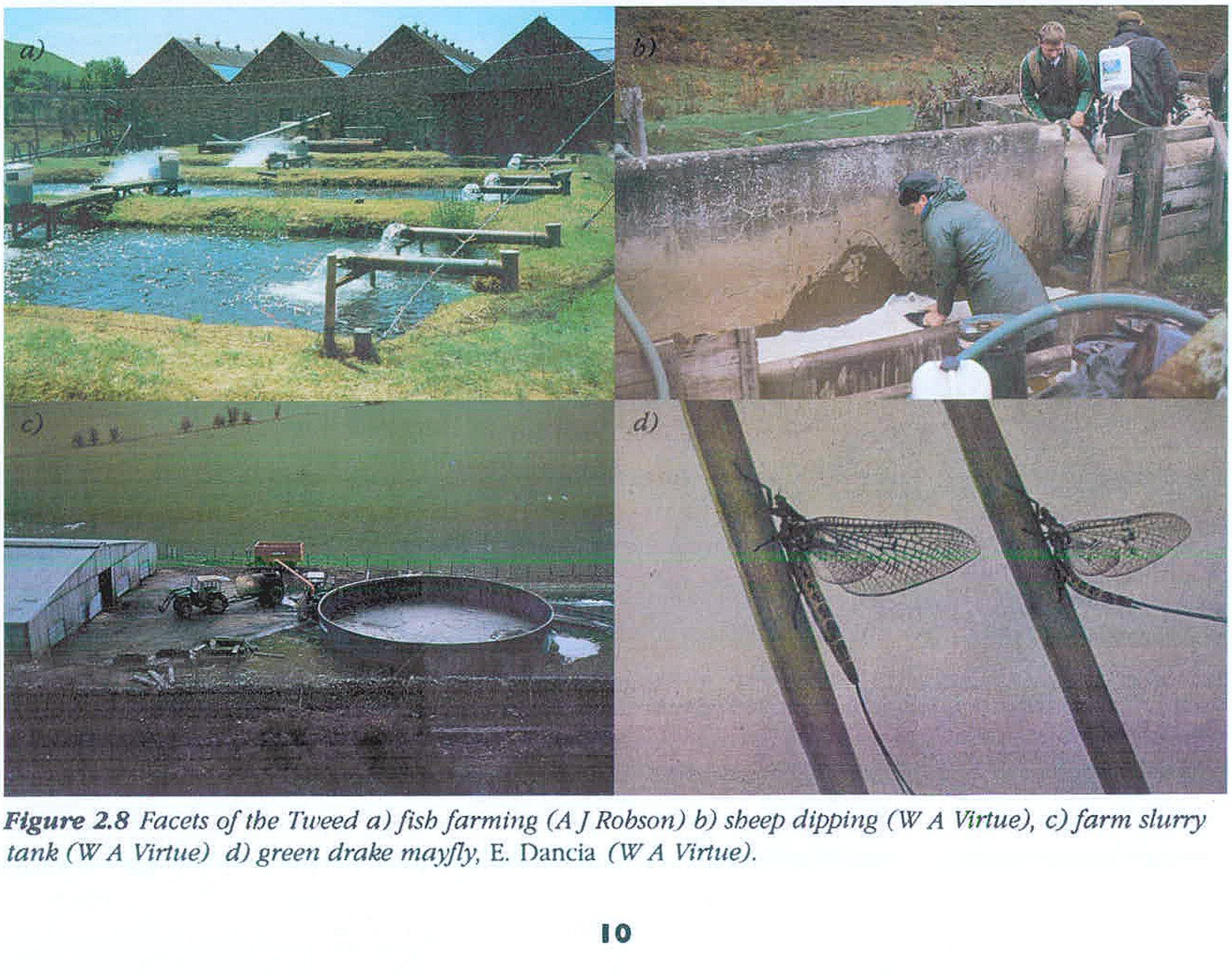


Figure 2.8 *Facets of the Tweed a) fish farming (A J Robson) b) sheep dipping (W A Virtue), c) farm slurry tank (W A Virtue) d) green drake mayfly,* E. Dancia *(W A Virtue).*

3 The data resource

For this report, data have been examined for those regularly monitored sites which have been sampled and analysed by the Tweed RPB between 1985 and 1994. Further data relating to pollution incidents and to short term water quality surveys/studies have not been used because of the complexities of handling such information.

The backbone of the data set is provided by the routine sampling of a large number of river sites which are analysed for up to 15 basic determinands including pH, biochemical oxygen demand (BOD) and nitrate (Table 3.1). More sophisticated measurements (Table 3.2) are made for a subset of sites under various environmental schemes such as the North Sea Action Plan (NSAP), the Paris Commission (PARCOM), the Global Environmental Monitoring Scheme (GEMS) and the Harmonised Monitoring Network (see Table 3.3 and Appendix D). Determinations at these sites include metals, such as lead and nickel, and micro-organic pollutants such as dieldrin, dichlorvos and atrazine. The frequency of measurement and the range of determinands measured depends on the location and the sampling plan. Samples are usually taken every two months (six samples per year), but there are variations and not all sites have been monitored for the full period. Locations of river sites are shown in Figure 3.1. Many of the sites are sampled under more than one scheme and hence provide overlapping results. For example, Lyne Water Foot is sampled for basic determinands as part of the routine Lyne Water sampling run (site code BR011) and also as part of the routine Tweed sampling run (site code PR008: a tributary to the Tweed), this doubles the number of samples for this location. In addition, this site is sampled for NSAP substances (UR014). The full list of sites and overlapping codes is shown in Appendix D.

Samples of sewage, industrial and fish farm effluent are also regularly analysed at the locations shown in Figure 3.2. Sewage treatment works provide the most widespread pollutant input to the river systems. Fish farms, direct industrial discharges and tips are more localised. Samples are usually taken every two months, but more frequent sampling occurs at some of the larger sewage treatment works.

***Table 3.1** Main determinands and types of location where analysis was carried out. See section 5.2 for an explanation of 'available'. (+ denotes small sewage treatment works (STW)).*

Determinand	Rivers	Sewage	Fish farms	Tips	Industry	Code
pH	●	●	●	●	●	2
Suspended Solids (mg l^{-1})	●	●	●	●	●	4
BOD (mg l^{-1})	●	●	●	●	●	5
Temperature (°C)	●		●	●		7
Dissolved Oxygen (mg l^{-1})	●		●	●		8
Dissolved Oxygen (% sat)	●		●	●		9
Permanganate Value (mg l^{-1})	●	●				10
Free & Saline Ammonia (mg l^{-1} N)	●	●	●	●		11
Albuminoid Nitrogen (mg l^{-1} N)		+				12
Nitrite (mg l^{-1} N)	●	●				13
Nitrate (mg l^{-1} N)	●	●	●	●		14
Chloride (mg l^{-1} Cl)	●	●	●	●		15
Soluble Phosphate (mg l^{-1} P)	●	●	●			17
Total Phosphate (mg l^{-1} P)	●	●	●			18
Silica (μg l^{-1} Si)	●					58
Conductivity (μS cm^{-1})	●		●	●	●	61
Zinc (μg l^{-1} available)		●		●	●	101
Lead (μg l^{-1} available)		●		●	●	102
Cadmium (μg l^{-1} available)		●		●	●	103
Nickel (μg l^{-1} available)		●		●	●	104
Iron (μg l^{-1} available)		●		●	●	105
Copper (μg l^{-1} available)		●		●	●	106
Chromium (μg l^{-1} available)		●		●	●	107

Table 3.2 *Determinands measured under environmental monitoring programmes.*

Determinand	Rivers	Sewage	Fish farms	Tip	Industry	Code
Total Hardness (mg l^{-1} $CaCO_3$)	●				●	19
Lindane (ng l^{-1})	●	●			●	76
Aldrin (ng l^{-1})	●	●			●	78
Mercury (µg l^{-1})	●	●			●	89
Arsenic (µg l^{-1})	●	●				90
Carbontetrachloride (µg l^{-1})	●	●			●	91
Pentachlorophenol (µg l^{-1})	●	●			●	92
Endrin (ng l^{-1})	●	●			●	93
Dieldrin (ng l^{-1})	●	●			●	94
pp'DDT (ng l^{-1})	●	●			●	98
Zinc (µg l^{-1} dissolved)	●	●	●	●	●	108
Lead (µg l^{-1} dissolved)	●	●	●	●	●	109
Cadmium (µg l^{-1} dissolved)	●	●	●	●	●	110
Nickel (µg l^{-1} dissolved)	●	●	●	●	●	111
Copper (µg l^{-1} dissolved)	●	●	●	●	●	113
Chromium (µg l^{-1} dissolved)	●	●	●	●	●	114
Hexachlorobenzene (ng l^{-1})	●				●	135
Hexachlorobutadiene (ng l^{-1})	●				●	136
Diazinon (ng l^{-1})	●				●	142
Endosulphan (ng l^{-1})	●	●			●	145
PCB (28,52,101,118,138,153,180)(ng l^{-1})	●	●			●	146
Atrazine (ng l^{-1})	●	●			●	147
Simazine (ng l^{-1})	●	●			●	148
Dichlorvos (ng l^{-1})	●	●			●	149
Fenitrothion (ng l^{-1})	●	●			●	150
Azinphos Methyl (ng l^{-1})	●	●			●	151
Trifluralin (ng l^{-1})	●					152
Chloroform (µg l^{-1})		●				153
Trichlorobenzene (ng l^{-1})		●				154
1,2 - Dichloroethane (µg l^{-1})		●				155
Zinc (µg l^{-1} total)	●	●				165
Malathion (ng l^{-1})	●					184
Propetamphos (ng l^{-1})	●					185
Pirimiphos Methyl (ng l^{-1})	●					186
Chlorfenvinphos (ng l^{-1})	●					217

Table 3.3 *Details of river sampling schemes. *Note that most Paris Commission sites started in 1989, but ceased in 1991. Three sites continue to be sampled.*

River sampling scheme	Number of sites	Approximate sampling frequency (year^{-1})
Routine	~100	6
North Sea Action Plan	~20	12
Harmonised Monitoring Network	3	12
GEMS (Tweed above Galafoot)	1	52
Paris Commission	13(3)*	12

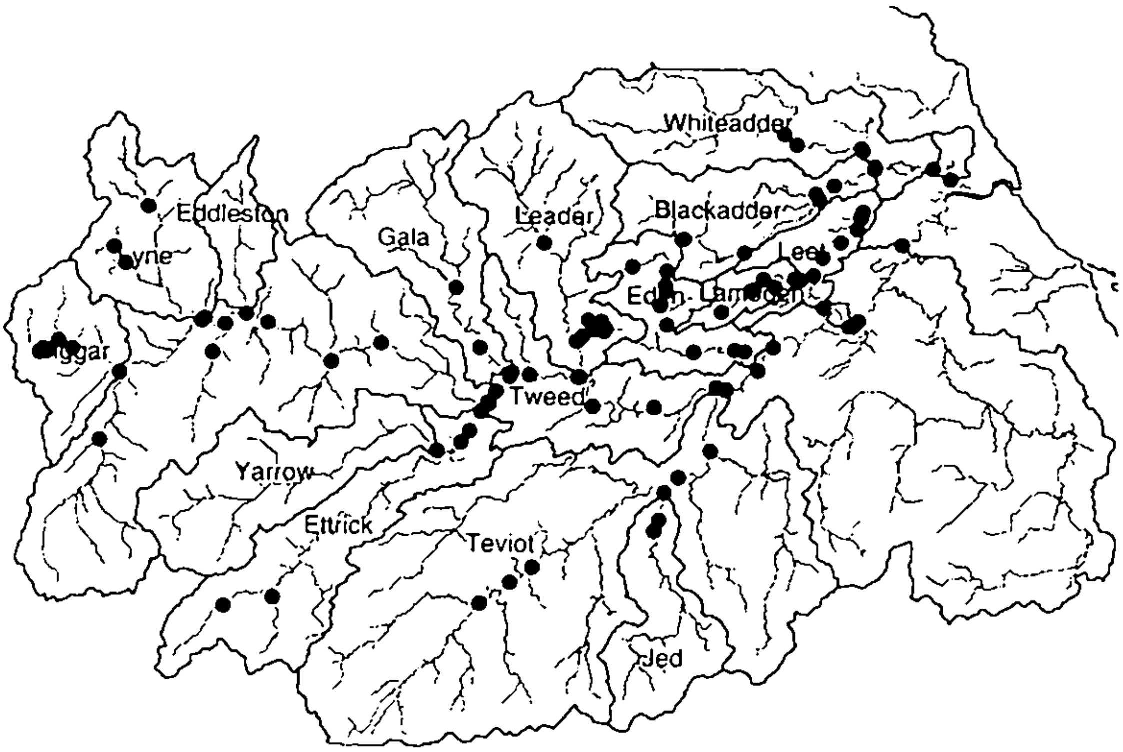
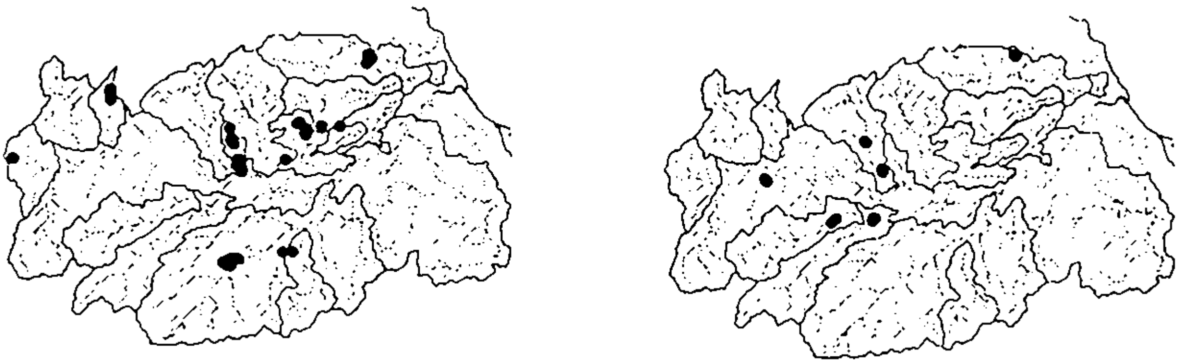


Figure 3.1 *Locations of river sampling sites in the Tweed area. Main river regions are also marked.*

Sewage treatment works

Industry



Landfill sites

Fish farms

Figure 3.2 *Locations of monitored sewage outfalls, industrial discharges, landfill site and fish farm sampling points.*

Sewage effluent is routinely analysed for nutrients, BOD and available metals (Section 5.2 and Table 3.1) to check for consent compliance. The larger sewage treatment works are also monitored for dissolved metals and micro-pollutants under the North Sea Action Plan (Table 3.2 and Appendix D). At some of these locations, extra samples are taken just upstream and downstream of sewage treatment works to monitor the effects on river water quality. For presentation purposes, sewage treatment works have been roughly grouped as large and small works. This has been done on the basis of the Tweed RPB Report 1992 – 1993 (sewage treatment works listed in the data tables correspond with larger works).

Industrial discharges to surface waters are few and declining. Basic determinands, analysed for consent compliance monitoring, comprise only pH, suspended solids, BOD and metals (Table 3.1). Further NSAP measurements of metals and micro-pollutants are extensive (selected from up to 25 determinands; Table 3.2) but are tailored to those substances that discharges are likely to contain. Note that data from the Chemical Spraying Company prior to its connection to local sewer are available but are not presented. Effluent from this source was extremely high in some micro-organics but discharges were infrequent and of small volume. The discharges were made to a soakaway which leaked into the surface water system.

Effluents from fish farms are routinely analysed for a range of basic determinands for consent compliance (Table 3.1). In addition, river water samples are taken upstream and downstream of fish farms for metal analysis. Landfill sites are only sampled at a limited number of locations, following improvements in management practices, although in the past they were extensively sampled. Determinands analysed for consent compliance include available metals but exclude nitrite and phosphorus species. Some further samples have been analysed for dissolved metals.

Not all the sites and effluent discharges were sampled for the full period (1985 – 1994). Some of the industrial discharges and fish farm effluents shown on the map no longer exist while others did not exist at the start of the project. Only sites where at least ten samples have been analysed are used in the plots and analyses. A robust estimate of the mean is used in many instances, to try and reduce the problem of outlying values affecting the averages. This robust estimate is the trimmed mean and is calculated as the average of the data once the top and bottom 5% of values have been excluded. In some cases, such as suspended solids, data is very strongly non-normal so neither the mean nor the trimmed mean represents a particularly useful measure; both should be viewed with caution. Note also that average values, as shown in plots and tables, do not allow for differences in sampling period or in sampling frequency.

4 A graphical approach to regional data analysis

4.1 Graphical presentation

The extensive and complex nature of the Tweed water quality data makes graphical presentation the most suitable method for examination. Graphs used include:

- regional map plots giving a broad spatial overview;
- line charts summarising the distribution of data at each of the sites and allowing intercomparison of these distributions;
- time series graphs showing full data series at each site;
- plots of other relationships e.g. concentration against flow or season.

Additionally, tables showing basic statistics have been used to provide further summary information.

In this report it is not possible to present all of the graphs that were used in the data analysis. For most determinands, regional maps are shown together with selected samples of other plots. For nitrate, a fuller selection of graphs is presented. These show the range of graphs, and the way in which these have been used to assist data interpretation. Each of the plot types highlights different features of the data. Together, the graphs allow an easily accessible overview of extensive data.

4.2 Nitrate: a worked example

Background

Nitrate levels in UK surface and ground waters have risen since the war following the increased use of nitrogen rich fertilisers. This increase is of concern for the public and for water supply authorities. High nitrate in surface waters, in combination with phosphate can cause eutrophication and excessive weed, algal and diatom growth. High nitrate in drinking waters can cause methaemoglobinaemia in infants and to prevent this, current drinking water standards are set at 11 mg l^{-1} N (maximum) and 6 mg l^{-1} N (guide).

Nitrate is highly soluble and is the main compound of nitrogen found in fresh waters. It is the fully oxidised form of nitrogen and, in the rivers, much of the oxidation is achieved by nitrifying bacteria. These bacteria are also active at sewage treatment works and sewage effluent is usually high in nitrates. Runoff from agricultural land can contribute high levels of nitrate especially during winter when rainfall is high and plant uptake is low.

Nitrate in the Tweed catchment

During the last decade, more than 12 500 routine nitrate determinations have been made at over 200 sites. Around half of these relate to river sites, the remainder to sewage treatment works, fish farms, tips and industrial discharges. To examine these data, simple graphs and summary tables have been used. Figure 4.1 shows a map of the Tweed catchment. Circles show nitrate concentrations; the area of each circle is proportional to average concentration and different colours denote the different site types. The map highlights the following:

- Nitrate is higher in the north eastern area of the study area (Leet Water, Eden Water, Lambden Water and Leader Water). This is an arable area where crops such as barley, wheat and potatoes are grown. Here, the watercourses are relatively small and slow flowing and are of very different character to the much faster flowing upland streams.
- Nitrate is elevated downstream of Biggar sewage treatment works (sited to the far west).
- Sewage is the most spatially widespread point source of nitrate but concentrations are variable.
- Fish farms and direct industrial sources are low in nitrate.
- Tip effluent can be a source of nitrate, but there is little evidence of any downstream effect on water quality.

Time series plots of the data reveal much more detail about nitrate variations (Figure 4.2). For the Tweed, the time series plots show averages of less than 2 mg l^{-1} N and a low seasonal variation. In contrast, time series plots of the arable lowland sites show much higher averages (6 to 20 mg l^{-1} N) and a marked sinusoid-like seasonal variation. Sewage effluent concentration varies from site to site. For example, very high nitrate concentrations occur for effluent from the Institute of Animal

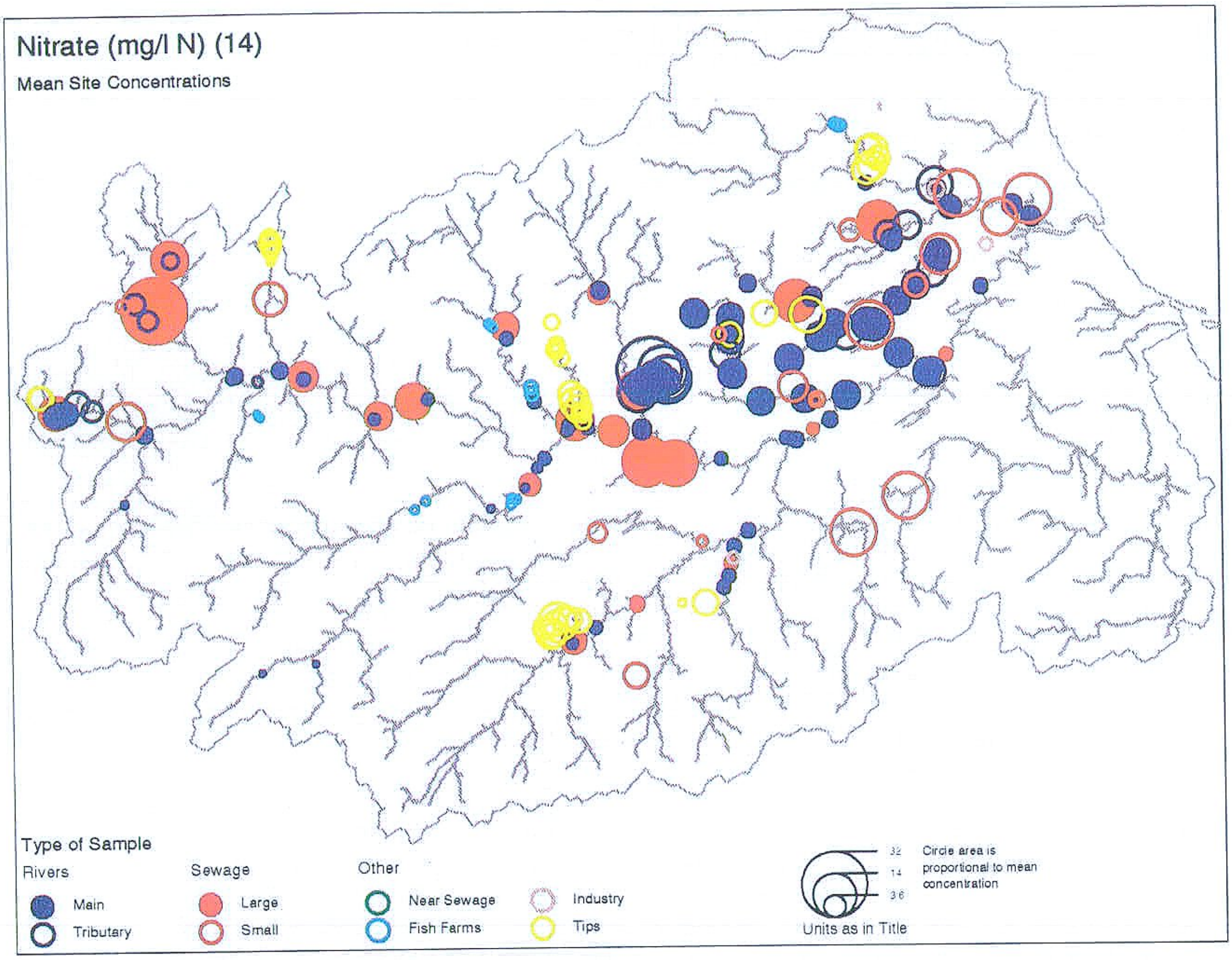


Figure 4.1 *Map of nitrate concentrations for the Tweed catchment. Closed circles and open circles are used to help distinguish (a) between samples on main rivers and samples taken on tributaries to those rivers and (b) between large and small sewage treatment works. Fish farm samples can refer either to upstream and downstream or to inlet and outlet water quality. Sites near sewage treatment works refer to water quality sampling points just upstream and down stream of sewage discharges – these sites only apply to metal determinations and are not present for nitrate.*

Physiology and Genetics Research (I.A.P.G.R.). Data for industrial discharges are limited to three sites. For fish farms nitrate concentrations are very low with no consistent increase in nitrate between inlet and outlet. Differences in sampling frequency can be identified from the graphs. Sewage effluent from Peebles and Duns has been sampled more than twice as frequently as at Denholm, whilst the septic tank at Lilliesleaf has only been sampled for a brief period. Data from landfills are also patchy – relatively few sites have been monitored since 1991/92 following improvements in tip management practice.

Figure 4.3 is intermediate between the map and time series plots. It displays measures of the data distribution at each site and allows easier cross comparison between river sites and local point source inputs. For each site, the mean and 5 and 95 percentiles are marked and a vertical line shows the data range and interquartile range. Sites are grouped by site type and by river region and are ordered from upstream to downstream. The different site types within each of the regions are 'stacked' vertically so that point inputs can be identified. For example, on Whiteadder Water there are inputs from two small sewage treatment works, from an industrial site and from a fish farm (with three sampling sites), whereas on Lambden Burn only one small sewage treatment works is monitored. High nitrate concentrations on Leet Water, Eden Water, Lambden Burn and parts of Leader Water can be readily identified, but these cannot be explained by any of the point source inputs in the locality. Here, there is a steady downstream increase in the mean and the range of the nitrate concentrations. Concentrations on the Tweed also increase downstream but more gradually. On the Biggar, concentrations decline downstream as sewage treatment works' inputs are diluted.

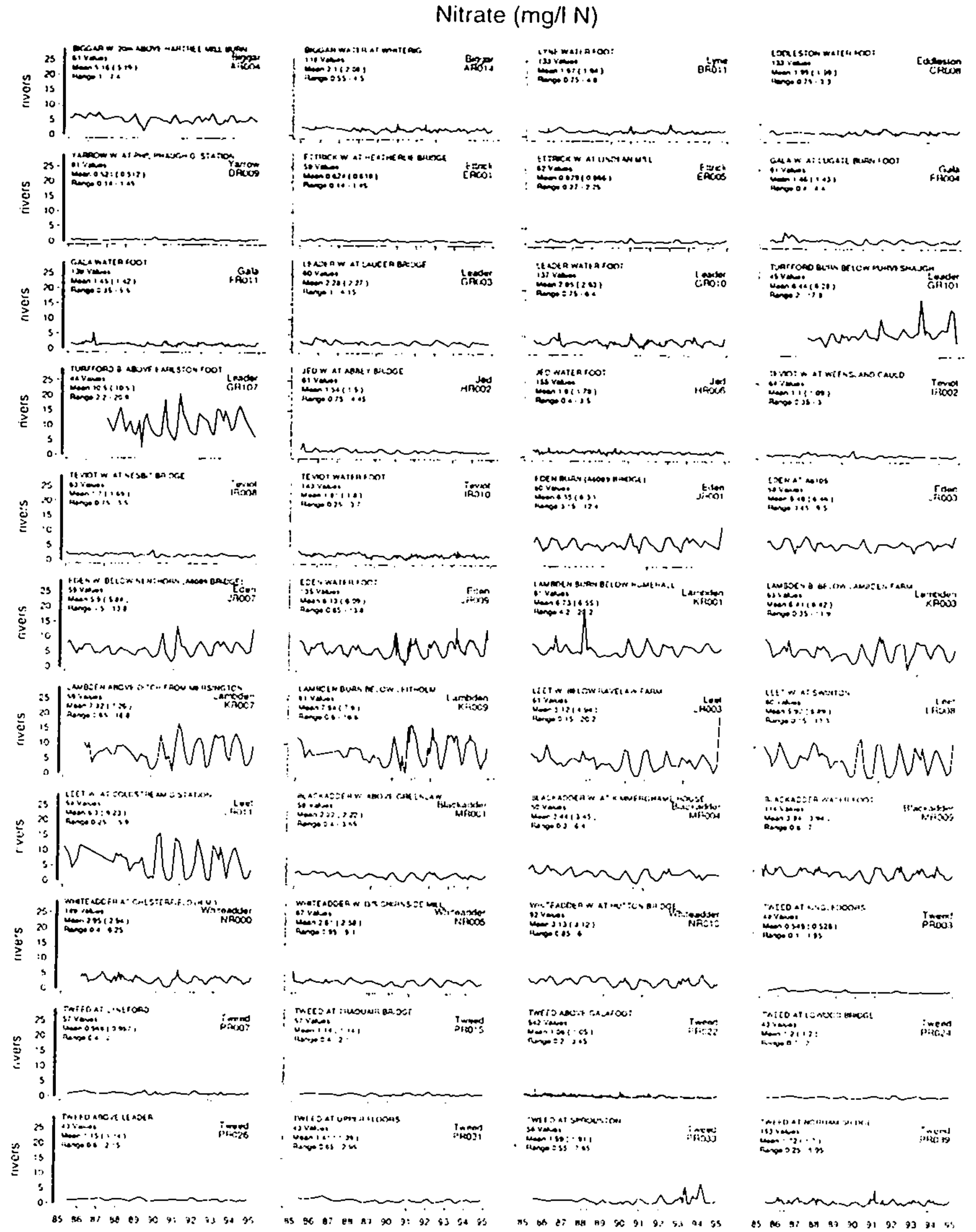


Figure 4.2 (continued overleaf) Time series plots are shown for a selection of the sampled sites for the years 1985-1994. Sites are grouped according to type and are roughly ordered from upstream to downstream. The same horizontal scale is used for all graphs. Vertical scales vary according to the site type but are fixed within each group (e.g. rivers, sewage treatment works, fish farms). The term 'settle' is used to indicate the smaller sewage treatment works. On each graph a bar is plotted alongside the y-axis to show the relative size of the river axis:- a short grey bar indicates that concentrations are much higher than in the rivers, a long grey bar indicates that concentrations are similar or low relative to the rivers. On each plot the range, the number of values, the mean and the trimmed mean (bracketed) are given. Note the elevated concentrations and striking seasonal variation in some of the arable regions.

Nitrate (mg/l N)

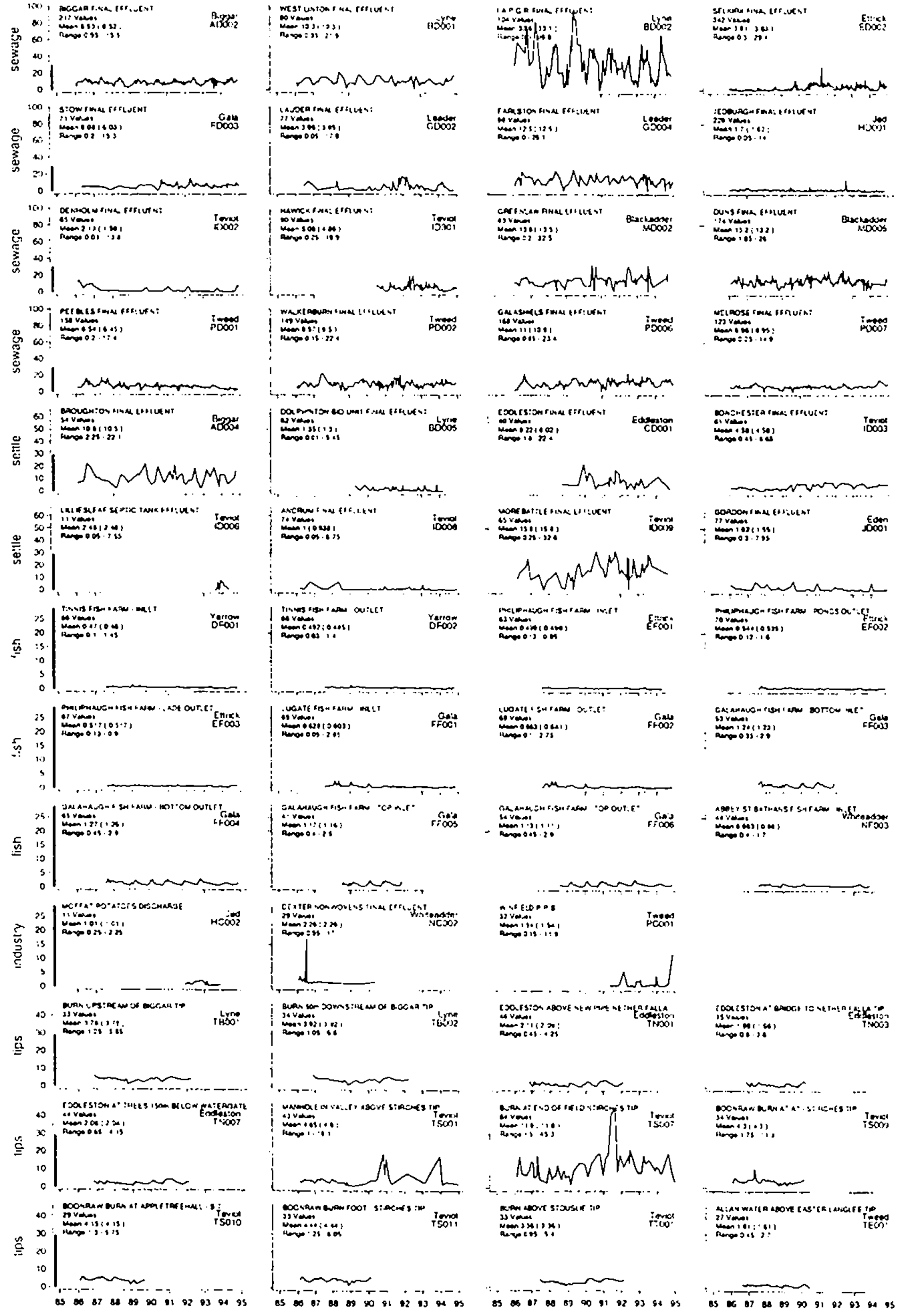


***Figure 4.2** continued*

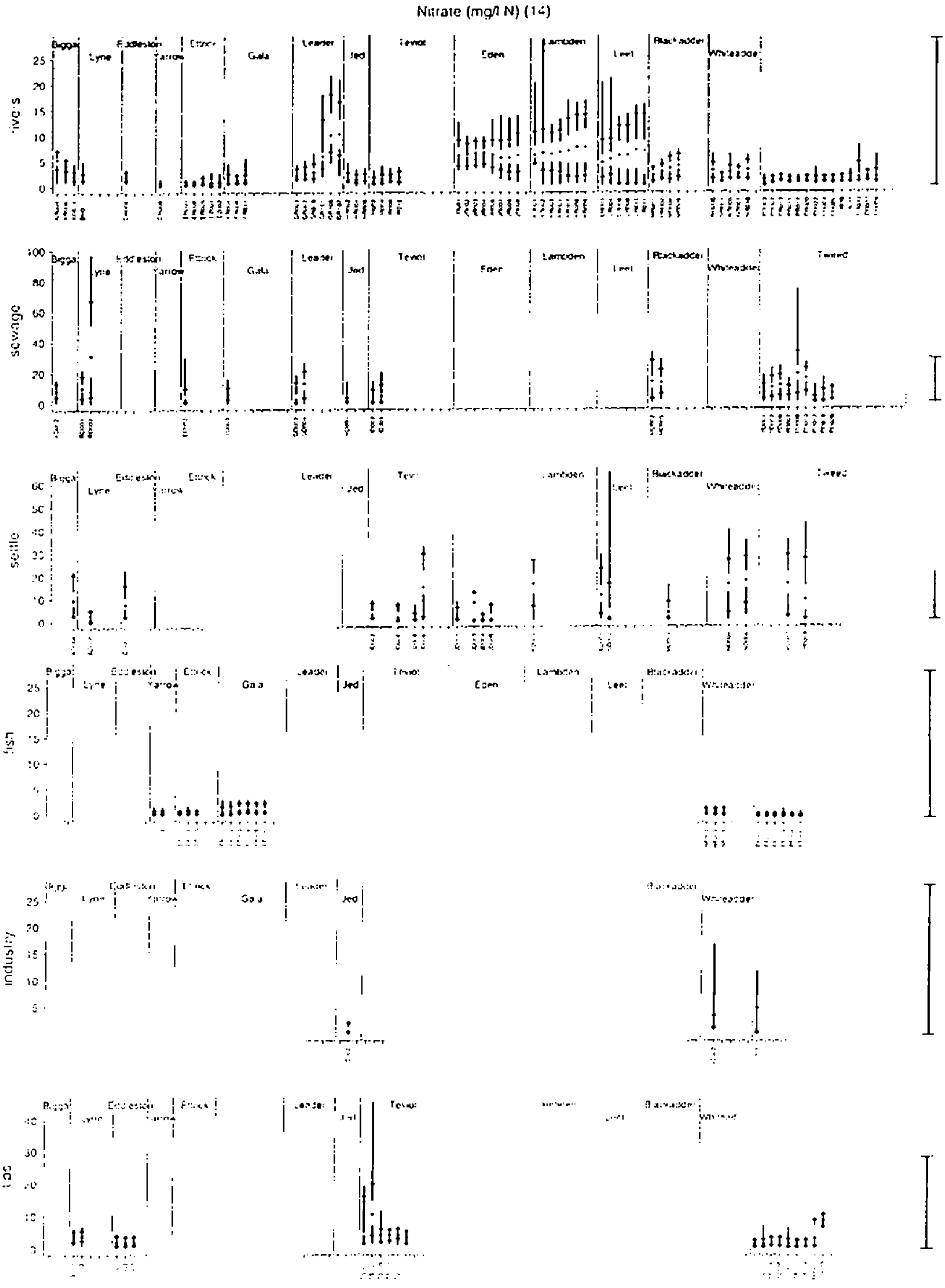


Figure 4.3 *Line chart displaying distributions of nitrate concentrations. For each site, the mean (•) and 5 and 95 percentiles (-) are marked. Vertical lines extend outwards from the interquartile range to data maximum and minimum. Sites are grouped by site type and by river region and are ordered from upstream to downstream. The term 'settle' is used to indicate smaller sewage treatment works. The different site types within each region are 'stacked' vertically so that point inputs can be identified and compared. All samples of the same type are plotted at the same scale, but different types are plotted at separate scales. The bar shown to the right shows the extent of the scale used for river sites and can be used to help compare scales.*

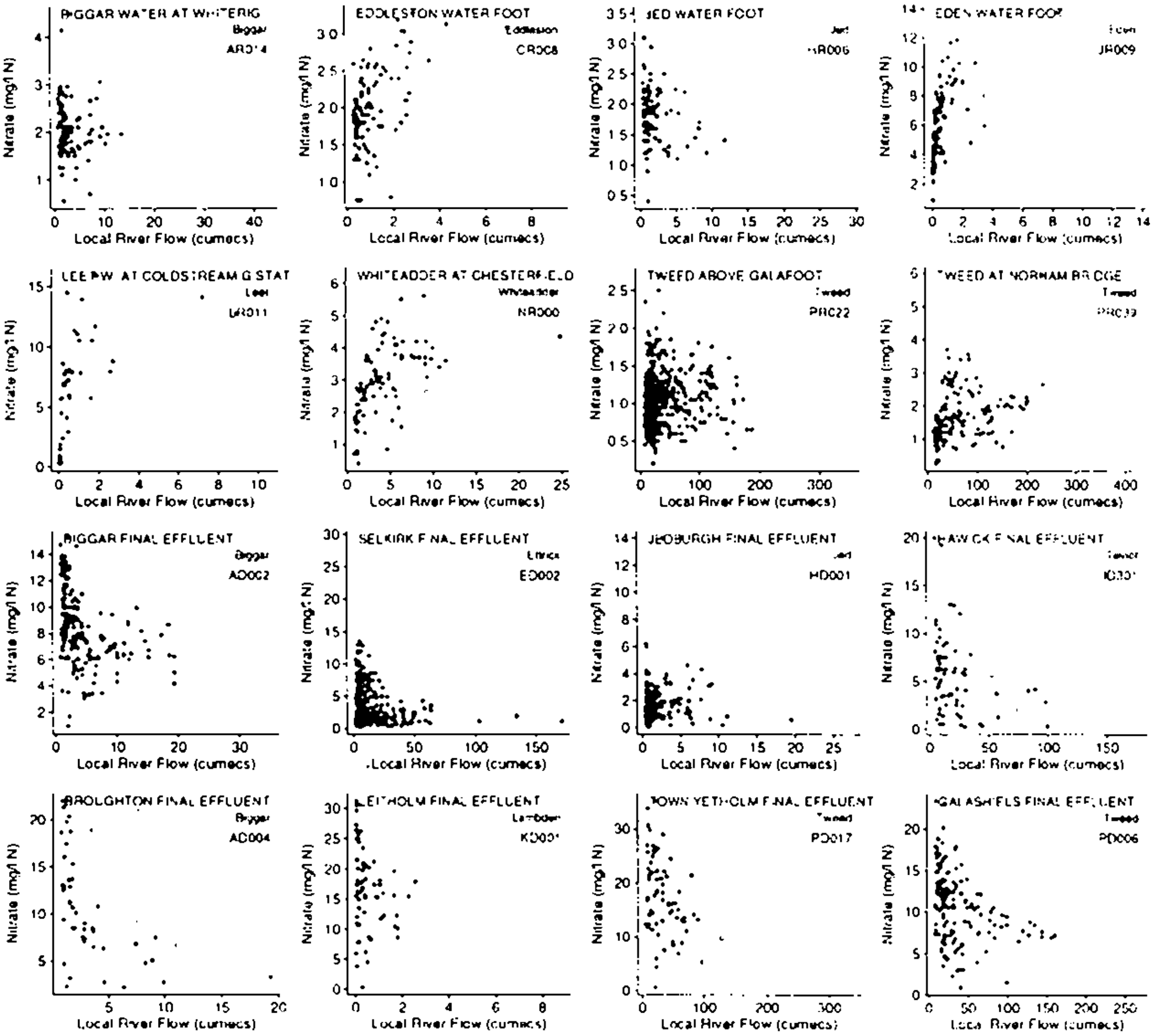


***Figure 4.4** Scatter plots of nitrate concentrations against flow for selected river and sewage sites. Flow volumes are given for the nearest downstream flow gauging station. Note that for sewage treatment works this means that the plotted flow is local river flow, rather than actual volume of discharge.*

***Table 4.1** Basic statistics for nitrate concentrations for 1985 - 1994. The mean, trimmed mean, median and percentiles are calculated for each of the site types. Minimum, median and maximum values of individual site averages are also given. The cutoff value shows the level above which points are considered to be outliers and have been omitted from calculations of the mean etc.; the number of points above the cutoff value is shown as the number excluded. For nitrate no cutoff value had to be imposed but for other determinands (see Appendix A) some points had to be excluded. The detection limit for nitrate is 0.1 mg l^{-1} N.*

Nitrate (mg l^{-1} N)	River	Sewage	Industry	Fish Inlet	Fish Outlet	Tips
Mean	3.9	8.8	1.8	0.6	0.7	3.8
Mean (trimmed)	3.4	7.9	1.4	0.6	0.6	3.4
Median	2.3	6.9	1.4	0.5	0.5	2.8
5 Percentile	0.6	0.5	0.4	0.2	0.2	0.4
95 Percentile	11.7	24	4.1	1.9	1.7	9.9
Site Average: Min.	0.5	0.6	1.0	0.3	0.3	0.4
Site Average: Median	3.0	6.7	1.2	0.5	0.5	3.4
Site Average: Max	31.5	32.4	1.8	1.2	1.2	11.2
Cutoff Value						
No. Measurements	6114	3886	72	397	751	1435
No. Excluded	0	0	0	0	0	0

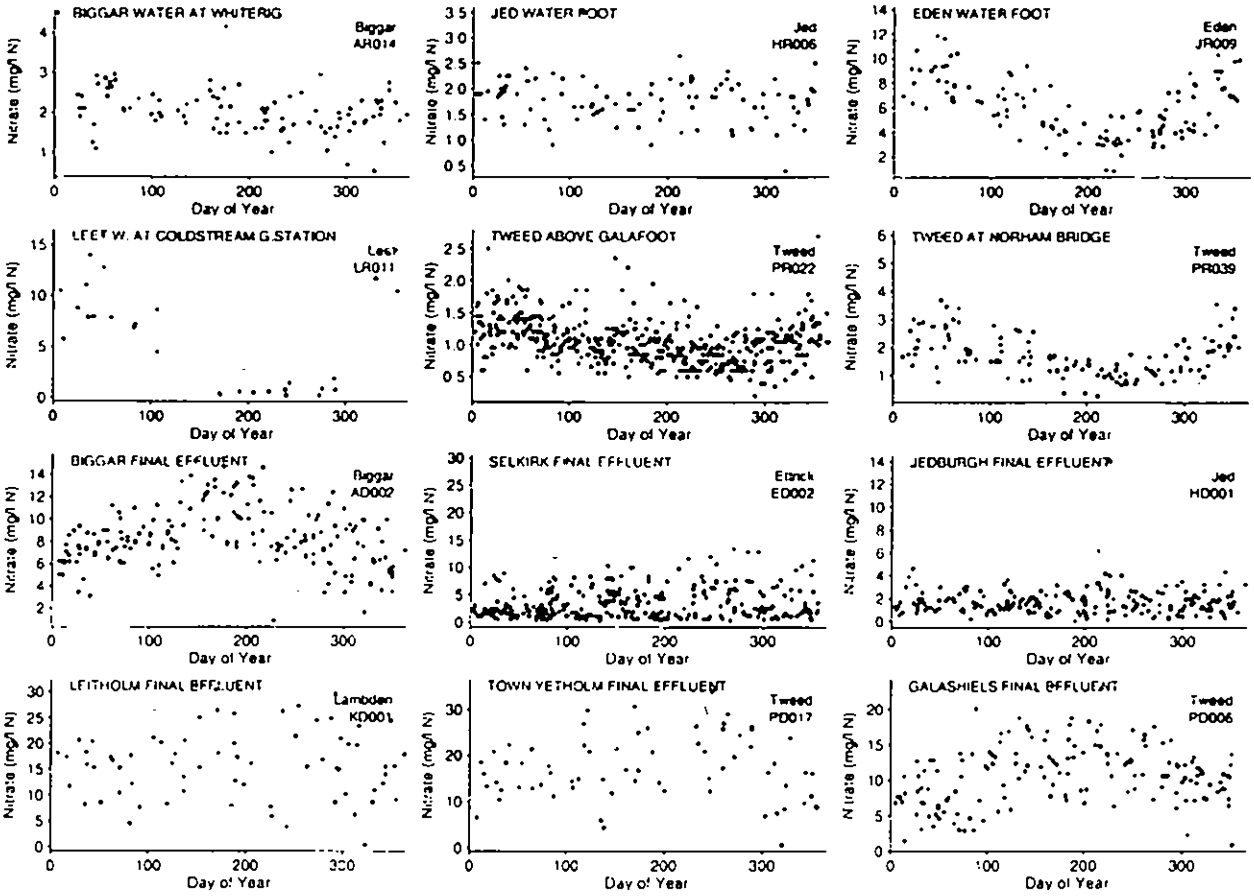


***Figure 4.5** Scatter plots showing seasonal variation of nitrate for rivers and sewage effluent. Nitrate concentrations are highest in the winter for the rivers, and highest in the summer for sewage effluent.*

At most river sites, nitrate rises rapidly with flow but then flattens off and may even decline (Figure 4.4). For sewage effluent, the opposite pattern is seen with nitrate concentrations usually being highest at low flows. This relationship occurs because during wet periods there is a greater throughput of water to treatment plants resulting in increased dilution. A strong seasonal pattern, which relates to the flow characteristics seen above, is seen for both river water and sewage effluent (Figure 4.5). For the rivers, maximum concentrations occur in the winter period, whilst for sewage effluent maximum concentrations are in the summer. Seasonal variation is most pronounced in the arable lowlands. For Jed Water Foot, there is very little seasonal variation and this may be because until recently the Jed has contained high proportions of effluent from Jedburgh. Some sewage treatment works show greater seasonal variations than others (e.g. Biggar and Galashiels display more variation than Selkirk and Jedburgh).

Basic statistics for the various site types are shown in Table 4.1. From this, the graphical information shown on map and time series plots can be quantified. Average riverine nitrate concentrations in the Tweed catchment are reasonably low for the UK (3.4 mg l^{-1} N for the trimmed mean) but, as noted from the plots above, show considerable variation from site to site (averages range from 1 – 32 mg l^{-1} N). Sewage treatment works effluent is, on average, more than twice as high in nitrate as river water (9 mg l^{-1} N), but site averages again range from 1 – 32 mg l^{-1} N. Fish and industrial samples average < 2 mg l^{-1} N, whereas tip samples are somewhat higher in nitrate (4 mg l^{-1} N).

Interpretation

The increased nitrate concentrations and the greater seasonal variations in the lowlands show the importance of diffuse agricultural sources. These are highest for Leet Water, which is predominantly arable and has a low population (<1000), for Lambden and Eden Water, which are mainly arable but with some livestock, and for the Turfford Burn, a poultry farming area. Other arable regions, e.g. the lower reaches of Blackadder and Whiteadder Water, are fed by upland headwater areas and have lower nitrate concentrations (although still higher than the Tweed river). Fertiliser is applied in the arable areas in January or February and continues regularly until the late spring. It is generally a mixture of ammonium nitrate, potassium and phosphate. In these areas nitrate concentrations are exacerbated by low rainfall and high evapo-transpiration. This alone may account for a doubling of nitrate concentrations, enough to explain part of the regional distribution of nitrate concentrations.

Silage and slurry are major sources of nitrate, although these are not evident in the most arable areas and are only significant where there is grassland and livestock. Grassland areas do not give rise to the high levels of nitrate seen for the Leet, Lambden and Eden. This is despite the practice, driven by inadequate storage conditions, of spreading silage effluent and slurry throughout the year. During the winter there is little or no nitrate uptake and wet conditions cause nitrate to be leached to the rivers. Nitrate concentrations in grassland areas are probably moderated by inputs of low-nitrate waters from upland headwater sources.

The seasonal patterns and flow relationships indicate that nitrate is much higher in soils than it is in groundwaters (nitrate is lowest during summer base flows when groundwater contributions are significant). The difference between nitrate levels in soils and groundwaters in winter is most pronounced in areas where nitrate is highest (hence the larger seasonal variation noted above). A downstream increase in nitrate is probably linked to the increasing proportions of intensively farmed land within the catchment. In the arable areas, nitrate enrichment has occurred at all levels of flow (i.e. for both ground and soil waters). Even at baseflows, nitrate concentrations are much higher than in upland headwater areas. Thus, although the increase in nitrate in lowland arable areas is greatest for the soils, it is still significant for the groundwaters.

In summary, the observed nitrate patterns indicate that diffuse agricultural sources are the major source of nitrates to the rivers. Point sources are much less important than these diffuse inputs. Nevertheless, where dilution is poor, there may be a significant rise in nitrate caused by sewage effluent.

5 Water quality

This section gives a comprehensive overview of the observed stream water chemistry from the 100 or so regularly monitored sites, emphasising river water quality and its relation to point source inputs. Relationships with flow are discussed. The determinands are grouped as:

- basic determinands,
- metals, and
- micro-organic pollutants.

The overview provided for each group is supplemented by a detailed, reference-like description of results for individual determinands, given in Appendix B. Section 6.1 records the characteristics of the different point source inputs while the role of diffuse sources is summarised in Section 6.2.

5.1 Basic determinands

Basic determinands include pH, temperature, suspended solids, dissolved oxygen, biochemical oxygen demand (BOD), nitrogen species (nitrate, total ammonia, nitrite), phosphate, chloride and silica. Many of these measurements are important measures of river water quality status and of the suitability of a watercourse for aquatic life. Here, the main results are summarised with more extensive details being provided in Appendix B. As with nitrate, the results are based on examination of regional maps, time series plots, flow relationships and tables of average concentrations. The regional maps are shown for most determinands (Figures 5.1 and 5.2) but only samples of the other graphs are included. The maps provide a simple overview of the spatial distribution of the various determinands and of the relative importance of the different point discharges. Summary tables showing means, medians and the range of site averages are presented in Appendix A. The tables highlight differences between river sites and the measured point source inputs.

The regional maps illustrate the varying river water quality spatial patterns and the distribution of point source inputs to the rivers. For most determinands, sewage treatment works are the main point source of materials. However, the ratio between average riverine and average sewage effluent concentrations is strongly dependent on the determinand considered. For example, total ammonia is around a hundred times higher in effluent than in the rivers and phosphate and BOD are 50 and 25 times as high. Contrastingly, suspended solids and nitrate are only three and five times as high.

For many determinands, highest concentrations are found in smaller watercourses draining the low lying eastern arable areas (Lambden Burn and the Leet, Eden and Leader Waters). Nitrate shows the strongest pattern, with high nitrate concentrations spread across all these watercourses (Figure 4.1 and 4.2). Phosphate is also elevated in the lowlands, but is more localised than nitrate. High concentrations are found mainly on Leet Water, Lambden Burn and Turfford Burn (a tributary of the Leader; Figures 5.1 and 5.3). Since phosphate levels are very high in sewage effluent, it is surprising that highest concentrations are found in the lowland arable areas where there is relatively little sewage discharge. Chloride is also high on Leet Water and Lambden Burn (i.e. the most easterly of the above rivers) Silica, BOD and total ammonia show a slight enhancement in the lowlands (Figures 5.1 and 5.2). Dissolved oxygen, pH and temperature show little regional variation because site to site variations are small relative to the mean (Figure 5.2). The situation is more complex for suspended solids because data distributions are much more skewed in the largest rivers. Usually suspended solids are higher in the lowlands (Figure 5.2), but at high flows, much greater concentrations are measured on rivers such as the Tweed and Teviot.

The elevated concentrations in the lowland arable areas probably arise from a combination of climatic and agricultural influences. Low rainfall and high losses by evapotranspiration concentrate rainfall, and provide less dilution for land derived inputs. In the relatively dry Leet Water (Table 2.1), climatic conditions could account for stream concentrations 1.5 to 2 times the Tweed average (depending whether the primary source is rainfall or the land, and assuming all other factors to be constant). This concentration factor is even greater (up to six times as high) when Leet Water is compared with the much wetter upland areas. Intensive arable farming practices in these drier lowland areas also impact on water quality: the land receives high nitrogen and phosphorus loads from slurry, silage effluent and other fertilisers. Spreading of these often continues through the winter to dispose of accumulating wastes, and nutrients are readily leached from the land in wet winter conditions. Riverine nitrate, phosphate, total ammonia, chloride and BOD levels are all likely to be affected by these applications. Particularly high phosphate concentrations on Turfford Burn are linked to chicken farms because phosphate-rich chicken litter is spread as a fertiliser. Chicken farming, combined with intensive arable farming practices, may also affect Leet Water.

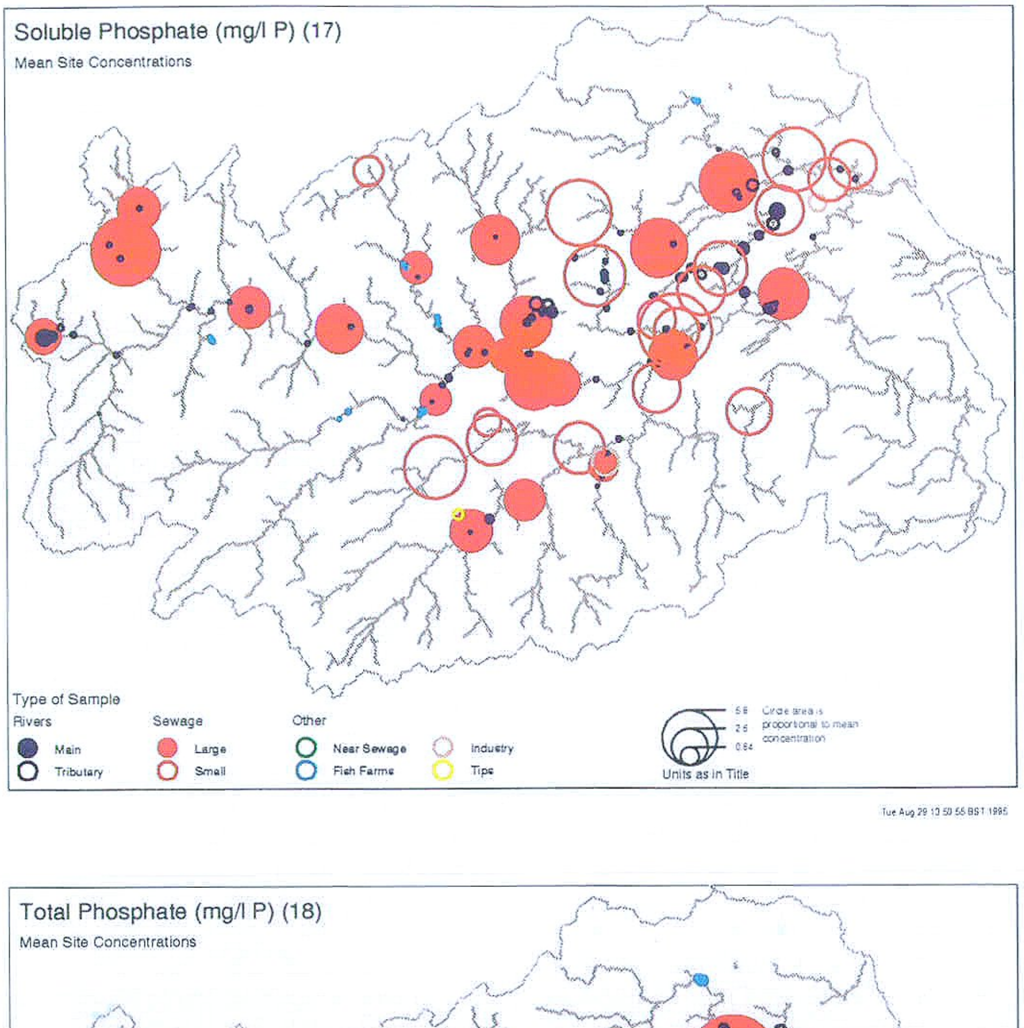
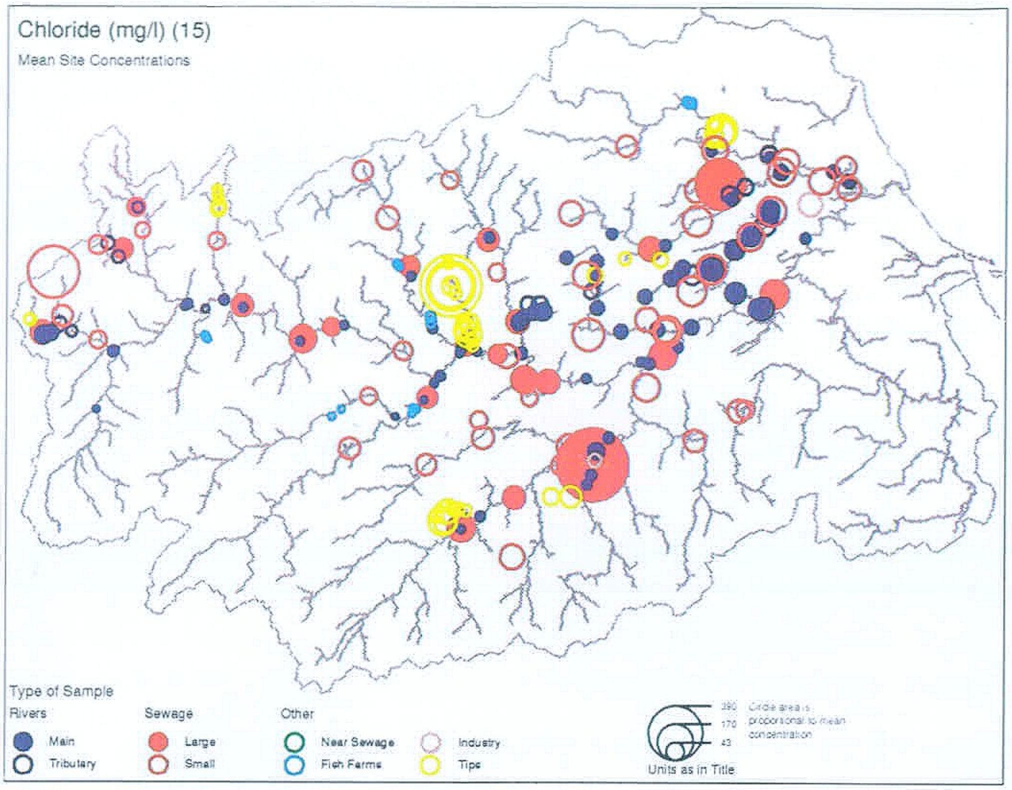


Figure 5.1 *Maps of average concentrations of soluble and total phosphate, chloride and silica concentrations. In all cases, highest river concentrations are found in the lowland arable areas (Leet, Lambden, and Leader Waters), reflecting the effect of diffuse sources, low rainfall and high evapotranspiration. Sewage inputs of phosphate are particularly high relative to background river levels.*



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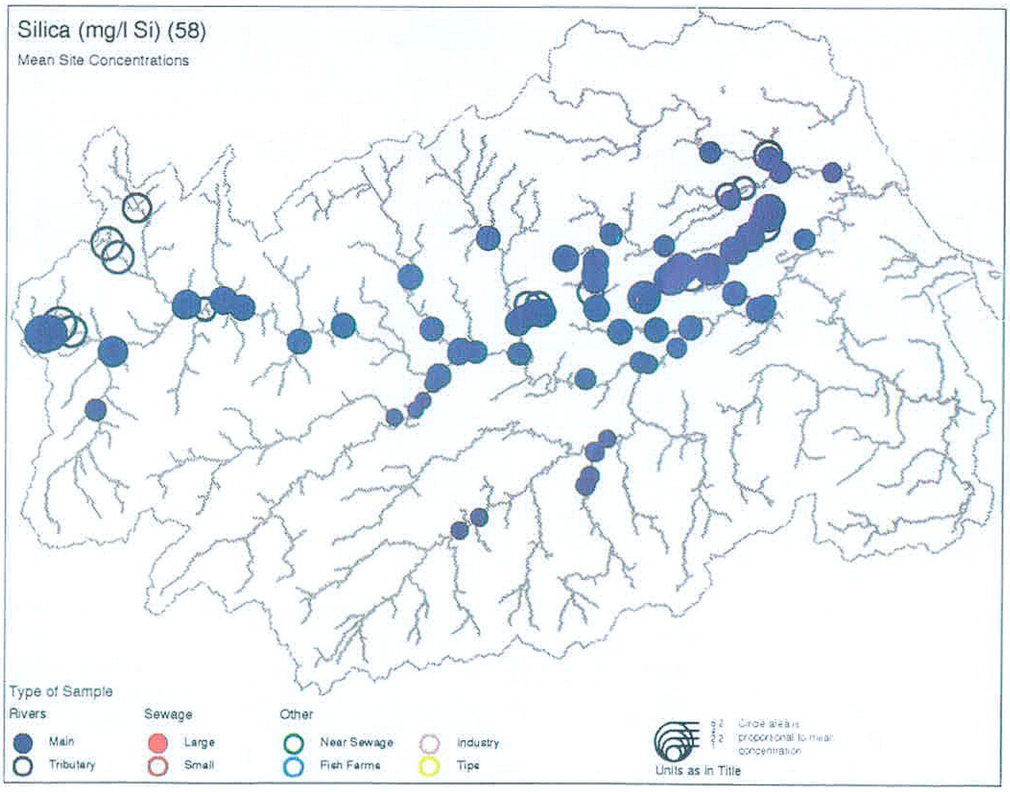

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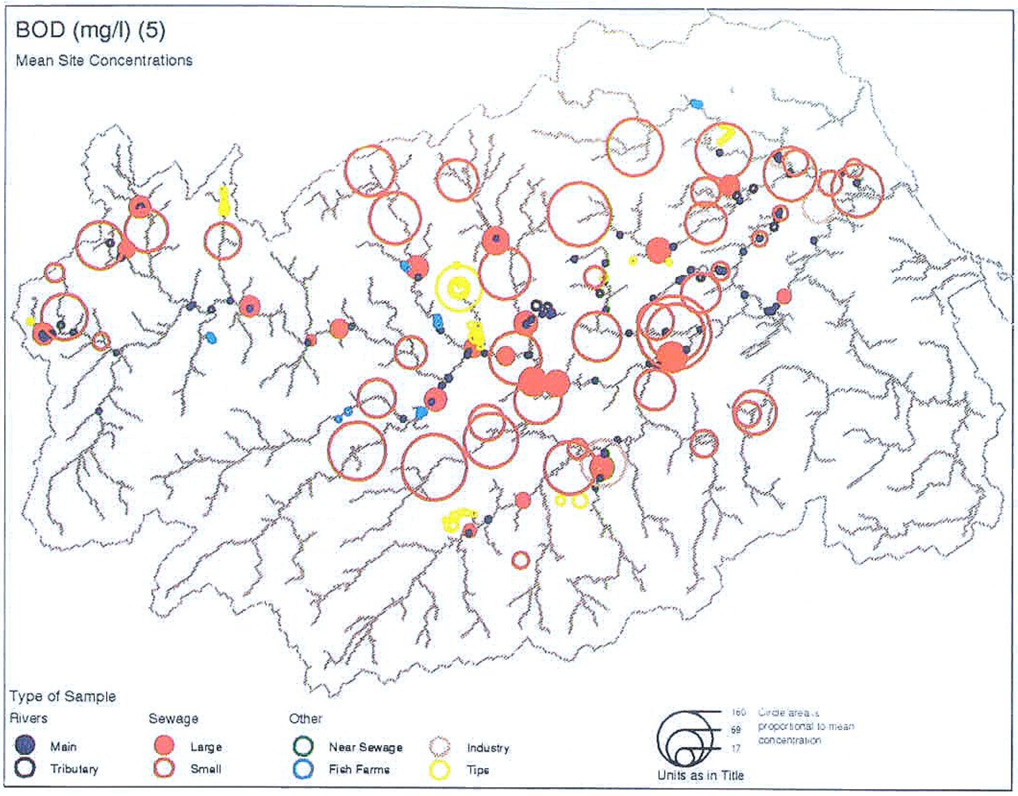
***Figure 5.1** continued*



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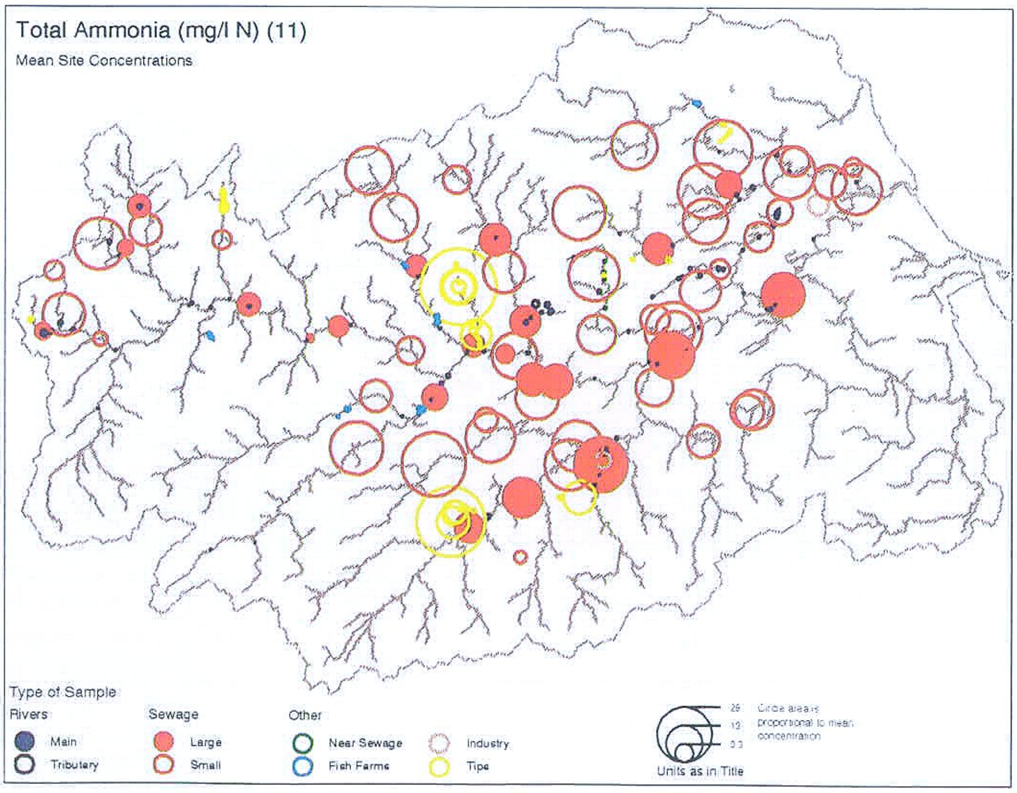

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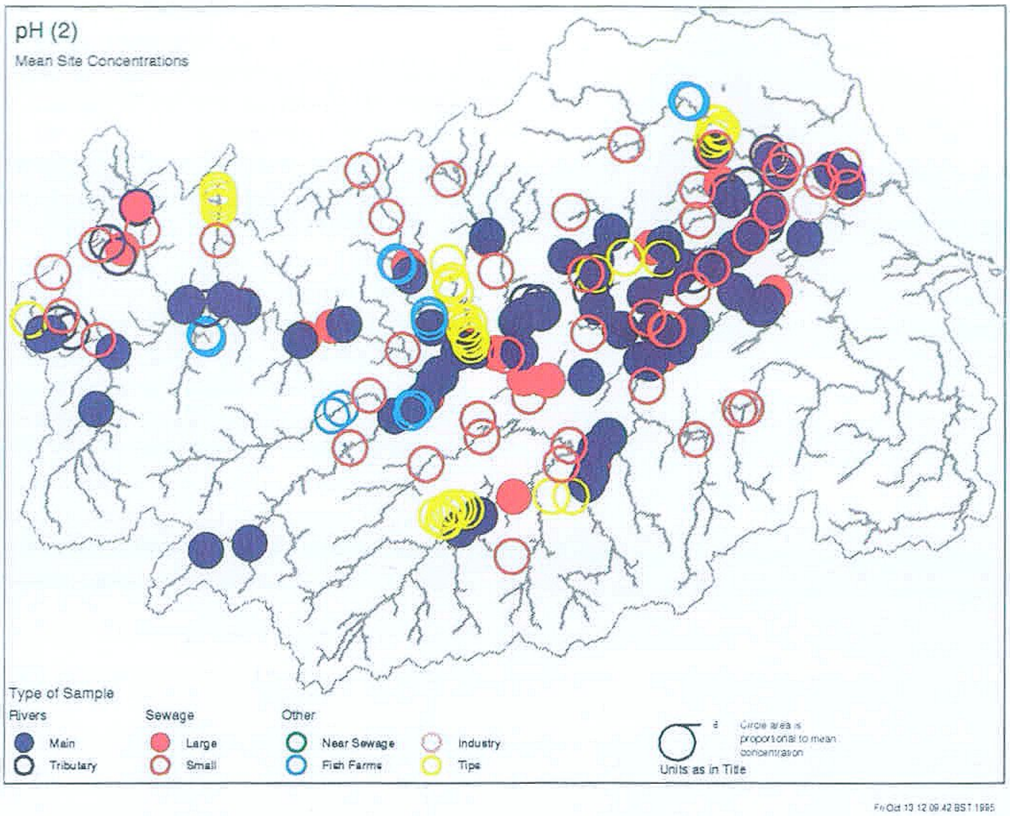
Figure 5.2 *Maps of average concentrations for biochemical oxygen demand, total ammonia, pH and suspended solids. Note the relatively small regional variation in pH (maps for temperature and dissolved oxygen, not shown, have a similar appearance). Sewage effluent provides the main point source of suspended solids, total ammonia and BOD.*



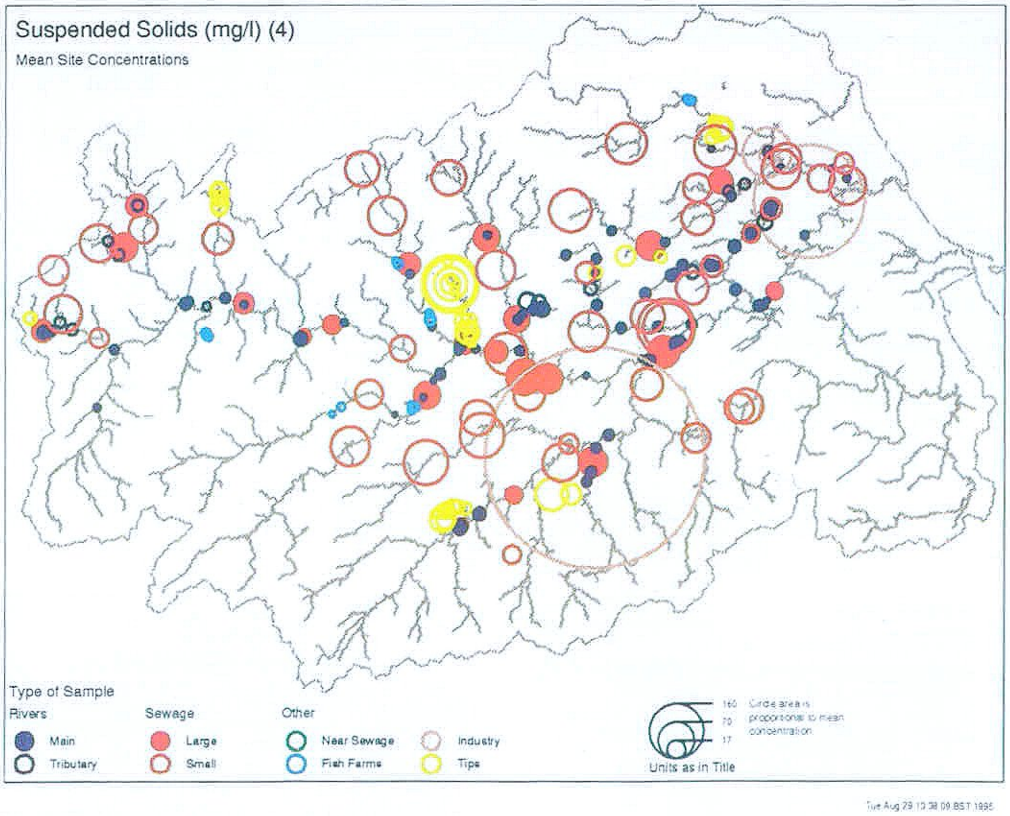


Figure 5.2 *continued*

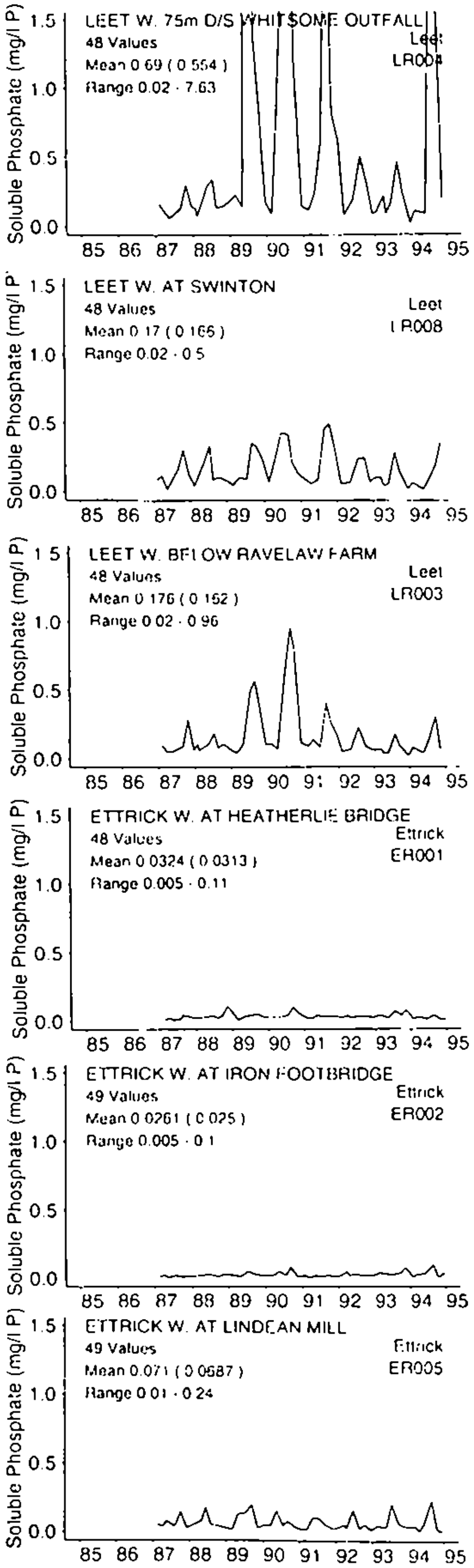


Figure 5.3 *Time series of soluble phosphate for three locations on a lowland (Leet Water) and upland (Ettrick Water) river, 1985 – 1994. Concentrations on the lowland Leet Water are much higher and show a large seasonal variation.*

Sewage treatment works effluent is high in BOD, suspended solids, total ammonia, nitrate, phosphate and chloride. Concentrations vary considerably from site to site, but much of the variation is attributable to consent conditions (Figure 5.4). Consent conditions are set in relation to available dilution and effectively determine the grade of treatment process required. The regional maps highlight the differences in effluent quality related to treatment process. Total ammonia, BOD and suspended solids are all significantly lower at main sewage treatment works (Figure 5.2) e.g. for BOD they are typically one third as low. Most sewage discharges have only a slight effect on downstream water quality; this is as it should be, given that consent levels are designed to prevent pollution of the river. However, there are a few sites where downstream changes can be clearly seen. High levels of nitrate, BOD, chloride, total ammonia and phosphate are found below Biggar sewage treatment works because the sewage effluent discharges

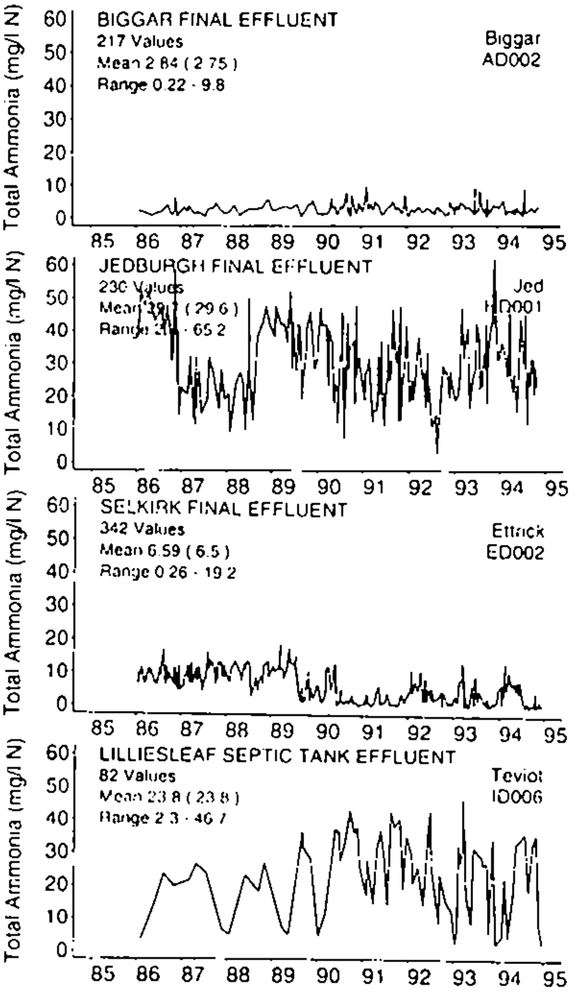


Figure 5.4 *Time series of total ammonia in sewage effluent, 1985 – 1994. Effluent from larger works (e.g. Biggar, Selkirk) contains less total ammonia than effluent from low grade treatment (e.g. Lilliesleaf septic tank). Effluent at Jedburgh is an exception, the result of high industrial loadings from fellmongering.*

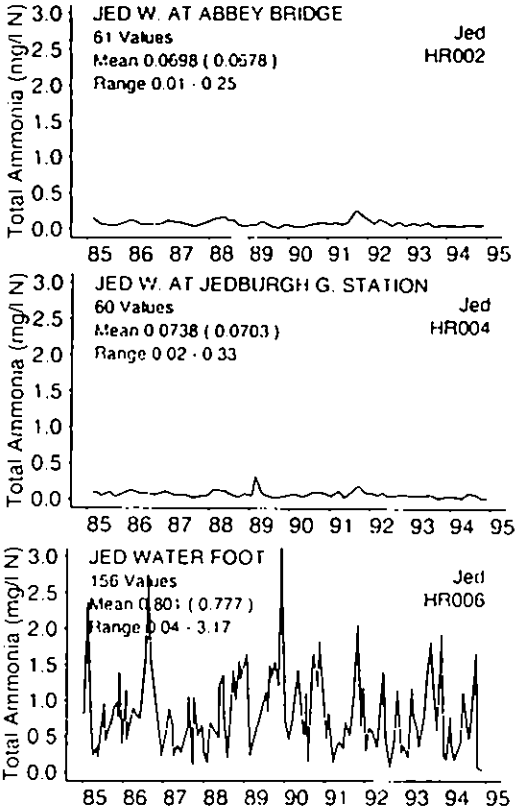


***Figure 5.5** Time series variations in total ammonia for three sites along the Jed, 1985 - 1994. Effluent from Jedburgh sewage treatment works has historically resulted in high concentrations at Jed Water foot because of industrial loadings.*

to a relatively small watercourse. Below Jedburgh, high levels of BOD, total ammonia and chloride have occurred because of industrial loadings on the works, in particular from fellmongering (Figure 5.5). Below Duns, where salt used in salmon smoking is discharged in sewage effluent, riverine chloride is above average.

There are few direct industrial inputs in the Tweed area. High nutrient loads are associated with food processing, e.g. potato washing, but have limited impact on the rivers. In practice most industrial discharges are made to sewer so industrial wastes primarily affect sewage effluent. Tip effluent contains a wide range of substances, but most do not make a significant impact on the rivers. Of the main determinands, suspended solids are proportionally the highest in tip leachate.

Fish farms in the Tweed area have little effect on river water quality. Of those determinands measured, total ammonia, suspended solids, BOD and phosphate levels are increased (Table 5.1). Dissolved oxygen (Figure 5.6) and, to a small degree, pH, temperature, nitrate and chloride show a decrease. These results compare reasonably well with data for other parts of the UK (Solbe, 1982; Table 5.1). Phosphate seems to have increased more in the Tweed catchment but the sample basis for the UK phosphate survey was very limited. All of the observed changes are small compared to the effects of sewage treatment works.

***Figure 5.6** Time series variations in dissolved oxygen concentrations for the inlet to and outlet from Tinnis fish farm, 1985 - 1994. Oxygen levels are depleted by the farm.*

***Table 5.1** Some determinands affected by fish farming. UK results are taken from Solbe, 1982. Note that the changes reported for the UK study are based on sites located downstream of fish farms. For the Tweed, the change is based on the outflow (except for the metals, which are measured downstream). * denotes data available from only a small number of sites.*

	Tweed catchment area			UK
	Inlet	**Outlet**	**Change**	**Change**
Suspended Solids (mg l^{-1})	3.7	4.6	0.9	2.1
BOD (mg l^{-1})	1.6	2.1	0.5	0.7
Dissolved Oxygen (mg l^{-1})	11	9.4	-1.6	-0.3
Total Ammonia (mg l^{-1} N)	0.06	0.16	0.1	0.07
Nitrate (mg l^{-1} N)	0.63	0.66	0.03	0.23
Total Phosphate (mg l^{-1} P)	0.09	0.14	0.05	0.004*
Iron (µg l^{-1})	62	76	6	
Copper (µg l^{-1})	3	3.7	0.7	

Many determinands show striking seasonal variations (e.g. Figures 4.5 and 5.7). For silica, nitrate, phosphate and oxygen, the seasonal variations are much greater on the small but nutrient rich lowland arable streams discussed above (Figure 5.8). For pH and temperature, seasonal variation is relatively uniform across the whole of the Tweed catchment (Figure 5.8). Seasonal variations arise because of changes in flow and temperature. Many are biologically mediated and are strongly linked to diatom and algal growth. Biological effects will be greatest where nutrient inputs are high and stream waters become eutrophic.

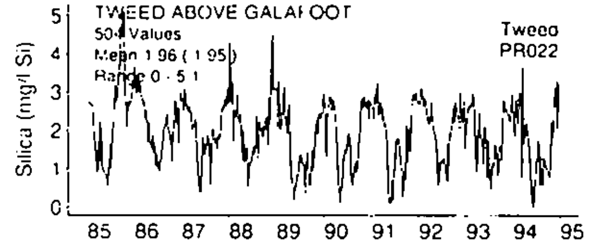


Figure 5.7 *Time series of silica variations at Tweed above Galafoot, 1985 – 1994. Minima correspond to spring and autumn diatom/algal blooms.*

The different determinands show varying flow relationships. For example, in the rivers, suspended solids increase rapidly with flow (Figure 5.9) whereas nitrate, silica and total ammonia initially increase but level off or decrease at high flows (Figures 5.10 and 5.11). The contrasting flow dilution effect seen at Jed Water Foot results from the high effluent discharge above this point. Phosphate and pH decrease with flow (Figure 5.12), and BOD shows little flow relationship. Differences in flow relationships are informative because they can suggest likely sources. In general, determinands that show flow dilution are likely to have either ground water sources (which contribute most at low flows) or significant point sources. Determinands that increase with flow may have sources from the upper soils and near surface runoff or from mobilisation of the sediments. For example, the increases in nitrate, total ammonia and silica at high flows suggest that near surface waters are important sources and that groundwaters carry comparatively low concentrations.

For sewage effluent, a flow relationship of dilution during high flow periods is typical (e.g. Figure 4.4). This can contrast with the riverine relationships. In cases where effluent significantly affects riverine concentrations the riverine flow relationship can be altered e.g. at Jedburgh, the typical riverine total

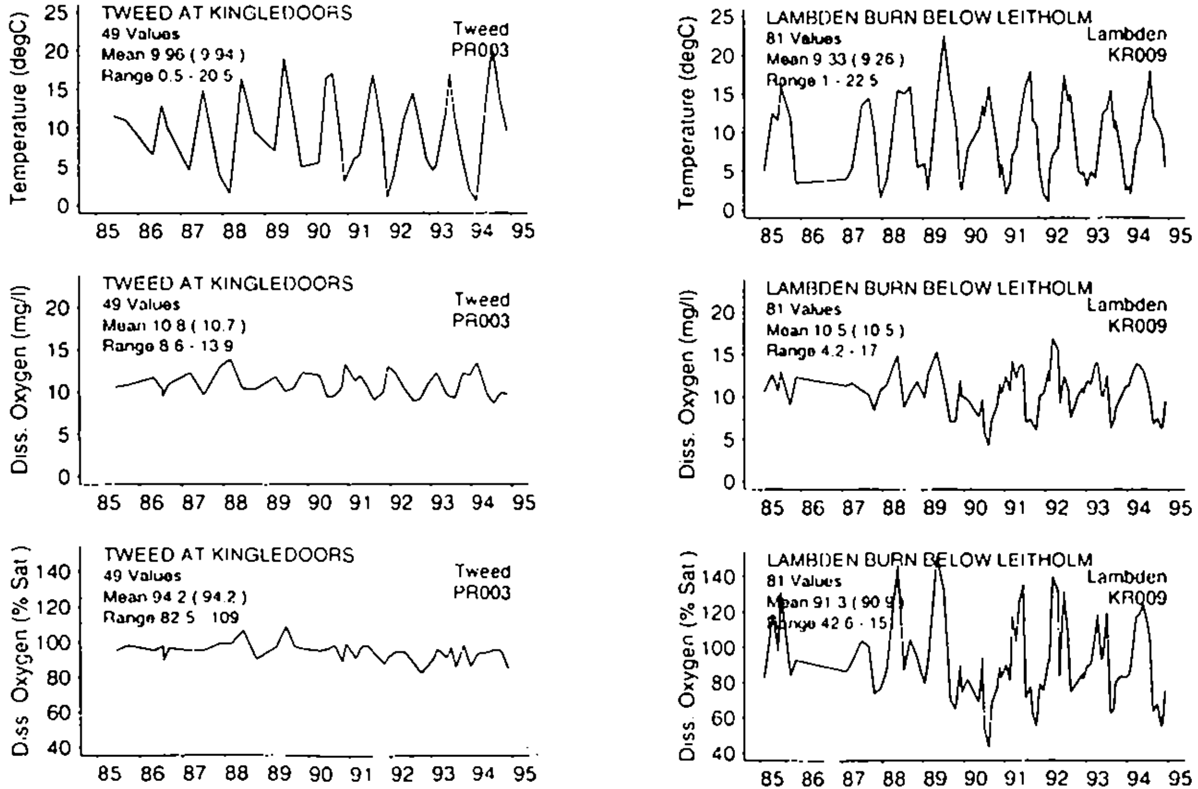


Figure 5.8 *Time series of temperature and dissolved oxygen for a lowland (Lambden Burn) and upland (Kingledoors) location 1985 – 1994. Much greater oxygen variations occur in the lowlands because of higher nutrient levels. There is relatively little temperature difference between the two sites.*

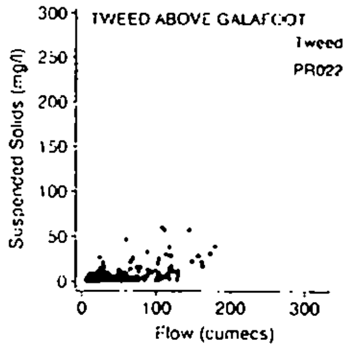


Figure 5.9 *Flow relationships for suspended solids at Tweed above Galafoot. Suspended solids increase rapidly at high flows.*

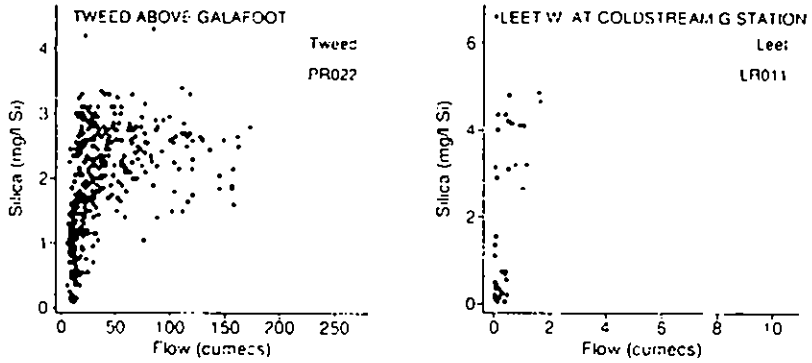


Figure 5.10 *Flow relationships for silica at Tweed above Galafoot and Leet Water. Silica initially increases with flow but then levels off.*

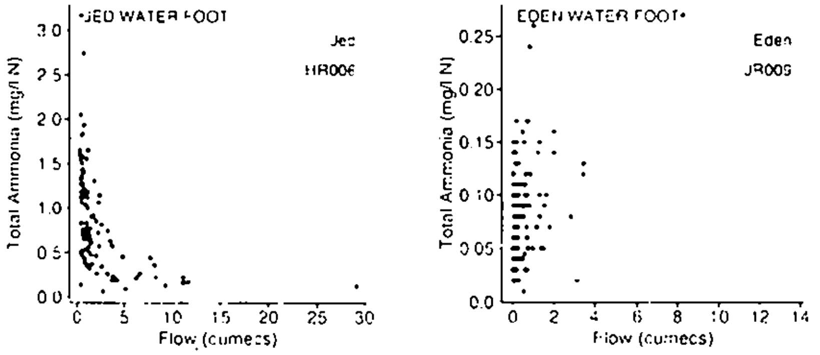


Figure 5.11 *Flow relationships for total ammonia at Jed and Eden Water foot. At most sites, e.g. Eden Water foot, total ammonia increases with flow.*

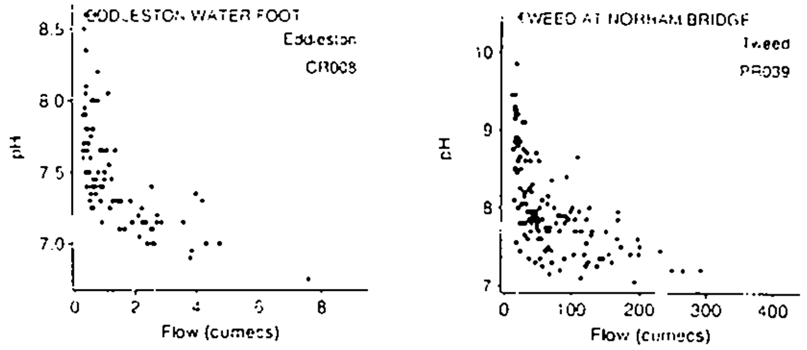


Figure 5.12 *Flow relationships for pH at Eddleston Water foot and Tweed at Norham Bridge. pH declines with flow because runoff from soils and ditches is more acidic than the groundwater sources that supply the rivers at low flows.*

ammonia increase with flow is altered to a decreasing flow relationship (Figure 5.11). Sewage effluent can also show a different distribution of concentrations to the rivers. Suspended solids and total ammonia are much less skewed than for the rivers whereas BOD is sometimes more skewed (e.g. Jedburgh and Selkirk).

Overall, the major regional river water quality variations relate to diffuse sources (e.g. nitrate, phosphate, silica and chloride). Seasonal and flow related variations can be strong, especially where concentrations are highest. Sewage effluent is the main point source of many determinands, but only a few sewage treatment works have a significant effect on downstream water quality and these relate mainly to poor dilution and/or to high industrial loadings. Industry, tips and fish farms have only a small impact on water quality.

5.2 Metals

Metal concentrations have been determined using Furnace Atomic Absorbtion Spectrophotometry (rivers samples) or Flame Atomic Absorbtion Spectrophotometry (effluent samples). Up to three types of determination are made:

- **total**, which is determined on an unfiltered and acid-digested sample,
- **dissolved**, which is determined on a sample that has been filtered through a 0.45 µm filter and,
- **available**, which is determined on an unfiltered sample and measures the amount which is dissolved and in suspension.

The distinction between dissolved and available metal concentrations is essentially operationally defined. In reality, fine colloidal particles smaller than 0.45 µm probably exist in waters (Gunn *et al.*, 1992). Finer filters are non-standard within the water industry and are impractical because of lengthy filtration times. For sewage treatment works and industry, an available metal determination is most widespread. For rivers, tips and fish farms, dissolved metals are measured under the various environmental monitoring programmes. Total metal concentrations have only been measured at a limited set of sites, often only for four (three Harmonised Monitoring sites and the Tweed above Galafoot).

Zinc, lead, nickel, copper, iron and chromium are the main metals that are determined. Determinations for cadmium, mercury and the metalloid arsenic are made at a few sites but concentrations tend to be below or very near detection limits. Many of the metals are toxic to aquatic life when present in excess, the most toxic being cadmium, mercury, arsenic and chromium. Most metals have anthropogenic sources e.g. electronics, fossil fuel combustion and pipework. The relative importance of natural sources is variable: chromium has few natural sources, whilst iron and zinc are abundant in nature.

The main features of the metals data are reported here and a more detailed description of each of the metals is given in Appendix B. Figures 5.13 – 5.15 show the spatial patterns of metal concentrations for both rivers and inputs. Appendix A provides tables of averages for river and point source samples.

Most of the riverine metal load in the Tweed area comes from iron (over 80% on average), followed by zinc (10 – 15%) and then copper, lead, nickel and chromium (in decreasing order; Figure 5.16). Relative proportions of metals in sewage can differ greatly from background river proportions. For example, the high metal load at Selkirk is proportionally enhanced in copper and chromium (Figure 5.16) and, at Galashiels, nearly 50% of the metal load is copper. In contrast, Biggar sewage effluent, which receives relatively little industrial effluent, has a fairly similar proportional breakdown of metals to the rivers.

Sewage effluent is an important source of metals e.g. copper, nickel, chromium and lead, although, in many cases total effluent output is dominated by just a few of the works. Selkirk sewage treatment works discharges the highest levels of almost all metals, whilst Galashiels is a notable but lesser source (see Figures 5.13 – 5.15). The impact on water quality is seen clearly on Ettrick Water where samples taken downstream of the Selkirk outfall show changes in proportions and increases in concentration (typically by a factor between two and ten; Figure 5.17). For copper, a proportional enhancement can still be seen at sites much further downstream even though much dilution has occurred by this stage e.g. Tweed at Galafoot and possibly Norham (Figure 5.17). Copper and chromium inputs at Selkirk probably make a significant impact on total river loads to the Tweed estuary (Figure 5.19 see Appendix B.2 for further details). Nickel is too near detection limits for any increase to be detected. Lead, iron and zinc are near to background levels and there does not appear to have been much overall effect from sewage discharges.

Domestic sources may also contribute to the metal load from sewage treatment works; it has been estimated for UK sewage treatment works that up to 20% of nickel, copper, lead and zinc can derive from domestic sources (pipework, household chemicals, medicines etc.; Hedgecott and Rogers, 1992). It is not possible to distinguish between domestic and industrial sources here. However, where there are very large site to site variations in heavy metals, an industrial source seems likely.

Other point sources of metals are negligible. Most industrial, fish farm and tip effluents have little impact on metal concentration. The exception is iron in tip effluent, which averages around 3600 µg l^{-1}.

For zinc and iron, the most prevalent metals, there is clearly an important background geological source. This geological source appears to be widespread; there are no strong regional variations across the Tweed area. Lead and copper may also have lesser background sources. Background levels of nickel and chromium are below detection limits.

The different analytical methods for metals allow investigation of the form in which the metals are found; in particular an approximate division between available particulate and dissolved components can be made. However, paired determinations are generally only available for a restricted set of sites and the results from these may not be representative of the larger data sets. Also, for the rivers, metal concentrations are often too low for sensible data analysis to be possible (this applies to nickel, chromium and possibly lead). Dissolved fractions are highest for zinc and copper and are lowest for iron (Table 5.2). Dissolved and available particulate proportions in sewage treatment works are highly site dependent (e.g. Selkirk discharges higher available particulate fractions than most other works). In effluent, nickel tends to have the highest dissolved fraction and iron the highest particulate fraction.

Metal concentrations are only weakly associated with flow for the rivers, although highest concentrations are usually seen at low flows. Only iron shows a tendency to increase with flow. For sewage effluent, flow relationships are weak, but metal concentrations tend to dilute at high flows. This is often only seen where concentrations are relatively high.

There have been substantial variations in metal concentrations over time for many sewage treatment works (Figure 5.18). For example, at Selkirk, nickel and iron concentrations have increased over the last decade, whereas copper and chromium and zinc have decreased. For Selkirk, these changes primarily relate to recent changes in treatment process: in 1989 a poly-electrolyte was introduced, and since 1992 a coagulating agent based on iron has been added. These process changes almost certainly explain the observed increase in iron, and decreases in zinc and copper. They may also be partially responsible for the unusually high particulate levels in the Selkirk effluent. It is not known why nickel should have increased since 1993 (nickel is used within the electronics industry). Decreases in chromium may also relate to a tannery which used chromium but has now closed down. Other time series trends in sewage effluent include a decline in copper at Galashiels, and an increase in zinc at Jedburgh. The spike in iron concentrations in 1991 for Jedburgh sewage effluent relates to a trial period in which iron was used as part of the treatment process. Further changes in treatment process at Jedburgh occurred in 1993 and 1994 to help control total ammonia and nitrate discharges.

Although sewage treatment works provide a significant metal load to the Tweed catchment, there are very few water quality problems in the region associated with the metals. Environmental Quality Standards (EQS) and drinking water standards have been met at all sites with the exception of the EQS for copper downstream of Selkirk. Details of the EQS and drinking water standards relative to mean river concentrations are given in Table 5.3.

Table 5.2 *Partitioning between dissolved and particulate components. Average ratios are shown together with the range of site averages (bracketed). * indicates that levels are probably too low in rivers for the ratios presented to be reliable.*

Metal	**Rivers ratios**		**Sewage ratios**	
	Dissolved:Available	**Dissolved:Total**	**Dissolved:Available**	**Dissolved:Total**
Zinc		0.64 (0.54-0.77)	0.60 (0.31-0.84)	0.63 (0.38-0.84)
Lead		0.52 (0.40-0.62)	0.47 (0.22-0.68)	
Nickel *		0.43 (0.39-0.47)	0.67 (0.47-0.8)	
Iron		0.28 (0.22-0.36)	0.39 (0.07-0.72)	
Copper	0.46 (0.30-0.58)	0.65 (0.52-0.8)	0.60 (0.1-3.2)	
Chromium *	0.042 (0.0-0.13)	0.19 (0.17-0.22)	0.72 (0.68-0.76)	

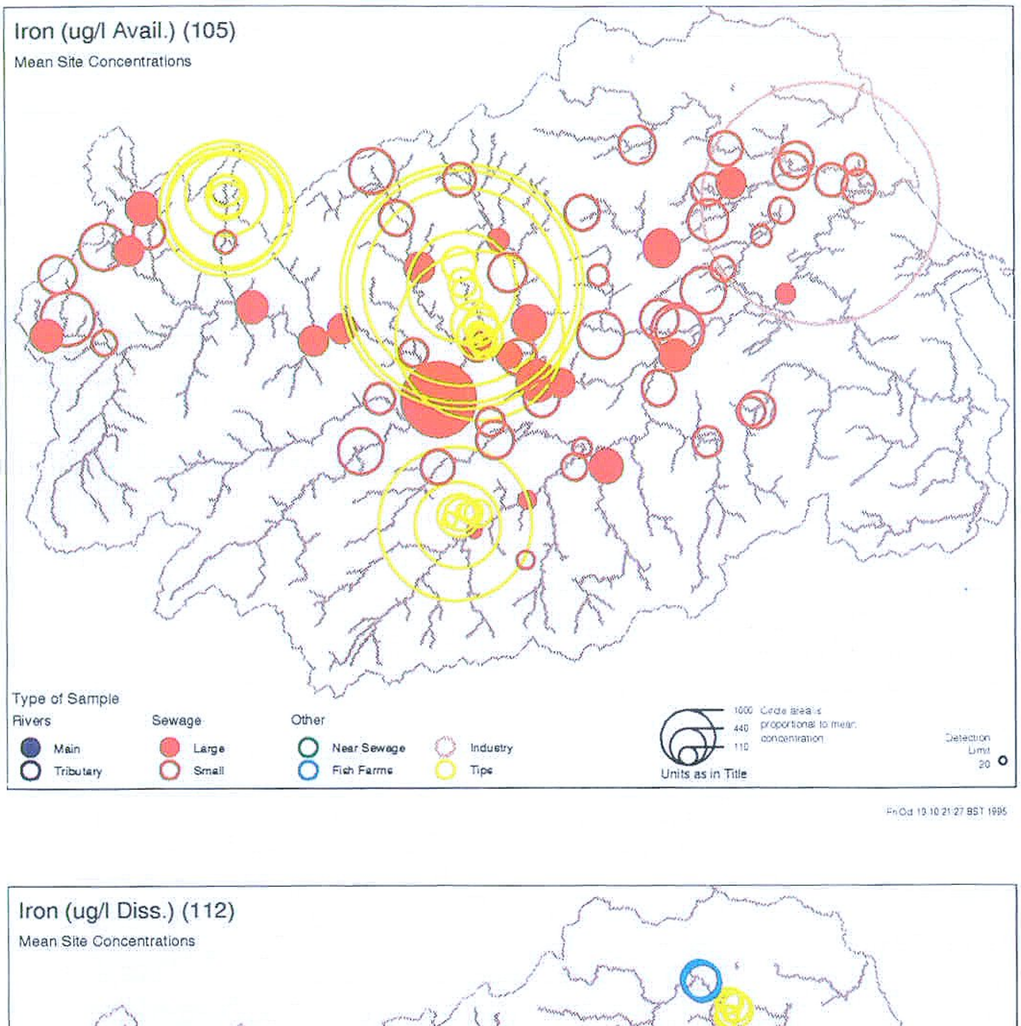
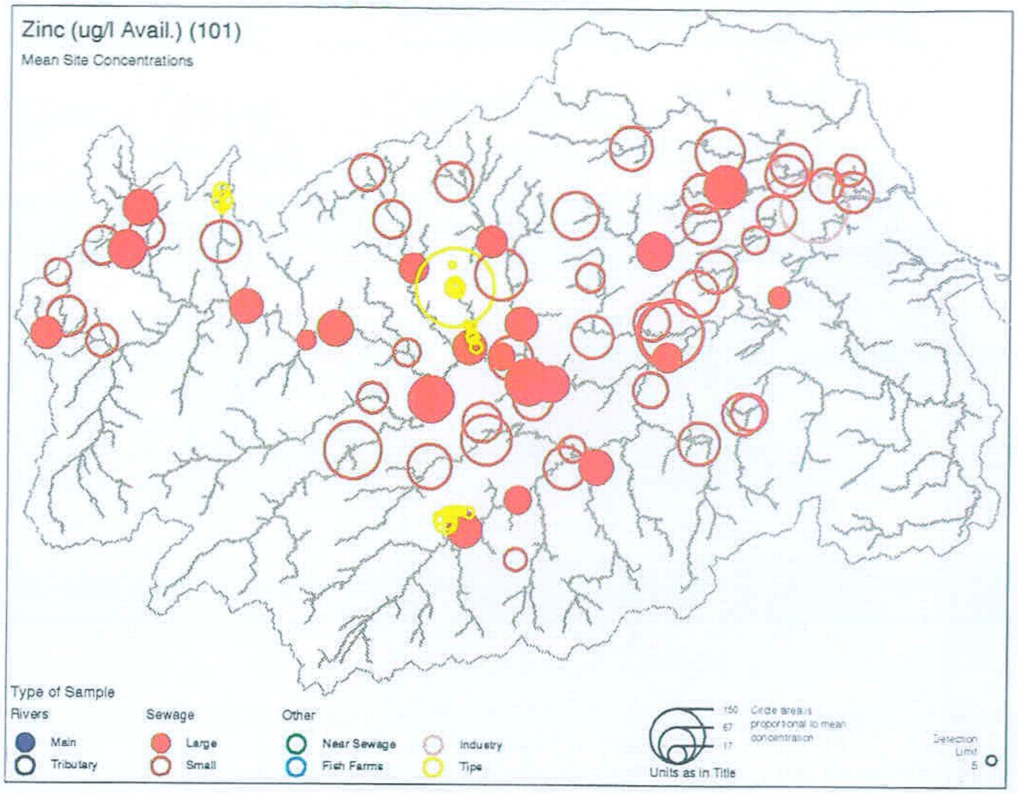


Figure 5.13 *Map of dissolved and available metal concentrations for iron and zinc. Available metal concentrations are measured for a wide range of effluents (but at no river sites). Both zinc and iron have a significant background geological source. The circle in the lower right hand corner of the plots shows the detection limit.*



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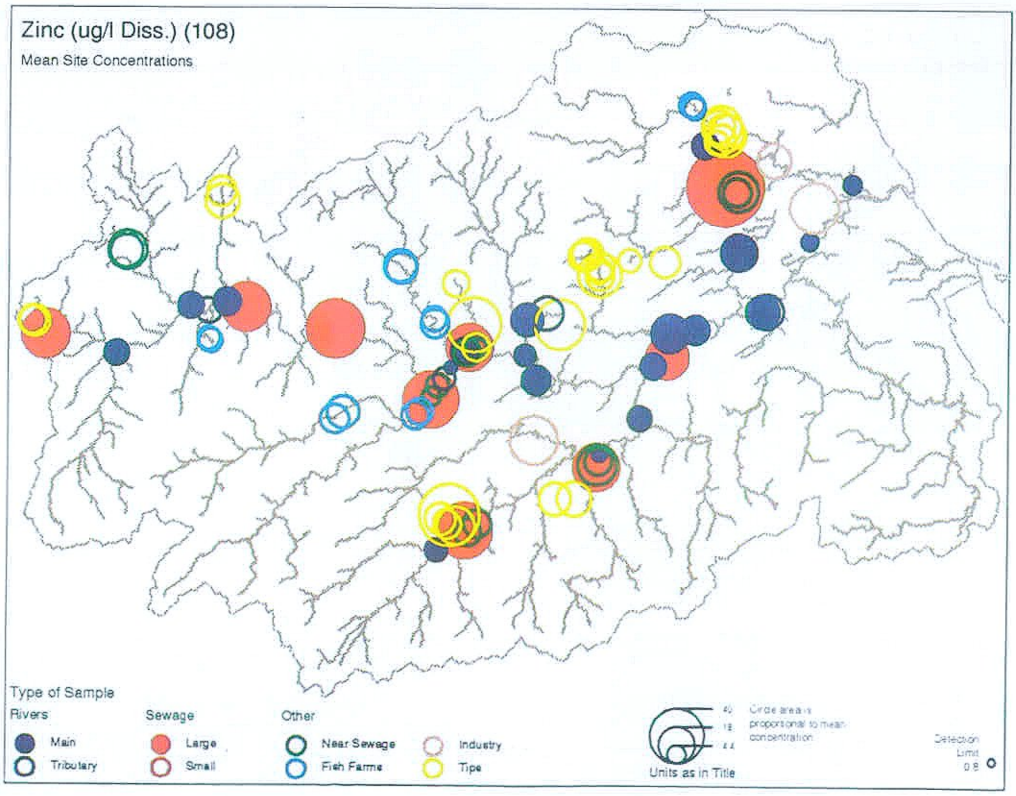

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Figure 5.13 *continued*

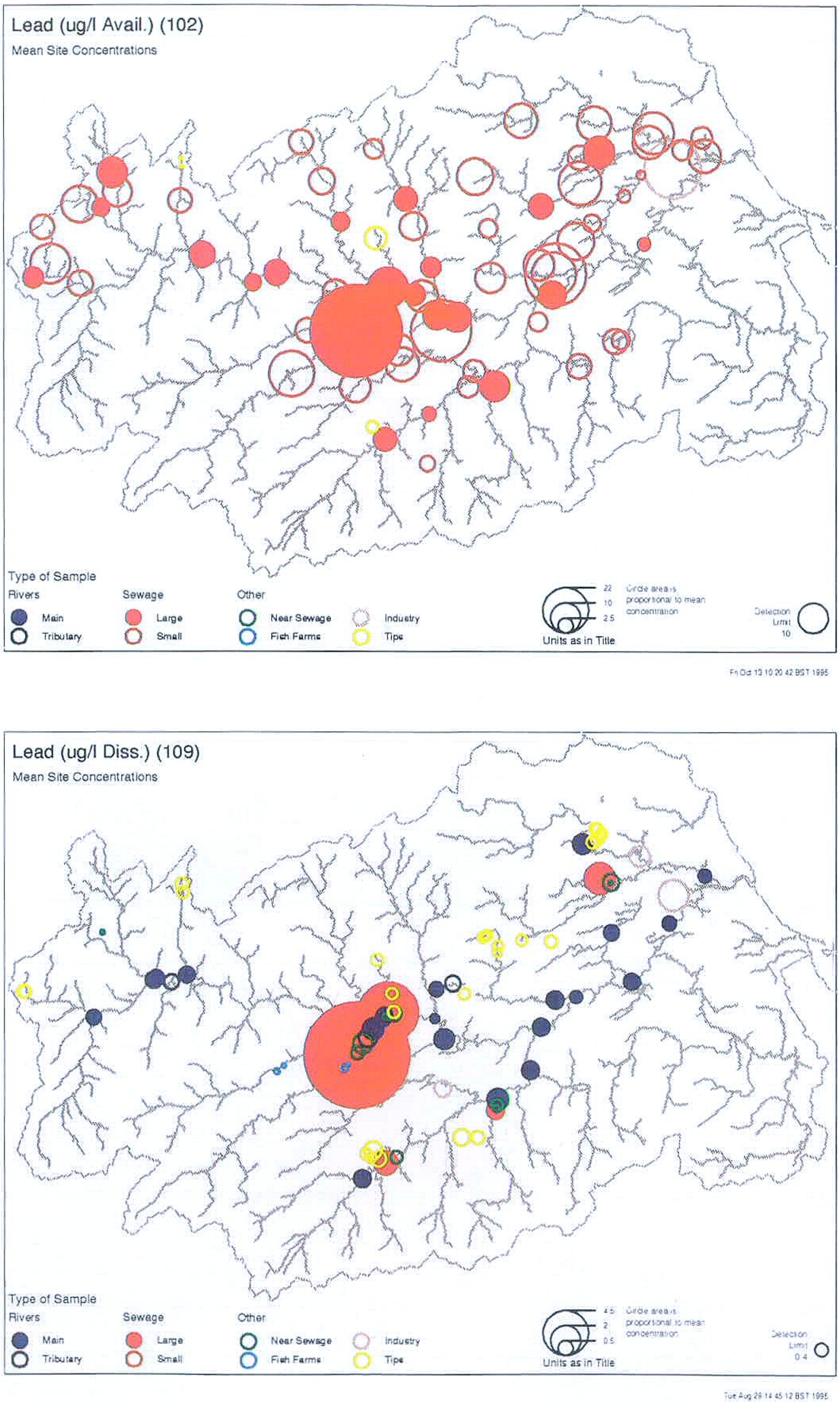

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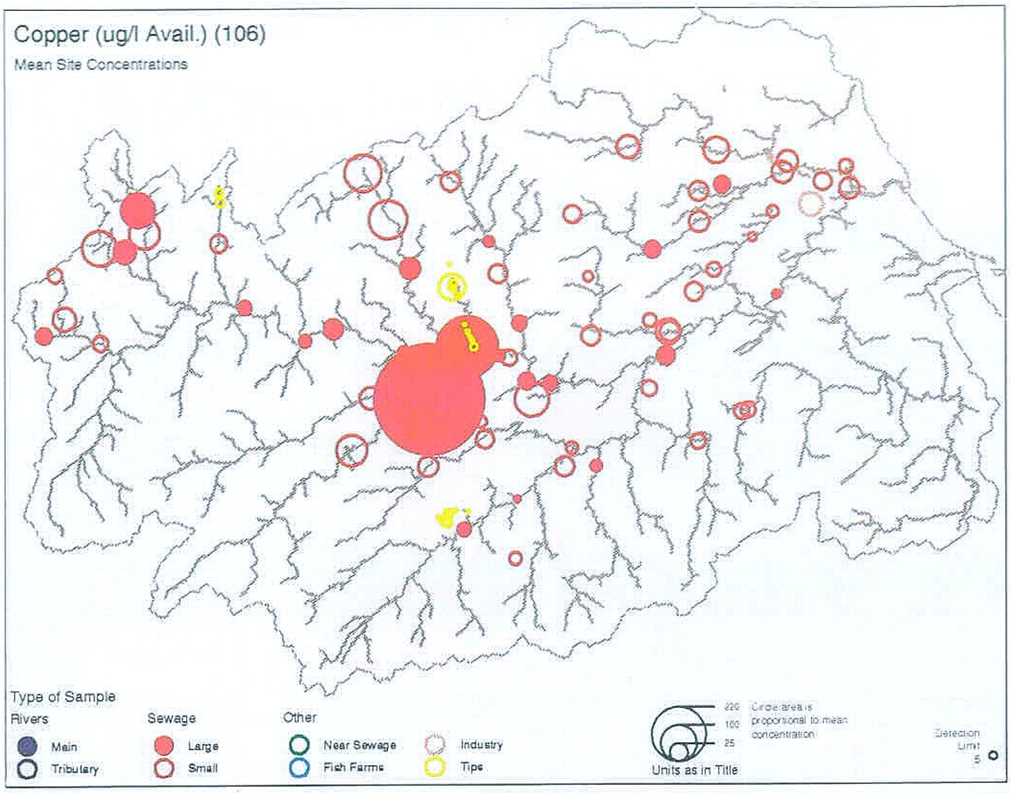
Figure 5.14 *Map of dissolved and available metal concentrations for lead and copper. Both metals have major point source inputs from Selkirk and Galashiels sewage treatment works.*



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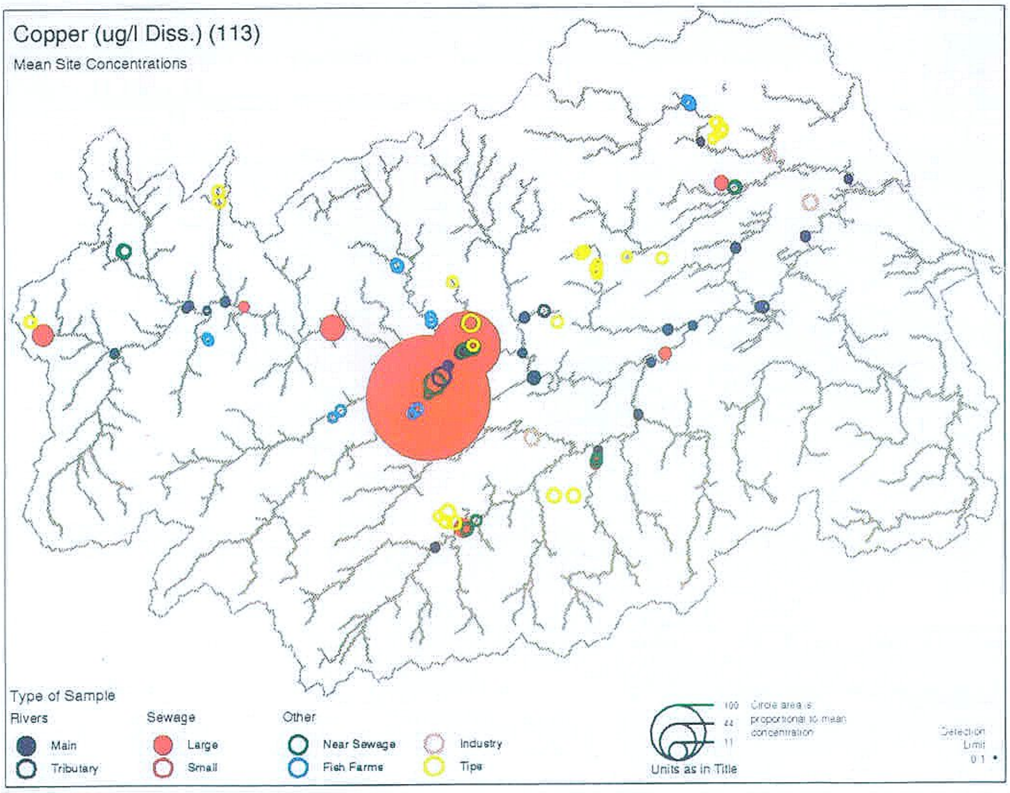

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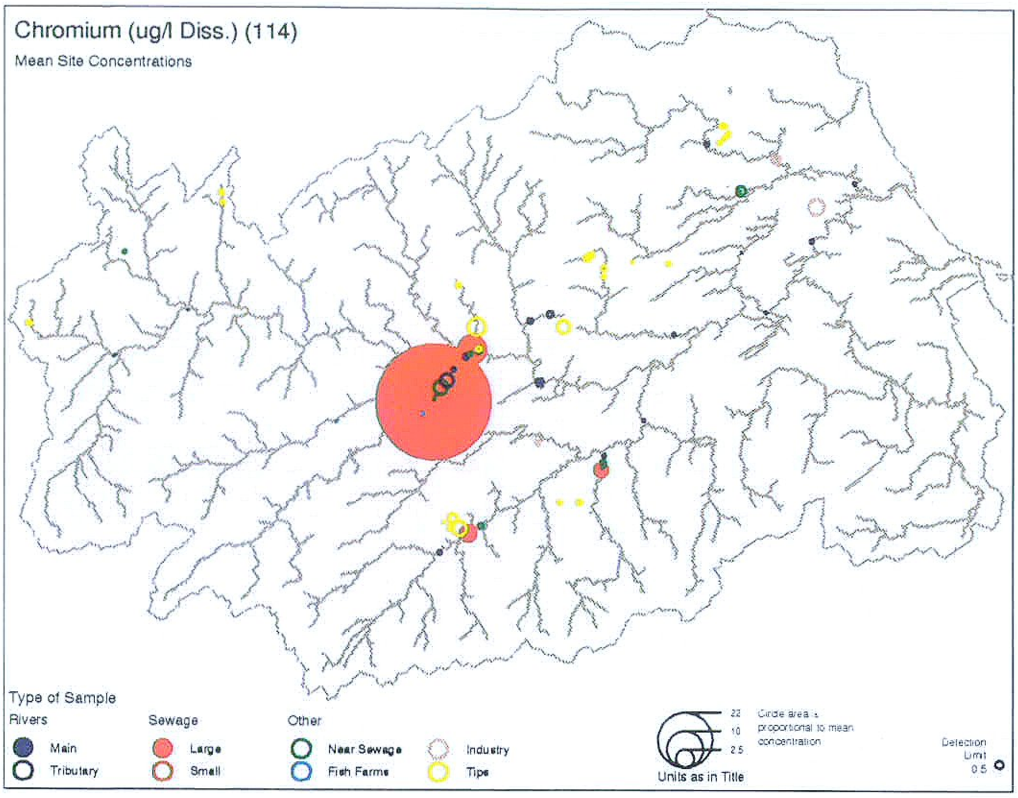
Figure 5.14 *continued*



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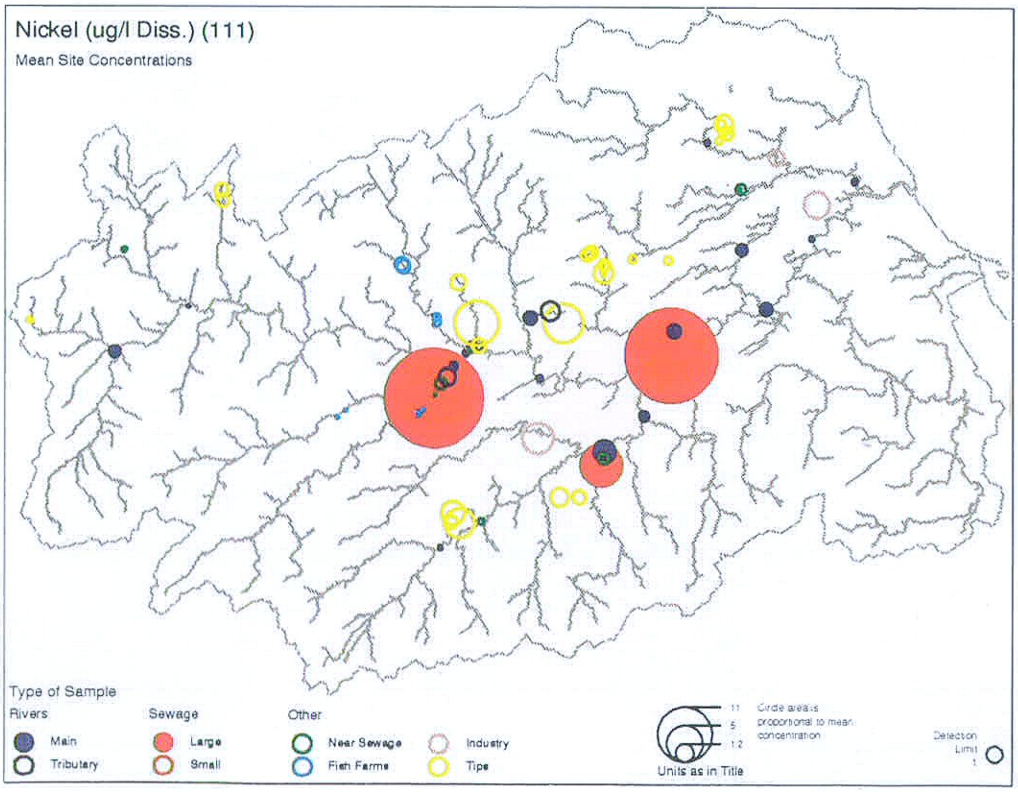

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Figure 5.15 *Map of dissolved chromium and dissolved nickel. Anthropogenic inputs from industrial loadings via sewage treatment works appear to dominate total inputs.*

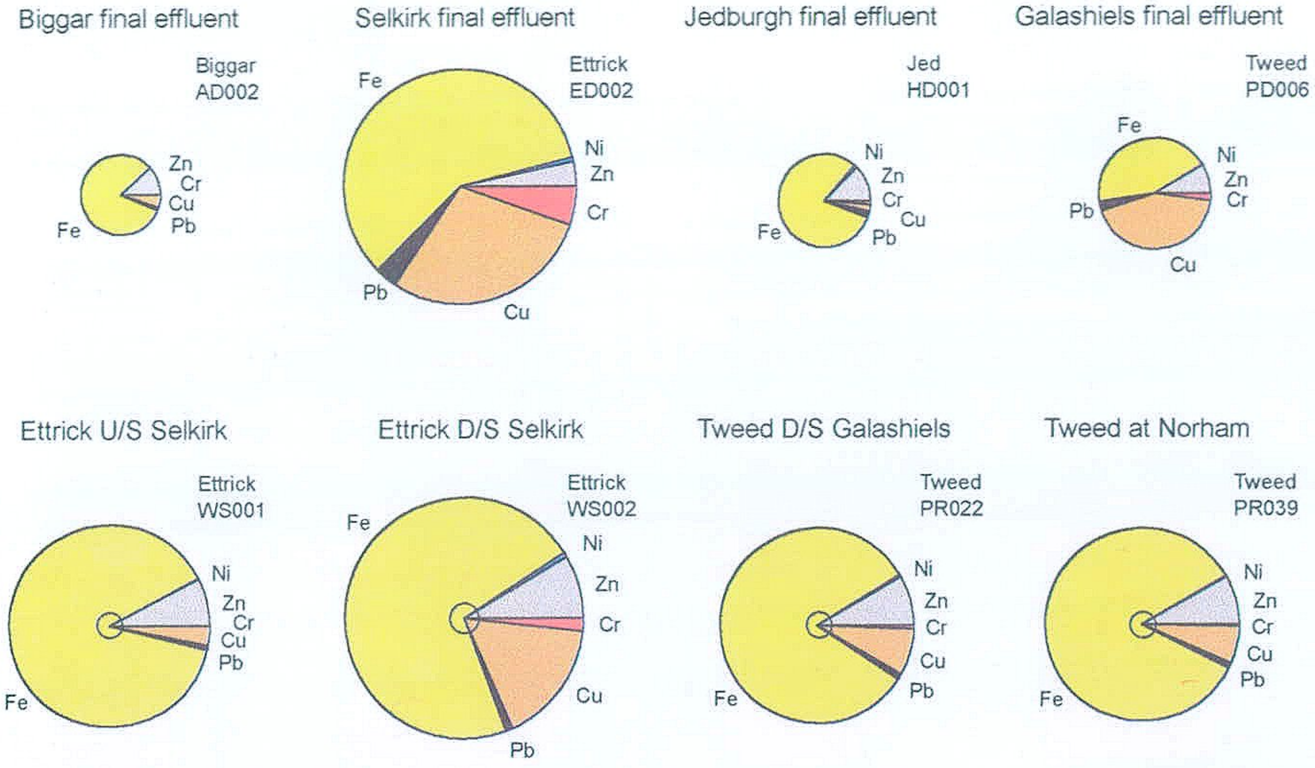


Figure 5.16 *Pie charts showing breakdown of metals at river sites and in sewage effluent. Circle areas are proportional to average concentrations. Sewage effluent is plotted at a smaller scale than river sites. The central circle on the river pie charts shows the size that these pie charts would appear if plotted at the same scale as the sewage effluent. Selkirk provides the highest metal load with enhanced levels of copper, chromium and lead. Galashiels also has a high proportion of copper. The high copper input from Selkirk works impacts downstream metal concentrations.*

Table 5.3 *Environmental and drinking water standards in relation to average concentrations for Tweed river and sewage effluent data. Units are $\mu g\ l^{-1}$. The range in EQS values arises because of the dependence on water hardness. Average concentrations for the Tweed catchment are given as dissolved for river sites and as available for sewage effluent.*

	Environmental quality standard	**Drinking water**		**Tweed average concentrations**	
	Salmonid species (Cyprinid species)	**Guide**	**Max**	**Rivers (Dissolved)**	**Sewage (Available)**
Zinc	8-125 (75-500)	100	5000	8.8	78
Lead	4-120 (50-200)	10	50	0.61	16
Nickel	50-200 (50-200)		50	<1	2.8
Iron	1000	50	200	254	483
Chromium	5-50 (150-250)		50	<0.5	15
Copper	1-28 (1-28)	100	3000	5	99
Cadmium	5		5	<0.5	<0.5
Mercury	1		1	<0.1	<0.1
Arsenic	50	100	50	<5	<5

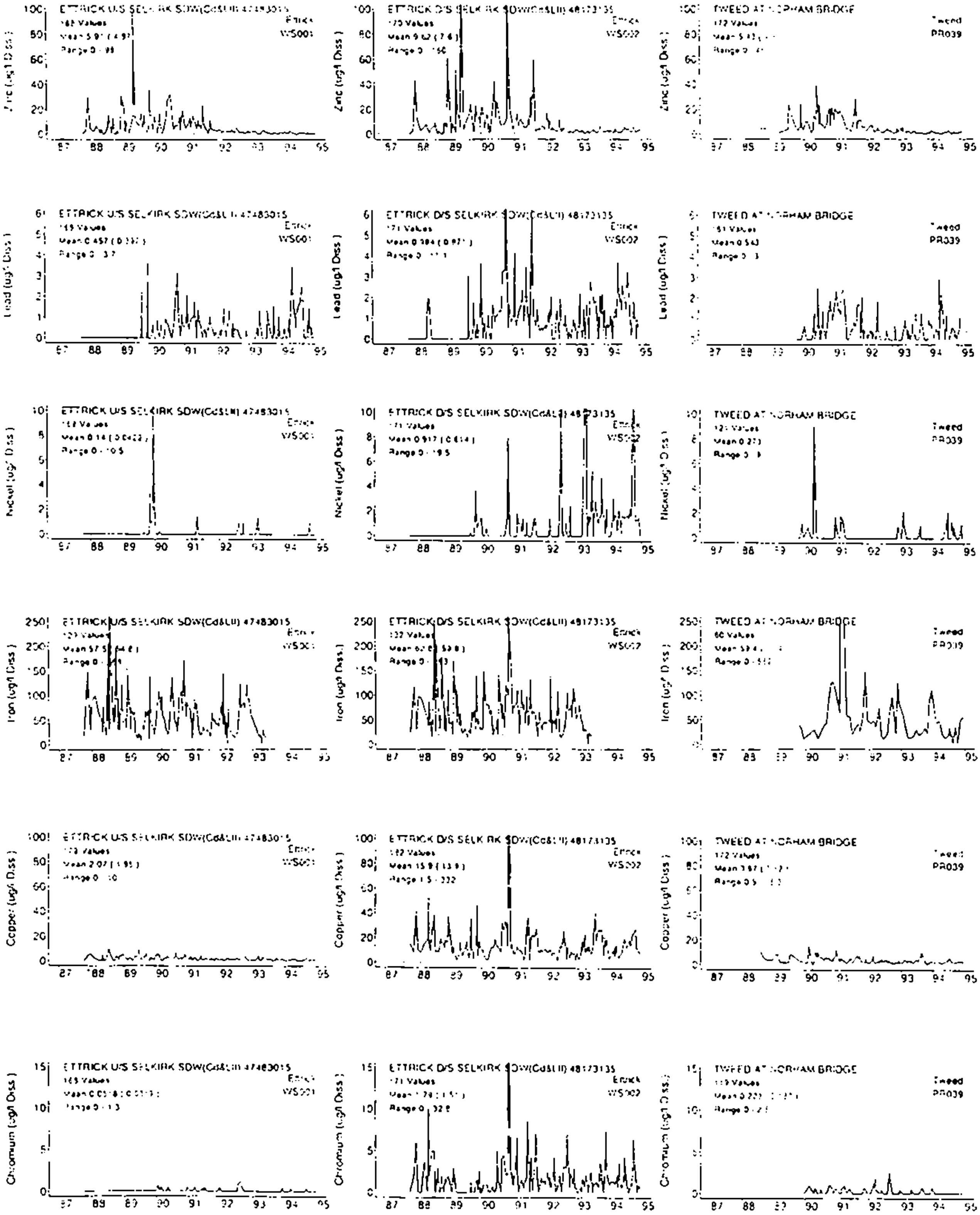


***Figure 5.17** Time series of dissolved metal concentrations for the Ettrick, upstream and downstream of Selkirk, and for Norham, 1987 – 1994. Copper and chromium concentrations are significantly increased by the input from Selkirk. Zinc concentrations have declined in recent years, but nickel and lead may have increased. Horizontal dotted lines show the detection limits.*

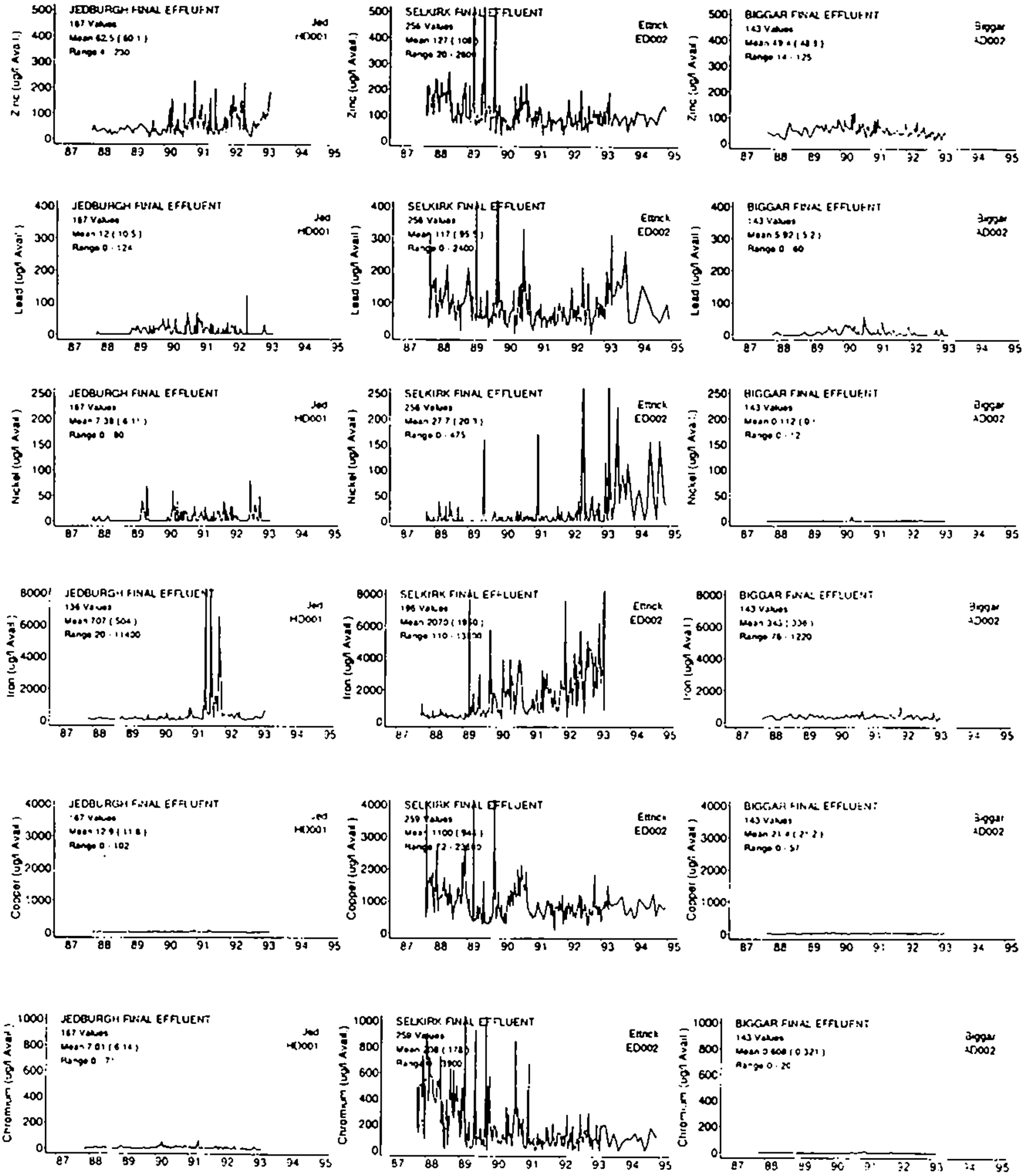


Figure 5.18 *Time series of available metal concentrations in sewage effluent, 1987 – 1994. At Selkirk concentrations are high because of loads from the electronics industry. Here, increasing iron concentrations are due to changes in the treatment process, whilst decreases in chromium are probably linked to the closing of a tannery. Increases in zinc concentrations at Jedburgh are also observed. The spike in iron concentrations at Jedburgh occurred when a different treatment process was tested for a trial period. Biggar sewage treatment works receives little industrial effluent and is low in metals.*

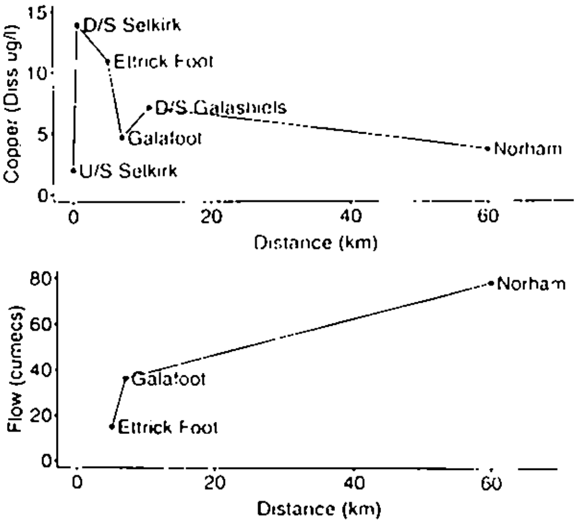


***Figure 5.19** Changes in copper concentration with distance downstream. Mean river flow is shown for comparison. Selkirk sewage effluent discharges between the upstream (U/S) and downstream (D/S) Selkirk sites. Galashiels sewage effluent discharges between Galafoot and D/S of Galashiels. The Ettrick joins the Tweed between Ettrick foot and Galafoot. Both Selkirk and Galashiels cause copper concentrations to rise. Comparison of river concentrations and river flows shows that the increases seen downstream of Selkirk and Galashiels are sufficiently large to also affect concentrations at Norham.*

Overall, sewage treatment works are the most significant point source of many metals, although landfills are a significant source of iron. Copper, chromium, nickel, lead and iron have industrial sources and are highest in effluent from larger towns, notably Selkirk. Copper and chromium in the Tweed are overwhelmingly dominated by this Selkirk discharge. Nickel is very near detection limits in many rivers. Zinc appears to derive mainly from background sources, whilst iron and lead have both background and industrial sources.

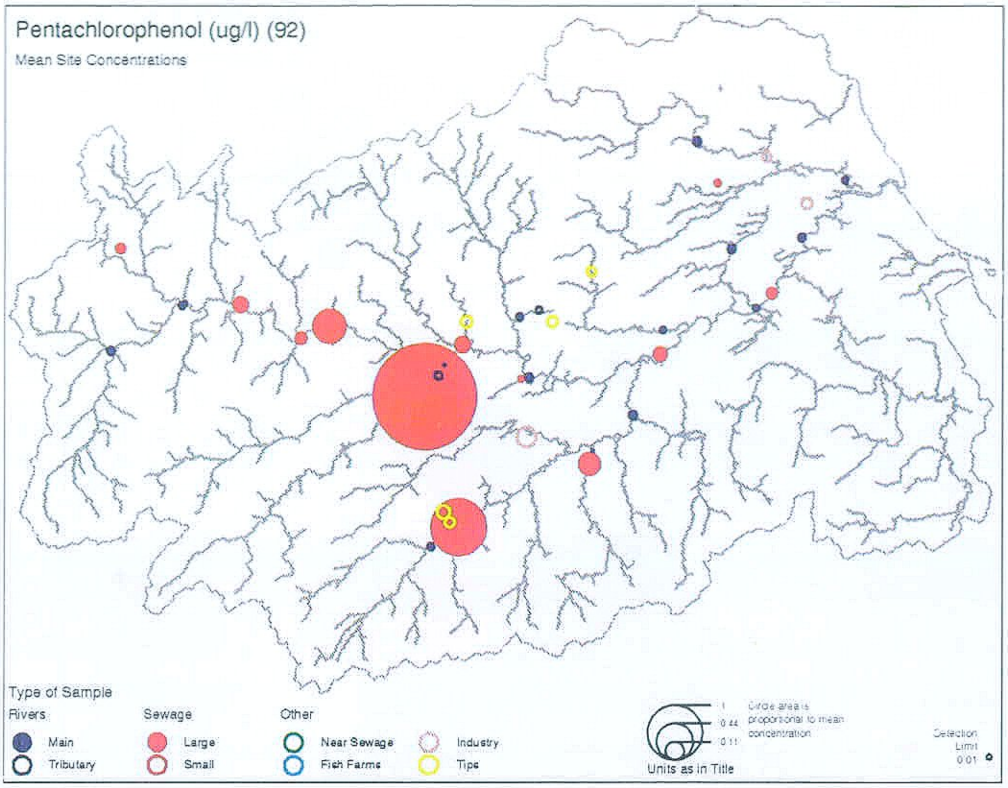
5.3 Micro-organic pollutant substances

Pesticides are analysed by the Tweed RPB using Capillary Gas Chromatography. Pesticides that are determined include organochlorine pesticides, organophosphorus insecticides and triazine herbicides. Organochlorine insecticides include substances such as lindane (gamma-HCH), pentachlorophenol (PCP), DDT and dieldrin and tend to be highly persistent, bioaccumulating in the food chain. They have agricultural, forestry and industrial uses but many have either been banned or have had their use restricted (NRA, 1995). Organophosphorus insecticides, include dichlorvos and fenitrothion, which are used to protect crops against a wide range of insect pests, and propetamphos and diazinon, which are used in sheep dips. They are highly toxic but biodegrade rapidly. The triazine herbicides, e.g. simazine and atrazine, are used for weed control. They are relatively non-toxic to man but are toxic to fish and are persistent. Simazine and atrazine were banned in 1993, apart from for use in agriculture and forestry.

For most species sampling began in 1989 or 1990 following the establishment of the North Sea Action Plan to reduce loads of "red list" substances. Micro-organics are analysed at approximately 15 river quality sites, between three and 12 sewage treatment works and for a few industrial/tip sites. Some sewage effluent samples are also analysed for chlorinated volatiles such as carbon tetrachloride and trichlorobenzene.

The micro-organic concentrations of rivers and point source inputs are summarised in Figures 5.20 – 5.21 and Tables 5.4 and 5.5. For the tables, the micro-organic have been divided into those detected regularly in the rivers, and those hardly detected in the rivers. Some of the latter have been detected in effluents discharged to the rivers, even though levels are very low in the rivers themselves. For many of the substances, even those which are regularly detected, concentrations are near to or below detection limits for a high proportion of samples. Because of this, time series plots of micro-organic concentrations tend to have a very spiky appearance. Also, average concentrations for a given site are often less than the detection limit, even though a significant number of measurements are at a detectable level. Caution has to be applied to data interpretation in such cases because of the high uncertainty attached to the averages.

Monitored point source inputs to the Tweed include sewage treatment works, industrial effluent and tip effluent. For many micro-organics, sewage treatment works are the only notable point inputs and these are highly site and species dependent because of variations in the industrial loadings to works. In some cases, the regional maps show how concentrations at one or two works dominate all other works (e.g. PCP, Figure 5.20 and pirimiphos methyl, Figure 5.21). Higher than average micro-organic concentrations can occur at Coldstream, Charlesfield, Hawick, Selkirk and Jedburgh, depending on the specific substance (see Table 5.4). For example, the maps show how pentachlorophenol is dominated by the inputs from Hawick and Selkirk, whilst diazinon has a large input at Coldstream. In some cases, only two to four sewage treatment works have been sampled so the picture is very limited.



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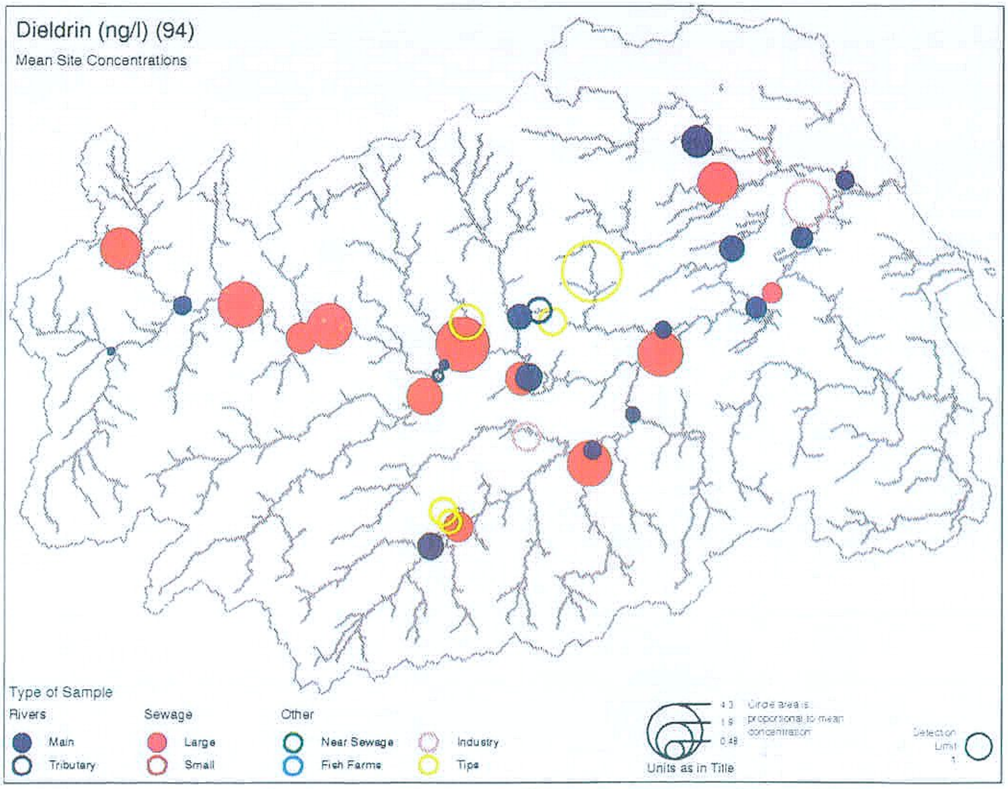

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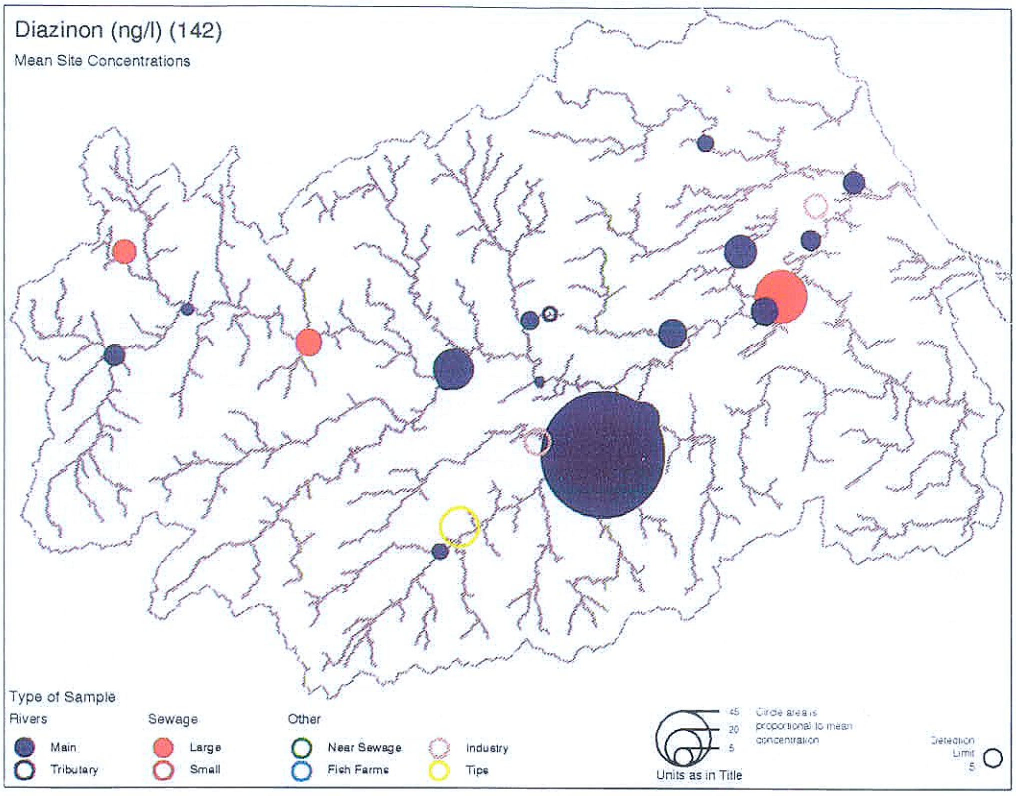
Figures 5.20 *Maps showing average concentrations of pentachlorophenol, dieldrin, diazinon and atrazine. Pentachlorophenol is dominated by the sewage effluent from Selkirk. Dieldrin has more even distribution in effluent. Concentrations are highest in the lowland arable areas to the northeast. High concentrations of diazinon have occurred at Jed Water foot because of industrial sources.*



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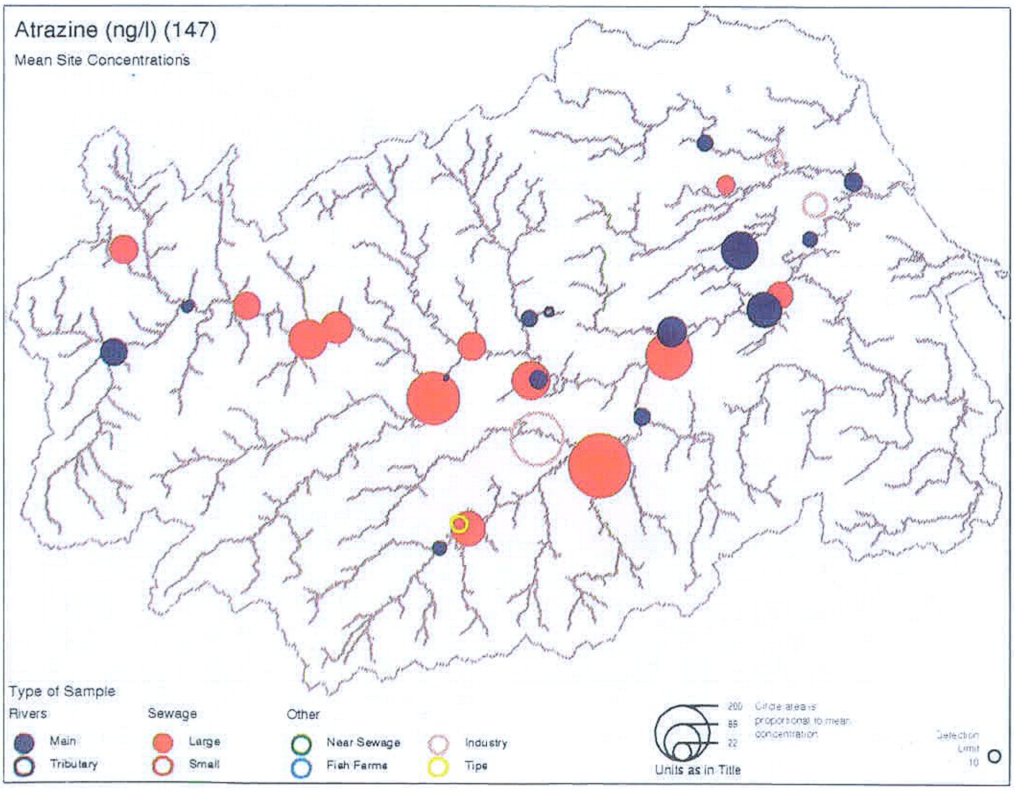

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***Figure 5.20** continued*

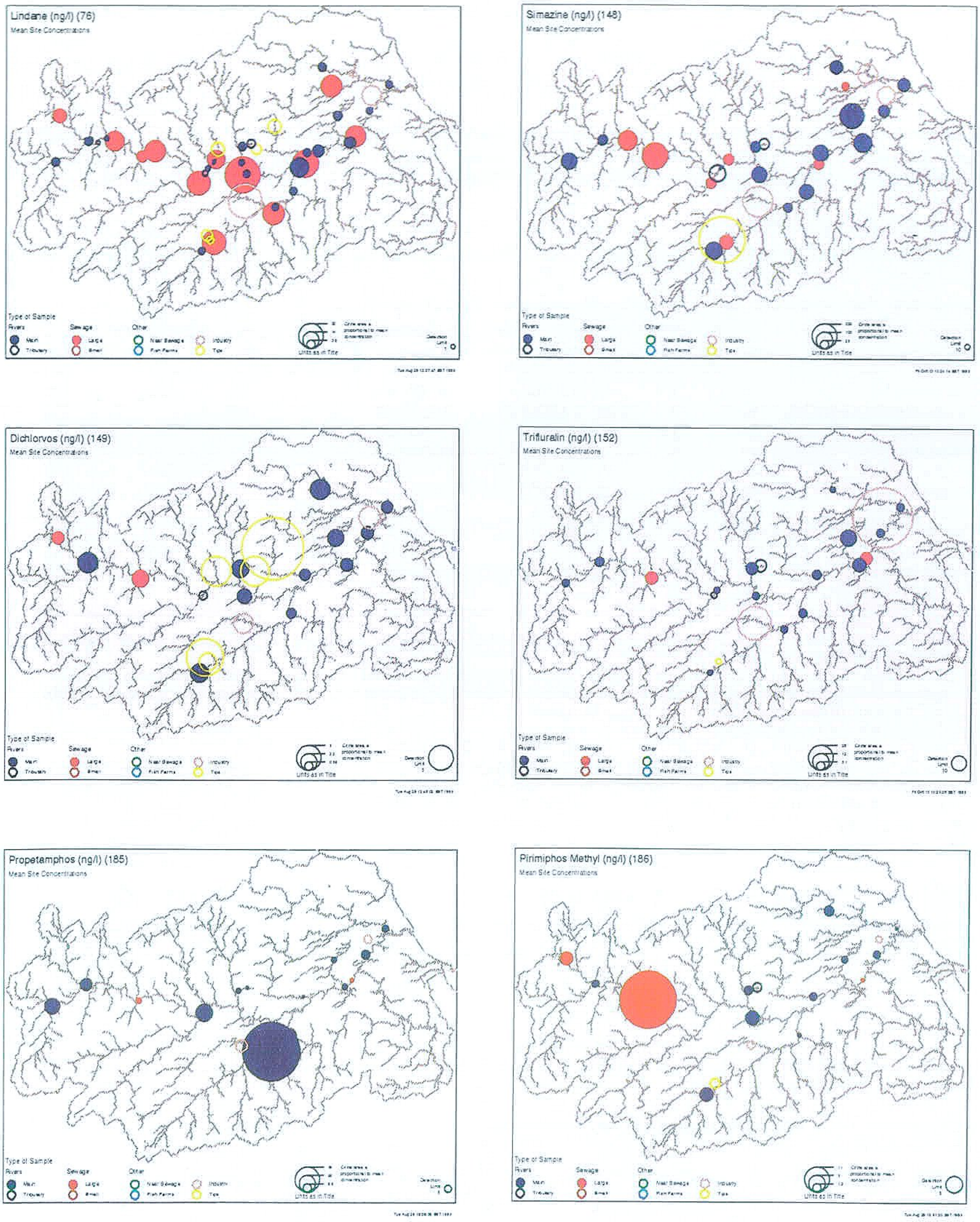

Figure 5.21 *Maps showing average concentrations of lindane, simazine, dichlorvos, trifluralin, propetamphos and pirimiphos methyl.*

Micro-organics which have a more widespread and uniform occurrence in sewage effluent include lindane, dieldrin and atrazine. For these there is probably a non-industrial origin or a background diffuse source. Note that dieldrin has not been used since the early 1970s and atrazine has been banned from non-agricultural use since 1993. Direct industrial inputs of micro-organics are small. Tips are sources of a few, mainly dichlorvos, fenitrothion, dieldrin and diazinon. Dichlorvos seems the most widespread, but no sources of this chemical have been established.

Occasional exceedances of the Environmental Quality Standards for micro-organics have occurred over the past six years, most commonly for diazinon, dichlorvos and fenitrothion. There have also been some problems relating to specific point discharges. For example, in the late 1980's macro-invertebrate populations below Galashiels sewage treatment works declined as a result of a synthetic pyrethroid mothproofing agent. Its use within the town has since been discontinued. More recently, invertebrate damage occurred downstream of Jedburgh caused by organophosphorus chemicals

Table 5.4 *Micro-organics found in detectable amounts in river waters.*

Determinand	Code	Detection Limit	Rivers(1)	Sewage(2)	Tips(3)	Use(4)	Type(5)	EQS(6)
Lindane (ng l^{-1})	76	1	0 - 4.5 (50)	**10 - 80 (40)**		A	siO_H	100
Pentachlorophenol (µg l^{-1})	92	0.1	0.02 - 0.037 (<0.2)	**5 S, 1.6 H**		ID		2
Dieldrin (ng l^{-1})	94	1.5	0 - 1 (10)	**0 - 4 (15)**		AID	siO_H	10
Diazinon (ng l^{-1})	142	5	1 - 12 (150)	only 3 sites (C)				100
Atrazine (ng l^{-1})	147	10	10 - 140 (1000)	**60 - 260 (1000)**		A	$swhO_N$	2000
Simazine (ng l^{-1})	148	10	30 - 270 (800)	only 3 sites		A	shO_N	2000
Dichlorvos (ng l^{-1})	149	5	0 - 6 (50)	only 4 sites		AD	O_P	1
Fenitrothion (ng l^{-1})	150	5	1 - 3 (20)	only 3 sites (C)		A	O_P	10
Malathion (ng l^{-1})	184	5	0 - 1.5 (4)	only 3 sites		AD	siO_P	10
Propetamphos (ng l^{-1})	185	5	0 - 20 (100)	only 2 sites		A		
Pirimiphos Methyl (ng l^{-1})	186	5	0 - 3 (80)	only 3 sites (Ch)		A		

(1) For rivers, the range of average values is given. Bracketed values give an approximate upper range (but not the absolute maximum as outlier points have been excluded).

(2) For sewage, C = Coldstream, Ch = Charlesfield, H = Hawick. **Highlighted parts indicate substantial sources.** Either average concentration for the individual sewage treatment works of significance are given or, where most sewage treatment works contribute, the range of averages and an approximate upper value.

(3) T = large source, t = small source.

(4) Main use A = agricultural, D = domestic, I = industrial (see NRA, 1995 for further details).

(5) O_H, O_N, O_P are organo-halogen, organo-nitrogen and organo-phosphorus compounds respectively. s = sediment associated movement, w = movement in solution, i = insecticide, h = herbicide.

(6) Environmental Quality Standards. Note that some of these are proposed standards.

Table 5.5 *Micro-organics that are not detected (or hardly detected) in river waters.*

Determinand	Code	Detection limit	Rivers	Sewage(1)	Tips	Type(2)
Aldrin (ng l^{-1})	78	1	●	●		siO_H
Carbon tetrachloride (µg l^{-1})*	91	1		●		C
Endrin (ng l^{-1})	93	0.5	●	●	●	siO_H
pp'DDT(ng l^{-1})	98	1	●	31 S +	●	O_H
Hexachlorobenzene (ng l^{-1})	135	3	●	12 S, 22 H +	●	O_H
Hexachlorobutadiene (ng l^{-1})	136	10				O_H
Endosulfan (ng l^{-1})	145	10		2J ●	●	O_H
PCB (28, 52, 101, 118, 138, 153, 180) (ng l^{-1})	146	10				O_H
Azinphos Methyl (ng l^{-1})	151	1	●	●	●	O_P
Trifluralin (ng l^{-1})	152	10	●	●		O_H
Chloroform (µg l^{-1})*	153	1.2				C
Trichlorobenzene (ng l^{-1})*	154	40		●		C
1,2 - Dichloroethane (µg l^{-1})*	155	1		●		C
Chlorfenvinphos (ng l^{-1})	217	10	●	*60 S,50 Ch*		

* denotes substances only measured in sewage effluent

● Sites with occasional spikes above detection limits. Average concentrations are given where they are above detection limits.

(1) S = Selkirk, H = Hawick, Ch = Charlesfield, J = Jedburgh. + denotes that some other site(s) are above the detection limit. *The entry in italics marks the fact that only three sites were monitored.* Note that only a very few sites were monitored for some other substances.

(2) O_H, O_N, O_P are organo-halogen, organo-nitrogen and organo-phosphorus compounds respectively. C = chlorinated volatiles, s = sediment- associated movement, w = movement in solution, i = insecticide.

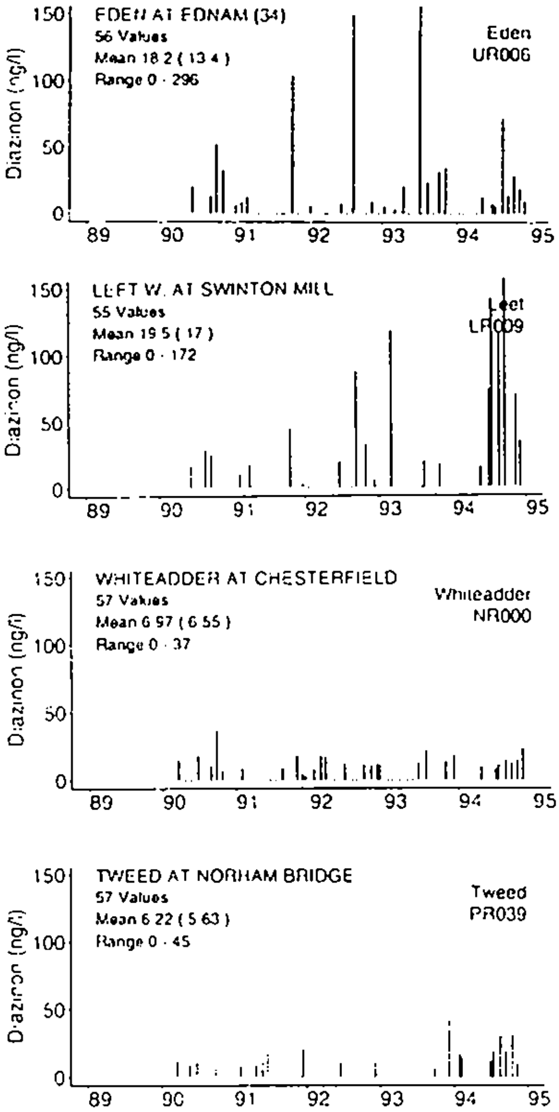

***Figure 5.22** Time series of diazinon concentrations at four river sites, 1989 – 1994. Concentrations have increased on some watercourses.*

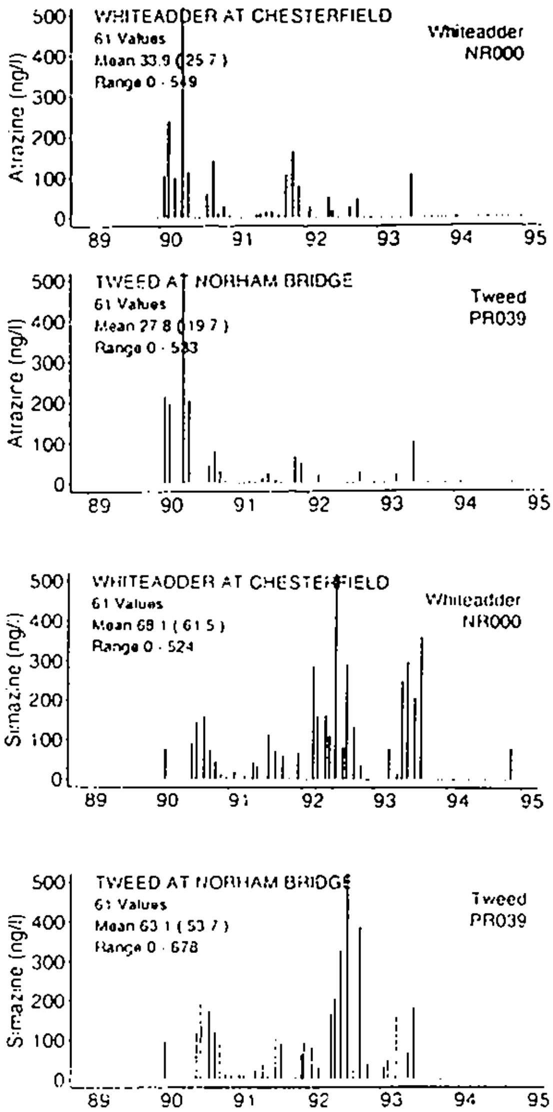

***Figure 5.23** Time series variations for atrazine and simazine on the Whiteadder and Tweed, 1989 – 1994.*

that were not removed by sewage treatment processes. The greater dilution available at the now relocated outfall seems to have remedied this, but a recently detected new insecticide (cypermethrin) could now have an adverse biological effect in the Teviot.

The regional maps have been used to assess the broad features of spatial riverine variations. Pentachlorophenol, dieldrin and lindane show a uniform spatial distribution. Contrastingly, atrazine, simazine and diazinon are higher in the lowlands, as are, to a lesser extent, dichlorvos, fenitrothion and pirimiphos methyl. For these, Leet Water, Turfford Burn and Eden Water usually have highest concentrations, whereas the less arable Eddleston and Gala Water and the lower reaches of the Tweed are relatively free of micro-organics.

The elevated levels of some of the micro-organic pollutants in lowland arable tributaries are probably the result of widespread and legitimate agricultural applications. Smaller streams and tributaries in localised areas are likely to experience the highest concentrations. These will not necessarily be picked up at the main sampling sites because in many cases dilution leads to concentrations lower than detection limits. Samples taken as part of the sheep dip survey (see Section 2.3) showed relatively high levels of sheep dip chemicals in local watercourses prior to the programme of education (1989/90). Afterwards, there was a significant decline in propetamphos and diazinon concentrations for the tributaries in these areas. Despite these local improvements, there has been little downward trend in either propetamphos or diazinon at the main river sampling sites.

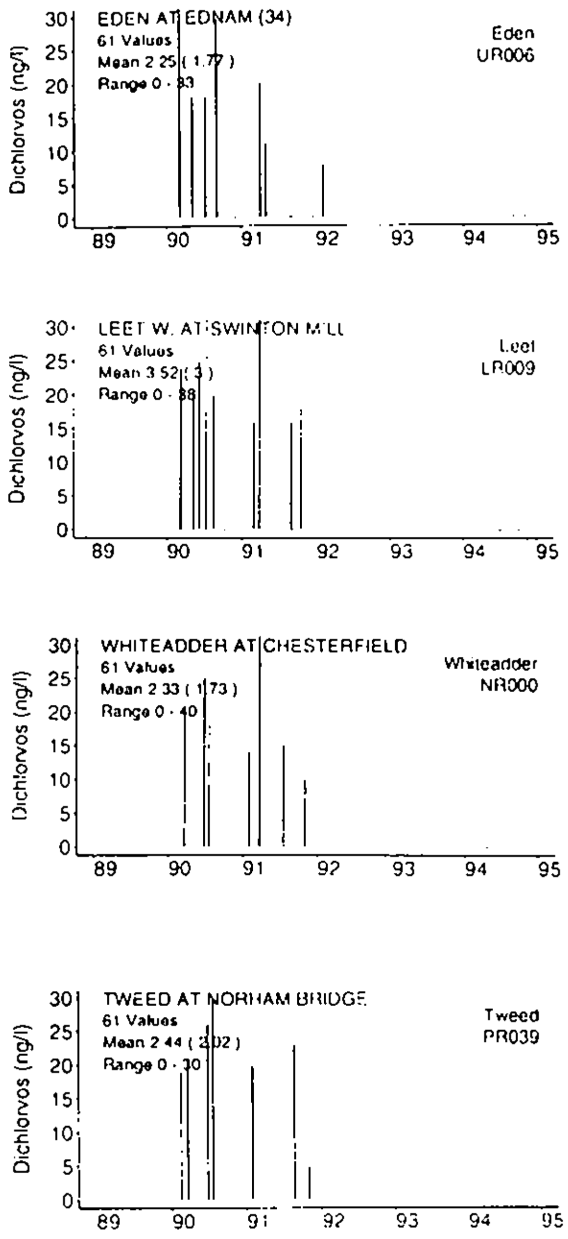

Figure 5.24 *Time series of dichlorvos concentrations at four river sites, 1989 – 1994. Concentrations have declined but there are no known sources within the catchment. The dots show values at the detection limit.*

Concentrations of diazinon have increased in Leet Water and a possible upward trend has been identified for Eden Water (Figure 5.22). Diazinon has uses in arable areas and this may explain the trend since there are few sheep in these two catchments, particularly the Leet.

The triazines, atrazine and simazine have declined following the ban on non-agricultural use in 1993 (Figure 5.23). Dieldrin, dichlorvos and trifluralin concentrations have demonstrated a downward trend at a several (Figure 5.24). A marked decline in pentachlorophenol concentrations at Hawick sewage treatment works is the result of mothproofing agents no longer being used (Figure 5.25).

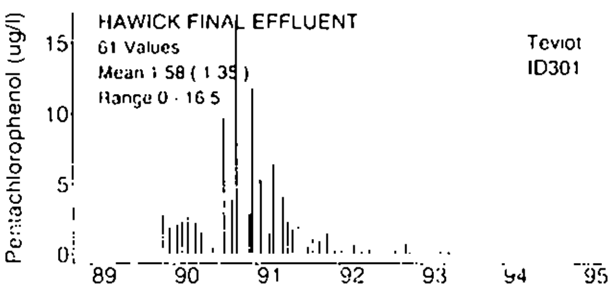

Figure 5.25 *Time series of pentachlorophenol concentrations in Hawick sewage effluent, 1989 – 1994. Concentrations declined rapidly once the use of mothproofing agents was stopped.*

Micro-organic concentrations in rivers tend, if anything, to dilute with flow. Most obvious dilution relationships are seen for atrazine and simazine; for the rest the relationship is fairly weak. There may also be a slight dilution effect for sewage effluent for some species – but again it is only weak.

Micro-organic loads are highly dependent on current and historical farming practice and industrial use. In many cases, legislation plays a key role in controlling use. Future changes connected to industrial activity are likely to have a rapid impact on river concentrations, as was seen for pentachlorophenol at Hawick. Agricultural changes will probably have a more gradual effect because of the diffuse nature of these inputs, but it will depend on the chemical and how it has been used. There may be significant reservoirs of persistent chemicals in old soakaways and these will complicate predictions of future change.

Overall, micro-organic levels are low for the Tweed. Pesticide levels tend to be higher in agricultural areas but on the main rivers they are well within drinking water quality guidelines (1 µg l^{-1} for individual pesticides and 5 µg l^{-1} in total) and are usually below EQS values. Nevertheless, net increases in micro-organic levels have occurred between the headwaters and the lower Tweed for diazinon, atrazine and simazine, and to lesser extent for fenitrothion, dichlorvos and trifluralin. It is not clear to what extent industrial loads (via sewage effluent) are contributing to the total export of micro-organics; concentrations of micro-organics are both very low and very variable and this makes further analysis difficult. However, it may be that diffuse inputs are the major source of micro-organics, and that these are reaching the rivers through legitimate use rather than through accidents and poor usage. Significant reservoirs of some persistent chemicals probably exist in old soakaways and it is possible that inputs from such sources are substantial relative to current use.

6 Inputs to the Tweed

6.1 Summary of point source inputs

Sewage

Sewage treatment works are the most widespread and significant point sources of many of the chemicals found in the Tweed waters. Usually they receive contributions from both domestic and industrial sources. In larger towns the industrial contribution may be greater than the domestic load. Around 87% of sewage treatment works now meet consents and this proportion is rising (in 1985 only 70% met consents). Incidents of poor quality effluent causing serious pollution are rare and have mainly been caused by high industrial loads or insufficient dilution in the receiving watercourse.

Sewage treatment works receive a substantial biodegradable load (e.g. from faecal matter and food processing wastes). This results in effluent which is high in BOD, suspended solids, ammonia, nitrate, phosphate and chloride. For phosphate there are additional sources from detergents. In general, larger works have more stringent consent standards and produce better quality sewage effluent, albeit in greater quantities. Higher grade treatment reduces suspended solids, ammonia, nitrite and BOD. There are exceptions to this general statement; for example, at Jedburgh, total ammonia and suspended solids are disproportionately high owing to high industrial loadings from fellmongering.

Heavy metal concentrations are higher in sewage effluent from the larger towns attributed to industrial inputs. This is particularly striking at Selkirk because of the thriving electronics industry. Selkirk sewage effluent dominates point inputs of copper and chromium to the Tweed. Nickel, lead and iron can also be very high in sewage effluent; though site to site variation is large. In the last ten years, metal concentrations have changed: nickel and iron have increased at Selkirk, but copper, chromium and zinc have decreased; copper has declined at Galashiels, whilst zinc has increased at Jedburgh. These changes can be linked to changes in industrial process or raw materials and to alterations in effluent treatment.

Sewage effluent is the only significant monitored point source of many micro-organics. Some micro-organics are widespread and are detected at most sewage treatment works (e.g. dieldrin and atrazine), whilst others are discharged from just a few (e.g. diazinon and pentachlorophenol). Highest discharge concentrations are from Selkirk, Hawick, Coldstream, Charlesfield and Jedburgh. These have varied over time in response to industrial and legislative changes and to improved treatment (either at the sewage treatment works or as part of factory processing). For example at Hawick, pentachlorophenol, a mothproofer which is no longer used, has declined.

There is usually only a weak relationship between effluent quality and river flows. Where such a relationship exists, concentrations typically dilute at higher flows. This pattern often contrasts with the riverine flow relationship. The distribution of species concentrations in effluent also differs from the rivers, tending to be less skewed.

Landfill sites

Landfill sites in the Tweed area have little impact on surface waters. A few localised poor quality waters are monitored but they are generally on small ditches and burns. The effect on larger watercourses is minimal. Although tip effluent contains a wide range of substances the concentrations are probably not significant in comparison with effluent from sewage treatment works. Of the monitored species, suspended solids and iron levels are most affected by tips. There is evidence of fairly widespread discharge of micro-organics, including dichlorvos, fenitrothion, dieldrin and diazinon.

Industry

Industry in the Tweed basin is limited in terms of the scale and range of processes. Most industrial effluent in the area is routed via sewage treatment works and combined with domestic effluent. This accounts for the elevated levels of some metal and micro-organic chemicals found in a number of sewage effluents. Of the direct dischargers, a potato packaging company, a chemical storage company, a non-woven cellulose fibre mill and a vegetable washery have been regularly sampled during the last decade.

Site to site variations in sewage effluent, particularly for metals and micro-organics indicate distinctive industrial loadings. Food processing and textiles are associated with high nutrient loads, whilst industries such as electronics result in a large metal load. In general, stricter regulation has led to improvements in industrial effluent quality. For example, a Krofta treatment plant installed at Dexter Nonwovens has improved effluent from this site.

Fish farms

Fish farms pose few water quality problems on the Tweed. Occasional failure to meet dissolved oxygen consents is usually a result of high stocking densities within the unit, often during low flows and warm weather. Studies of fish farms in other areas of Scotland have found more serious effects (Tervet, 1981) due to:

- reduced river flows following water abstraction;
- pollution (particularly associated with waste food and faecal material); and
- disease.

In some cases, farm effluent may form the majority flow in the watercourse and this can reduce water quality because of high suspended solids, high BOD and associated oxygen depletion problems. Biological effects of accidental fish release and spread of disease cannot be quantified from the water quality data that has been examined here.

Fish farms in the Tweed region cause increased levels of total ammonia, suspended solids, BOD, phosphate, iron and copper. Dissolved oxygen and, to a small degree, pH, temperature, nitrate, chloride, zinc, nickel and lead, all decrease. The observed changes are small relative to average river water quality but may be significant relative to the water quality of the intake. Fish farms tend to be sited where water quality is particularly good, so an increase of 2 mg l^{-1} of suspended solids may represent a doubling relative to the intake. However, in general, the water quality changes due to fish farms in the area are small compared to the effects of sewage treatment works.

6.2 Summary of diffuse inputs

Almost all determinands have both diffuse and point sources. For some, the diffuse component is rather more significant in relation to point source inputs than for others. Basic determinands with the most notable diffuse sources include nitrate, phosphate, chloride and silica. All these determinands show very similar spatial patterns; concentrations are highest in the arable farming region around Lambden Burn, Leet Water and Leader Water and are much lower elsewhere.

Some metals may also have diffuse sources which provide a significant proportion of riverine levels. Zinc and iron appear to have the largest diffuse component which relates to geological sources. Copper and lead have lower background inputs, whilst background levels of nickel and chromium are beneath detection limits. In all cases there are point source inputs from sewage treatment works, although the relative importance varies.

For many of the micro-organic pollutants, data are too limited or too near detection limits for it to be possible to separate diffuse and point sources. However, the pattern of higher concentrations, seen in the lowlands for atrazine, simazine and diazinon and to a lesser extent for dichlorvos, fenitrothion and pirimiphos methyl, suggests a diffuse agricultural source. For pentachlorophenol, dieldrin and lindane there may again be a diffuse source but the spatial distribution is much more even.

7 Taking things further

The analysis detailed in this report represents an important step towards understanding water quality at the river basin level. Nevertheless, further developments are desirable. For example, there is a need to examine chemical loads in rivers, as well as average concentrations, and to relate these loads to sources. In many respects, such developments are still hampered by insufficient information, even given the large data sets which have been analysed. For example, for many point discharges, there is little or no quantitative information on time variations in volumes of discharges. Even so, simple loads analysis for the rivers, using existing database information, can be informative. Figure 7.1 illustrates this. Nitrate loads, average concentrations and loads per unit area are given for

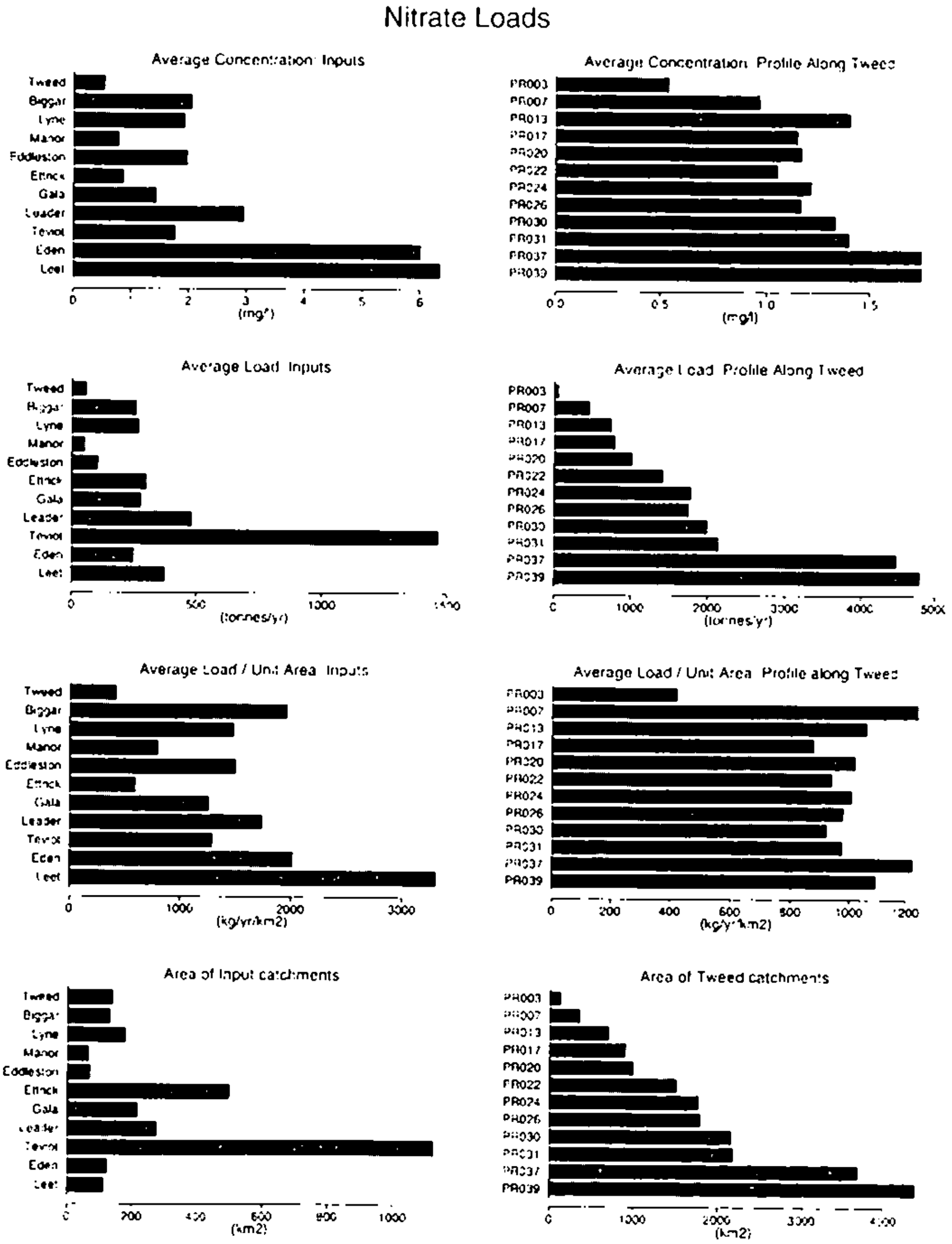

***Figure 7.1** Nitrate loads for main input tributaries to the Tweed (left column) and for sites along the Tweed (right column) – all ordered from upstream to downstream. Concentrations, load per unit area of catchment and catchment areas are also shown. Areas with high nitrate concentrations (Leet and Eden Waters) do not make the highest contributions to total loads.*

the Tweed and its main tributaries. Although nitrate concentrations are much higher in the lowland arable tributaries this represents only a moderate part of the total nitrate load of the Tweed river. This is because the high concentrations are offset by low average runoff, the result of relatively low rainfall combined with high evaporation. Larger catchments with high runoff, such as the Teviot river, contribute substantially to the overall load, even though concentrations are low. In other words, lowland areas appear much less important when loads are considered. At present, monitoring programmes are heavily focused on rivers with high concentrations. In future it may be sensible to revise sampling sites to give higher weighting to a load based perspective.

One reason for studying water quality is to improve understanding of present-day environmental processes and to enable better prediction of future water quality changes. An important component of the LOIS programme will be to forecast water quality changes for the next 100 years. Ideally, these models should be based on a detailed process-based description of the system. However, the system is highly complex and it will be necessary to focus on a few key processes. The analysis presented here helps with this by providing a baseline assessment of sources – i.e. whether they are mainly point based or diffuse and whether diffuse sources are primarily linked to geology or agriculture. Even so, much information and many parameters will be required before the component processes can be characterised and this will require additional but highly focused monitoring. It will also be necessary to specify scenarios of future change in a way that can be applied to such models and this may not be simple because of the qualitative nature of economic and political information.

One route forward, may be the development of models of intermediate complexity. For example, simple empirical regression techniques may provide a useful means of obtaining crude predictions when lack of suitable data prevents use of more sophisticated models. In Appendix C, an example of such an analysis is given for nitrate. For this, simple regional analysis techniques were used to formally link land use, geology and other factors to nitrate concentrations. Some potentially relevant catchment descriptors were not used at this stage because quantitative information was lacking. The analysis identified three catchment variables which together explained most of the nitrate variation. These were:

- the proportion of mown/grazed land,
- the proportion of tilled land and
- the proportion of area with a macroporous soil structure above shallow groundwater.

However, there were close correlations between many of the catchment properties, and this means that other combinations of variables could also explain the nitrate patterns. This uncertainty may be serious in relation to the reliability of future predictions. Nevertheless such an approach, though simplistic, is one means of obtaining a best-estimate of future change.

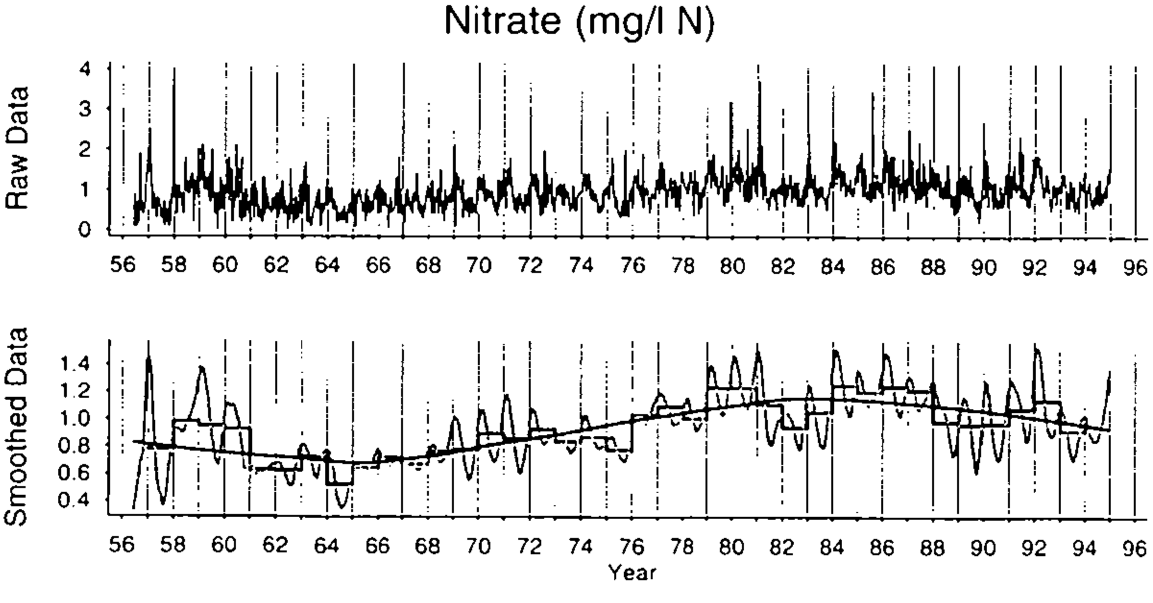

***Figure* 7.2** *Time series of nitrate concentrations for the Tweed above Galafoot for the years 1957 – 1995. The top graph shows the full data series. The lower graph shows three smoothed measures of change: the stepped curve shows the annual average concentration; the two curved lines show locally weighted smoothed averages highlighting (a) long-term changes (b) seasonal variations.*

Whatever modelling approach is used, there will inevitably be a high level of uncertainty. Part of this will relate to structural inaccuracies in the models, to missing or misrepresented processes, and to unknown or ill-defined parameters. An even higher degree of uncertainty will result from highly speculative scenarios. However, there are other ways in which it may be possible to improve the modelling of change. One will be to make fuller use of information from the past. In this report, 10 years of data records have been used, but records for this area extend much further back. The difficulty is that, as yet, they are only stored in paper format. The single exception to this is a 40 year record for a site at Tweed above Galafoot. This highly informative data shows how water quality has changed over the years, e.g. it demonstrates that nitrate has increased over this period Figure 7.2. If this type of information can be linked to the land use changes that are known, then this must surely improve our ability to model into the future.

Whilst predictive models are useful for the purposes of environmental management decisions and guidelines, they can never substitute for monitoring programs no matter how well the functioning of the environment is thought to be understood. The two aspects must in fact complement each other. For the future, the interplay between applied monitoring, focused process studies, utilisation of historical records, and basin scale modelling must be extended and strengthened.

8 Conclusions

The Tweed catchment area is a complex and variable system, even though the rivers are clean and the region is largely rural. The wide variety of determinands which have been measured exhibit a spectrum of regional responses. Inputs range from point sources, such as sewage discharges (e.g. pentachlorophenol), to diffuse sources, linked either to agricultural practice (e.g. nitrate) or to the underlying geology (e.g. iron). Many determinands show regional patterns arising from a combination of these sources (e.g. zinc and phosphate). Further variations arise because point source inputs can be widespread across the whole region (e.g. phosphate) or may be limited to localised industrial activities (e.g. copper). Where determinands have a major industrial source, there can be additional changes through time in response to improved treatment facilities, changing legislation, or changes in the industrial market.

The Tweed river system is in many regards a closely managed system. Regulation is enacted by the Tweed RPB, for example by monitoring for compliance of sewage and industrial discharges and by inspecting and advising on farm practices. Changes in legislation have the potential to affect many aspects of water quality, either where specific chemicals are banned or restricted, or where compliance with consents becomes enforceable. Many future changes in the river water quality of the Tweed may well be the result of political moves rather than natural causes such as climate change. Nevertheless, it is critical that the basic scientific processes affecting water quality are understood.

Effective presentation of the data is invaluable in highlighting the varying characteristics of the different chemical species present in the Tweed watercourses. It provides insights into dominant processes governing water quality and into the relative importance of point and diffuse input sources. Such an approach is an essential prerequisite for more detailed studies of both rural and industrial catchments.

The data collected by the Tweed River Purification Board constitute an extensive resource with much potential for scientific study and use in environmental management. With over half a million measurements spread across more than a hundred sampling sites, these data provide a major base on which to build a detailed understanding of water quality variations at the regional scale. It is important that sampling should continue at a similar level, although the focus of the programme may change over time in the light of improved understanding.

The analysis of the Tweed RPB data provides a prime example of the value of fully examining data from extensive water quality monitoring programmes. Fundamental to the analysis has been the effective use of data presentation techniques, e.g. regional concentration maps used in conjunction with compact time series plots. Patterns which have not previously been discerned from raw data and report tables become obvious once clearly presented. Data from other similar water quality monitoring programmes have not yet been exploited to the full; for many there is a wealth of information that has yet to be accessed. The techniques presented here provide one means of exploiting such information.

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Appendix A: tables of average concentrations

The tables give averages of data for sites where more than 10 samples have been collected between the years 1985 and 1994. For some determinands, a few points with very high and rather improbable values have been excluded. The value above which points have been excluded is shown as a *cutoff value*. The total number of samples and the number which were removed are also shown. Mean, median and trimmed mean values have been calculated. The trimmed mean is the mean of values after the top and bottom 5% of values have been removed. It is a more robust estimate of the mean when there are possible outlier values. The 5 and 95 percentiles of the data are shown, these give an idea of the typical range of the data. For each site, a trimmed mean has been calculated and the maximum, minimum and median of these site means are shown.

Appendix A

pH (2)

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	7.8	7.2	7.5	7.5	7.3	7.4
Mean (trimmed)	7.8	7.2	7.4	7.5	7.3	7.4
Median	7.8	7.2	7.4	7.5	7.3	7.3
5 Percentile	7.1	6.7	6.6	7.0	6.9	6.7
95 Percentile	8.7	7.8	8.9	8.4	7.9	8.1
Site Average: Min	7.3	6.6	7.2	7.3	7.1	6.7
Site Average: Median	7.9	7.2	7.4	7.4	7.3	7.4
Site Average: Max	8.3	8.0	7.8	7.7	7.6	8.1
Cutoff Value		10		10	10	
No. Measurements	5807	5177	245	396	751	1434
No. Excluded	0	1	0	1	0	0

Suspended Solids (mg l^{-1}) (4) Detection Limit=1

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	10.3	51	239	3.7	4.6	21.4
Mean (trimmed)	4.9	44	116	2.7	3.7	13.6
Median	3.0	34	32	2.0	3.0	6.0
5 Percentile	1.0	9	5	1.0	1.0	1.0
95 Percentile	30.0	136	1058	10.2	11.5	102.8
Site Average: Min	1.6	12	21	1.8	2.6	2.9
Site Average: Median	5.5	45	398	2.6	3.7	9.5
Site Average: Max	16.8	171	2539	4.2	5.6	173.1
Cutoff Value		1000				400
No. Measurements	5669	5266	258	397	751	1434
No. Excluded	0	3	0	0	0	8

BOD (mg l^{-1}) (5): Detection Limit=0.5

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	2.1	56.8	27	1.6	2.1	5.9
Mean (trimmed)	2.0	46.3	19	1.6	2.0	3.0
Median	1.9	26.0	15	1.6	2.0	1.8
5 Percentile	1.0	5.0	6	0.9	1.0	0.9
95 Percentile	3.7	228.0	74	2.7	3.5	20.0
Site Average: Min	1.3	5.3	14	1.4	1.7	1.2
Site Average: Median	2.0	40.8	53	1.6	1.9	1.9
Site Average: Max	5.4	275.7	108	1.8	2.7	106.0
Cutoff Value	25	600				
No. Measurements	5718	5252	212	397	751	1435
No. Excluded	4	3	0	0	0	0

Temperature (°C) (7)

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	9.4			9.9	9.8	8.4
Mean (trimmed)	9.3			9.8	9.8	8.3
Median	9.0			9.5	9.5	8.0
5 Percentile	2.0			3.0	3.0	3.0
95 Percentile	17.5			18.0	17.0	15.0
Site Average: Min	7.5			9.3	9.3	6.4
Site Average: Median	9.2			9.8	9.7	8.3
Site Average: Max	10.5			10.2	10.4	10.8
Cutoff Value	30					
No. Measurements	5725			403	766	1427
No. Excluded	1			0	0	0

Dissolved Oxygen (mg l^{-1}) (8): Detection Limit=0.2

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	11.0			10.7	9.4	8.4
Mean (trimmed)	11.0			10.6	9.4	8.6
Median	11.0			10.6	9.4	9.6
5 Percentile	8.1			9.0	6.8	0.3
95 Percentile	13.7			12.3	11.9	12.1
Site Average: Min	9.3			10.2	8.3	0.0
Site Average: Median	10.9			10.7	9.3	9.9
Site Average: Max	12.2			10.8	11.0	11.1
Cutoff Value	25.0					
No. Measurements	5715			403	767	1426
No. Excluded	2			0	0	0

Dissolved Oxygen (% Sat.) (9)

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	95			94	82	71.1
Mean (trimmed)	94			94	82	73.2
Median	93			93	82	83.6
5 Percentile	73			83	65	2.6
95 Percentile	126			105	98	98.0
Site Average: Min	80			89	73	0.5
Site Average: Median	94			94	82	84.4
Site Average: Max	108			95	96	92.4
Cutoff Value						
No. Measurements	5714			403	767	1426
No. Excluded	0			0	0	0

Total Ammonia (mg l^{-1} N) (11): Detection Limit=0.01

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	0.13	12.77	2.32	0.06	0.17	4.3
Mean (trimmed)	0.09	11.61	2.08	0.06	0.16	1.7
Median	0.08	7.90	0.80	0.06	0.15	0.1
5 Percentile	0.02	0.74	0.12	0.01	0.03	0.0
95 Percentile	0.36	38.52	8.15	0.14	0.38	24.5
Site Average: Min	0.04	0.63	0.19	0.04	0.05	0.0
Site Average: Median	0.09	10.82	2.24	0.05	0.15	0.2
Site Average: Max	0.76	39.94	4.19	0.09	0.24	0.5
Cutoff Value	4	75				
No. Measurements	6150	5260	73	397	751	1435
No. Excluded	3	5	0	0	0	0

Albuminoid N (mg l^{-1} N) (12): Detection Limit=0.1

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	3.45					
Mean (trimmed)	3.32					
Median	3.30					
5 Percentile	0.70					
95 Percentile	6.90					
Site Average: Min	0.93					
Site Average: Median	3.40					
Site Average: Max	6.18					
Cutoff Value	30					
No. Measurements	1127					
No. Excluded	3					

Nitrite (mg l^{-1} N) (13): Detection Limit=0.01

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	0.02	0.53				
Mean (trimmed)	0.014	0.41				
Median	0.01	0.30				
5 Percentile	0.00	0.00				
95 Percentile	0.05	1.89				
Site Average: Min	0.00	0.10				
Site Average: Median	0.02	0.35				
Site Average: Max	0.02	1.37				
Cutoff Value		10				
No. Measurements	553	3809				
No. Excluded	0	2				

Nitrate (mg l^{-1} N) (14): Detection Limit=0.1

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	3.9	8.8	1.8	0.6	0.7	3.8
Mean (trimmed)	3.4	7.9	1.4	0.6	0.6	3.4
Median	2.3	6.9	1.4	0.5	0.5	2.8
5 Percentile	0.6	0.5	0.4	0.2	0.2	0.4
95 Percentile	11.7	24.1	4.1	1.9	1.7	9.9
Site Average: Min	0.5	0.6	1.0	0.3	0.3	0.4
Site Average: Median	3.0	6.7	1.2	0.5	0.5	3.4
Site Average: Max	31.5	32.4	1.8	1.2	1.2	11.2
Cutoff Value						
No. Measurements	6114	3886	72	397	751	1435
No. Excluded	0	0	0	0	0	0

Chloride (mg l^{-1}) (15): Detection Limit=1

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	25	119	53	8.0	8.6	57
Mean (trimmed)	23	84	46	7.7	8.4	40
Median	20	64	40	7.0	7.0	24
5 Percentile	8	29	17	5.0	5.0	11
95 Percentile	62	434	114	14.5	14.5	248
Site Average: Min	7	30	22	6.2	6.1	12
Site Average: Median	22	69	35	6.4	6.7	25
Site Average: Max	72	688	70	12.6	12.4	483
Cutoff Value	200		300			750
No. Measurements	5708	5174	63	397	751	1434
No. Excluded	2	0	0	0	0	2

Soluble Phosphate (mg l^{-1} P) (17): Detection Limit=0.01

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	0.09	3.85	1.44	0.03	0.04	0.21
Mean (trimmed)	0.07	3.58	0.61	0.02	0.04	0.21
Median	0.05	3.11	0.44	0.02	0.03	0.18
5 Percentile	0.01	0.61	0.02	0.01	0.01	0.05
95 Percentile	0.00	9.18	1.96	0.08	0.10	0.52
Site Average: Min	0.02	1.41	0.59	0.02	0.02	0.21
Site Average: Median	0.07	4.44	0.98	0.03	0.04	0.21
Site Average: Max	0.51	10.32	1.37	0.03	0.05	0.21
Cutoff Value	1.5					
No. Measurements	5884	1911	43	397	750	11
No. Excluded	9	0	0	0	0	0

Total Phosphate (mg l^{-1} P) (18): Detection Limit=0.01

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	0.19	5.6		0.09	0.14	
Mean (trimmed)	0.16	5.3		0.08	0.13	
Median	0.13	5.0		0.07	0.11	
5 Percentile	0.05	1.5		0.03	0.04	
95 Percentile	0.55	11.1		0.20	0.32	
Site Average: Min	0.07	2.9		0.07	0.07	
Site Average: Median	0.15	5.1		0.08	0.12	
Site Average: Max	1.04	9.4		0.10	0.17	
Cutoff Value	2					
No. Measurements	2868	965		350	597	
No. Excluded	4	0		0	0	

Silica (mg l^{-1} Si) (58): Detection Limit=0.2

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	2.4					
Mean (trimmed)	2.4					
Median	2.4					
5 Percentile	0.4					
95 Percentile	4.9					
Site Average: Min	1.0					
Site Average: Median	2.3					
Site Average: Max	5.6					
Cutoff Value	12					
No. Measurements	4624					
No. Excluded	1					

Conductivity (µS cm^{-1}) (61): Detection Limit=10

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	352		644	121	130	593
Mean (trimmed)	338		630	119	128	485
Median	306		564	103	107	364
5 Percentile	108		301	76	78	171
95 Percentile	782		1168	195	214	1910
Site Average: Min	90		630	83	85	169
Site Average: Median	320		630	97	100	448
Site Average: Max	811		630	180	193	3953
Cutoff Value						
No. Measurements	5790		31	397	751	1435
No. Excluded	0		0	0	0	0

Zinc (µg l^{-1} available) (101): Detection Limit=5

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean		78	30			7
Mean (trimmed)		68	14			4
Median		60	2			0
5 Percentile		15	0			0
95 Percentile		180	158			32
Site Average: Min		18	3			0
Site Average: Median		70	84			4
Site Average: Max		225	165			86
Cutoff Value		1500	500			200
No. Measurements		3848	123			648
No. Excluded		2	1			16

Zinc (µg l^{-1} dissolved) (108): Detection Limit=0.8

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	8.8	41	76.9	10.8	10.8	15.3
Mean (trimmed)	6.8	38	50.3	8.0	8.3	12.1
Median	4.7	34	26.9	5.0	5.0	7.7
5 Percentile	0.8	10	3.7	0.0	0.0	0.0
95 Percentile	29.0	92	303.5	46.2	37.1	55.8
Site Average: Min	2.4	25	15.6	7.5	6.5	7.1
Site Average: Median	9.4	32	32.1	9.8	8.6	12.7
Site Average: Max	20.0	81	228.6	13.9	13.5	38.4
Cutoff Value			2000			200
No. Measurements	1196	451	148	120	180	1237
No. Excluded	0	0	1	1	0	6

Zinc (µg l^{-1} total) (165): Detection Limit=0.8

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	7.8	78				5.0
Mean (trimmed)	6.5	73				4.4
Median	4.6	67				4.2
5 Percentile	1.1	29				1.2
95 Percentile	24.7	162				9.8
Site Average: Min	2.0	47				4.4
Site Average: Median	7.8	62				4.4
Site Average: Max	17.4	107				4.4
Cutoff Value						
No. Measurements	1010	535				32
No. Excluded	0	0				0

Lead (µg l^{-1} available) (102): Detection Limit=10

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean		16	7			0.3
Mean (trimmed)		11	2			0.0
Median		0	0			0.0
5 Percentile		0	0			0.0
95 Percentile		70	46			0.0
Site Average: Min		1	1			0.0
Site Average: Median		7	19			0.0
Site Average: Max		90	36			5.3
Cutoff Value		400	200			100
No. Measurements		3848	123			648
No. Excluded		7	0			2

Lead (µg l^{-1} dissolved) (109): Detection Limit=0.4

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	0.6	11.8	1.5	0.1	0.0	0.4
Mean (trimmed)	0.5	7.9	1.1	0.0	0.0	0.3
Median	0.5	0.0	0.8	0.0	0.0	0.0
5 Percentile	0.0	0.0	0.0	0.0	0.0	0.0
95 Percentile	2.1	50.0	5.8	0.0	0.0	1.8
Site Average: Min	0.2	0.0	0.6	0.0	0.0	0.0
Site Average: Median	0.6	0.7	1.5	0.0	0.0	0.3
Site Average: Max	1.0	24.6	2.1	0.0	0.0	0.7
Cutoff Value			50	4	4	4
No. Measurements	1169	556	148	120	180	1238
No. Excluded	0	0	1	1	0	6

Appendix A

Lead (μg l^{-1} total) (166): Detection Limit=0.4

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	1.2	9.0	8.0			0.6
Mean (trimmed)	1.1	2.5	0.7			0.0
Median	1.0	0.0	0.0			0.0
5 Percentile	0.0	0.0	0.0			0.0
95 Percentile	3.2	51.0	29.1			0.0
Site Average: Min	0.7	0.0	0.0			0.0
Site Average: Median	1.1	0.0	25.7			0.0
Site Average: Max	1.7	104.5	51.4			6.3
Cutoff Value						
No. Measurements	606	3253	123			648
No. Excluded	0	0	0			0

Carbon (μg l^{-1} available) (103): Detection Limit=5

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean		0	0			0
Mean (trimmed)		0	0			0
Median		0	0			0
5 Percentile		0	0			0
95 Percentile		0	0			0
Site Average: Min		0	0			0
Site Average: Median		0	0			0
Site Average: Max		0	0			0
Cutoff Value						
No. Measurements		3847	123			647
No. Excluded		0	0			0

Carbon (μg l^{-1} dissolved) (110): Detection Limit=0.5

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	0.0	0	1.3	0.0	0.0	0.0
Mean (trimmed)	0.0	0	0.2	0.0	0.0	0.0
Median	0.0	0	0.0	0.0	0.0	0.0
5 Percentile	0.0	0	0.0	0.0	0.0	0.0
95 Percentile	0.1	0	2.2	0.0	0.0	0.1
Site Average: Min	0.0	0	0.0	0.0	0.0	0.0
Site Average: Median	0.0	0	0.5	0.0	0.0	0.0
Site Average: Max	0.0	0	1.7	0.0	0.0	0.1
Cutoff Value						
No. Measurements	1176	556	147	120	180	1238
No. Excluded	0	0	0	0	0	0

Carbon (μg l^{-1} total) (167): Detection Limit = 0.5

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	0.2	3.7	9.1			0.3
Mean (trimmed)	0.1	1.8	0.6			0.2
Median	0.0	0.0	0.0			0.0
5 Percentile	0.0	0.0	0.0			0.0
95 Percentile	0.9	17.6	4.7			1.4
Site Average: Min	0.0	0.0	0.1			0.0
Site Average: Median	0.1	0.0	0.9			0.1
Site Average: Max	0.6	6.0	1.8			2.3
Cutoff Value						
No. Measurements	1473	337	147			1238
No. Excluded	0	0	0			0

Nickel (μg l^{-1} available) (104): Detection Limit=10

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean		3	4			1
Mean (trimmed)		1	0			0
Median		0	0			0
5 Percentile		0	0			0
95 Percentile		10	20			0
Site Average: Min		0	0			0
Site Average: Median		0	12			0
Site Average: Max		15	24			4
Cutoff Value		300	100			60
No. Measurements		3848	123			648
No. Excluded		4	1			1

Nickel (μg l^{-1} dissolved) (111): Detection Limit=1

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	0	19	32	0	0	1
Mean (trimmed)	0	10	16	0	0	1
Median	0	0	3	0	0	0
5 Percentile	0	0	0	0	0	0
95 Percentile	2	98	201	1	0	4
Site Average: Min	0	0	1	0	0	0
Site Average: Median	0	0	3	0	0	1
Site Average: Max	2	36	148	1	1	7
Cutoff Value						
No. Measurements	854	555	148	120	180	1238
No. Excluded	0	0	0	0	0	0

Nickel (μg l^{-1} total) (168): Detection Limit=5

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	0					
Mean (trimmed)	0					
Median	0					
5 Percentile	0					
95 Percentile	2					
Site Average: Min	0					
Site Average: Median	0					
Site Average: Max	0					
Cutoff Value						
No. Measurements	338					
No. Excluded	0					

Iron (μg l^{-1} available) (105): Detection Limit=20

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean		483	225			3578
Mean (trimmed)		362	58			2474
Median		297	50			400
5 Percentile		70	10			39
95 Percentile		1409	334			19012
Site Average: Min		74	49			66
Site Average: Median		339	1901			440
Site Average: Max		1736	3754			19545
Cutoff Value		8000	5000			
No. Measurements		3431	123			648
No. Excluded		7	14			0

Iron (μg l^{-1} dissolved) (112): Detection Limit=20

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	54	115		62	76	112
Mean (trimmed)	45	98		54	66	88
Median	40	80		44	52	56
5 Percentile	7	31		7	10	9
95 Percentile	125	298		171	246	382
Site Average: Min	46	50		17	20	16
Site Average: Median	46	112		54	91	86
Site Average: Max	49	136		131	113	278
Cutoff Value		1500				
No. Measurements	365	556		120	180	1141
No. Excluded	0	6		0	0	0

Iron as Fe (μg l^{-1} total) (169): Detection Limit = 20

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	219					
Mean (trimmed)	164					
Medium	112					
5 Percentile	38					
95 Percentile	921					
Site Average: Min	154					
Site Average: Median	160					
Site Average: Max	205					
Cutoff Value						
No. Measurements	338					
No. Excluded	0					

Copper (µg l^{-1} available) (106): Detection Limit=5

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean		99	9			4
Mean (trimmed)		50	6			2
Median		22	0			0
5 Percentile		0	0			0
95 Percentile		640	57			16
Site Average: Min		4	3			0
Site Average: Median		23	20			1
Site Average: Max		895	37			51
Cutoff Value		4000	100			
Number Measurements		3853	123			648
Number Excluded		6	1			0

Copper (µg l^{-1} dissolved) (113): Detection Limit=0.1

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	4.0	244.9	17.5	3.0	3.7	4.0
Mean (trimmed)	3.3	207.5	11.4	2.7	3.4	3.5
Median	2.8	101.0	5.8	2.0	3.0	3.0
5 Percentile	0.7	0.0	1.1	0.0	0.0	0.5
95 Percentile	10.1	873.8	67.9	8.0	9.0	11.5
Site Average: Min	1.6	3.5	4.2	2.7	2.5	2.4
Site Average: Median	3.0	10.7	7.1	2.8	3.7	3.7
Site Average: Max	10.6	510.1	63.3	3.3	4.2	8.6
Cutoff Value			300	20	20	50
No. Measurements	1431	639	148	120	180	1238
No. Excluded	0	0	1	0	1	1

Copper (µg l^{-1} total) (170): Detection Limit=0.1

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	5.4					
Mean (trimmed)	4.5					
Median	3.6					
5 Percentile	1.1					
95 Percentile	14.3					
Site Average: Min	2.5					
Site Average: Median	4.2					
Site Average: Max	17.6					
Cutoff Value	60					
No. Measurements	595					
No. Excluded	1					

Chromium (µg l^{-1} available) (107): Detection Limit=10

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean		15	6			0
Mean (trimmed)		3	0			0
Median		0	0			0
5 Percentile		0	0			0
95 Percentile		76	21			0
Site Average: Min		0	0			0
Site Average: Median		0	21			0
Site Average: Max		161	42			6
Cutoff Value		1000	200			
No. Measurements		3849	123			648
No. Excluded		4	1			0

Chromium (µg l^{-1} dissolved) (114): Detection Limit=0.5

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	0.3	48	1.0	0	0	0.3
Mean (trimmed)	0.2	29	0.6	0	0	0.2
Median	0.0	0	0.0	0	0	0.0
5 Percentile	0.0	0	0.0	0	0	0.0
95 Percentile	1.0	247	4.3	0	0	1.4
Site Average: Min	0.0	0	0.1	0	0	0.0
Site Average: Median	0.2	0	0.8	0	0	0.1
Site Average: Max	1.3	98	1.8	0	0	2.3
Cutoff Value			50	1	1	
No. Measurements	851	634	147	120	180	1238
No. Excluded	0	0	1	0	0	0

Chromium (µg l^{-1} total) (171): Detection Limit=0.5

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	0.8					
Mean (trimmed)	0.6					
Median	0.6					
5 Percentile	0.0					
95 Percentile	2.2					
Site Average: Min	0.4					
Site Average: Median	0.5					
Site Average: Max	0.7					
Cutoff Value						
No. Measurements	334					
No. Excluded	0					

Mercury (µg l^{-1}) (89): Detection Limit=0.1

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	0.0	0.1	0.1			0.1
Mean (trimmed)	0.0	0.0	0.1			0.1
Median	0.0	0.0	0.0			0.1
5 Percentile	0.0	0.0	0.0			0.0
95 Percentile	0.2	0.3	0.4			0.5
Site Average: Min	0.0	0.0	0.0			0.0
Site Average: Median	0.0	0.0	0.1			0.1
Site Average: Max	0.1	0.1	0.1			0.3
Cutoff Value	1	1.2	2			1
No Measurements	772	983	148			78
No Excluded	4	2	1			1

Arsenic (µg l^{-1}) (90): Detection Limit=5

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	0.3	1.0	2.3			2.3
Mean (trimmed)	0.2	0.6	1.6			1.8
Median	0.0	0.0	0.1			0.5
5 Percentile	0.0	0.0	0.1			0.0
95 Percentile	1.6	3.8	10.1			13.2
Site Average: Min	0.1	0.0	0.1			0.4
Site Average: Median	0.2	0.6	0.4			0.5
Site Average: Max	0.7	5.7	7.3			8.1
Cutoff Value	50					
No. Measurements	393	982	133			78
No Excluded	0	1	0			0

Arsenic (µg l^{-1} dissolved) (183): Detection Limit=5

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	0.3					9.0
Mean (trimmed)	0.1					4.3
Median	0.0					0.0
5 Percentile	0.0					0.0
95 Percentile	2.0					73.9
Site Average: Min	0.1					0.0
Site Average: Median	0.2					0.3
Site Average: Max	0.2					68.1
Cutoff Value						
No Measurements	224					430
No.Excluded	0					0

Lindane (ng l^{-1}) (76): Detection Limit=1

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	3.0	23	60.3			5.7
Mean (trimmed)	2.4	19	37.1			4.1
Median	2.0	17	12.0			2.0
5 Percentile	0.0	0	0.0			0.0
95 Percentile	9.3	66	285.7			21.0
Site Average: Min	0.4	6	2.5			2.7
Site Average: Median	2.4	22	36.9			5.9
Site Average: Max	5.1	29	398.0			9.3
Cutoff Value	50	400	1000			
No. Measurements	986	515	169			78
No Excluded	6	6	14			0

Pentachlorophenol (µg l^{-1}) (92): Detection Limit=0.01

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	0.02	0.42	0.41			0.04
Mean (trimmed)	0.02	0.14	0.15			0.03
Median	0.01	0.05	0.04			0.02
5 Percentile	0.00	0.00	0.00			0.00
95 Percentile	0.08	1.65	1.21			0.11
Site Average. Min	0.00	0.01	0.03			0.03
Site Average. Median	0.02	0.07	0.09			0.04
Site Average. Max	0.03	1.06	1.98			0.06
Cutoff Value		20	20			
No. Measurements	658	524	172			78
No. Excluded	0	11	5			0

Dieldrin (ng l^{-1}) (94): Detection Limit=1

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	0.8	2.6	10.9			1.7
Mean (trimmed)	0.5	2.1	3.5			1.3
Median	0.0	0.0	0.0			0.0
5 Percentile	0.0	0.0	0.0			0.0
95 Percentile	4.0	10.7	53.5			8.2
Site Average. Min	0.1	0.5	0.3			0.7
Site Average. Median	0.5	2.3	2.0			1.0
Site Average. Max	1.3	4.1	54.4			5.1
Cutoff Value	15	20.0	500.0			
No. Measurements	672	510	175			78
No. Excluded	1	2	1			0

Diazinon (ng l^{-1}) (142): Detection Limit=5

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	11	21	23			25
Mean (trimmed)	6	15	12			22
Median	0	0	7			13
5 Percentile	0	0	0			0
95 Percentile	64	105	80			112
Site Average. Min	0	6	7			22
Site Average. Median	5	8	10			22
Site Average: Max	67	40	90			22
Cutoff Value	200	500				200
No. Measurements	634	105	127			25
No. Excluded	8	1	0			0

Atrazine (ng l^{-1}) (147): Detection Limit=10

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	45	108	1440			16
Mean (trimmed)	19	76	162			16
Median	0	0	13			13
5 Percentile	0	0	0			0
95 Percentile	233	595	2340			42
Site Average. Min	0	20	20			16
Site Average. Median	15	69	109			16
Site Average. Max	77	263	13323			16
Cutoff Value	2000	1000	50000			
No. Measurements	660	336	129			19
No. Excluded	1	1	4			0

Simazine (ng l^{-1}) (148): Detection Limit=10

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	86	113	10278			776
Mean (trimmed)	59	80	2369			776
Median	15	0	105			664
5 Percentile	0	0	0			92
95 Percentile	454	710	68080			1565
Site Average. Min	2	20	113			776
Site Average. Median	59	39	236			776
Site Average. Max	182	239	78539			776
Cutoff Value	1000	1000				
No. Measurements	656	140	117			13
No. Excluded	2	0	0			0

Dichlorvos (ng l^{-1}) (149): Detection Limit=5

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	2	2	16			7
Mean (trimmed)	1	0	9			5
Median	0	0	0			0
5 Percentile	0	0	0			0
95 Percentile	20	18	142			25
Site Average. Min	0	1	3			3
Site Average. Median	1	0	4			7
Site Average. Max	3	2	58			11
Cutoff Value	100	100	400			100
No. Measurements	667	137	142			78
No. Excluded	4	3	2			2

Fenitrothion (ng l^{-1}) (150): Detection Limit=5

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	2	144	302			4.9
Mean (trimmed)	0	46	72			2.7
Median	0	0	0			0
5 Percentile	0	0	0			0
95 Percentile	13	805	1676			22.8
Site Average. Min	0	1	1			1.2
Site Average. Median	1	44	46			2.2
Site Average. Max	3	117	1572			13.7
Cutoff Value	100		10000			70
No. Measurements	665	110	139			78
No. Excluded	1	0	3			1

Malathion (ng l^{-1}) (184): Detection Limit=5

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	1	1	5			1
Mean (trimmed)	0	0	0			1
Median	0	0	0			0
5 Percentile	0	0	0			0
95 Percentile	6	0	0			1
Site Average. Min	0	0	0			1
Site Average. Median	0	0	0			1
Site Average. Max	4	0	24			1
Cutoff Value						
No. Measurements	592	99	111			19
No. Excluded	0	0	0			0

Propetamphos (ng l^{-1}) (185): Detection Limit=5

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	9	3	11			
Mean (trimmed)	5	1	9			
Median	0	0	0			
5 Percentile	0	0	0			
95 Percentile	50	20	45			
Site Average. Min	1	1	5			
Site Average. Median	4	2	8			
Site Average. Max	70	2	12			
Cutoff Value	200	200	200			
No. Measurements	441	68	76			
No. Excluded	9	1	1			

Pirimiphos Methyl (ng l^{-1}) (186): Detection Limit=5

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	1	62	2			2
Mean (trimmed)	0	18	1			2
Median	0	0	0			0
5 Percentile	0	0	0			0
95 Percentile	11	220	15			11
Site Average. Min	0	0	1			2
Site Average. Median	1	3	1			2
Site Average. Max	3	58	1			2
Cutoff Value	100		100			
No. Measurements	590	94	96			19
No. Excluded	2	0	0			0

Aldrin (ng l') (78): Detection Limit=1

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	0	0.8	38.6			0
Mean (trimmed)	0	0.0	3.0			0
Median	0	0.0	0			0
5 Percentile	0	0.0	0			0
95 Percentile	0	0.0	65.6			0
Site Average: Min	0	0.0	0			0
Site Average: Median	0	0.0	0.1			0
Site Average: Max	0	1.4	134.2			0
Cutoff Value						
No. Measurements	348	335	118			78
No. Excluded	0	0	0			0

Carbontetrachloride (µg l') (91): Detection Limit=1

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean		0				
Mean (trimmed)		0				
Median		0				
5 Percentile		0				
95 Percentile		0				
Site Average: Min		0				
Site Average: Median		0				
Site Average: Max		0				
Cutoff Value						
No. Measurements		249				
No. Excluded		0				

Endrin (ng l') (93): Detection Limit=0.5

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	0.0	0.1	4.9			0.1
Mean (trimmed)	0.0	0.0	0.0			0.0
Median	0.0	0.0	0.0			0.0
5 Percentile	0.0	0.0	0.0			0.0
95 Percentile	0.0	0.0	0.0			0.0
Site Average: Min	0.0	0.0	0.0			0.0
Site Average: Median	0.0	0.0	0.0			0.0
Site Average: Max	0.0	0.3	1.9			0.4
Cutoff Value						
No. Measurements	350	325	119			78
No. Excluded	0	0	0			0

pp' DDT (ng l') (98): Detection Limit=1

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	0.1	6.2	20.5			0.4
Mean (trimmed)	0.0	0.4	4.7			0.1
Median	0.0	0.0	0.0			0.0
5 Percentile	0.0	0.0	0.0			0.0
95 Percentile	0.0	11.8	120.5			1.2
Site Average: Min	0.0	0.1	0.0			0.0
Site Average: Median	0.0	0.5	0.2			0.1
Site Average: Max	0.5	20.3	67.0			0.9
Cutoff Value						
No. Measurements	347	325	119			78
No. Excluded	0	0	0			0

Hexachlorobenzene (ng l') (135): Detection Limit=3

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	0	5	236			2
Mean (trimmed)	0	2	38			1
Median	0	0	0			0
5 Percentile	0	0	0			0
95 Percentile	0	32	965			12
Site Average: Min	0	0	0			0
Site Average: Median	0	0	3			2
Site Average: Max	0	10	552			5
Cutoff Value		300				
No. Measurements	350	333	119			78
No. Excluded	0	2	0			0

Hexachlorobutadiene (ng l') (136): Detection Limit=10

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	0	0	1			0
Mean (trimmed)	0	0	0			0
Median	0	0	0			0
5 Percentile	0	0	0			0
95 Percentile	0	0	0			0
Site Average: Min	0	0	0			0
Site Average: Median	0	0	0			0
Site Average: Max	0	0	0			0
Cutoff Value						
No. Measurements	318	292	119			78
No. Excluded	0	0	0			0

Endosulphan (ng l')(145): Detection Limit=1

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	0.4	0.6	6.4			0.3
Mean (trimmed)	0.0	0.9	0.9			0.1
Median	0.0	0.0	0.0			0.0
5 Percentile	0.0	0.0	0.0			0.0
95 Percentile	1.6	3.8	18.3			2.4
Site Average: Min	0.0	0.0	0.0			0.0
Site Average: Median	0.1	0.1	1.6			0.0
Site Average: Max	1.2	1.0	14.9			1.9
Cutoff Value		40	300			
No. Measurements	344	326	117			78
No. Excluded	0	3	1			0

PCB (28,52,101,118,138,153,180) (ng l') (146): Detection Limit=10

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	0	0	0			0
Mean (trimmed)	0	0	0			0
Median	0	0	0			0
5 Percentile	0	0	0			0
95 Percentile	0	0	0			0
Site Average: Min	0	0	0			0
Site Average: Median	0	0	0			0
Site Average: Max	0	0	0			0
Cutoff Value						
No. Measurements	631	312	115			76
No. Excluded	0	0	0			0

Azinphos Methyl (ng l') (151): Detection Limit=1

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	0.3	0.2	4.2			0.2
Mean (trimmed)	0.0	0.0	0.0			0.0
Median	0.0	0.0	0.0			0.0
5 Percentile	0.0	0.0	0.0			0.0
95 Percentile	0.0	0.0	0.0			0.0
Site Average: Min	0.0	0.0	0.0			0.0
Site Average: Median	0.0	0.0	0.0			0.0
Site Average: Max	1.8	0.0	8.2			0.0
Cutoff Value						
No. Measurements	667	109	142			78
No. Excluded	0	0	0			0

Trifluralin (ng l') (152): Detection Limit=10

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	8	9	691			40
Mean (trimmed)	4	7	185			1
Median	2	3	18			1
5 Percentile	0	0	0			0
95 Percentile	33	36	4519			44
Site Average: Min	1	6	50			1
Site Average: Median	3	7	163			1
Site Average: Max	11	7	3346			1
Cutoff Value			20000			
No. Measurements	665	79	129			20
No. Excluded	0	0	2			0

Appendix A

Chloroform (μg l^{-1}) (153): Detection Limit=1.2

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	0					
Mean (trimmed)	0					
Median	0					
5 Percentile	0					
95 Percentile	0					
Site Average: Min	0					
Site Average: Median	0					
Site Average: Max	0					
Cutoff Value						
No. Measurements	249					
No. Excluded	0					

1,2 - Dichloroethane (μg l^{-1}) (155): Detection Limit=1

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	0.05					
Mean (trimmed)	0					
Median	0					
5 Percentile	0					
95 Percentile	0					
Site Average: Min	0					
Site Average: Median	0					
Site Average: Max	0					
Cutoff Value						
No. Measurements	249					
No. Excluded	0					

Trichlorobenzene (ng l^{-1}) (154): Detection Limit=40

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	0					
Mean (trimmed)	0					
Median	0					
5 Percentile	0					
95 Percentile	0					
Site Average: Min	0					
Site Average: Median	0					
Site Average: Max	0					
Cutoff Value						
No. Measurements	249					
No. Excluded	0					

Chlorfenvinphos (ng l^{-1}) (217): Detection Limit=10

	River	Sewage	Industry	Fish Inlet	Fish Outlet	Landfill Sites
Mean	12	44	19			
Mean (trimmed)	2	19	10			
Median	0	0	0			
5 Percentile	0	0	0			
95 Percentile	51	248	161			
Site Average: Min	0	0	0			
Site Average: Median	1	30	11			
Site Average: Max	171	36	22			
Cutoff Value						
No. Measurements	485	78	78			
No. Excluded	0	0	0			

Appendix B: detailed results for specific determinands

B.1 Main determinands

pH

The pH of a water sample indicates the balance between the acids and bases in the water and is a measure of the hydrogen ion concentration ($pH \equiv -\log_{10}H^+$). Acidic waters ($pH < 5.6$) are generally associated with moorland and forested areas in the uplands where the soils are thin and acidic and rainwater inputs have relatively little contact with the rocks. Downstream, waters are generally more alkaline because rainwater is neutralised by chemical weathering of the rocks and by reactions with biologically generated carbon dioxide from the soils. River water pH can show diurnal variation (which may not be picked up by the normal sampling programme). The diurnal variation results from plant activity in the streams during the summer. During daytime, dissolved CO_2 is consumed by photosynthesis to generate dissolved oxygen. At night the reverse process occurs because of plant respiration. The changes in dissolved CO_2 concentrations affect pH because CO_2 is weakly acidic: pH is thus highest during the daytime when CO_2 concentrations are lowest.

For the Tweed and its tributaries, river water pH is typically between 7 and 9, with most rivers exhibiting an annual range of 1–2 pH units. As can be seen from Figure 5.2, the regional variation in pH is relatively small – individual site averages vary between 7.3 and 8.3 (Appendix A). However, pH tends to increase downstream, being lower in the upland headwater areas and higher in the lowland agricultural areas at all levels of flow. For example, Figure B1 shows the increase in pH along the length of Blackadder Water.

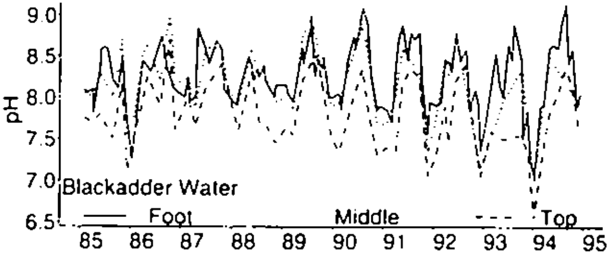

Figure B1 *Time series of pH variations at three sites along the Blackadder for the years 1985 – 1994. pH increases downstream.*

The increase is probably linked with land use patterns and nutrient levels. Occasional high pH values (pH 9 and higher) occur on the lower Tweed (e.g. Norham; Figure B2). These are the result of diatom growth during the late spring and autumn, and of filamentous algal growth in the summer.

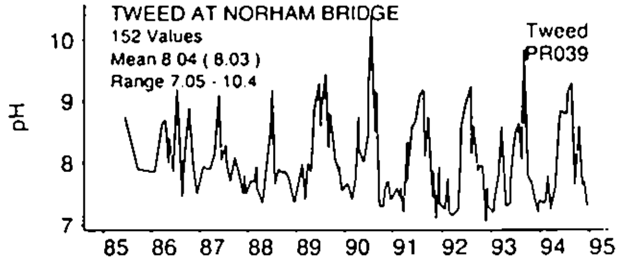

Figure B2 *Time series of pH measurements at Norham Bridge, 1985 – 1994. There is a seasonal pattern with high values corresponding to periods of diatom/algal growth.*

River pH shows a strong decreasing relationship with increasing flow. This decrease is rapid at moderate flows, but flattens off thereafter (Figure 5.12). The pattern is consistent with a high pH groundwater source at low flows which is augmented by more acidic near-surface waters at high flows. Because of its links with flow, pH also exhibits seasonal variation (see Figures B1 and B2) and, on average, is higher in the summer than in the winter.

Most effluent discharged to the rivers is at a lower pH than river water, but not substantially so. For example, sewage effluent has an average pH of 7.2 and tip effluent an average of 7.4, whereas river pH averages 7.8. Fish farming appears to affect pH slightly, causing a decrease of about 0.2 pH units.

Suspended solids

For the Tweed, there is particular concern about anthropogenically generated suspended solid levels because of the fishing amenity value of the river – highly turbid waters are undesirable for good fishing. River engineering operations such as dredging and bank maintenance are probably the major source of suspended solids to the rivers.

However, natural erosion processes can be exacerbated by agricultural and forestry activity. In addition, industrial and sewage effluent provide further inputs.

Suspended solids are strongly affected by flow and rise substantially at very high flows (Figure 5.9), resulting in a strongly skewed distribution (Figure B3). Average concentrations given below (and in the figures and tables), therefore need to be treated with caution as there are a small number of samples with an extremely high suspended load. Suspended solids measurements are associated with high sampling errors because concentrations vary widely across the width of a river and within a given reach.

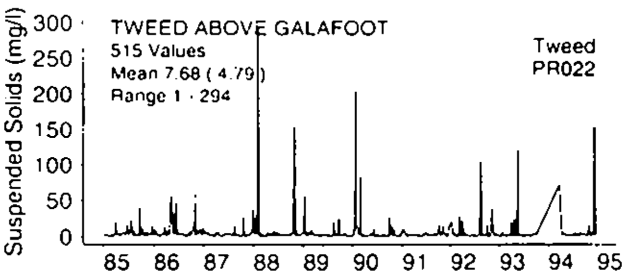

Figure B3 *Time series of suspended solids concentrations for Tweed above Galafoot, 1985 – 1994. The distribution of suspended solid concentrations is strongly skewed.*

On average, the Tweed and its tributaries carry approximately 10 mg l^{-1} of suspended solids; individual site averages varying between 2 and 17 mg l^{-1} (Appendix A). No obvious trends from upstream to downstream can be picked out from the regional map (Figure 5.2), but smaller water courses in arable areas have a tendency towards higher suspended solids. The Tweed is lower in suspended solids than a number of its tributaries. Maximum suspended solids are site dependent, varying between 50 and 700 mg l^{-1} with the highest of these occurring in Turfford Burn and Jed, Gala and Teviot Water (500 mg l^{-1} or more).

From the regional plot (Figure 5.2), it is clear that sewage treatment works (average 50 mg l^{-1}) are the dominant point sources of suspended solids and cause downstream increases in river suspended solids. Concentrations vary considerably between works, and Jedburgh and Selkirk works have been prone to occasional high loads (Figure B4). Usually the distribution of suspended solids in effluent is much less skewed than for the rivers. Sewage effluent suspended solids correlate weakly with flow.

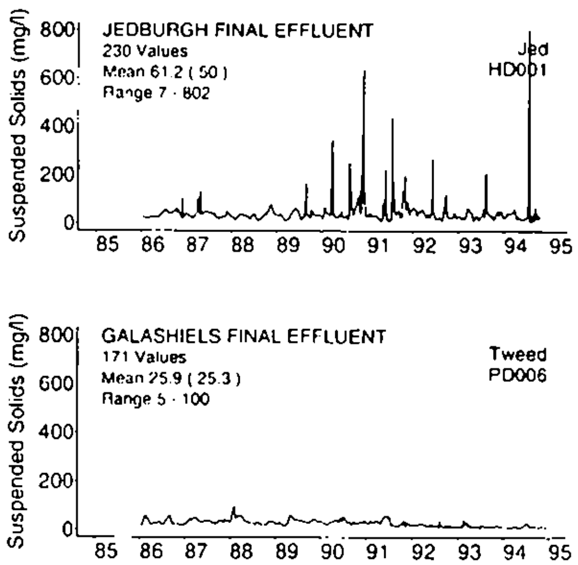

Figure B4 *Time series of suspended solid concentrations for Jedburgh and Galashiels sewage effluent, 1985 – 1994. Jedburgh appears prone to occasional high effluent loads.*

The only industrial discharge with high suspended solids has been from a potato packaging factory (average 740 mg l^{-1}, now relocated and discharging 3 mg l^{-1}). Effluent from landfill sites generally increases suspended solids levels in nearby streams. Overall, average suspended solids for tip effluent are around 20 mg l^{-1} – i.e. double the average in the rivers. Fish farming causes a much smaller rise in suspended solids, typically around 1 mg l^{-1}. At some of the locations, this difference is significant in that it represents a doubling of suspended solids concentrations.

Dissolved oxygen

Dissolved oxygen is essential for plant growth and fish life. The amount of dissolved oxygen in solution varies naturally depending on the temperature, salinity, turbulence, atmospheric pressure, photosynthetic activity and river discharge. Dissolved oxygen increases during the day when plants photosynthesize and this contributes to diurnal and seasonal fluctuations.

For the Tweed river and tributaries, dissolved oxygen concentrations average around 11 mg l^{-1} (94% saturation). Averages for individual sites range between 9 and 12 mg l^{-1} with 90% of samples in the range 8 – 14 mg l^{-1} (75 – 130% saturation), although the full data range is somewhat greater (1 – 25 mg l^{-1} or 14 – 160% saturation; see Appendix A). There is a strong seasonal variation in dissolved oxygen (Figure 5.8); at most sites the highest dissolved oxygen concentration occurs in the spring and the lowest in the autumn, though this varies slightly from year to year probably because of variations in the timing of algal and diatom blooms. The seasonal oxygen variation is greatest in agricultural areas (e.g. Leet Water, Lambden Burn, Eden Water), presumably due to the higher weed growth in these streams. Note that there is surprisingly little temperature difference between these sites and others with much smaller seasonal oscillations (Figure 5.8).

Fish farms cause a reduction in dissolved oxygen; typically, average oxygen may decline from 11 to just over 9 mg l^{-1} (94 to 82% saturation). Seasonal oxygen variations are slightly exaggerated at the outlet from the fish farms (Figure 5.6) with oxygen minima occurring slightly earlier. Tip effluent is often very depleted in dissolved oxygen and some samples contain less than 1 mg l^{-1} indicating that reducing conditions exist. However, dissolved oxygen levels appear to recover fairly rapidly as there is only a small effect downstream of the tips. No dissolved oxygen measurements have been made on industrial or sewage effluent.

Biochemical oxygen demand

The biochemical oxygen demand (BOD) is an indication of the oxygen required to degrade any organic matter and to oxidise inorganic matter. BOD can be very high in sewage effluent and even higher in farm slurry and silage effluent because of the large organic content. Silage effluent BOD is typically 200 times as concentrated as raw domestic effluent, whilst slurry is about 100 times as concentrated (Royal Commission, 1992). Discharges of high BOD effluent cause oxygen depletion which can destroy plant life and fish. BOD should normally be less than 3 mg l^{-1} for a river to be considered of Class 1 (unpolluted). The maximum permitted BOD for sewage effluent is usually not more than 20 mg l^{-1} assuming an 8:1 dilution in the river (Royal Commission, 1992).

Biochemical oxygen demand in the rivers of the Tweed basin averages around 2 mg l^{-1} with 90% of values in the range 1 – 3.7 mg l^{-1}. Individual site averages vary between 1.3 and 5.4 mg l^{-1} (Appendix A). The regional plot of BOD (Figure 5.2) shows highest average BOD values in lowland areas (e.g. Lambden Burn, Leet Water and Turfford Burn), and lowest values in headwater areas. The graphs show limited point source inputs in these lowland areas indicating the importance of diffuse sources. Potential sources of BOD are the spreading of slurry or other fertilizer (e.g. chicken litter, sewage sludge) on the land. Effluent from silage and slurry storage tanks may also have an impact.

The regional plots clearly show sewage treatment works to be the main point source of BOD. Biochemical oxygen demand of effluent averages around 50 mg l^{-1}. Samples range up to 500 mg l^{-1}, with individual sites averaging between 5 and 280 mg l^{-1}. Sedimentation units and septic tanks have typical BOD of around 100 mg l^{-1} whereas the larger sewage treatment works usually average less than 35 mg l^{-1}.

Industrial BOD is very variable. From the limited data available, the only direct industrial discharge with high BOD in the Tweed area has been from potato packaging. BOD in refuse site effluent is, on average, about 50% higher than in rivers (3 mg l^{-1}). However, this source probably provides only a small contribution to the rivers, relative to the much higher discharge flows from sewage treatment works. 95% of tip effluent has a BOD of less than 20 mg l^{-1}. Biochemical oxygen demand is slightly elevated by fish farms (on average from 1.6 to 2 mg l^{-1}), but again, this is small relative to sewage effluent inputs.

Biochemical oxygen demand shows little relationship with flow or with season, and it does not show any consistent rise or decline downstream. Riverine BOD has a slightly skewed distribution, whereas BOD in effluent can be very skewed at some sites (e.g. Jedburgh, Selkirk, Newtown St. Boswells).

Nitrogen species

Four measures of nitrogen are determined. These are, free and saline ammonia (i.e. combined NH_3 and NH_4^+), nitrate, nitrite and albuminoid nitrogen (a measure of the organic nitrogen content). Of these, nitrate and free and saline ammonia (also referred to here as total ammonia) are the most common measurements. Albuminoid nitrogen is only measured for a few sewage treatment works. Nitrite is mainly measured at sewage treatment works, with only a few river measurements being taken.

The average relative proportions of nitrate species in different sample types are very distinctive (Figure B5). In rivers, almost all nitrogen exists as nitrate with just a small amount of total ammonia being present. Sewage treatment works are the most significant point source of nitrogen. For these, around half of the nitrogen load (as mg l^{-1} N) is total ammonia and only a third nitrate. Albuminoid nitrogen makes up most of the remaining nitrogen load – nitrite makes only a very small contribution. For the other point sources, only nitrate and total ammonia have been measured. Nitrogen levels in industrial and tip effluent are higher than in the rivers, and typically just over half is total ammonia. Fish farms cause a very slight increase in nitrogen, mainly due to an increase in the total ammonia component.

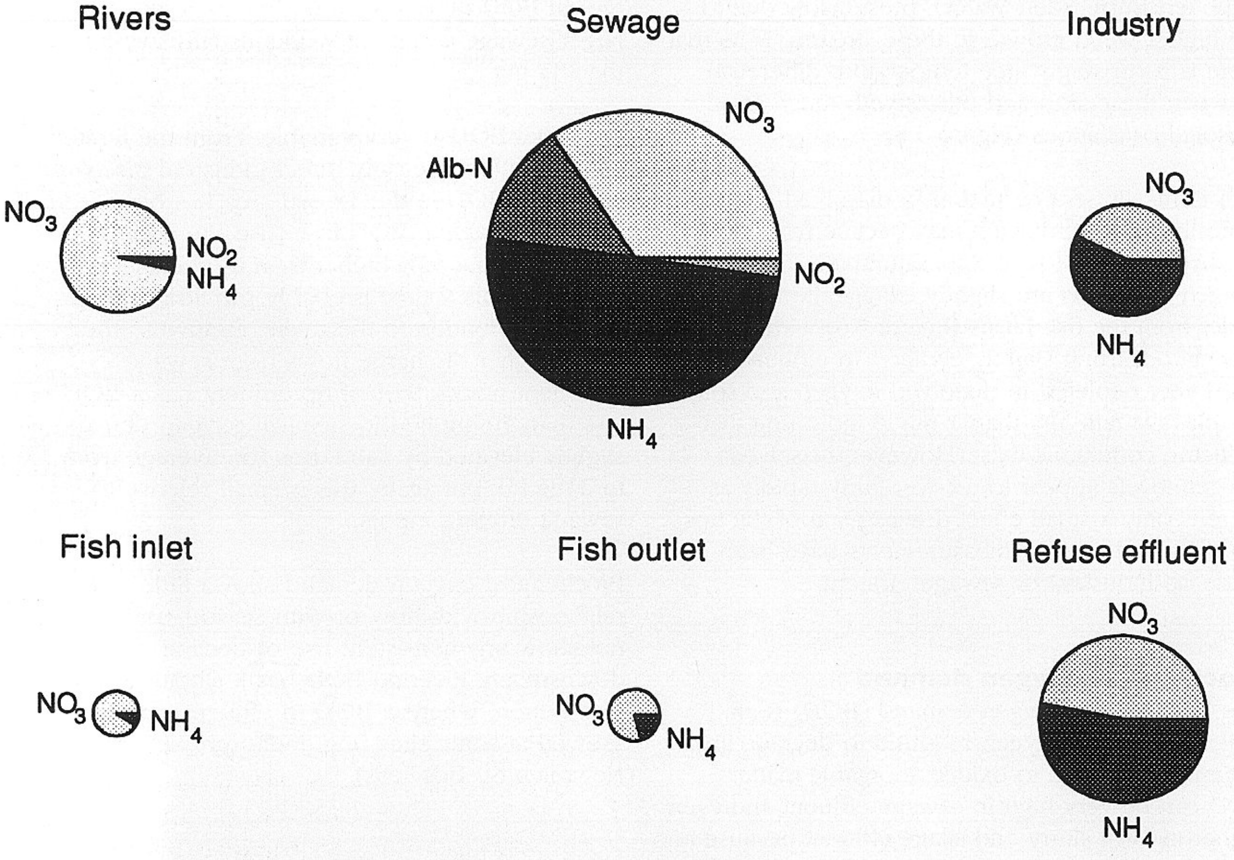

***Figure B5** Pie charts showing relative contributions of nitrate (NO_3), total ammonia (NH_4), nitrite (NO_2) and albuminoid nitrogen (Alb-N) to total nitrogen content (as mg l^{-1} N). The area of each circle is proportional to the average total nitrogen content. Sewage effluent contains most nitrogen; industrial and refuse effluent contain similar total N to the rivers (but with a higher proportion as total ammonia). In river samples most nitrogen is as nitrate, whereas in sewage effluent around half of the nitrogen is as total ammonia. Note that albuminoid nitrogen is only measured for sewage effluent, nitrite is only measured for rivers and sewage effluent.*

Total ammonia (or free and saline ammonia)
Un-ionised or free ammonia (NH_3) is the most reduced inorganic form of nitrogen in water and is very soluble in water. Most un-ionised ammonia is rapidly converted to ammonium ions (NH_4^+) but a small amount can remain in river water. The percentage of un-ionised ammonia in solution increases with pH, temperature and salinity (Mainstone *et al.*, 1989). Fish are intolerant to high levels of un-ionised ammonia because it reduces the oxygen carrying capacity of the blood (M^{c}Neely *et al.*, 1979). The EEC Fresh Water Fish Directive stipulates that total ammonia should not exceed 0.8 mg l^{-1} N (mandatory) and recommends guide levels of 0.03 mg l^{-1} N for salmonid waters and 0.15 mg l^{-1} N for cyprinid waters.

Ammoniacal compounds occur naturally in fresh waters and mainly originate from decomposing plant and animal matter. Sewage effluent is the largest source of total ammonia in rivers; about 60% of the nitrogen in sewage effluent is as ammonia (Mallet *et al.*, 1992; Royal Society, 1983). Other sources are silage, unused fertiliser, drainage from livestock wastes and runoff from sewage sludge spread on the land. Textile industries can produce effluent high in total ammonia.

In the rivers of the Tweed basin, total ammonia occurs in low amounts; concentrations average around 0.1 mg l^{-1} N with 90% of observations lying between 0.02 and 0.4 mg l^{-1} N, and many streams never exceeding 1 mg l^{-1} N. Concentrations are highest in some arable areas and downstream of problem sewage treatment works e.g. Biggar Water and (historically) Jed Water (Figure 5.5). At Jedburgh, this is partly because of particularly high total ammonia in sewage effluent due to loadings from fellmongering (Figure 5.4). At most river sites, total ammonia shows an increase with flow, but the reverse is seen at sites, such as Jed Water Foot, which have historically been severely affected by sewage discharges (Figure 5.11).

Sewage effluent is the dominant point source of total ammonia. For the Tweed, sewage effluent contains an average of around 12 mg l^{-1} N of total ammonia, with concentrations typically in the range 1 - 40 mg l^{-1} N. Average concentrations at individual works range between 1 and 40 mg l^{-1} N. The regional map for total ammonia indicates that other point inputs to the rivers are small in comparison with sewage treatment works. Some is leached from tips but this has only a small impact on river water quality except on some of the small water courses (e.g. Stirches where an average of 5 mg l^{-1} N is found in one of the burns). The only monitored industrial source of total ammonia has been from potatoes (average 4 mg l^{-1} N). Fish farms cause an increase in ammonia (Figure B6) but the increase is insignificant in comparison with sewage effluent. Typically, concentrations of ammonia average 0.06 mg l^{-1}N above a fish farm and 0.16 below it. This rise is explained by the excretion of un-ionised ammonia by fish; free ammonia is the chief excretory product of fish (Mainstone *et al.*, 1989).

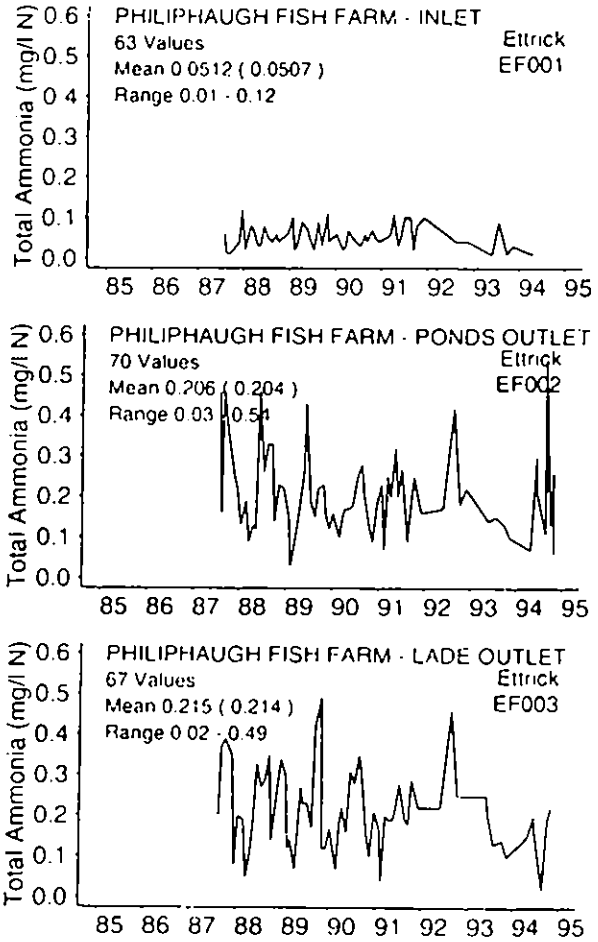

***Figure B6** Time series of total ammonia concentrations at Philiphaugh fish farm, 1985 - 1994. Total ammonia increases because of excretory products.*

Nitrate
See Chapter 4.

Nitrite
Nitrite contains nitrogen in an intermediate oxidation state and is seldom high in surface waters unless they are badly polluted by inadequately treated sewage effluent. However, when present, nitrite is extremely harmful to aquatic life.

Data for nitrite are relatively limited in the Tweed basin and levels are generally low. Nitrite makes up a very small fraction of the total nitrogen budget. Measurements for some of the main river sites average 0.015 and reach 0.05 mg l^{-1} N (the detection limit is 0.01 mg l^{-1} N). Concentrations are higher for the sewage treatment works with an overall average of 0.5 mg l^{-1} N and a typical range of 0 – 2 mg l^{-1} N. There is a large site to site variation (averages range between 0.1 and 1.4 mg l^{-1} N; see regional map).

Albuminoid nitrogen
Albuminoid nitrogen is a measure of the organic nitrogen in solution. In the Tweed catchment, albuminoid nitrogen is only measured for sewage effluent. The average concentration is 3.3 mg l^{-1} N and typically values are in the range 0.5 –7 mg l^{-1} N.

Phosphate species
High phosphorus can be detrimental to water quality since, in combination with nitrates, it leads to the eutrophication of surface waters. Common sources of phosphates are human excrement, detergents, industrial effluents and agricultural drainage from fertilized land (M^c^Neely *et al.*, 1982).

For the Tweed, total and soluble phosphate have been measured. Total phosphate includes both dissolved-reactive plus particulate phosphate species, whilst the soluble phosphate includes only dissolved-reactive phosphate. Soluble phosphate measurements are the most common; total phosphate has not been measured for many sewage treatment works and there are no phosphate measurements for tip leachate. The relationship between total and soluble phosphate is variable. However, river water samples tend to contain a lower proportion of soluble phosphate than sewage effluent. Data for five sewage treatment works were examined and, for these, the proportion of soluble phosphate was found to vary between 55% and 79%. This compares with the river sites where average proportions of soluble phosphate ranged from 35% to 56%. Two fish farms were examined and the results of this indicated that the proportion of soluble phosphate increased downstream of these sites by around 10%.

Average phosphate in the Tweed basin is 0.2 mg l^{-1} P of which 0.1 mg l^{-1} P is soluble. Total phosphate is very variable; site averages range from <0.1 to 1 mg l^{-1} P total (Appendix A), although typically samples are lower than 0.6 mg l^{-1} P. The high river concentrations in the lowland agricultural areas (Lambden Burn and Leet Water) mean that these streams are classed as eutrophic and suggest an important diffuse source (Figure 5.3). Phosphates bind well to soil particles and, once bound, are not readily leached. However, high river phosphate concentrations can occur when there is erosion of very fine soil particles or where there is direct runoff of slurry/fertilizers from recent application to the fields or from storage tanks. Slurry contains a high proportion of phosphorus relative to nitrate when compared with crop requirements (OECD, 1986) e.g. 1% dry weight phosphorus cf. 2.5% nitrogen (Gasser, 1980). Additionally, there are a number of chicken farms on Turfford Burn, Lambden Burn and Leet Water. The litter from these is phosphate rich and is directly spread as a fertilizer. Similar diffuse sources of phosphate have been noted elsewhere, e.g. in Devon the land contributed around 35 – 40% of the phosphate in the river, the rest came from sewage treatment works (NRA, 1992). Much of the detected dissolved riverine phosphate is likely to be bound to very fine silts.

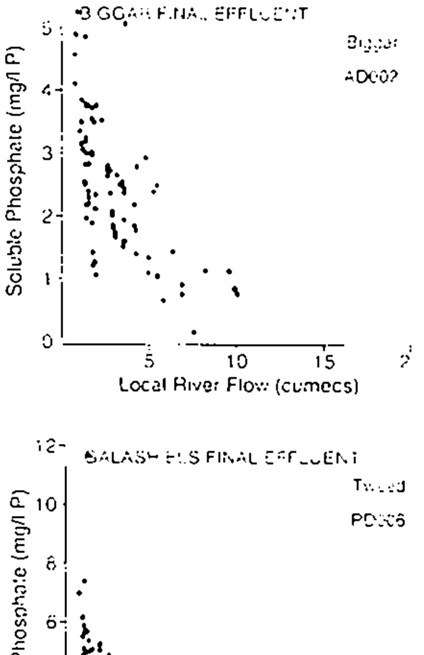

***Figure B7** Flow relationships for soluble phosphate in effluent from Biggar and Galashiels sewage treatment works. In common with many other determinands a dilution relationship is seen.*

The most important point sources of phosphates on the Tweed are the sewage treatment works, for these soluble concentrations average between 1 and 10 mg l^{-1} P, with individual samples ranging up to 15 mg l^{-1} P. Both soluble and total phosphate in effluent are very high relative to riverine concentrations, so it is perhaps a little surprising that diffuse sources seem to make the most impact on river concentrations. Fish farms are a minor source of phosphate causing concentrations to increase slightly (0.05 mg l^{-1} P). Effluent from a potato packaging factory contains around 2 – 3 mg l^{-1} P of total phosphate.

Phosphate concentrations are highest at low flows and lowest at higher flows, and this is most marked for the more eutrophic streams in arable areas (Figure 5.3). A pattern of phosphate dilution at higher flows is observed at some sewage treatment works - but in many cases these flow relationships are weak (Figure B7).

Chloride

In low salinity, natural waters, chloride is a non-toxic major inorganic anion. Natural inputs arise from rainfall, particularly from Atlantic frontal systems. Sewage effluent can be high in chloride owing to the salt content of urine.

The spatial pattern of river chloride concentrations is similar to that of nitrate. Highest concentrations are found in lowland agricultural areas and where there is significant sewage effluent entry nearby (e.g. Biggar Water because of low dilution, and Jed Water because of poor quality effluent). In the lowland agricultural regions, high chloride is due partly to slurry/silage applications and partly to high evaporation which concentrates rainfall inputs. River chloride site averages range from 7 to 70 mg l^{-1}.

Sewage effluent contains high levels of chloride with average concentrations between 30 and 700 mg l^{-1}, although the median of these is 70. Particularly high concentrations are found in effluent from Jedburgh (due to fellmongering) and Duns (due to high salt use in salmon smoking) – Figures 5.1 and B8. At Jedburgh this has historically caused a significant downstream rise (Figure B8). At Duns, the increase over time is due to the growth of the fish smoking industry (Figure B8). Sewage treatment has little effect on chloride concentration; effluent concentrations are not affected by the grade of treatment.

None of the monitored direct industrial discharges are high in chloride. Fish farms make virtually no impact on chloride. Some tips do contribute chloride, but it is rather variable and in most cases the contribution is likely to have rather less impact than the sewage treatment works.

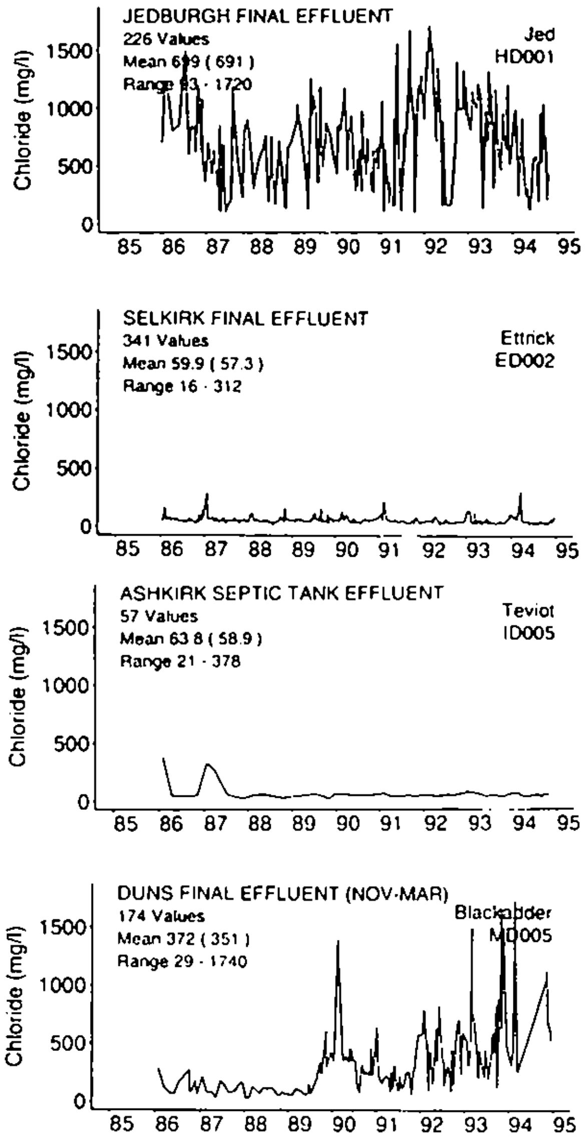

***Figure B8** Time series of chloride concentrations for sewage effluent, 1985 - 1994. Effluent from Jedburgh is high in chloride because of discharges from fellmongering. At Duns the high chloride is due to salt used in salmon smoking.*

Silica

Silica is found in abundance in the earth's crust, being present in most rocks. It is mainly produced from chemical weathering of silicate bearing rocks and minerals and from soils; there are few anthropogenic sources. Solubility controls in the stream play an important role in controlling stream silica, but biological activity such as diatom growth can cause silica depletion during algal blooms. Silica is not detrimental to humans or fish.

For the Tweed, silica measurements are only made for the rivers. The average silica concentration is 2.4 mg l^{-1} Si with individual site averages varying between 1 and 6 mg l^{-1} Si. Concentrations tend to decrease downstream and are highest in the upper reaches of Biggar Water, Lambden Burn and Leet Water (Figure 5.1).

Silica exhibits a strong seasonal variation and is highest in winter and lowest in spring/summer (Figure B9). For the Tweed above Galafoot, where the sampling frequency is every week (rather than every two months as elsewhere), there appear to be two summer troughs - one early and one late (Figure 5.7). It is likely that these are the result of biological activity relating to diatom growth and decay in both the spring and autumn.

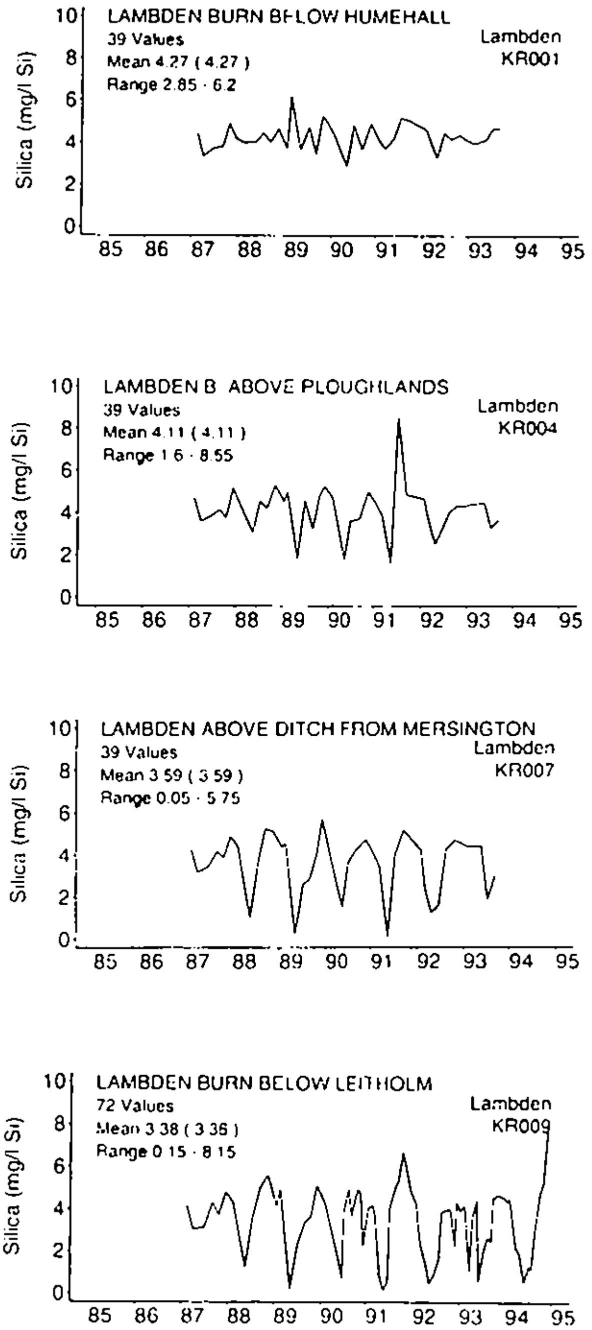

***Figure B9** Time series variations for silica at four sites along the Lambden Burn, 1985 - 1994. Annual maxima do not change downstream, but annual minima become more marked due to diatom growth.*

Silica concentrations are strongly linked with flow. Concentrations rise rapidly as flow increases but then quickly level off suggesting a source of silica from soil and near surface waters (Figure 5.10). This is consistent with the higher than average silica concentrations in arable areas (where there is more soil disturbance). At low flows, silica concentrations can plummet due to diatom uptake and these decreases are most marked on the nutrient rich streams. On some of the lowland streams, e.g. Lambden Burn and Leet Water, the annual minima silica concentrations become more pronounced downstream. However, there is little corresponding trend in annual maxima which remain near constant, perhaps partly because of solubility controls (Figure B9). There is a gradual downstream biological uptake of silica at low flows, probably in line with increased nitrate and phosphate concentrations. At higher flows, there is no opportunity for any loss via biological growth.

B.2 Metals

Zinc

Zinc can be highly toxic to both fish and aquatic organisms when present in excess, but it is relatively non-toxic to humans. Zinc is abundant in nature and is widely used in industry (e.g. paints, textiles, printing, chemicals). Further inputs to the environment occur through fossil fuel burning and pesticide and fertiliser application. Usually, zinc is found in the presence of other pollutants such as copper and cadmium. It is readily adsorbed onto sediments and soils (especially iron oxides) and is more soluble at low pHs.

Average zinc concentrations of the Tweed rivers are between 2 and 20 $\mu g\ l^{-1}$ in dissolved form (overall average 8 $\mu g\ l^{-1}$), though individual samples can range much higher (up to 500 $\mu g\ l^{-1}$). Average sewage effluent concentration is 80 $\mu g\ l^{-1}$ of which 40 $\mu g\ l^{-1}$ is in dissolved form (N.B. there are more sites monitored for available zinc and this might bias the averages). The regional map for available zinc (Figure 5.13) shows that higher grade treatment causes a reduction in zinc concentrations; this is likely to relate to the lower levels of suspended solids in the effluent. Sewage effluent shows little spatial variation for zinc (Figure 5.13) and, in comparison with other metals, is only moderately higher than the background river level (five times as high). This suggests that a background geological source of zinc is important. Zinc does not appear to have any other major point sources. Tip effluent averages around 7 $\mu g\ l^{-1}$, i.e. less than a tenth of that seen in sewage discharges. Fish farms cause virtually no increase in zinc concentrations and industrial contributions are very limited.
Zinc shows little relationship with flow for either sewage effluent or rivers. Proportions of dissolved and particulate zinc are very scattered; dissolved zinc averages around 60% of total for rivers but is extremely variable for sewage treatment works. In particular, Selkirk works has a much higher proportion of particulate zinc than many other sewage treatment works (Figure B10). Time series plots of zinc show some marked drifts over time. At many locations zinc was higher during the years 1989-1991. This pattern is widespread and is found for both river and sewage samples; it is not known why this occurred. Over and above this, there has been a decline in zinc at Selkirk sewage treatment works, and an increase at Jedburgh.

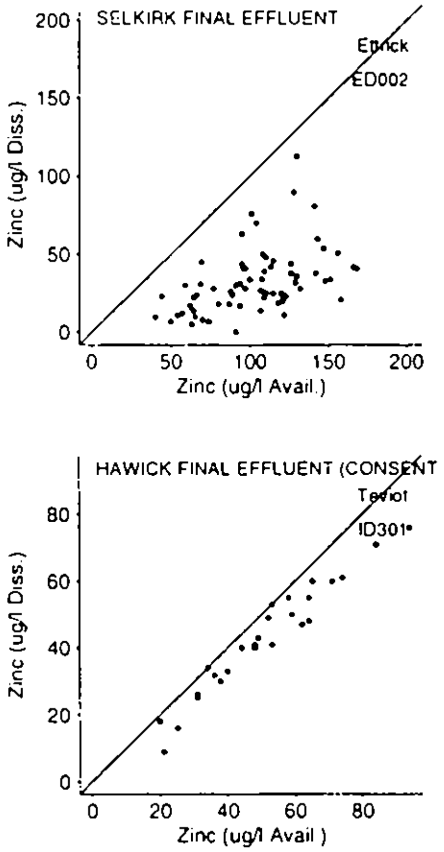

***Figure B10** Dissolved and available zinc concentrations in sewage effluent at Selkirk and Hawick. At Selkirk a much higher proportion of the zinc is in particulate form. The solid line is a reference 1:1 line.*

Lead

Concentrations of dissolved lead in river water are generally small owing to its low solubility. Nevertheless, most aquatic life is sensitive to lead. The main natural source of lead is weathering of sulphide ores, but anthropogenic inputs are generally high relative to this. Sources include pipework, batteries and burning of leaded fuel. Lead salts are also commonly used in industrial processes (e.g. printing, dying, photography, paints).

Lead concentrations in the Tweed rivers are typically low, many samples being near or below detection limits (0.4 µg l^{-1}). Concentrations are usually less than 2 µg l^{-1} in dissolved form (3 µg l^{-1} total) and average around 0.6 µg l^{-1} (1.2 µg l^{-1} total). The most significant point source of lead in the area is from Selkirk sewage treatment works (Figure 5.14) which, on average, discharges approximately 100 µg l^{-1} compared with the median sewage effluent level of 7 µg l^{-1}. This lead is likely to originate from the electronics industry. Galashiels effluent is also higher than the norm with an average of 18 µg l^{-1} . There are no other notable point sources; tips in the area give rise to very little lead whilst industrial contributions are insignificant. Fish farms do not affect lead concentrations.

Lead shows a very weak relationship with flow; a small dilution above lowest flows is apparent where concentrations are highest – e.g. Selkirk sewage treatment works. The separation between dissolved and particulate lead for most river and sewage treatment works is difficult to judge because the levels are so low. However, smaller sewage treatment works tend to have higher proportions of particulate lead. For Selkirk sewage treatment works, only 22% of the available fraction is as dissolved; furthermore, the proportion of dissolved lead decreases as available lead concentration increases.

Nickel

Nickel in drinking water has a relatively low toxicity to humans, but it can impair growth in aquatic life. Nickel commonly forms stable, usually soluble, complexes making it a relatively mobile metal (Mallet *et al.*, 1992). Anthropogenic sources include nickel plating, ore processing, fossil fuels and waste incineration.

Nickel is not as widely measured on the Tweed as some of the other metals and is relatively near to or below the 1 µg l^{-1} detection limit for most river sites (Figure 5.15). Measurements for sewage treatment works and tips are also typically below detection limits. The exceptions to this are food processing (potatoes average 30 µg l^{-1}) and sewage treatment works at Selkirk, Kelso, Jedburgh, Galashiels and Charlesfield: averages 27, 10, 7, 5 and 3 µg l^{-1}, respectively. Nickel is one of the few metals which is almost all in dissolved form in the Selkirk discharge (Figure B11). At Selkirk, nickel concentrations decline at high flows.

Iron

Iron is the fourth most abundant element in the earth's crust. It is a minor plant nutrient but is harmful in excess because it fixes other essential elements. Iron is not harmful in drinking water but is undesirable for aesthetic reasons. Iron is found in the ferrous (Fe^{2+}) and ferric (Fe^{3+}) states and is more soluble at lower pHs and in the ferrous state. The ferrous state is only present in water under reducing conditions; in non-reducing conditions it is oxidised and precipitated in the ferric form, mainly as iron oxides and hydroxides. Iron derives naturally from weathering of rocks but is also found in rainfall. Industrial activity contributes significant amounts of iron to the environment e.g. from coal burning, mining and mineral processing.

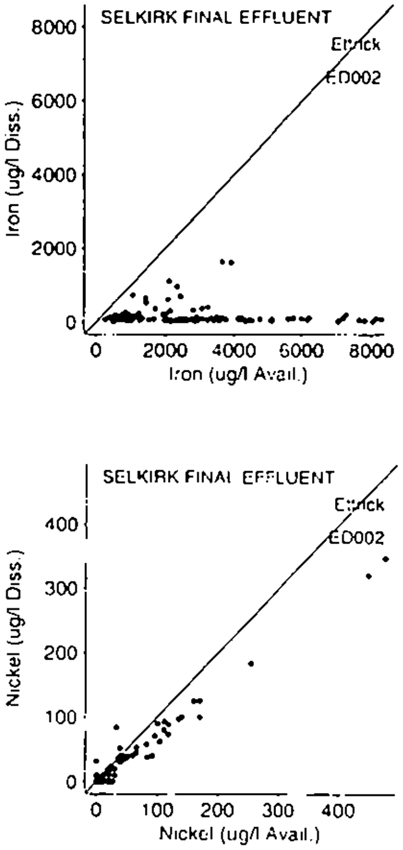

Figure B11 *Dissolved against available metal concentrations for iron and nickel in Selkirk effluent showing very variable partitioning. Nickel is almost all in dissolved from, iron is predominantly as particulates (cf. also Figure B10).*

Iron is only measured at a few Tweed river sites, although a number of samples are analysed upstream and downstream of sewage treatment works. For the river sites, averages are around 200 µg l^{-1} of which 50 µg l^{-1} is in dissolved form. Sewage effluent averages 480 µg l^{-1} (115 µg l^{-1} as dissolved) but is dominated by Selkirk works especially for the particulate component. Selkirk discharges an average of 190 µg l^{-1} iron as dissolved and a remarkable 2000 µg l^{-1} as available (Figure B11); this high value is due to iron being added as part of the effluent treatment process.

From the regional maps, it can be seen that point sources of iron, other than sewage treatment works, are more significant than for the other metals (Figure 5.13). Tip effluent contains significantly higher iron levels (average 3600 µg l⁻¹ available), than sewage effluent, even compared with Selkirk. The iron content is probably due to there being high proportions of iron/steel in refuse and reducing conditions within the tips. Some high iron levels have historically been measured for the potato packing site at Winfield. Fish farms cause a very slight increase in iron but levels are so low that this is unimportant.

Dissolved iron increases slightly at high flows in the rivers (it is the only metal to do this; Figure B12) but has a strong decreasing flow relationship at some sewage treatment works. Iron has the lowest dissolved fraction of the metals considered; in rivers around 30% of available iron is in dissolved form. Extremely variable partitioning is observed at different sewage treatment works; e.g. a higher proportion of iron is as dissolved at Galashiels in comparison with Selkirk.

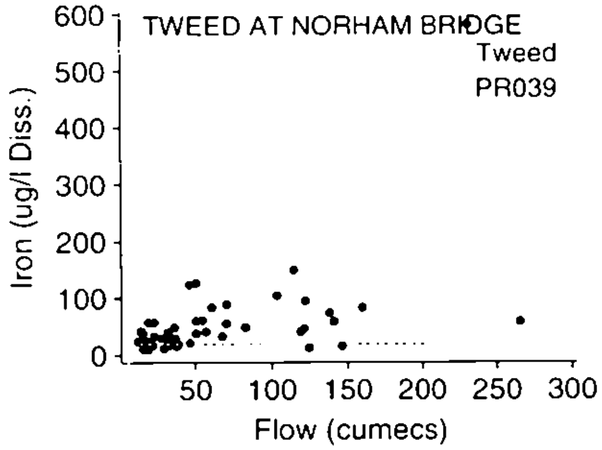

***Figure B12** Riverine flow relationship for iron. Iron is the only metal that increases with flow in the rivers.*

Chromium

Chromium is essential for animal growth, but is harmful in excess. For plants, it interferes with the uptake of essential nutrients. Natural sources of chromium are rare, but chromium is commonly used in industrial and domestic applications. These include central heating, fridges, metal plating, paper and textile dying. Chromium can also be found in some fertilisers and pesticides.

For the Tweed catchment, chromium levels are close to the detection limit of 0.5 µg l⁻¹ (Figure 5.15). Only the Ettrick Water below Selkirk and the Tweed above Galafoot have many samples above the detection limit (averages for these are 1.5 and 0.4 µg l⁻¹ respectively). Selkirk sewage treatment works discharges over 200 µg l⁻¹ (available) which is nearly two orders of magnitude higher than that from most other sewage treatment works, although it has declined in recent years. It is also much higher than any tip, industrial or fish farm effluent. Galashiels, Charlesfield and Jedburgh works are lesser sources; chromium concentrations are 40, 17 and 6 µg l⁻¹ respectively.

Chromium generally decreases with increasing flow for both rivers and sewage effluent. Levels of chromium in the Tweed rivers are not sufficiently high to assess the partitioning of chromium. However, for sewage effluent, the dissolved component is high (72% in dissolved form) and this proportion does not vary substantially from site to site.

Copper

Copper is an essential plant and animal nutrient though large doses can be harmful. Fish can experience growth inhibition at low concentrations and some species of invertebrates are sensitive at concentrations as low as 5 µg l⁻¹. In humans, too much copper can cause damage to the liver. Only trace amounts of copper are generally found in natural waters. However, significant copper inputs can arise from widespread industrial use (e.g. textiles, electrical products) and from domestic use (Hedgecott and Rogers, 1992). In agriculture, copper is used as a fungicide and a pesticide and in copper deficient areas it is applied as a trace element.

Dissolved copper concentrations in the Tweed and its tributaries average 4 µg l⁻¹ and are typically in the range 0 – 10 µg l⁻¹. Total copper concentrations are slightly higher (average 5.4; typical range 1–14 µg l⁻¹). The distribution of copper is skewed and copper concentrations over 20 µg l⁻¹ are found occasionally at a number of sites.

The regional map shows the high degree to which point sources from Selkirk (average 900 µg l⁻¹ available, of which 510 µg l⁻¹ is dissolved) and Galashiels sewage treatment works (300 µg l⁻¹) dominate inputs (Figure 5.14). In comparison, other sewage effluents are relatively low in copper (the median is 22 µg l⁻¹). The high copper in the Selkirk effluent arises from electronics industry waste and in the past has meant that Ettrick Water has failed the Environmental Quality Standard for copper downstream of Selkirk, e.g. in 1991. The effect of this discharge to the river is substantial; concentrations rise from 2 µg l⁻¹ upstream to 14 µg l⁻¹ just downstream, decreasing to 10 µg l⁻¹ at Ettrick Water Foot, 5 km downstream (Figures 5.18 and 5.19). The shift in average concentration is matched by a 30 fold increase in the spread (0 – 10 µg l⁻¹ upstream, 1 – 330 µg l⁻¹ just downstream). The input of copper is sufficiently large that its effects are seen even further downstream (e.g. Tweed above Galafoot; Figure 5.19). A simple calculation based on mean flows and average concentrations suggests that, if there was no loss of dissolved copper from the river, up to 2.7 µg l^{-1} of the 4.9 µg l^{-1} of dissolved copper at Tweed above Galafoot, and up to 1.2 µg l^{-1} of the measured 3.83 µg l^{-1} at Norham could derive from the Selkirk input. The effluent from Galashiels will further increase this. In fact, concentrations at Norham are only 0.5 µg l^{-1} higher than the average basin-wide river concentration. Thus, it appears that there is a net loss of dissolved copper within the river system.

There are no other significant point sources of copper. Tips average less than 5 µg l^{-1}, and fish farms only cause a very slight increase in dissolved copper concentrations (averages rise from 3 µg l^{-1} upstream to 3.7 µg l^{-1} downstream). The only industries monitored have been for the relocated potato packing company (average 40 µg l^{-1}). There is a tendency for copper concentrations in sewage effluent to be higher towards the far north/north-west of the Tweed catchment. This may indicate a background geological source relating to the Pentland hills, although this is not evident from copper concentrations further downstream in the rivers. Note that, in some areas, soils are copper deficient and agricultural additions are made to animal foodstuffs.

Total and dissolved copper concentrations show a slight tendency to decline at higher flows for rivers, and a noticeable decline with flow for sewage treatment work effluent. On average, around 60% of copper is in dissolved form for both sewage effluent and river water, though there is some variation across sewage treatment works.

Other metals and metalloids

Determinations are also made for the metals cadmium and mercury and for the metalloid arsenic. Cadmium and mercury are two of the most toxic pollutants found in freshwaters, whilst arsenic has a toxicity dependent on the chemical form in which it is present. All of these substances have a number of industrial sources. Cadmium can derive from non ferrous metal industries, batteries and pigments. Mercury is used in paints, pharmaceutical and dental work. Arsenic is discharged from mine workings and the semiconductor industry, and is found in preservatives and pesticides.

On the Tweed, cadmium levels are too low for detection (<0.5 µg l^{-1}). River water concentrations of mercury are either at or very near the detection limit (0.1 µg l^{-1}) with almost all values less than 1 µg l^{-1}. Effluent for sewage treatment works, tips and industry also contain less than 1 µg l^{-1} mercury, with only the odd outlying value. Arsenic too is almost always lower than detection limits (5 µg l^{-1}) in the rivers, but has been detected in the effluent from Charlesfield sewage treatment works (average 9 µg l^{-1}), from Winfield potato packaging company (8 µg l^{-1}) and in one of the discharges at Easter Langlee tip (8 µg l^{-1}). High concentrations of dissolved arsenic have been found for one of the Cleugh tip outfalls (70 µg l^{-1}); this is thought to be due to a natural source.

Overall, dissolved and total metal concentrations in the rivers are very low for cadmium, mercury and arsenic and are well below environmental and drinking water quality standards.

Appendix C: further regional analysis of nitrate

Nitrate concentrations on the Tweed have been rising since the war (Figure 7.2). In many lowland tributaries of the Tweed, nitrate concentrations can exceed drinking water standards and some stretches are eutrophic because of the combined effects of high nitrate and high phosphorus inputs. Nitrate concentrations are highest in soil waters, but even the ground waters of the lowland regions are high in nitrate relative to the baseflows in headwater streams. This may have long term implications for water supplies.

Here, a simple regression analysis is used to link nitrate concentrations to factors such as land use, geology and soil structure. The main objectives of this analysis are to select a small number of variables which might best explain the water quality. The results are preliminary rather than definitive, but provide an example of how regional analysis may be taken forward. Ideally, other catchment descriptors would also be used. For example, some distinction between crop types and identification of intensive animal farming (pigs and poultry) would be sensible, as would variables describing average runoff and evapotranspiration. This information is presently not readily available in a form suitable for analysis, but these variables could be incorporated at a later stage.

The main stages to the approach are to:

1. Calculate the boundaries of the drainage areas corresponding to each of the water quality sampling sites.

2. Calculate the proportions of different soils and land uses within each catchment boundary. In addition derive average elevation, total catchment area, and estimate volumes of sewage effluent.

3. Reduce the number of variables (before regression), removing variables which are only found in very small proportions.

4. Regress nitrate on the remaining variables, selecting a small subset of the explanatory variables which best explain water quality.

The first two stages were carried out within the ARC/INFO geographical information system. Digital land elevation data were used to characterise the flow pathways. From this, the boundaries of the contributing catchment area were calculated, along with catchment area and average elevation. Once the boundaries had been derived, information from relevant geographical data sets was overlain to obtain catchment properties. So, for example, the proportions of moorland, rough grassland, and arable land were calculated for each of the water quality sampling sites. Data on geology (from the British Geological Survey), land use (ITE; Fuller, 1993) and soil properties (the HOST data set; Boorman *et al.*, 1995) were treated in this way. Estimation of sewage input was included because of the contribution of sewage effluent to nitrate levels, e.g. the high nitrate concentrations on Biggar Water are mainly due sewage effluent. This was crudely based on average dry weather flows for main sewage treatment works in the area and was expressed as a proportion of the river flow (for this, flow was assumed to be proportional to catchment area). Some tiny watercourses were eliminated from the analysis because they appeared to be outlier values. These were sites on Turfford Burn which is extremely high in nitrates; analysis was highly influenced by these points when they were included.

The results of the analysis identify a strong link between land use and nitrate concentrations. Three main explanatory variables were selected:

- proportion of tilled land;
- proportion of mown/grazed grass;
  and the
- proportion of soils which have a macroporous structure overlying shallow groundwater (<2m; Host Classification 5; Boorman *et al.*, 1995).

Together, these three variables explained 93% of the total variation. Regional distributions of these classifications are shown in Figure C1, and the links with nitrate together with fitted regression slopes are shown in Figure C2.

Although, the analysis gave a good fit to the data, great care would need to be exercised for these results to be extrapolated to other areas or to land use change scenarios. Many of the geological types, land uses etc. are strongly correlated and alternative sets of explanatory variables with only slightly different degrees of fit can be identified. Also, a large number of variables were used in the regression (even after the reduction at stage 3). It is therefore possible that some variables were

Figure C1 *Distributions of variables used to explain nitrate variations. Shading is graded from black (100%) to white according to the percentage cover within each 1 km grid square. (a) mown/grazed grasslands (b) tilled land (c) soils with macroporous flow structure overlying a shallow groundwater (<2m). Data shown are from the ITE landcover map (Fuller, 1993) and HOST (Boorman et al., 1985).*

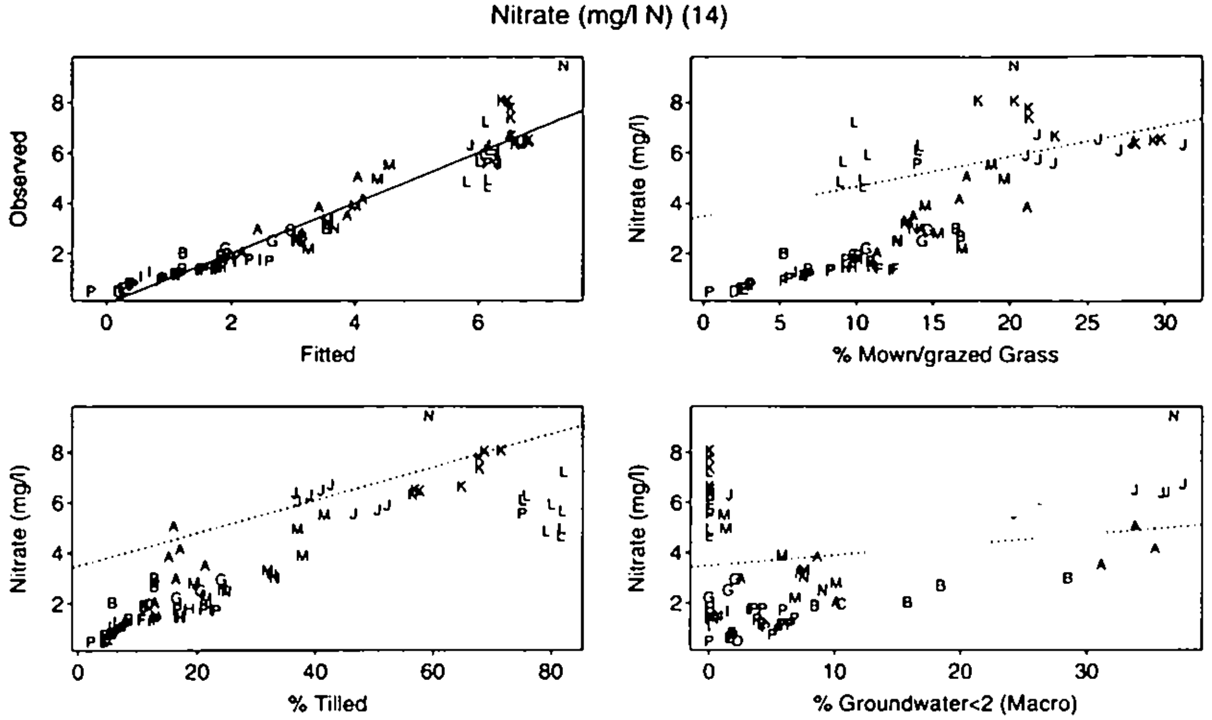

Figure C2 Fitted regression lines for nitrate. The top left graph shows observed against predicted nitrate concentrations together with a 1:1 line. The remaining graphs show nitrate against the three selected explanatory variables. The lines show the multiple regression slopes of the fitted relationships. The letters used on the graphs denote the different tributaries and are alphabetically ordered from upstream to down stream (see Appendix D; letters used correspond to the first letter of the site code).

selected during regression due to a coincidental correlation, rather than a causal effect. This is unlikely to be the case for the two land use variables, which agree with known theory, but could perhaps apply to the HOST soil type. Further analysis and application to other areas would be required to make the approach more robust.

Appendix D: tables of sample site details

These tables give details of sample sites including the site description, an approximate grid reference and the site codes. Some sites have been sampled under more than one sampling scheme, e.g. North Sea Action Plan (NSAP) and Paris Commission (PARCOM) and these are indicated. For each site the river system to which the site is attached is shown. For rivers, the type column indicates whether a site is located on the main river in the area (r) or is a tributary (t).

River and tributary sites

Type	River Area	Codes				Grid ref		Site description
		Regular	Duplicate	NSAP	PARCOM	East	North	
r	Biggar	AR004				3050	6366	BIGGAR W. 20m ABOVE HARTREE MILL FARM
t	Biggar	AR005				3049	6366	HARTREE MILL BURN FOOT
r	Biggar	AR006				3058	6368	BIGGAR W. AT HEAVYSIDE FARM (RAIL BR.)
t	Biggar	AR007				3067	6377	SPITTAL BURN AT B7016
t	Biggar	AR009				3081	6370	KIRKLAWHILL BURN AT FOOT
r	Biggar	AR014	PR005	UR019	YR001	3127	6348	BIGGAR WATER AT WHITERIG
t	Lyne	BR003				3153	6505	CAIRN BURN AT B7059
t	Lyne	BR008				3132	6451	TARTH W. 100m BELOW BLYTH BRIDGE
r	Lyne	BR011	PR008	UR014	YR002	3209	6400	LYNE WATER FOOT
t	Lyne	BR012				3120	6466	TARTH 50m BELOW BACK BURN
r	Eddleston	CR008	PR011	UR016	YR004	3249	6404	EDDLESTON WATER FOOT
r	Yarrow	DR009				3438	6276	YARROW W. AT PHILIPHAUGH G. STATION
r	Ettrick	ER001				3461	6284	ETTRICK W. AT HEATHERLIE BRIDGE
r	Ettrick	ER002				3470	6295	ETTRICK W. AT IRON FOOTBRIDGE
r	Ettrick	ER005				3481	6313	ETTRICK W. AT LINDEAN MILL
r	Gala	FR004				3455	6430	GALA W. AT LUGATE BURN FOOT
r	Gala	FR006				3479	6373	GALA W. AT GALA G. STATION
r	Gala	FR011	PR023		YR011	3510	6350	GALA WATER FOOT
r	Leader	GR003				3540	6473	LEADER W. AT LAUDER BRIDGE
t	Leader	GR007				3573	6380	LEADER W. ABOVE TURFFORD BURN
r	Leader	GR008	GR108			3574	6380	TURFFORD BURN AT FOOT
r	Leader	GR010	PR027	UR017	YR005	3577	6346	LEADER WATER FOOT
t	Leader	GR101				3600	6390	TURFFORD BURN BELOW PURVESHAUGH
t	Leader	GR102				3584	6400	TRIB. OF TURFFORD BURN ABOVE GRAIN STORE
t	Leader	GR103				3597	6399	TRIB. OF TURFFORD BURN AT BRIDGE
t	Leader	GR104		UR009		3601	6392	TRIB. OF TURFFORD B. BELOW PURVESHAUGH
r	Leader	GR105				3601	6391	TURFFORD BURN TRIB. FOOT
r	Leader	GR106				3591	6391	TURFFORD BURN AT A6105 LAYBY
r	Leader	GR107		UR008		3579	6385	TURFFORD B. ABOVE EARLSTON FOOT
r	Jed	HR002				3650	6203	JED W. AT ABBEY BRIDGE
r	Jed	HR004				3655	6213	JED W. AT JEDBURGH G. STATION
r	Jed	HR006	IR007	UR021		3660	6239	JED WATER FOOT
r	Teviot	IR002				3511	6153	TEVIOT W. AT WEENSLAND CAULD
r	Teviot	IR004				3532	6167	TEVIOT W. AT HORNSHOLE BRIDGE
r	Teviot	IR008				3674	6253	TEVIOT W. AT NESBIT BRIDGE
r	Teviot	IR010	PR032		YR006	3719	6335	TEVIOT WATER FOOT
r	Teviot			UR007		3705	6278	TEVIOT AT ORMISTON MILL (33)
r	Teviot			UR013		3481	6134	TEVIOT ABOVE HAWICK
r	Eden	JR001				3626	6451	EDEN BURN (A6089 BRIDGE)
r	Eden	JR002				3660	6447	EDEN W. AT MACK'S MILL
r	Eden	JR003				3659	6433	EDEN AT A6105
r	Eden	JR004				3659	6427	EDEN W. BELOW EAST MAINS
r	Eden	JR005				3654	6414	HAREFORD BURN AT HAREFORD BRIDGE
r	Eden	JR006				3661	6396	EDEN W. BELOW WHITEHILL (A6089 BRIDGE)
r	Eden	JR007				3687	6370	EDEN W. BELOW NENTHORN (A6089 BRIDGE)
r	Eden	JR008				3727	6372	EDEN W. AT PIPERS GRAVE
r	Eden	JR009	PR034		YR007	3765	6375	EDEN WATER FOOT
r	Eden			UR006		3738	6371	EDEN AT EDNAM (34)
r	Lambden	KR001				3714	6408	LAMBDEN BURN BELOW HUMEHALL
r	Lambden	KR002				3742	6428	LAMBDEN B. AT STONEFOLDBRAE FORD
r	Lambden	KR003				3746	6429	LAMBDEN B. BELOW LAMBDEN FARM
r	Lambden	KR004				3755	6440	LAMBDEN B. ABOVE PLOUGHLANDS
t	Lambden	KR006				3766	6432	SPRINGSWELLS BURN (A697 BRIDGE)
r	Lambden	KR007				3785	6440	LAMBDEN ABOVE DITCH FROM MERSINGTON
r	Lambden	KR008				3786	6439	LAMBDEN AT LEITHOLM BRIDGE
r	Lambden	KR009				3791	6439	LAMBDEN BURN BELOW LEITHOLM
r	Lambden			UR022		3804	6443	LAMBDEN WATER FOOT (45)
r	Leet	LR003				3852	6504	LEET W. BELOW RAVELAW FARM
r	Leet	LR004				3851	6501	LEET W. 75m D/S WHITSOME OUTFALL
r	Leet	LR005				3850	6497	REDLAW BURN FOOT
r	Leet	LR007				3846	6487	HARCARSE BURN FOOT
r	Leet	LR008				3830	6474	LEET W. AT SWINTON
r	Leet	LR009		UR004		3813	6460	LEET W. AT SWINTON MILL

River and tributary sites, continued

Type	River Area	Codes				Grid ref		Site description
		Regular	Duplicate	NSAP	PARCOM	East	North	
r	Leet	LR010				3814	6413	LEET W. AT CHARTERPATH BRIDGE
r	Leet	LR011		UR005		3840	6395	LEET W. AT COLDSTREAM G. STATION
r	Blackadder	MR001				3677	6477	BLACKADDER W. ABOVE GREENLAW
r	Blackadder	MR002				3736	6465	BLACKADDER W. AT LINTMILL
r	Blackadder	MR004				3809	6515	BLACKADDER W. AT KIMMERGHAME HOUSE
t	Blackadder	MR006				3806	6521	LANGTON BURN AT CAIRNHILL
t	Blackadder	MR007				3824	6528	LANGTON BURN FOOT
r	Blackadder	MR009	NR008	UR023		3863	6544	BLACKADDER WATER FOOT
r	Whiteadder	NR000		UR002	YR013	3938	6535	WHITEADDER AT CHESTERFIELD (H.M.)
r	Whiteadder	NR001				3786	6567	WHITEADDER W. ABOVE CUMLEDGE
t	Whiteadder	NR004				3850	6564	BILLIE BURN AT FOOT
r	Whiteadder	NR005				3851	6561	WHITEADDER W. D.S CHIRNSIDE MILL
r	Whiteadder	NR007				3863	6546	WHITEADDER W. ABOVE BLACKADDER
r	Whiteadder	NR010	PR045			3920	6546	WHITEADDER W. AT HUTTON BRIDGE
r	Whiteadder			UR012		3774	6577	WHITEADDER AT COCKBURN
r	Tweed	PR003				3108	6284	TWEED AT KNIGLEDOORS
r	Tweed	PR007	PQ001	UR011	YR003	3206	6397	TWEED AT LYNEFORD
t	Tweed	PR010	PQ003			3229	6394	MANOR WATER FOOT (T.10)
r	Tweed	PR013				3271	6396	TWEED AT PEEBLES DUMP
r	Tweed	PR015	PQ005			3333	6359	TWEED AT TRAQUAIR BRIDGE
r	Tweed	PR017				3382	6377	TWEED BELOW JUNIPER BANK
t	Tweed	PR020				3487	6322	TWEED AT OLD TWEED BRIDGE
r	Tweed	PR021		UR018	YR009	3489	6321	ETTRICK WATER FOOT (T.21)
r	Tweed	PR022	PQ009		YR010	3509	6346	TWEED ABOVE GALAFOOT
r	Tweed	PR024				3528	6348	TWEED AT LOWOOD BRIDGE
r	Tweed	PR026				3575	6346	TWEED ABOVE LEADER
r	Tweed	PR030				3649	6319	TWEED NEAR RUTHERFORD
r	Tweed	PR031				3710	6337	TWEED AT UPPER FLOORS
t	Tweed	PR033	PQ017			3750	6353	TWEED AT SPROUSTON
r	Tweed	PR036	PQ019		YR008	3844	6395	LEET WATER FOOT (T36)
r	Tweed	PR037				3848	6400	TWEED AT COLDSTREAM BRIDGE
r	Tweed	PR039	PQ000	UR001	YR012	3890	6472	TWEED AT NORHAM BRIDGE
r	Tweed		PQ013	UR010		3590	6319	TWEED AT DRYBURGH
r	Tweed			UR015		3217	6367	MANOR WATER AT CADEMUIR
r	Tweed			UR020		3496	6333	TWEED AT BOLESIDE (30)

Main sewage treatment works

River Area	Codes		Grid ref		Site description
	Regular	NSAP	East	North	
Biggar	AD002		3049	6368	BIGGAR FINAL EFFLUENT
Lyne	BD001		3152	6506	WEST LINTON FINAL EFFLUENT
Lyne	BD002	UD010	3138	6460	I.A.P.G.R. FINAL EFFLUENT
Ettrick	ED002	UD003	3474	6298	SELKIRK FINAL EFFLUENT
Gala		FD003	3454	6441	STOW FINAL EFFLUENT
Leader	GD002		3540	6470	LAUDER FINAL EFFLUENT
Leader	GD004		3573	6381	EARLSTON FINAL EFFLUENT
Jed	HD001	UD004	3657	6224	JEDBURGH FINAL EFFLUENT
Teviot	ID002		3570	6188	DENHOLM FINAL EFFLUENT
Teviot	ID301	UD001	3512	6155	HAWICK FINAL EFFLUENT (CONSENT D)
Blackadder	MD002		3720	6461	GREENLAW FINAL EFFLUENT (AUG-SEP)
Blackadder	MD005	UD012	3797	6532	DUNS FINAL EFFLUENT (NOV-MAR)
Tweed	PG001	UD005	3270	6398	PEEBLES FINAL EFFLUENT
Tweed	PD002	UD006	3369	6375	WALKERBURN FINAL EFFLUENT
Tweed	PD006	UD002	3516	6355	GALASHIELS FINAL EFFLUENT
Tweed	PD007		3551	6345	MELROSE FINAL EFFLUENT
Tweed	PD009	UD013	3581	6317	NEWTOWN ST. BOSWELLS FINAL EFFLUENT
Tweed	PD010		3607	6315	ST. BOSWELLS FINAL EFFLUENT
Tweed	PD012	UD007	3735	6345	KELSO FINAL EFFLUENT
Tweed	PD016	UD011	3857	6411	COLDSTREAM FINAL EFFLUENT
Tweed	PD020	UD008	3337	6362	CHARLESFIELD FINAL EFFLUENT

Appendix D

Other sewage treatment works

River Area	Codes		Grid ref		Site description
	Regular	NSAP	North	East	
Biggar	AD001		3061	6434	ELSRICKLE SEPTIC TANK EFFLUENT
Biggar	AD003		3071	6387	SKIRLING SEPTIC TANK EFFLUENT
Biggar	AD004		3111	6360	BROUGHTON FINAL EFFLUENT
Lyne	BD004		3159	6480	ROMANNOBRIDGE SEPTIC TANK EFFLUENT
Lyne	BD005		3110	6464	DOLPHINTON BIO UNIT FINAL EFFLUENT
Eddleston	CD001		3241	6469	EDDLESTON FINAL EFFLUENT
Yarrow	DD001		3410	6299	YARROWFORD SEPTIC TANK EFFLUENT
Ettrick	ED001		3389	6242	ETTRICKBRIDGE SEPTIC TANK EFFLUENT
Gala	FD001		3402	6545	HERIOT SEPTIC TANK EFFLUENT
Gala	FD002		3429	6494	FOUNTAINHALL SEPTIC TANK EFFLUENT
Leader	GD001		3498	6536	OXTON SEPTIC TANK EFFLUENT
Leader	GD003		3550	6435	BLAINSLIE SEPTIC TANK EFFLUENT
Teviot	ID003		3568	6123	BONCHESTER FINAL EFFLUENT
Teviot	ID004		3622	6224	LANTON SED. TANK EFFLUENT
Teviot	ID005		3473	6224	ASHKIRK SEPTIC TANK EFFLUENT
Teviot	ID006		3535	6254	LILLIESLEAF SEPTIC TANK EFFLUENT
Teviot	ID007		3530	6273	MIDLEM SEPTIC TANK EFFLUENT
Teviot	ID008		3630	6244	ANCRUM FINAL EFFLUENT
Teviot	ID009		3770	6251	MOREBATTLE FINAL EFFLUENT (AUG-SEP)
Eden	JD001		3649	6432	GORDON FINAL EFFLUENT
Eden	JD002		3652	6367	SMAILHOLM SEPTIC TANK EFFLUENT
Eden	JD003		3717	6384	STICHILL SEPTIC TANK EFFLUENT
Eden	JD004		3737	6371	EDNAM WEST SEPTIC TANK EFFLUENT
Eden	JD005		3739	6371	EDNAM EAST SEPTIC TANK EFFLUENT
Lambden	KD001		3788	6439	LEITHOLM FINAL EFFLUENT
Leet	LD002		3831	6474	SWINTON FINAL EFFLUENT (JUN-SEP)
Leet	LD003		3766	6415	ECCLES SED. TANK EFFLUENT
Leet	LD001		3853	6502	WHITSOME FINAL EFFLUENT (JAN-APR)
Blackadder	MD001		3632	6500	WESTRUTHER SEPTIC TANK EFFLUENT
Blackadder	MD003		3772	6491	FOGO SEPTIC TANK EFFLUENT
Blackadder	MD004		3771	6524	GAVINTON FINAL EFFLUENT (JUL-SEP)
Whiteadder	ND001		3693	6573	LONGFORMACUS SEPTIC TANK EFFLUENT
Whiteadder	ND002		3791	6569	PRESTON SED. TANK EFFLUENT
Whiteadder	ND004		3870	6557	CHIRNSIDE FINAL EFFLUENT
Whiteadder	ND005		3864	6545	ALLANTON SED. TANK EFFLUENT
Whiteadder	ND006		3935	6551	FOULDEN FINAL EFFLUENT
Whiteadder	ND007		3938	6527	PAXTON SED. TANK EFFLUENT
Tweed	PD005		3447	6349	CLOVENFORDS SED. TANK EFFLUENT
Tweed	PD008		3562	6343	NEWSTEAD SED. TANK EFFLUENT
Tweed	PD013		3716	6309	HEITON SOUTH SEPTIC TANK EFFLUENT
Tweed	PD017		3818	6283	TOWN YETHOLM FINAL EFFLUENT
Tweed	PD018		3826	6285	KIRK YETHOLM SEPTIC TANK EFFLUENT
Tweed	PD019		3908	6535	HUTTON FINAL EFFLUENT
Tweed	PD021		3587	6298	TRAQUAIR SEPTIC TANK EFFLUENT

Industry sites

River Area	Codes		Grid ref		Site description
	Regular	NSAP	East	North	
Jed	HC001		3512	6351	DISCHARGE FROM BORDER SHEEPSKINS
Jed	HC002		3659	6229	MOFFAT POTATOES DISCHARGE
Jed			3841	6404	CHEMICAL SPRAYING COMPANY - COLDSTREAM
Whiteadder	NC001	UC004	3849	6563	DEXTER NONWOVENS - INFLUENT
Whiteadder	NC002	UC001	3851	6561	DEXTER NONWOVENS FINAL EFFLUENT
Whiteadder	NC102		3851	6563	DEXTERS NON-WOVEN EFFLUENT (CONSENT A)
Whiteadder	NC202		3851	6562	DEXTERS NON-WOVEN EFFLUENT (CONSENT B)
Whiteadder	NC302		3851	6562	DEXTERS NON-WOVEN EFFLUENT (CONSENT C)
Tweed	PC001	UC002	3896	6510	WINFIELD P.P.S
Tweed		UC005	3896	6254	PINNACLEHILL INDUSTRIAL ESTATE (40)

Fish farm sites

River Area	Codes		Grid ref		Site description
	Regular	NSAP	East	North	
Yarrow	DF002		3379	6285	TINNIS FISH FARM - OUTLET
Yarrow	DF001	FT001	3369	6277	TINNIS FISH FARM - INLET
Yarrow		FT002	3378	6284	YARROW D/S TINNIS E.F. (LIST II) 3780 2845
Ettrick	EF001	FP001	3457	6280	PHILIPHAUGH FISH FARM - INLET
Ettrick	EF002		3458	6286	PHILIPHAUGH FISH FARM - PONDS OUTLET
Ettrick	EF003	FP002	3461	6285	PHILIPHAUGH FISH FARM - LADE OUTLET
Gala	EF001	FL001	3439	6444	LUGATE FISH FARM - INLET
Gala	EF002		3442	6441	LUGATE FISH FARM - OUTLET
Gala	EF003		3477	6380	GALAHAUGH FISH FARM - BOTTOM INLET
Gala	EF004		3477	6380	GALAHAUGH FISH FARM - BOTTOM OUTLET
Gala	EF005	FG001	3477	6386	GALAHAUGH FISH FARM - TOP INLET
Gala	EF006		3476	6386	GALAHAUGH FISH FARM - TOP OUTLET
Gala		FG002	3478	6381	GALA D/S GALAHAUGH FF (LIST II) 47803818
Gala		FL002	3441	6441	LUGATE D/S LUGATE FF (LIST II) 4410 4419
Whiteadder	NF003	FA001	3759	6621	ABBEY ST. BATHANS FISH FARM - INLET
Whiteadder	NF004		3762	6620	ABBEY ST. BATHANS F.F. - OUTLET TO LADE
Whiteadder	NF005		3764	6620	ABBEY ST. BATHANS F.F. - OUTLET TO RIVER
Whiteadder		FA002	3762	6620	LADE FOOT A ST. B FF (LIST II) 7620 6205
Whiteadder		FA003	3762	6618	WHITEADDER D/S A ST. B FF (LIST II) 7627 6180
Tweed	PF001	FH001	3231	6362	HUNDLESHOPE FISH FARM - TOP INLET
Tweed	PF002		3231	6362	HUNDLESHOPE F.F. - DISCH. TOP 3 PONDS
Tweed	PF003		3230	6363	HUNDLESHOPE F.F. - DISCH. 4th POND
Tweed	PF004		3229	6364	HUNDLESHOPE F.F. - INLET BOTTOM PONDS
Tweed	PF005		3229	6365	HUNDLESHOPE F.F. - DISCH. FROM FRY TANKS
Tweed	PF006		3228	6366	HUNDLESHOPE F.F. - DISCH. BOTTOM PONDS
Tweed	PF008		3228	6366	DISCHARGE FROM HUNDLESHOPE FISH FARM
Tweed		FH002	3229	6364	HUNDLESHOPE BURN (LIST II) 2295 3645

Sites near sewage treatment works

River Area	Codes		Grid ref		Site description
	Regular	NSAP	East	North	
Lyne		WA001	3139	6460	BURN ABOVE I.A.P.G.R (LIST II) 1390 4696
Lyne		WA002	3137	6459	BURN D/S I.A.P.G.R. (LIST II) 1378 4596
Ettrick		WS001	3474	6301	ETTRICK U/S SELKIRK SDW (cd&LII) 47483015
Ettrick		WS002	3481	6313	ETTRICK U/S SELKIRK SDW (cd&LII) 47483135
Jed		WJ001	3658	6227	JED U/S JEDBURGH SDW (LIST II) 65842278
Jed		WJ002	3659	6231	JED U/S JEDBURGH SDW (LIST II) 65952318
Teviot		WH001	3516	6154	TEVIOT U/S HAWICK SDW (LISTII) 51621543
Teviot		WH002	3526	6163	TEVIOT D/S HAWICK SDW (LISTII) 52651635
Blackadder		WD001	3810	6526	LANGTON B. U/S DUNS SDW (LISTII) 81085266
Blackadder		WD002	3812	6527	LANGTON B. D/S DUNS DDW (LISTII) 81225273
Blackadder		WD003	3814	6527	BLACKADDER D/S DUNS SDW. O/F LIST II
Tweed		WG001	3514	6349	TWEED U/S GALA SDW (LISTII) 51403497
Tweed		WG002	3523	6353	TWEED D/S GALA SDW (LISTII) 52303531

Landfill sites

River Area	Codes		Grid ref		Site description
	Regular	NSAP	East	North	
Lyne	TB001	TB901	3034	6383	BURN UPSTREAM OF BIGGAR TIP
Lyne	TB002	TB902	3036	6382	BURN 50m DOWNSTREAM OF BIGGAR TIP
Eddleston	TN001	TN901	3242	6524	EDDLESTON ABOVE NEW PIPE NETHER FALLA
Eddleston	TN003		3243	6519	EDDLESTON AT BRIDGE TO NETHER FALLA TIP
Eddleston	TN007	TN902	3243	6513	EDDLESTON AT REES 150m BELOW WATERGATE
Teviot	TS001		3495	6172	MANHOLE IN VALLEY ABOVE STIRCHES TIP
Teviot	TS007		3498	6173	BURN AT END OF FIELD STIRCHES TIP
Teviot	TS009		3509	6176	BOONRAW BURN AT A7 - STIRCHES TIP
Teviot	TS010		3517	6174	BOONRAW BURN AT APPLETREEHALL - S.T.
Teviot	TS011		3503	6176	BOONRAW BURN FOOT - STIRCHES TIP
Teviot	TT001	TS901	3485	6167	BURN ABOVE STOUSLIE TIP
Teviot	TG001	TG901	3658	6438	EDEN UPSTREAM GORDON QUARRY
Teviot	TG005	TG902	3659	6433	EDEN 50m D/S DITCH - GORDON QUARRY
Teviot		TS902	3493	6162	BURN BELOW STIRCHES TIP (LIST II)
Teviot		UT001	3495	6172	MANHOLE BY LEACHATE LAGOON-STIRCHES TIP
Teviot		UT002	3502	6161	BURN BELOW DYKE - STIRCHES TIP
Eden	TW006	TW904	3660	6443	EDEN 50m BELOW DITCH FROM FAWSIDE TIP
Eden	TW001	TW901	3642	6455	EDEN ABOVE FAWSIDE TIP
Eden		TW902	3646	6457	EDEN D/S FAWSIDE TIP (LII) 6431 4553
Eden		TW903	3640	6454	EDEN U/S FAWSIDE TIP (LII) 6600 4455 (E)
Eden		UT005	3659	6434	GORDON QUARRY OUTLET
Tweed	TM001	TM901	3692	6450	BURN TO WEST OF CATMOSS TIP
Tweed	TM003	TM902	3731	6449	BURN TO EAST OF CATMOSS TIP
Tweed	TE001		3521	6363	ALLAN WATER ABOVE EASTER LANGLEE TIP
Tweed	TE007		3523	6361	ALLAN W. 300m D/S FOOT OF DITCH E.L. TIP
Tweed	TE008		3521	6362	ALLAN W. U/S OF PIPE IN ELLWYN GLEN
Tweed	TE010	TF902	3523	6355	ALLAN WATER FOOT - EASTER LANGLEE TIP
Tweed	TF001	TF901	3501	6424	ALLAN WATER ABOVE FARKNOWES TIP
Tweed	TF007		3497	6445	ALLAN W. AT U/S END MAIN LEACHATE LAGOON
Tweed	TF014		3505	6412	ALLAN WATER AT WATERGATE - FARKNOWES TIP
Tweed	TN002	UT003	3521	6379	DISCHARGE ABOVE LAGOON - E. LANGLEE TIP
Tweed	TN004	UT004	3616	6379	DISCH. FROM LEACHATE LAGOON - E.E. TIP
Eddleston	TN005		3242	6520	NEW PIPE FROM NETHER FALLA TIP
Eddleston	TN006		3244	6507	DISCH. TO EDDLESTON 10m BELOW WATERGATE
Eddleston	TD001		3243	6505	DISCH. FROM OLD TILE DRAIN 50m D/S W/G.
Eddleston	TD002		3243	6503	DISCH. FROM OLD GRAVEL SEAM 75m D/S
Jed	TG002	TD901	3633	6189	EAST DRAIN - DUNION HILL TIP
Jed	TG003	TD902	3612	6189	WEST DRAIN - DUNION HILL TIP
Teviot	TG004		3659	6432	OUTFALL END OF GORDON QUARRY
Teviot	TS002		3657	6435	PIPE TO HEAD OF DITCH - GORDON QUARRY
Teviot	TS003		3658	6435	FOOT OF DITCH - GORDON QUARRY
Teviot	TL001		3492	6163	INLET TO 1st PUMPWELL STIRCHES TIP
Teviot	TL002		3494	6162	CULVERTED BURN OUTLET STIRCHES TIP
Tweed	TL003	TL901	3788	6580	CLEUGH 1 (788 580)
Tweed	TL004	TL902	3793	6584	CLEUGH 2 (793 584)
Tweed	TL005	TL903	3797	6588	CLEUGH 3 (797 588)
Tweed	TL006	TL904	3799	6591	CLEUGH 4 (799 591)
Tweed	TE002	TL905	3793	6598	CLEUGH 5 (793 598)
Tweed	TE003	TL906	3790	6598	CLEUGH 6 (790 595)
Tweed	TE004		3513	6380	HEAD OF BURN TO NORTH OF E. LANGLEE TIP
Tweed	TE005		3519	6366	NEW PIPE - E. LANGLEE TIP
Tweed	TE009		3519	6367	OLD PITPE - E LANGLEE TIP
Tweed	TF003		3520	6378	FOOT OF BURN TO NORTH OF E. LANGLEE TIP
Tweed	TF004		3516	6372	PIPE IN ELLWYN GLEN - E. LANGLEE TIP
Tweed	TF005		3500	6420	Fe STAINED DISCH. AT FOOT OF BANK F/TIP
Tweed	TF006		3500	6420	Fe STAINED DISCH. BY FORMER INTAKE F/TIP
Tweed			3500	6420	DISCH. FROM MAIN UNDERBRAIN. SYS. F/TIP
Tweed			3500	6420	PIPE BELOW TRUCKCRETE OFFICE - F/TIP

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