Interim Report R&D Project 152

Torridge River Quality and Fishery Status

WRc plc

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Torridge River Quality and Fishery Status

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CONTENTS

CONTENTS - continued

CONTENTS - continued

LIST OF TABLES

LIST OF FIGURES

FIGURES Continued....

EXECUTIVE SUMMARY

This report describes the work undertaken during the first year (1 April 1990 to 1 March 1991) under NRA Project Reference Nº D2/152. The project aims are to determine what effects land use change and other environmental factors have on salmonid fisheries, to identify mechanisms and quantify effects. Recommendations will be produced for the future management of salmon and trout stocks in rivers where land use change occurs.

The work has concentrated on the basic characterisation of land use, water quality and the status of salmonid stocks, involving: the selection of five study sub-catchments; installation of continuous water quality monitoring equipment; automatic sampling of flow events; a juvenile salmonid survey; identification of land uses; and the development of *in situ* ecotoxicology experiments.

The salmonid survey has confirmed the generally poor status of the stock and there is evidence of declining density from headwaters downstream, the cause of which appears to be independent of habitat. Water quality has been found to decline during flow events with raised ammonia, suspended solids, BOD and nitrite levels. A gross pollution event was, however, encountered on only one occasion. Concentrations of sediment fines in spawning gravel and suspended solids appear high.

The experimental approach is examined and the proposed programme for 1991/92 is presented.

KEY WORDS

Fisheries, Salmonids, River Torridge, Land use, Agriculture, Water Quality

NRA Interim Report 152/2/SW

1. INTRODUCTION

The Project is jointly funded from the national R&D programmes of the National Rivers Authority (NRA) and the Ministry of Agriculture Fisheries and Food (MAFF) and will run from April 1990 to April 1993.

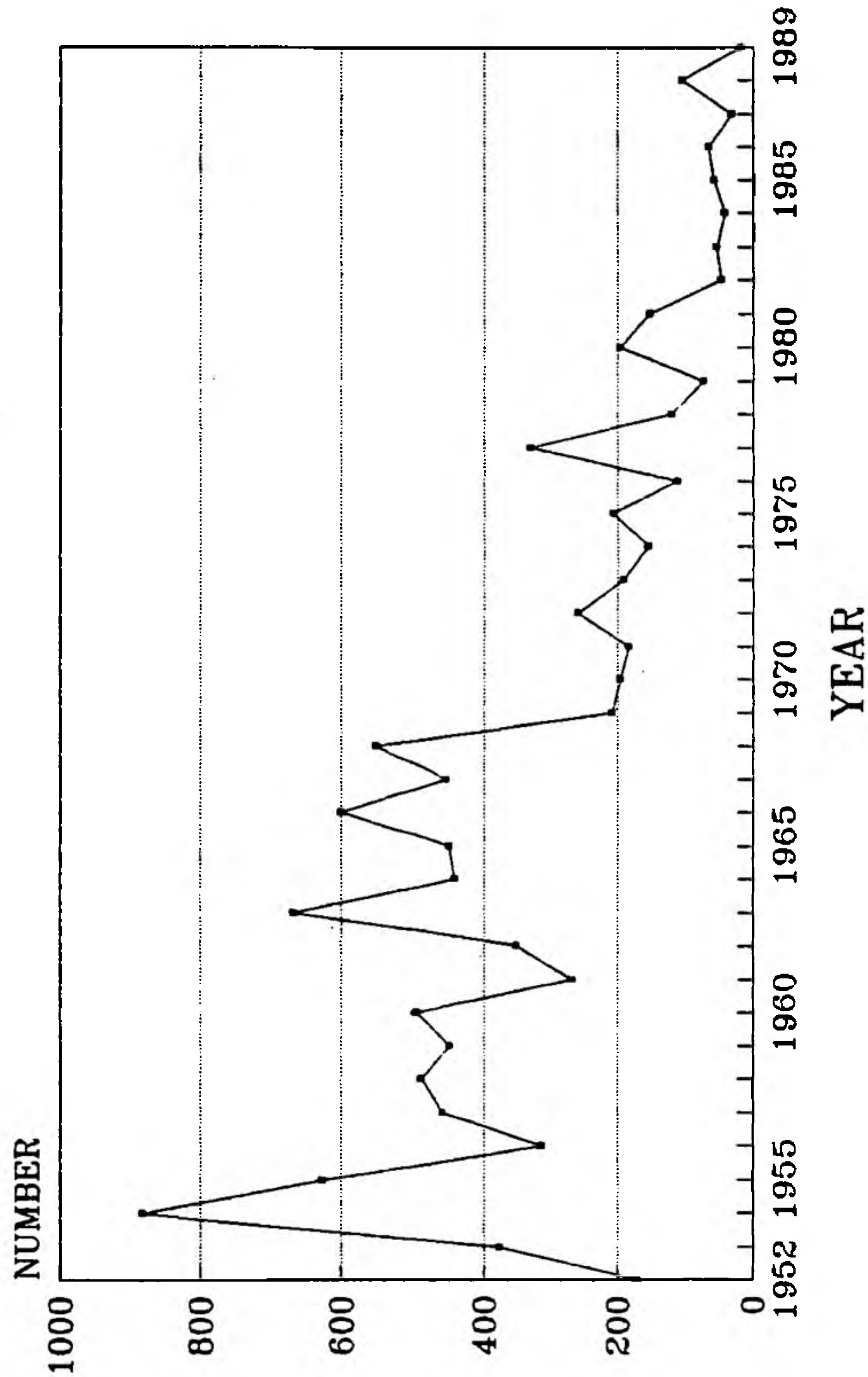
It has been initiated to investigate the circumstantial evidence linking changes in land use to deterioration in river water quality and salmonid populations in certain parts of the UK. Current understanding of the impacts of various land uses and other environmental factors, on water quality and, salmonid fisheries is generally poor, and scientific investigation of the relationship between these is therefore urgently required to provide the basis for effective management.

Though the Torridge catchment is situated in North Devon, the project's findings and recommendations will be applicable nationally. It was selected the basis of a significant decline in rod catch, recorded in recent years (Figure 1.1) along with a general deterioration of river quality and juvenile salmonid stocks. Salmon rod catch has fallen from an annual mean of 471 in the 1950's and 60's to 77 in the 1980's, with a low of 19 fish in 1989. A decline in juvenile salmonid densities has been recorded since the first electrofishing survey was conducted in 1964.

Considerable concern has been voiced over a possible causal link between recent changes in land use practices in the catchment and these observations. The primary land use in the area is grassland supporting dairy, beef and sheep livestock, and changing techniques have led to an intensification of agricultural practices over the last 40 years. The following significant changes were recorded over the 30 year period 1952 to 1982 (Harrod 1987):

a) A decrease in arable land.
b) A 56% decrease in rough grazing.
c) A 67% increase in grassland converted to permanent use.
d) A 155% increase in dairy cattle from 13,800 to 35,000.
e) A 54% increase in beef cattle from 31,600 to 48,900.
f) A 70% increase in sheep from 81,000 to 141,000.
g) The use of silage in place of traditional fodder crops.

Fig.1.1 The annual Torridge rod catch of salmon 1952-89.



The project aims to identify the factors responsible for the observed deterioration in both the salmonid populations and water quality and to quantify the effects. The benefit from this will be the production recommendations and guidelines, applicable nationally, for the future management of salmonid stocks in catchments where land use change occurs. The findings will also have a specific local application in the future management of Torridge Catchment where they form an integral part in the formation of the Torridge Management Plan (NRA 1990) currently under development by the NRA South West Region. This is the first catchment in the UK to be subject to an integrated multi-diciplinary Management Plan, a technique that is being developed for use nationally. The project forms an essential part of plans to meet a fisheries target of improving parr and fry production back to their 1964 levels.

2. OBJECTIVES

2.1 Overall project objectives

To identify the factors responsible for the observed deterioration in both salmonid populations and river quality.

2.2 Specific objectives

1. To determine what effects changing land use and other environmental factors have on salmonid fisheries and to identify mechanisms and quantify effects.

2. To produce recommendations and guidelines for future management of salmon and trout stocks in rivers where land use change occurs.

3. WORK PROGRAMME 1990/91

3.1 Introduction

The general approach adopted for the project is the comparison of contrasting intensively and extensively farmed areas, with respect to land use, water quality and salmonid population status. Work in the first year has concentrated on the selection of study catchments, the establishing of field surveys and a base line characterisation of these three factors.

3.2 Selection of study areas

Sub-catchments of the Torridge were selected that provide contrasting areas of extensive and intensive farming land-use.

3.3 Land use characterisation

A survey of land use within study catchments has been undertaken using field observations, data from the NRA Farm Campaign (4.2.2) and air photography. The co-operation of farmers has been sought to monitor seasonal practices.

3.4 Water quality monitoring

Continuous water quality monitors and automatic samplers have been installed on each study stream. Automatic sampling of flow events and spot sampling will be undertaken and submitted for laboratory analysis.

3.5 *In situ* bioassays

In situ bioassays have been initiated using buried salmon eggs and caged juvenile salmon on each study stream.

A WRc fish monitor is being installed on one study stream.

3.6 Juvenile salmonid survey and redd density survey

A quantitative electrofishing survey of juvenile salmonids was undertaken on each study stream in the summer (June-August) and repeated at selected sites in the autumn (October-November) 1990.

Redd density surveys of each study stream have been undertaken during the spawning season in conjunction with the NRA SW's routine survey of major tributaries.

3.7 Review of other environmental and management factors

Non-agricultural influences such as predation, angling, river management and flow regime have been reviewed. Specific attention is being paid to development of the Torridge Management Plan.

4. PROGRESS

4.1 Selection of study streams

4.1.1 Methods

The selection of sites was based on a survey of existing reports (e.g. salmonid population, water quality, pollution events and land use), consultation with the relevant NRA SW Officers, and field inspections with members of the NRA Warden Service. This was undertaken during a two month period of catchment familiarization by the project field staff in April/May 1990.

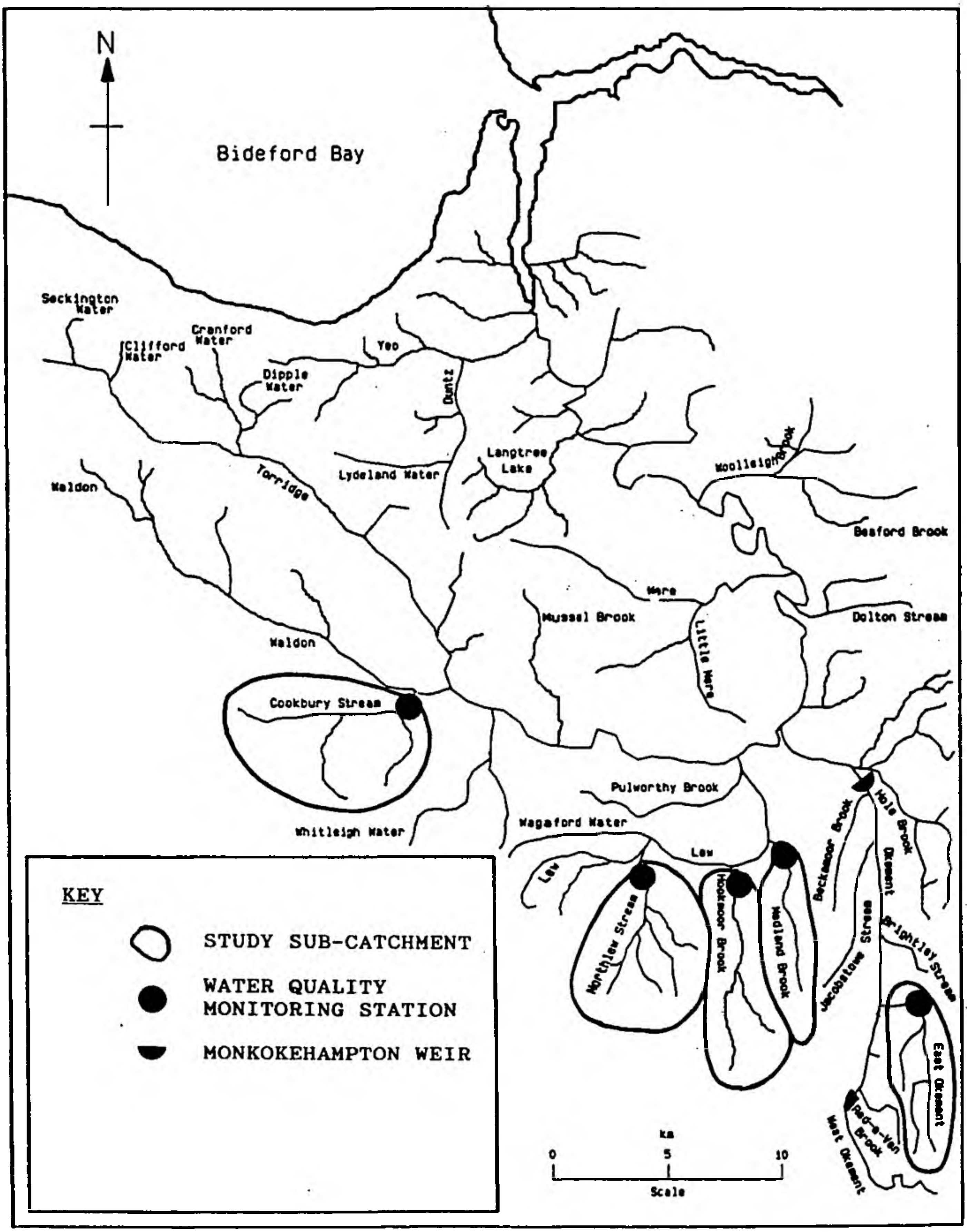
4.1.2 Results

Five sub-catchments, here-after referred to as 'study catchments', were approved by a meeting of the Project Steering Group in June 1990 (Table 4.1, Figure 4.1).

Table 4.1 - Choice of study catchments

Major sub-Catchment	Study catchment	Farming land use
R. Okement	R. East Okement	Extensive
R. Lew	Medland Brook	Intensive
	Hookmoor Brook	"
	Northlew Stream	"
R. Waldon	Cookbury Stream	"

Fig.4.1 Map of the Torridge Catchment showing the five Study Catchments.



4.1.3 Discussion

East Okement

The R. Okement has the largest catchment of any Torridge Tributary (141 km^2), is oligotrophic in character and is steeper and faster flowing than other tributaries.

The River East Okement (E. Okement) is one of two tributaries of the River Okement draining the Dartmoor National Park, the only substantial area of unimproved land in the Torridge Catchment.

The predominant land use on the E. Okement, which has a catchment of 20.1 km^2, is combined military training and extensive sheep and cattle grazing. Salmon and sea trout are confined to its lower 4 km by an impassable waterfall. The moorland above contains a trout population which is believed to be genetically distinct from the Torridge stock.

The spawning potential of the R. Okement for migratory salmonids has only been realised since 1978 with the provision of a fish pass at the formerly impassable Monkokehampton Weir (Figure 4.1).

Lew Catchment

The Lew catchment is the second largest catchment on the Torridge (117 kg^2) and has been identified as the second most important spawning tributary on the Torridge on the basis of redd surveys. It has suffered a decline in water quality and salmonid population, in common with much of the Torridge catchment. In recent years there have been some signs of improvement in water quality, but the status of juvenile salmon is still believed to be poor. The land use is predominately dairy farming and beef and sheep production. Three subcatchments of the River Lew have been selected as study catchments.

Cookbury Stream

The Cookbury Stream is a tributary of the River Waldon, the third largest tributary of the Torridge (76 km^2), and has suffered a severe decline in salmonid population. A qualitative electrofishing survey of the stream in 1989 found no salmon and very few trout. The land use is predominately beef and sheep production and dairy farming.

4.2 Catchment characterisation

4.2.1 Introduction

An inventory has been made of each of the study catchments comprising:

- Catchment size;
- Land-use;
- Stock density;
- Farm density and type;
- Incidence of polluting farms;
- Incidence of reported pollutions;
- Riparian management.

The principal sources of information used were:

- Aerial photography surveys of each catchment commissioned for the Project.
- The Torridge Farm Campaign and the Torridge Management Plan (NRA 1990).
- A field survey of riparian management conducted by the project staff.
- Existing reports on soil and land use.

4.2.2 Results

Size of Study Catchments

Table 4.2 - Area (km^2) of study sub-catchments

Torridge catchment (km^2)	Main sub-catchments (km^2) (%total)			Study catchments (km^2)	
875	Okement	141	(16%)	E. Okement	20.1
	Lew	117	(14%)	Medland	13.6
				Hookmoor	16.4
				Northlew	18.0
	Waldon	76	(9%)	Cookbury	21.5

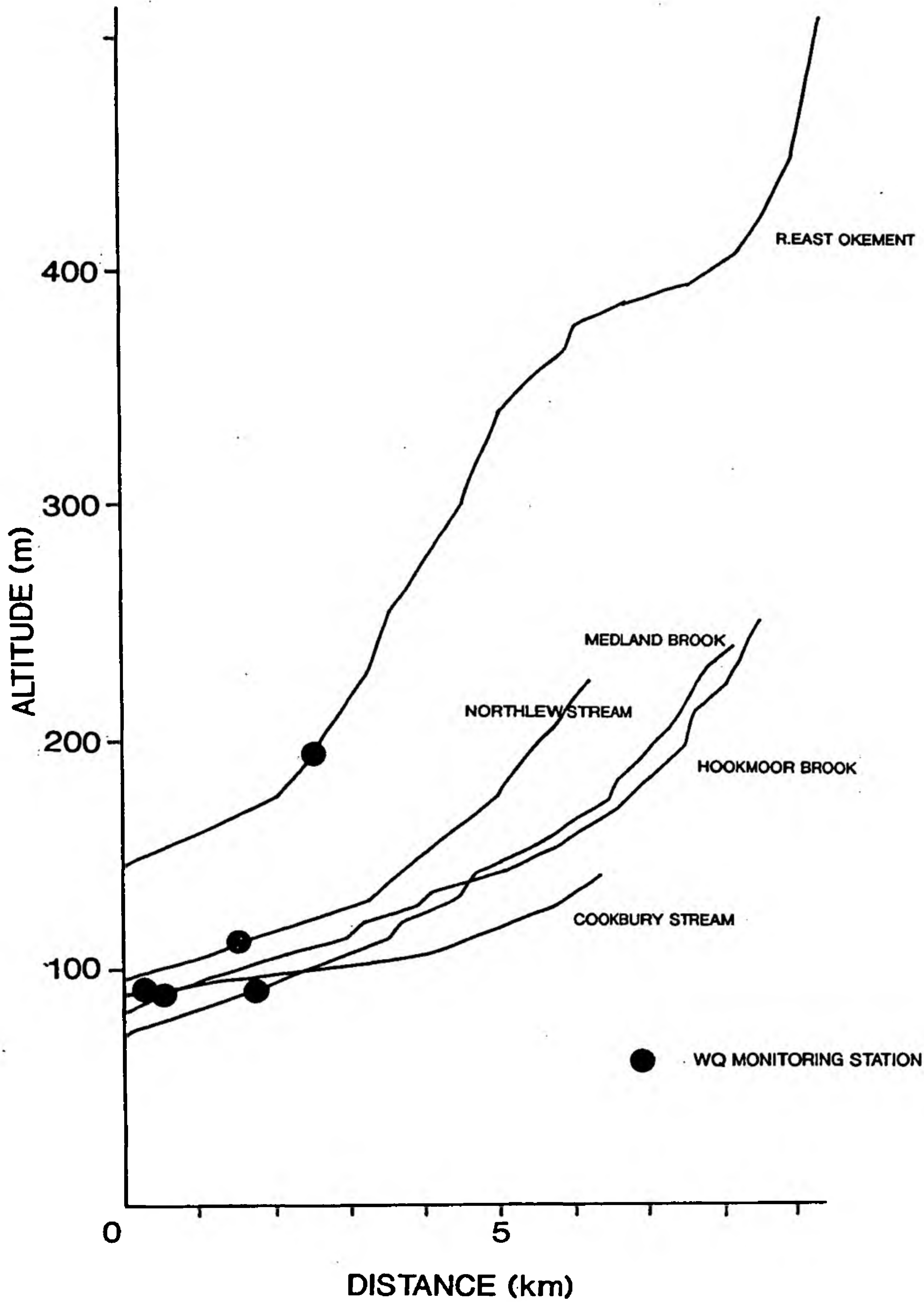
Gradient

Figure 4.2 shows the gradient profile of each of the study catchments. This clearly identifies differences in the character of the study streams; the E. Okement being the steepest and the Cookbury Stream exhibiting the lowest gradient. The flow in each study catchment is being gauged by NRA SW Hydrometric Services and the implications of flow and gradient will be assessed once this work is complete.

Pedology

The pedology of the study catchments has been assessed as this may have a bearing on the loadings of fines within river bed gravels and suspended solid loadings. The major soil types found in each catchment are described in Table 4.3.

Fig.4.2 Study Catchment river profiles showing altitude (m) against distance from confluence with major Torridge Tributary (km).



The E. Okement is characterised by acidic peat in the upper reaches, thin gritty loams on the slopes of Dartmoor and loams at the foot of the catchment. The soils of the Lew catchments and the Cookbury Stream are similar with loams dominating the former and clayey loams the latter.

Table 4.3 - Major soil types found in each study catchment

Location	Soil	Soil and site characteristics association
E. OKEMENT MOORLAND	CROWDY	Thick very acid amorphous raw peat soils. Perennially wet. Hagged and eroded in places
SLOPES OF DARTMOOR	MOOR GATE	Well drained humose gritty loamy soils. Occasionally thin iron pan. Many steepslopes often bouldery and rocky
FOOT OF CATCHMENT	DENBIGH 1	Well drained medium loamy and medium silty soils over rock
LEW TRIBUTARIES		
DOMINANT	NEATH	Well drained medium loamy soils over rock intermixed with medium loamy and clayey slowly permeable sub-soils and slight seasonal waterlogging
SUB-DOMINANT	HALLSWORTHY 2	Slowly permeable seasonally water-logged clayey loamy silty soils
COOKBURY		
DOMINANT	HALLSWORTHY 2	
SUB-DOMINANT	NEATH	

Land Use

The principal land-uses in the study catchment (Table 4.4) were assessed by mapping details from air photographs onto enlarged copies of the OS 1:25000 series maps. The detail on the photographs afforded the identification of:

- Unimproved pasture
- Improved pasture
- Arable land
- Deciduous woodland
- Coniferous woodland
- Field drain systems
- Agricultural buildings

Table 4.4 - Principal land uses identified by area (% of sub-catchment)

	Unimproved pasture	Deciduous woodland	Conifer plantation	Improved * pasture
Cookbury	5.7	4.5	4.5	85.3
Northlew	2.6	2.9	6.7	87.7
Hookmoor	2.9	7.3	3.2	86.6
Medland	5.3	10.0	0.2	84.5
E. Okement	73.9	2.9	0.2	23.0

* Total covers all land not falling into the other three classifications and therefore includes buildings, roads etc.

Unimproved pasture accounts for only some 5% of the intensively farmed catchments but 74% of the E. Okement catchment. With the exception of a few fields around E. Okement Farm, the only farm on the moor, improved pasture on the East Okement is confined to the slopes and foot of Dartmoor. Most of this is drained by a single tributary joining the E. Okement above the continuous monitoring station.

Woodland accounts for some 10% of the Cookbury and Lew catchments and there are some substantial conifer plantations on the Northlew and Cookbury streams. The lower slopes and floors of the valleys of all the catchments tend to be wooded (Figure 4.3).

Arable farming appears to be limited to a few fields in the Cookbury catchment.

Farm density

From air photographs 118 groups of farm buildings were identified within the study catchments (Table 4.5). In some cases these represent satellite over-wintering facilities within the same agricultural undertaking. The highest density (2.12/km^2) was found on the Medland Brook and the lowest (0.35/km^2) on the E. Okement. The density of buildings on the Cookbury Stream was lower than on the Lew tributaries.

Table 4.5 - Density of agricultural buildings

	Farms (Air photos)	N/km^2	Farms (Farm campaign)
COOKBURY	27	1.25	21
NORTHLEW	31	1.71	19
HOOKMOOR	24	1.46	20
MEDLAND	29	2.12	22
E. OKEMENT	7	0.35	7
TOTAL	118		89

Table 4.6 shows the types of farm determined from the NRA SW Farm Campaign data (Section 4.4.2(g)), collected between 1984 and 1987.

Fig. [illegible] The Hookmoor (top) and East Okement (bottom) Catchments.

[illegible]

Farms that support only sheep or only beef cattle are uncommon and tend to be the smaller undertakings. Dairy farms dominate on the Lew sub-catchments (>50%) but were not so common on the Cookbury Stream (38%). Most dairy farms also support sheep and beef cattle. There are no arable farms.

Table 4.6 - Types of farm recorded in the Farm Campaign in each study catchment

	Dairy*	Sheep/Cattle	Sheep	Cattle
COOKBURY	8 (38%)	9 (43%)	3 (14%)	1 (5%)
NORTHLEW	14 (74%)	5 (26%)		
HOOKMOOR	10 (50%)	7 (35%)	1 (5%)	2 (10%)
MEDLAND	11 (50%)	7 (32%)	1 (5%)	3 (13%)
E. OKEMENT	1 (20%)	3 (60%)	1 (20%)	

* Most dairy farms also run sheep/cattle

Stock density

Relative stock density was assessed using the records of the Farm Campaign. Table 4.7 shows the number and density of animals in each sub-catchment. Sheep are the most common in all catchments followed by cattle. The density of dairy cows in the Cookbury catchment (14.7/km^{-2}) is much lower than that of the Lew catchments (>33/km-2), and they are almost absent on the E. Okement.

The highest stock density is found on the Medland Brook, the smallest of all the catchments, which also has the highest density of farms.

Table 4.7 - Numbers of stock animals on each study catchment expressed as total number of animals and density (number/km^2)

	Dairy N (N/km^2)		Sheep		Cattle		Followers		Pigs	
COOKBURY	316	(14.7)	2265	(105.1)	1153	(53.5)	180	(8.4)	270	(12.5)
NORTHLEW	776	(42.9)	1878	(104.1)	1013	(56.1)	415	(22.9)	120	(6.6)
HOOKMOOR	540	(32.9)	2434	(148.4)	1302	(79.4)	255	(15.5)	8	(0.5)
MEDLAND	565	(41.4)	2814	(206.1)	1170	(85.7)	235	(17.2)		
E. OKEMENT	7	(0.4)	2054	(102.2)	223	(11.1)	3	(0.1)		
TOTAL	2204		11445		4861		1088		398	

Farm campaign

Between 1984 and 1987 each farm in the Torridge catchment was inspected by staff from South West Water Authority to identify sources of agricultural pollution (NRA 1990). A total of 989 farms were visited and classified as:

RED : polluting at time of visit
GREEN : at risk of polluting
BLUE : no risk of polluting

All red and green farms where advised on remedial action and visited by ADAS where necessary. Follow-up inspections were undertaken (Table 4.8).

Table 4.8 - Incidence of 'Red' farms in the Torridge Catchment

	Total	
1st Visit	232	23%
2nd Visit	113	11%
3rd Visit	21	2%

The results of the 1st visit to farms in the study catchments are shown in Table 4.9.

Table 4.9 - Results of 1st visit to farms in the study catchments during the Farm Campaign

	Total visited	Red	Green	Blue
COOKBURY	21	0	5 (24%)	16 (76%)
NORTHLEW	19	8 (42%)	4 (21%)	7 (37%)
HOOKMOOR	20	6 (30%)	4 (20%)	10 (50%)
MEDLAND	22	5 (23%)	4 (18%)	13 (59%)
E. OKEMENT	7	0	1 (14%)	6 (76%)

These show a highly variable incidence of polluting farms, of particular note being the absence of red farms and the low numbers of green farms on the Cookbury Stream. Red and Green farms accounted for 40-60% of farms in the Lew catchments, the majority being red.

Reported pollution incidents 1987-90

Following the Farm Campaign there has been a significant reduction in the number of serious farm pollution incidents reported on the Torridge but little change in total number (Table 4.10; after NRA 1990).

Table 4.10 - Incidence of reported farm pollution events in the Torridge Catchment 1987-89 (after NRA 1990)

	Total	Serious
1987	70	49
1988	85	31
1989	77	15

Table 4.11 shows the pollution events reported on the study catchments over this period.

The NRA is generally dependent on the public for the reporting of pollution events. Very few people, even farmers, live in houses overlooking or bordering the study streams and it is likely that the bulk of events do not get reported. Three of the five reports on Northlew 87/88 are attributable to SWW staff visiting a temporary monitoring station just downstream from a farm, whilst three of the five Medland events were reported by a householder living by the brook.

In many cases the source has not been identified and the effects on the aquatic environment have not been quantified.

Table 4.11 - Incidence of reported pollution events on the study catchments 1987-91

	Catchment	Suspected cause	Effect on fish population (number of dead salmonids)
1987	NORTHLEW	SILAGE	(8 salmonids)
	NORTHLEW	SLURRY	Not Known
	NORTHLEW	YARD WASHINGS	Not Known
1988	NORTHLEW	SLURRY	Not Known
	NORTHLEW	SLURRY	Not Known
	HOOKMOOR	SILAGE	Not Known
	HOOKMOOR	SLURRY	Not Known
	MEDLAND	SLURRY	Not Known
	MEDLAND	SILAGE	Not Known
	MEDLAND	SILAGE	(11 salmonids)
1989	COOKBURY	FISH FARM CLEANING PONDS	Not Known
	NORTHLEW	SLURRY	Not Known
	HOOKMOOR	SLURRY	Not Known
	HOOKMOOR	SLURRY	Not Known
	MEDLAND	SLURRY	Not Known
1990	HOOKMOOR	SUSPENDED SOLIDS	Not Known
1991	MEDLAND	SLURRY	Not Known

Riparian management

A survey of riparian management was undertaken in the Lew and Cookbury catchments to identify land drainage methods, sources of sediment, levels of bank protection and incidence of gross polluting discharges.

Gross polluting discharges

No gross discharges were found on any study catchment. Sewage fungus has been encountered on two occasions; in a stream from the Northlew Sewage Treatment Works, emptying downstream from the monitoring station, and in a minor farm ditch.

Land-drainage

There is an almost universal presence of field drains in the improved pastures of the catchments (Figure 4.3). These drain to the watercourses through ditches along field boundaries. Table 12 shows the incidence of drains and ditches on the banks of each study stream. The figure for drains is a minimum estimate as some are very difficult to identify.

Table 4.12 - Incidence of field drains and ditches emptying directly into watercourses

	Drains N/km	Ditches N/km
COOKBURY	3.7	9.4
NORTHLEW	3.3	10.6
HOOKMOOR	3.6	13.1
MEDLAND	1.5	4.5

Animal Access

The height of river banks vary from 0.5-2 m and therefore stock does not have complete access to the river beds. As a consequence most fields have a number of specific access points cut through the bank by the animals. There is little attempt to manage these and during the summer low flows many comprised of a ramp of trampled soil extending almost half way across the river bed, especially on the Cookbury Stream. As a consequence they may be a major source of suspended solid in the water and fines within the bed substrates.

Table 4.13 - Incidence of animal access points

	N/km
COOKBURY	7.1
NORTHLEW	10.1
HOOKMOOR	11.1
MEDLAND	5.2
E. OKEMENT	Unlimited

The fencing of banks is not a common practice, but ranges from single strands of barbed wire tacked to trees to comprehensive triple strand barbed wire or electric fences. It is most commonly employed to keep stock away from particularly dangerous banks and pools and there is little evidence of it being used specifically to protect banksides.

Vegetation cover

Trees line the banks of all the study streams with the exception of the moorland on the E. Okement and a few fields on the other catchments (Figure 4.3). The width of tree cover varies from single trees growing from the bank to mature deciduous woodland, the former being the most common. In most pastures bordering streams trees have been cut back leaving only those with root systems growing on the banks. There is little attempt to manage the trees or remove fallen trees straddling the watercourse, consequently trash dams are common.

The tree canopy provides shade across much of the bed and is a contributory factor to the relatively low summer water temperatures experienced (4.3.3).

Ground vegetation, like tree cover, is generally restricted to the immediate bankside, mainly by grazing pressure. In places, especially on the Cookbury Stream, vegetation is absent and only tree roots provide protection from erosion. Vegetation can be significant in the interception of surface runoff.

4.2.3 Discussion

A number of differences between the study catchments have been highlighted, particularly with regard to land use.

Among the intensively farmed study catchments the Cookbury catchment contains both fewer farms and supports lower stock densities than the Lew catchments. The Farm Campaign also highlights a lower incidence of dairy farms and farms which were polluting at the time of visits in this catchment. The area of unimproved farmland outside the moorland area of the E. Okement is low (<5.7%) and there is extensive use of field drainage in the improved pastures. Relatively few field drains empty directly into the watercourses and much of the runoff is carried by ditches from fields on the higher ground. These ditches tend to empty directly into the watercourses in the Cookbury and Lew study catchments and 'natural' riparian wetland are rare.

The number of reported pollution incidents in the study catchments is relatively low (1987-1991; 17), probably due to their sparse population and events are often difficult to follow up. The full frequency and impact of historical major pollution events is therefore unclear.

Gross impacts from continuous farm discharges were not encountered during field work and river walking and it appears that the Farm Campaign of 1984-87 has been effective in controlling these.

Differences in gradient, flow and soil type have been identified between catchments and the influence of these on suspended solid and gravel sediment loadings requires further investigation. Erosion of banks by stock is common, especially on the Cookbury Stream.

The protection of banksides with fencing and the control of animal access points is not a common management practice and there is little attempt to remove trash dams from watercourses.

4.3 Water quality monitoring

4.3.1 Introduction

Monitoring stations have been established towards the bottom of each study catchment (Figure 4.1). Water quality sampling has been undertaken using three methods; continuous monitoring, auto sampling of flow events and spot sampling.

NRA SW Hydrometric Services are gauging flow in each of the study catchments, on behalf of the project, and ratings will be prepared in due course. A disused gauging station on the Hookmoor Brook has been renovated specifically for this purpose.

All five study catchments are also currently sampled monthly within the NRA SW routine water quality sampling programme.

4.3.2 Methods

Continuous monitoring

The equipment at each site comprises of a pHOX 100 DPM multiparameter monitor measuring:

Dissolved Oxygen (DO)	% saturation and mg/l
Temperature	°C
pH	
Turbidity	FTU
Ammonium	N mg/l

These are connected to loggers (Technolog Tinylogs) which also record water depth from pressure transducers. One complete set of spare equipment has been maintained.

The 100 DPMs, loggers and automatic water samplers (4.3.2) are housed in steel security bins. The probe heads are fixed to steel stakes on the river bed, located in areas of continuous unbroken flow (glides). The loggers record at hourly intervals and the data is downloaded to a PC via a Technolog Megalogger.

Maintenance of the equipment is carried out on a weekly basis with recalibration fortnightly. These have been found to be the optimum working conditions for both machines and operator.

The continuity of sampling has proved difficult to maintain for a number of reasons. Considerable problems have been experienced with technical failures of the equipment, which have now been largely resolved with the manufacturers. The summer drought in 1990 caused some spurious readings, especially with ammonia and DO probes, as it proved difficult to maintain sufficient flow over the heads at times. The lenses on turbidity heads were badly affected by rapid build-ups of biological material and colonisation by water snails. The servicing of equipment by manufacturers has been found to take 3-6 weeks, and simultaneous failures of three of the six sets have occurred.

Autosampling

A Rock and Taylor 48-interval automatic water sampler has been installed at each monitoring station. These are triggered by float switches and are used specifically to sample flow events. Set to take hourly samples, they provide 48 hours cover; a convenient timespan covering the average duration of events and operation over the weekends. When emptying the samplers the conductivity of each sample is recorded and the turbidity assessed by eye to identify times of the peak flow (lowest conductivity, highest turbidity). Eight to ten samples are selected for laboratory analysis covering the peak and span of each event. The samplers contain 500 ml bottles and two are combined to produce a composite one litre sample, the minimum volume required by the laboratory.

Laboratory analysis has been sub-contracted by NRA SW to South West Water plc, pending the opening of a new laboratory for NRA SW and Wessex Region at Exeter in June 1991. To comply with the SWW laboratory systems and provide compatible data with the NRA SW's routine sampling throughout the Torridge the standard sanitary river quality parameter suite used by the NRA SW has been adopted (Appendix B).

Spot sampling

A spot sampling programme has been devised covering 30 confluence points across the five study catchments. These are all located at vehicle access points and the survey utilises one man-day, including delivery to the laboratory. A base line survey was undertaken during low flows in December 1990 and one survey per month, during flow events is planned for Jan-April 1991.

4.3.3 Results

The streams respond quickly to rainfall events with rapid increases in water level and flow. Turbidity (suspended solids) also increases and normally obscures the river beds. Flow tends to peak sharply and then fall quickly, previous levels being reached between 24 and 48 hours later. The rise in water level is particularly marked in the Cookbury Stream due to it's shallow gradient (4.4.2).

Rainfall over the period of study has been sporadic, with near drought conditions over the summer. None of the study streams ceased flowing though levels were very low, especially on the Medland Brook (Figure 4.4). The first significant flow events occurred in early October and others followed in late October and mid to late November. All five streams overtopped their banks in late December and early January following a dry start to December.

The relatively dry January was followed by the major freeze-up in early February.

The results are presented and interpreted with reference to the EEC Council Directive of 1978 (on the quality of freshwaters needing protection or improvement to support fish life; CEC 1978) and its subsequent amendments and the River Quality Objectives (RQO's) system developed by the National Water Council (NWC). The latter is included since it is a measure of water quality commonly used and understood in the water industry, using a small number of parameters (principally ammonia, B.O.D. and D.O). This sets out maximum values for these parameters (Table 4.14) according to a river's use (Appendix B).

Under this classification the River Okement has been assigned the highest RQO class 1a whilst the majority of the Torridge Catchment, including the Cookbury and Northlew Streams and Medland and Hookmoon Brooks are Class 1b. Both these classification indicate water of high quality suitable for potable supplies, game or other high class fisheries and high amenity value.

Fig.4.4 SUMMER LOW FLOW ON THE MEDLAND BROOK.

MEDLAND BROOK U/S MONITORING POINT AUGUST 1990

MEDLAND BROOK D/S MONITORING POINT NOVEMBER 1990

Table 4.14 - NWC river quality classification (after NRA 1990)

Class	1a	1b	2
DO % saturation	>80	>60	>40
BOD mg/l	<3	<5	<9
	(ave <1.5)	(ave <2.0)	(ave <5)
Ammonia mg/l NH_4^+	<0.4	<0.9	-

Values expressed as 95 percentiles

Continuously monitored data

1. Dissolved Oxygen

Table 4.15 shows the range of DO values recorded for each station.

Table 4.15 - Range of continuously monitored DO data

	Summer Aug/Sept	Autumn Oct/Nov	Winter Dec/Jan
DO % saturation			
COOKBURY	55-83	66-79	86-94
NORTHLEW	66-80	58-95	84-95
HOOKMOOR	57-87	55-95	*
MEDLAND	25-82	55-95	84-95
E. OKEMENT	90-100	91-97	90-105

* Equipment failure

The % saturation of DO in the Lew and Cookbury catchments fell as low as 55% at times during the summer and autumn and did not exceed 87% in summer, DO levels rose following flow events. Problems were encountered in maintaining sufficient flow over the DO probes and local de-oxygenation around the probe is believed to account for the extremely low value of 25% recorded on the Medland Brook in August/September (Figure 4.5).

DO remained above 90% on the E. Okement throughout the monitored period.

The % saturation of DO increased from summer to winter in the Lew and Cookbury catchments with minimum levels rising from 55% to 84%. Summer low flows have therefore resulted in short periods when the study streams bordered on a Class 2 DO classification. The E. Okement remained within Class 1a throughout.

2. pH

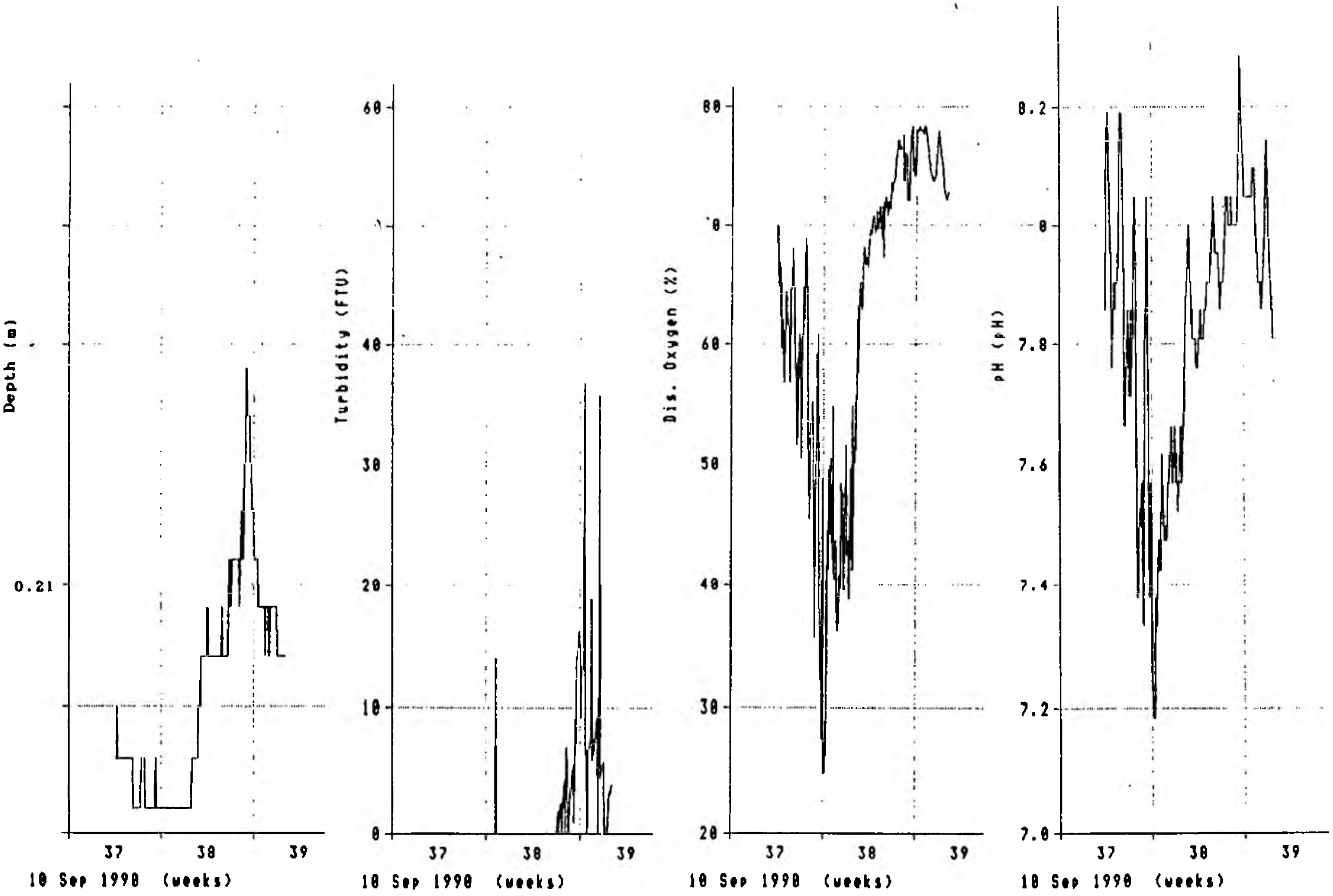
Table 4.16 shows the range of pH recorded at the monitoring stations.

Table 4.16 - Range of continuously monitored pH data

	Summer Aug/Sept	Autumn Oct/Nov	Winter Dec/Jan
COOKBURY	7.5-8.2	7.0-8.2	7.7-8.5
NORTHLEW	8.0-8.4	7.5-8.5	7.0-7.3
HOOKMOOR	7.9-8.1	7.2-8.0	*
MEDLAND	7.2-8.2	7.1-7.9	7.0-8.1
E. OKEMENT	6.9-7.7	6.2-7.8	5.8-7.7

Continuously monitored depth (m), turbidity (FTU), dissolved oxygen (%) and pH levels for the Medland Brook during Summer low flow.

Fig.4.5



The E. Okement exhibits the lowest pH recorded for any site at 5.8. The other study catchments have average pHs above 7.0 and maximums >8. Average pH fell with increased winter flow. Freshwater fish in general can be expected to live successfully in a pH range of 6.5-9.0 (Solbé 1988), though salmonids are able to survive a lower pH.

Some public concern has been expressed concerning the toxicity of aluminium at low pH and its effects on the Torridge spawning grounds. In acid waters aluminium is generally most toxic over a range of pH from 4.4 to 5.4 with a peak around 5.0-5.2 (O'Donnell *et al* 1984). No substantial sub-lethal effects have been demonstrated over the pH range 5.5-6.9 however.

3. Temperature

Table 4.17 shows the temperature ranges recorded at the monitoring stations.

Table 4.17 - Range of continuously monitored temperature (°C)

	Summer Aug/Sept	Autumn Oct/Nov	Winter Dec/Jan
COOKBURY	8.2-12.7	7.1-11.7	3.0-9.5
NORTHLEW	**	8.0-13.5	1.2-8.0
HOOKMOOR	7.0-11.5	9.5-13.4	**
MEDLAND	8.0-13.9	6.0-13.7	2.5-11.9
E. OKEMENT	8.0-14.2	5.5-12.5	0.6-2.5

** Equipment failure

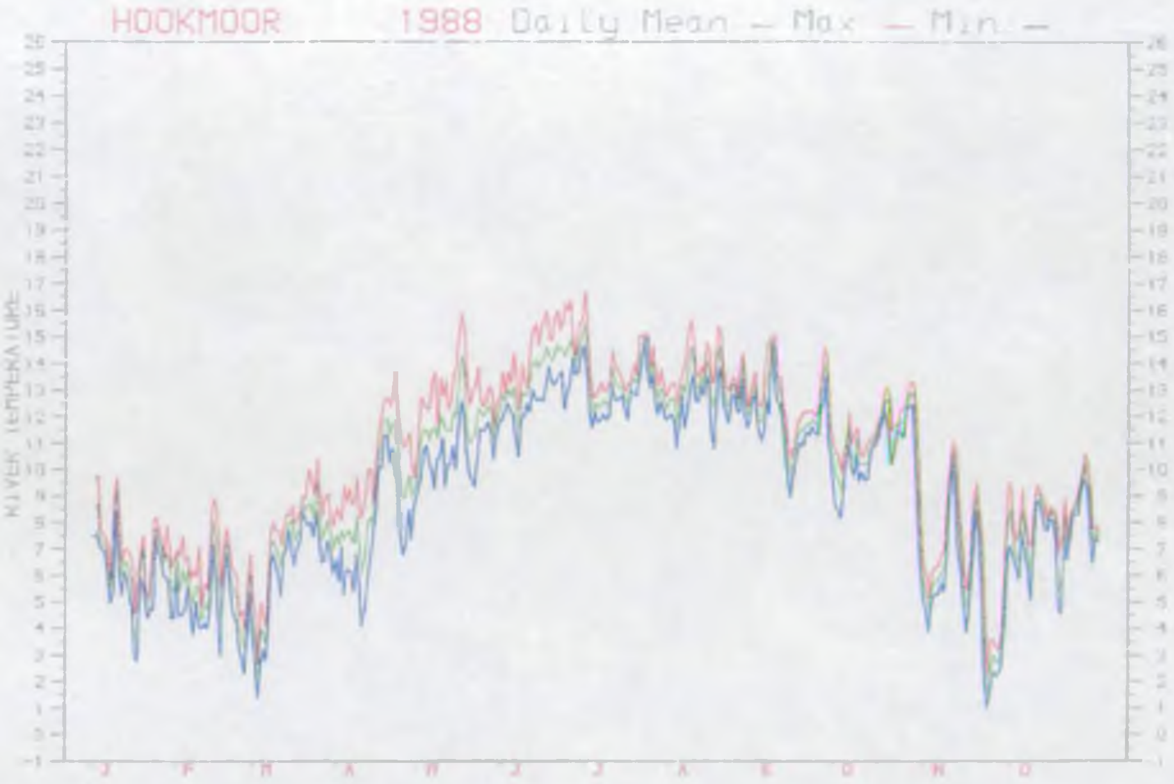
Charts from a thermograph operated on the Hookmoor Brook since mid-1987 by SWW/SW NRA were made available to the project. These were submitted for analysis to the Exeter University Geography Department, which is conducting long-term water temperature monitoring on the River Exe. Hourly temperature readings were transferred to a computer database and daily max, mean and min values calculated. The results for the two complete years available, 1988 and 1989 are shown in Figure 4.6.

In both years temperature did not exceed the limits acceptable for salmonid fish, average summer temperatures falling around 13-14 °C in 1988 and 15-16 °C in 1989. A maximum of 19 °C was recorded on one day during the drought of 1989. Summer temperatures were found to be lower and winter higher than might be expected from similar improved farmland catchments (personal communication, Dr B. Webb). Diurnal variation was also smaller. This behaviour is similar to that of afforested catchments and may be attributable to the tree cover bordering the Hookmoor Brook (Figure 4.3). Tree cover is abundant on all the study streams, with the exception of the Dartmoor area, and may therefore have a significant impact during drought years, in maintaining relatively low water temperatures.

4. Turbidity

Peaks in turbidity were associated with increases in flow and fell with falling river level. Table 4.18 shows the turbidity ranges recorded at the monitoring stations.

Fig.4.6 DAILY MEAN, MAXIMUM AND MINIMUM WATER TEMPERATURE (°C) RECORDED IN THE HOOKMOOR BROOK IN 1988 AND 1989.



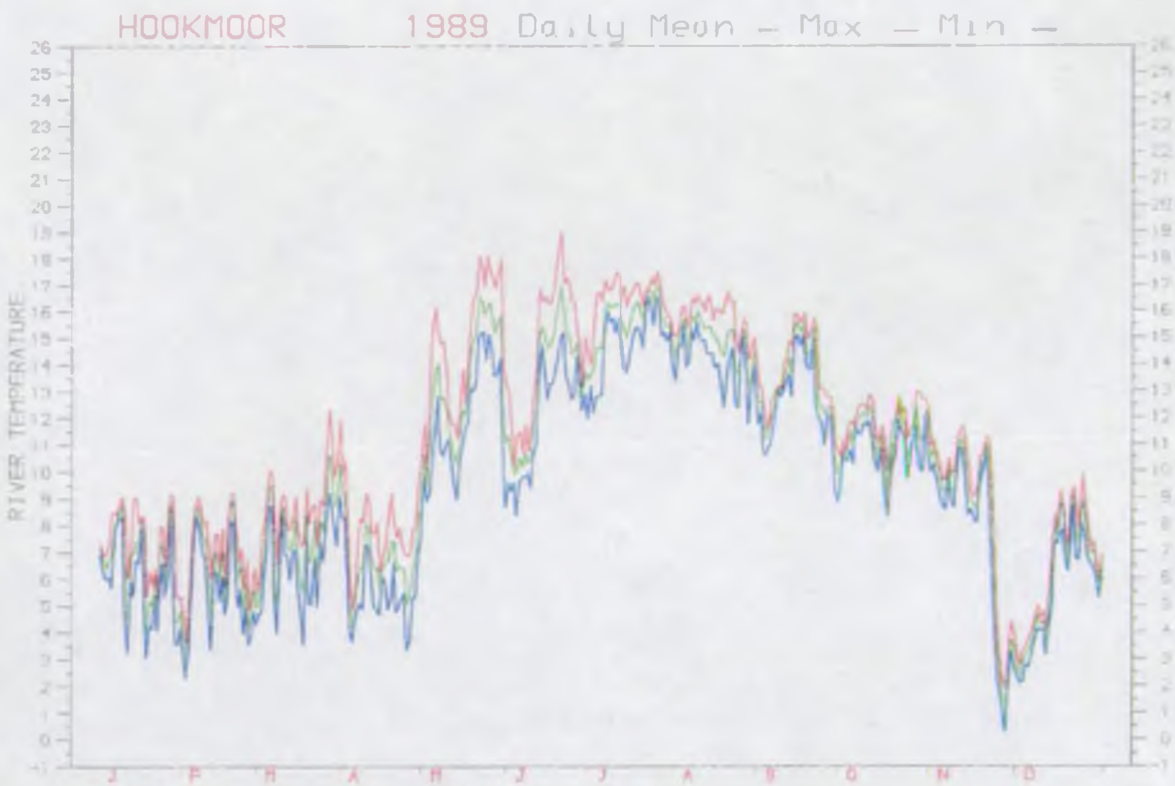


Table 4.18 - Range of continuously monitored turbidity (FTU) data

	Summer Aug/Sept	Autumn Oct/Nov	Winter Dec/Jan
COOKBURY	0-350	0-400	0-450
NORTHLEW	0-125	0-320	0-175
HOOKMOOR	0-20	0-320	*
MEDLAND	0-40	0-275	0-450
E. OKEMENT	0-6	0-6	

The Cookbury Stream exhibited a persistent coloration throughout the summer low flows (Figure 4.7).

An examination for the presence of algae proved negative and the cause appears to be fine in-organic suspended solids caused by stock trampling the river bed (4.4.2). The Cookbury Stream also exhibited the highest turbidity readings during flow events and silting of the bed is highly visible throughout its length. The concentration of suspended solids in dry flow events is given in (b.v.).

5. Ammonia

In water an acid-base equilibrium exists between unionised ammonia (NH_3) and the ammonium (NH_4+) ion:

$$NH^{4+} \rightleftharpoons NH_3 + H^+$$

Unionised ammonia has been identified as the main toxic species to fish (Seager *et al* 1988). The unionised component is low below pH 7 but increases with pH >7. Its concentration is also influenced by temperature and total dissolved solids (TDS).

Fig. 4.7 TURBIDITY IN THE COOKBURY STREAM DURING SUMMER LOW FLOWS.

COOKBURY STREAM MONITORING POINT AUGUST 1990

MEDLAND BROOK MONITORING POINT AUGUST 1990

The EC Directive (CEC 1978) specifies a mandatory maximum value for unionised ammonia of 0.025 mg/l, expressed as NH_3 (0.0206 mg/l expressed as N).

The pHOX ammonia probes employed at the monitoring stations record the concentration of the ammonium ion (NH_4) expressed as mg/l N. Table 4.19 shows the ammonium ranges recorded at the monitoring stations.

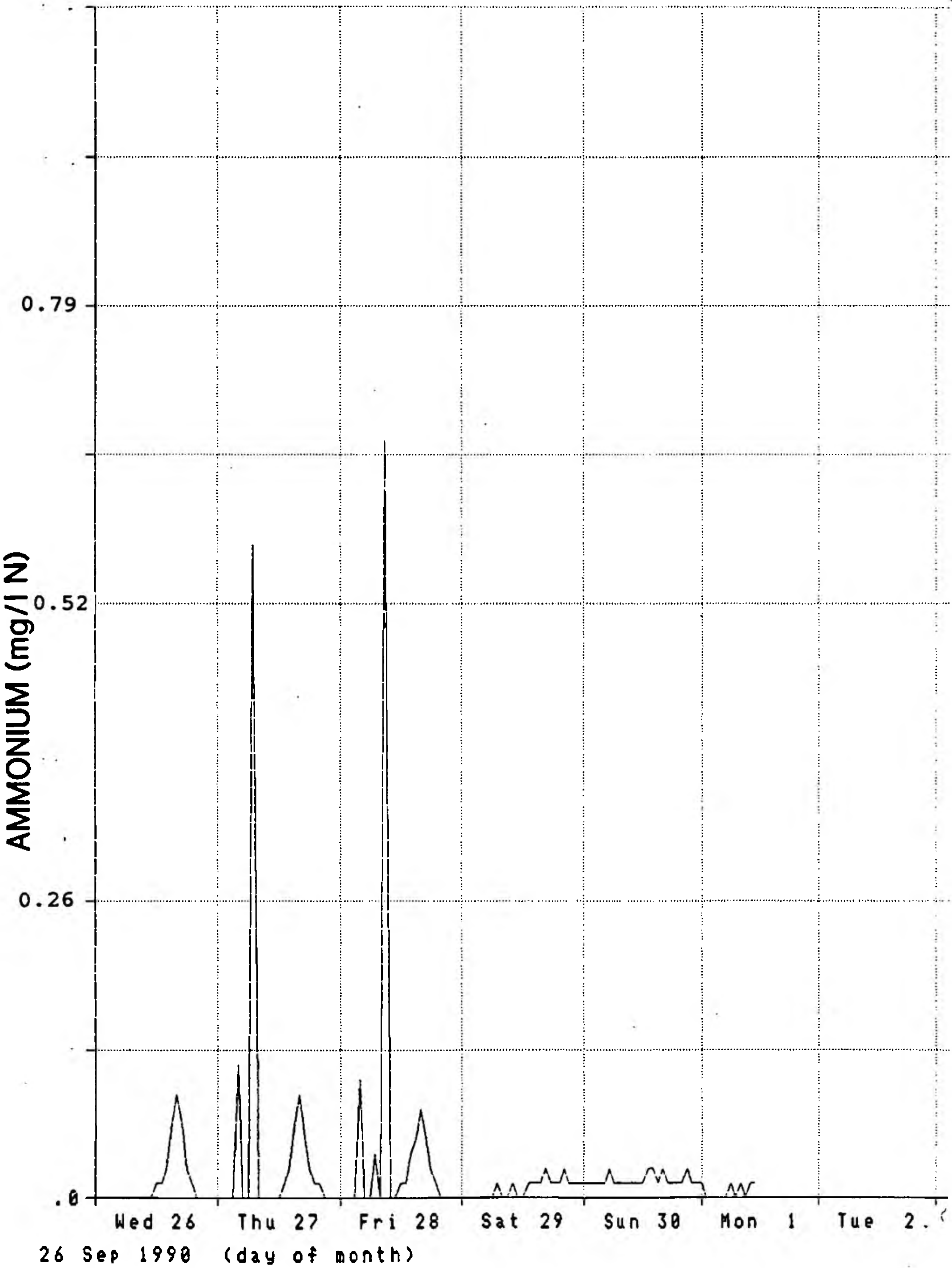
Table 4.19 - Range of ammonia (ammonium ion as mg/l N) recorded at monitoring stations

	Summer Aug/Sept	Autumn Oct/Nov	Winter Dec/Jan
COOKBURY			0.10-0.71
NORTHLEW	0.0-0.79	0.05-1.44	Logger failed
HOOKMOOR	0.0-0.04	0.0-0.10	
MEDLAND	0.0-0.65	0.0-0.44	0.0-1.70
E. OKEMENT	0.0-0.29	0.08-0.26	

Increases were recorded on all the study streams during flow events, but were generally of short duration, lasting a few hours.

Diurnal pulses were recorded on the Medland Brook (Figure 4.8) which do not relate to changes in other parameters and appear to be caused by regular inputs. The amplitude of these increased from autumn to winter with maximums of 0.06 mg/l N to 0.33 mg/l N respectively.

Fig.4.8 Diurnal peaks in Ammonium ion concentration (mg/l N) in the Medland Brook.



The largest ammonium ion concentration (Figure 4.9) was recorded on the Medland Brook at New Year (1990/91) measuring 1.7 mg/l N. It coincided with a report to the River Warden of the brook 'smelling strongly' and is believed to have been caused by a slurry spill. Figure 4.9 illustrates initial increases in turbidity and ammonium in response to flow events in the Medland Brook over the Christmas period. The simultaneous large and sustained peak of these two parameters, not associated with a flow event, then occurred over a two day period after New Year. Figure 4.10 shows the recorded levels of ammonium and turbidity on the Cookbury Stream over the same period.

Table 4.20 shows the concentration of unionised ammonia (mg/l) calculated from the observed concentration of ammonium during peak events on each study stream. The EC Directive maximum of 0.025 mg/l was exceeded on both the Northlew Stream and the Medland Brook (underlined in Table 4.20).

Autosampling of Flow Events

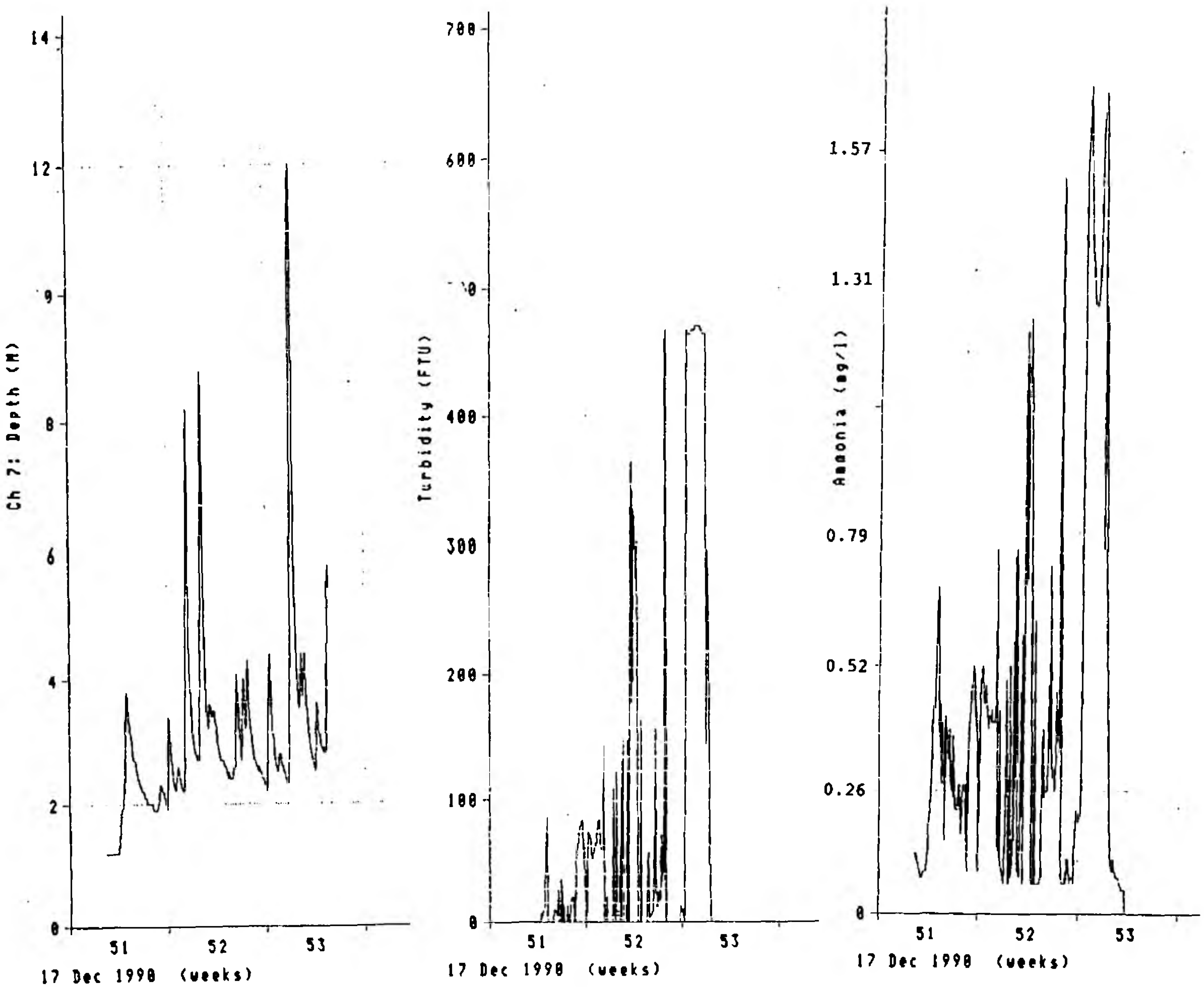
Eleven flow events were sampled from August to the end of January, comprising some 500 water samples.

1. pH

The pH values recorded in the laboratory from flow event sampling were lower than those recorded by the continuous monitoring equipment and covered the range 5.7 to 7.8, the lowest being found on the E. Okement (Table 4.21). In all sites pH fell after the break of the drought in October. The apparent discrepancy between continuously monitored and laboratory sampled data appears to be a function of pH instability between sampling and analysis.

Fig. 4.9

Continuously monitored depth (m), turbidity (FTU) and ammonium concentration (mg/l N) for the Medland Brook over the period: 17th Dec to 5th Jan 1990/91.



Continuously monitored depth (m), turbidity (FTU) and ammonium concentration (mg/l N) for the Cookbury Stream over the period: 10th Dec to 7th Jan 1990/91

Fig.4.10

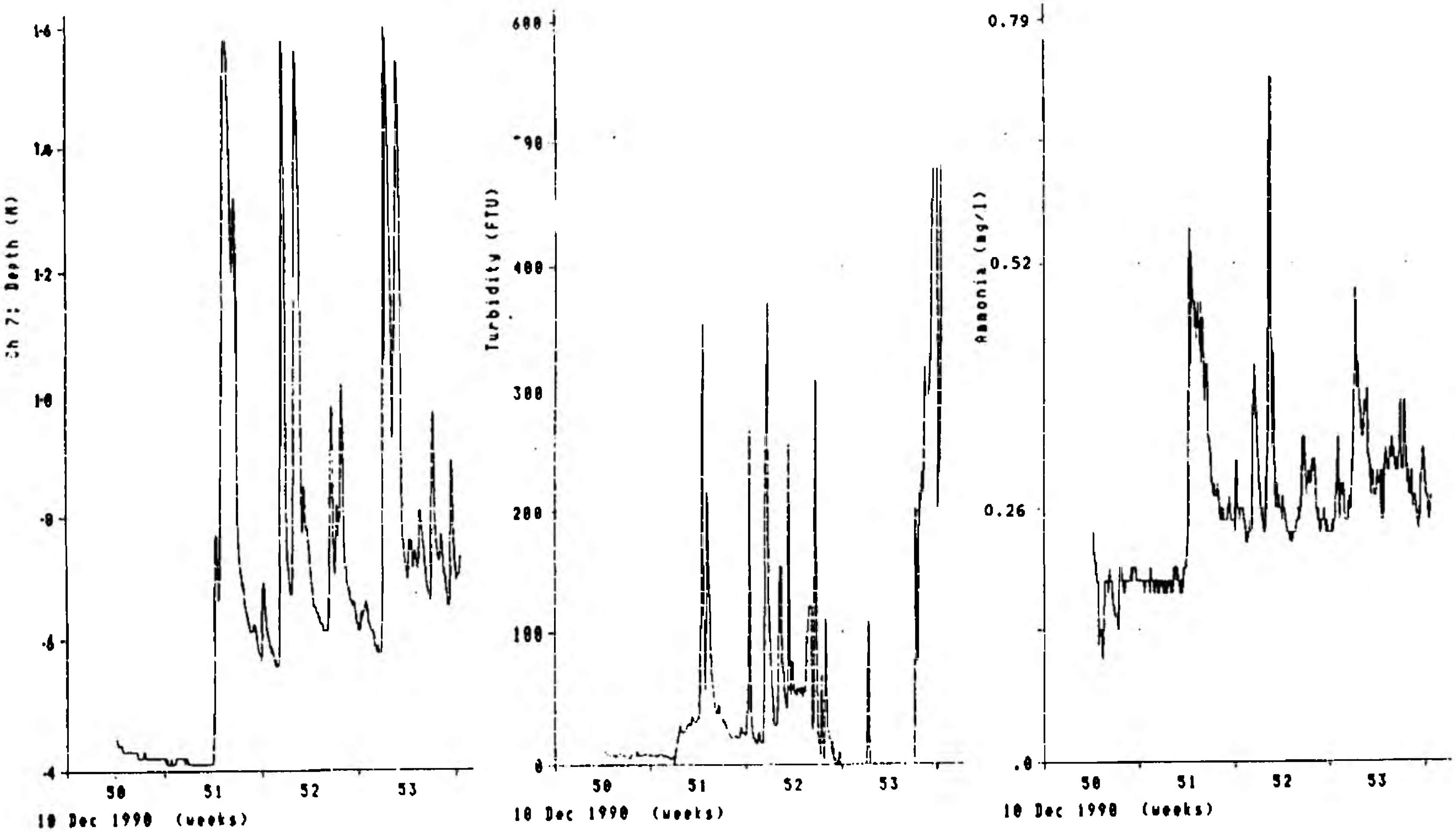


Table 4.20 - Concentrations of unionised ammonia (mg/l as N) recorded by continuous monitors during flow events on each study stream

COOKBURY		Wk 51	Wk 52	Wk 1 (1991)	
Ammonium	mg/l	0.71	0.92	0.58	
Temperature	°C	8.5	9.3	9.5	
pH		8.5*	8.1*	8.0	
Unionised	mg/l	0.011	0.017	0.018	
NORTHLEW		**Wk 38**	**Wk 42**	**Wk 43**	**Wk44**
Ammonium	mg/l	0.99	0.73	0.44	1.83
Temperature	°C	11.0	13.5	12.5	10.5
pH		8.4*	8.0	8.2*	8.05*
Unionised	mg/l	0.020	0.018	0.011	0.030
HOOKMOOR		**Wk 42**	**Wk 43**		
Ammonium	mg/l	0.13	0.16		
Temperature	°C	13.4	12.3		
pH		7.75	7.9		
Unionised	mg/l	0.002	0.004		
MEDLAND		**Wk 47**	**Wk 51**	**Wk 52**	**Wk 1 (1991)**
Ammonium	mg/l	0.58	0.84	1.94	2.17
Temperature	°C	10.0	11.9	10.0	10.5
pH		7.95	7.75	7.9	7.9
Unionised	mg/l	0.011	0.009	0.035	0.035
E. OKEMENT		**Wk 37**	**Wk 47**		
Ammonium	mg/l	0.34	0.37		
Temperature	°C	9.5	14.0		
pH		7.8	7.55		
Unionised	mg/l	0.004	0.003		

* To allow for the effect of CO_2 at the gill surface of fish, effective percentages of unionised ammonia for pH > 8.0 have been calculated by substituting 8.0 for the measured water pH (Seager *et al* 1988).

Table 4.21 - Levels of pH recorded in automatic samples

	Min	Summer Max	January Max
COOKBURY	6.7	7.6	7.1
NORTHLEW	6.7	7.8	6.9
HOOKMOOR	6.7	7.8	7.0
MEDLAND	6.6	7.8	7.2
E. OKEMENT	5.7	6.8	6.8

2. Conductivity

Conductivity ranged from 45 µS/cm to 78 µS/cm on the E. Okement and 116 µS/cm to 277 µS/cm on the other sites (Table 4.22). The highest levels being found on the Medland Brook. Conductivity fell as flow increased during events but recovered as flow subsided. There was an overall reduction in conductivity between summer and winter.

3. BOD

The average BOD (5 day total AT as mg/l oxygen) during base flows on all streams was below 2 mg/l (Table 4.23). Zero BOD was not encountered in any sample. BOD exceeded 3 mg/l during most flow events on the Lew Tributaries and the Cookbury Stream and 43% of events on the E. Okement. High BOD's were only maintained for a few hours in each case and consequently based on 95 percentiles the E. Okement would qualify as Class 1A and the remainder Class 1B.

Table 4.22 - Levels of conductivity recorded from automatic samples (µS/cm at 20 °C)

	Summer max	Summer min	Winter max	Winter min
COOKBURY	226	170	166	131
NORTHLEW	212	163	143	116
HOOKMOOR	220	164	128	108
MEDLAND	275	225	174	117
E. OKEMENT	67	50	78	45

Table 4.23 - Levels of BOD recorded during flow events (5 day total ATU as mg/l oxygen)

	Events Monitored	BOD >3 mg/l	BOD >5 mg/l	BOD >9 mg/l	Range mg/l
COOKBURY	11	10 (91%)	6 (54%)	2 (18%)	1.5 - 14.0
NORTHLEW	9	9 (100%)	6 (33%)	2 (22%)	1.0 - 10.2
HOOKMOOR	9	7 (78%)	4 (44%)	0	1.0 - 8.3
MEDLAND	9	8 (89%)	5 (55%)	0	1.6 - 8.8
E. OKEMENT	7	3 (43%)	0	0	0.8 - 3.5

4. Ammonia

The laboratory records the concentration of total ammonia as ammoniacal nitrogen (NH_3-N as mg/l N at 20 °C). The highest concentration recorded during a flow event was 0.62 mg/l (Table 4.24) on the Hookmoor Brook.

Table 4.24 - Levels of ammonia (NH_3-N) recorded during flow events

	Events monitored	>0.4 mg/l	Max	Min
COOKBURY	11	2 (18%)	0.47	0.02
NORTHLEW	9	2 (22%)	0.44	0.03
HOOKMOOR	9	1 (11%)	0.62	0.02
MEDLAND	9	0	0.36	0.02
E. OKEMENT	7	0	0.30	0.01

5. Suspended solids

The principle effect of suspended solids on fish is physical damage caused by abrasion. Damage may occur to gills and skin and may affect oxygen uptake and electrolyte balance.

The EC Directive (CEC 1978) states that the average concentration of suspended solids should be <25 mg/l whilst accepting that floods are liable to cause particularly high concentrations. In-organic suspended solids concentrations exceed 25 mg/l on the Cookbury and Lew catchments during almost all the flow events examined.

Table 4.25 - Levels of suspended solids recorded during flow events

	Maximum mg/l	% organic	Base flows mg/l
COOKBURY	558	(13%)	14-25
NORTHLEW	1300	(19%)	1-24
HOOKMOOR	743	(18%)	1-23
MEDLAND	557	(19%)	1-22
E. OKEMENT	81	(48%)	1-3

6. Nitrate

Nitrates can contribute to eutrophication. However, the anion NO_3^- is not considered particularly toxic to fish.

Table 4.26 - Levels of nitrate recorded during flow events (mg/l)

	Max mg/l	Min mg/l
COOKBURY	5.70	0.13
NORTHLEW	3.99	0.73
HOOKMOOR	3.51	0.30
MEDLAND	4.36	0.20
E. OKEMENT	0.48	<0.10

7. Nitrite

The nitrite ion NO_2^- is encouraged to form in alkaline waters but its effects are countered by the presence of chloride. EIFAC standards propose a level of 10 µg/l nitrite-N where there is only one mg/l chloride present to 150 µg/l in waters of 40 mg/l chloride. Chloride concentrations averaged 10 mg/l in the E. Okement and 30 mg/l in the other study catchments.

Table 4.27 - Levels of nitrite recorded during flow events (µg/l)

	Max µg/l	Min µg/l
COOKBURY	79	9
NORTHLEW	91	7
HOOKMOOR	64	9
MEDLAND	80	11
E. OKEMENT	11	<5

8. Phosphate

The EC Directive suggests a limit of 0.2 mg/l as PO_4 for salmonid streams as phosphates are an important cause of eutrophication. This level was exceeded on only one occasion during a flow event on the Cookbury Stream.

Table 4.28 - Maximum levels of phosphate recorded during flow events (mg/l)

	Max mg/l
COOKBURY	0.23
NORTHLEW	0.16
HOOKMOOR	0.15
MEDLAND	0.19
E. OKEMENT	0.01

4.3.4 Discussion

The results, from this preliminary data collection and analysis, indicate that at basal flows the water quality in all the study catchments, and specifically the E. Okement, is generally good. There is however a deterioration in water quality during flow events, which, whilst not apparently reaching lethal levels for salmonid fish, may have sub-lethal impacts in the four intensively farmed study catchments.

The drought conditions which prevailed over the summer of 1990, for the second year running, resulted in very low flows in the study catchments. Water temperature, however, did not exceed 19 °C in any study catchment, probably as a consequence of the shading of the river beds afforded by tree cover. D.O. rarely fell below 60% saturation and it is possible that localised deoxygenation around D.O. probes during low flow may have been a contributory factor on these occasions.

Rising water, during flow events, was however accompanied by peaks in unionised ammonia, suspended solids, BOD and nitrite. This was especially apparent during the spate conditions of Christmas and New Year with elevated ammonia levels recorded in several parts of the Torridge Catchment. Rapid and sustained colouring from suspended solids is also a feature of all the study streams, except the E. Okement, during flow events. Throughout the period of study there were however no reported incidences of fish kills on any of the study streams and no dead fish were encountered by the Project Staff in the field.

Repeated exposure to these poor quality events may have a chronic effect on the fish populations of the study catchments. In order to assess the consequences of these episodes further measurement of the frequency, magnitude and duration of events for different water quality parameters, and it's interpretation using both published and experimental ecotoxicological data is essential.

Polluting events other than those associated with flow events are rare, and with the exception of small ammonia pulses on the Medland Stream there appear to be no persistent gross discharges to the watercourses. Continuous monitoring recorded evidence of only one major pollution event on the Medland Brook at New Year with Elevated levels of ammonia (max 1.7 mg/l NH_4^+) and turbidity during a period of particularly high flows.

In planning future work the labour intensive nature of the collection of water quality data is an important consideration. It currently takes two man days per week to maintain equipment and download data from the five sites. The emptying of water samplers takes one day per flow event, including delivery to laboratory, but it is often also necessary to visit equipment during a flow event to ensure that it is functioning correctly.

4.4 *In situ* bioassays

4.4.1 Egg Planting

Green salmon ova were planted out in Harris boxes on one riffle in each of the five study streams in December. The locations were selected following site visits with the Upper Torridge Warden and are in close proximity to the continuous WQ monitoring stations.

Sixteen boxes each containing 50 eggs were planted at each site, 4 boxes being placed in each of four artificial redds. This afforded four removals each of four boxes (one per redd); post planting, mid-development, pre-hatch and post hatch (Dec, Jan, Feb, March, approx.).

The redds were constructed by breaking up the gravel to a depth of 15 cm using a pickaxe and a 1" water pump. Working upstream redds 0.5 m long and 2 m wide were formed. Metal stakes (40 cm) were hammered into the centre of each redd at 40 cm intervals, flush with the surface of the gravel. A single Harris box, charged with eggs and gravel, was wired to each stake and buried such that its top surface was below the level of the original gravel bed.

Results

The results are being analysed and will be presented in the October 1991 progress report to the Project Steering Group.

Gravel sampling

Loughborough University Department of Geography was contracted to sample the gravel substrate at each site prior to planting. The resulting report is presented in Appendix D in its entirety in accordance with WRc procedures for sub-contracted work. It identifies high concentrations of fines in the gravel of the Cookbury and Lew catchments (Figure 4.11) and suggests that the source of this material may be land use related.

Fig.4.11 LOADING OF FINES (<1mm) IN SPAWNING GRAVEL IN THE HOOKMOOR BROOK.

The 10% loading identified in gravel core samples from the Hookmoor, Cookbury Northlew and Medland Brooks.

A <5% (by weight) loading typical of U.K. streams.

4.4.2 Juvenile salmon

A cage has been designed (Figure 4.12) and the first fish were placed out in March, coinciding with the completion of the egg bioassay. Initial results will be presented to the October 1991 Steering Group Meeting.

4.4.3 Fish pathology

A formal arrangement has been made with the NRA Anglian Region Fish Laboratory for pathological studies on fish from the bioassay and wild samples. The work is being undertaken as part of an NRA national research project (Fish Diseases: Disease status of fish as an additional indicator of surface water quality, Ref Nº 229).

4.4.4 Fish monitor

A caravan-mounted WRc Fish Monitor is currently being operated at the foot of the Hookmoor Brook using a supply of juvenile brown trout obtained from NRA SW. Initial results will be presented to the October 1991 Steering Group Meeting.

4.5 Juvenile salmonid survey and redd density survey

4.5.1 Introduction

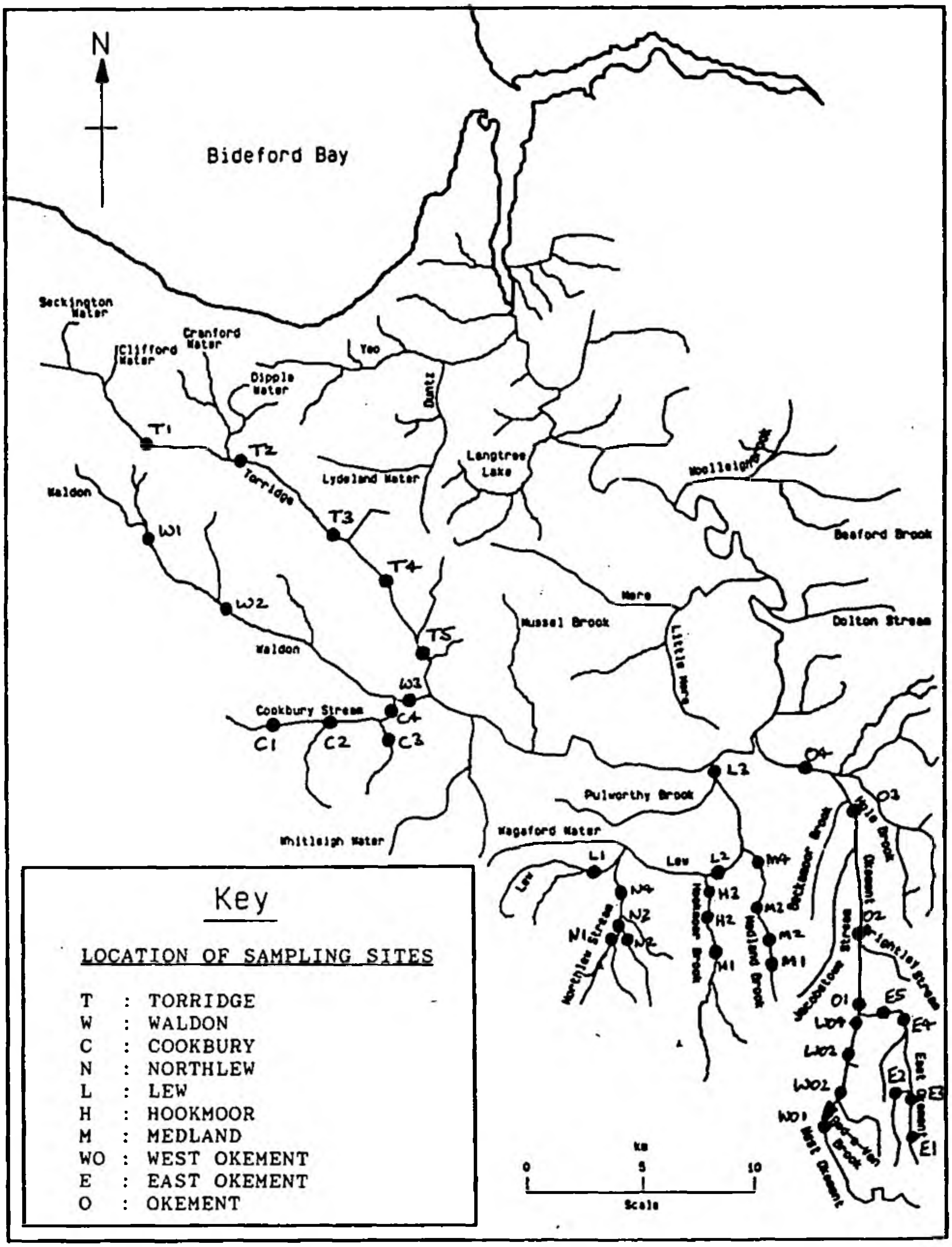
A preliminary assessment of the juvenile salmonid stocks in the study catchments was undertaken to assess distribution and density in the study catchments to provide a basis for future work. The fish stocks of the River Torridge have been routinely surveyed by the SWWA/NRA since 1964 and in 1990 a survey comprising 10 quantitatively sampled sites on the R. Okement, and 14 semi-quantitatively sampled sites on the R. Lew, R. Waldon and the Upper Torridge was undertaken (Figure 4.13). Only four of these sites were however within the study catchments (2-E. Okement, 1-Northlew Stream, 1-Hookmoor Brook).

Fig.4.12 DEPLOYMENT OF A JUVENILE SALMON BIOASSAY CAGE.

CAGE STAKED IN POSITION

FILLING BASE WITH RIVER BED SUBSTRATE

Fig.4.13 Map showing the locations of the 1990 fisheries survey sites



WO1, E1, E2, E3 NOT ACCESSIBLE TO SALMON

A quantitative sampling survey was consequently undertaken in the study catchments by the Project Staff, in June-August 1990, comprising a further 16 sites.

A smaller quantitative survey of 9 sites was undertaken in the autumn (Oct-Nov) to examine the feasibility of studying temporal change in density. A 15 site semi-quantitative survey of the Hookmoor Brook was also undertaken, at this time, to examine in more detail observations in the summer on spatial density variation within the Lew study catchments (4.5.2).

Surveys of spawning distribution (redd counts) were undertaken in the study catchments in November and January and the results are included in this section as they assist in the interpretation of juvenile survey data.

4.5.2 Results

Distribution

Figures 4.14 and 4.15 show the distribution (presence/absence) of juvenile salmon and trout compiled from all the 1990 survey sites.

Salmon

Juvenile salmon were absent from the four sites surveyed in the Cookbury Stream but were present in the four other study catchments. In the Lew study catchments fry were found at 11 of the 13 sites though the distribution of parr was more restricted, being absent from the Medland Brook and present at only half of the Northlew Stream and Hookmoor Brook sites. The upper reaches of the E. Okement are not accessible to migratory fish due to an impassable waterfall (Fig. 4.1) but salmon fry and parr were found at the three sites surveyed below this point.

Fig.4.14 The distribution of salmon fry and parr from the 1990 fisheries survey.

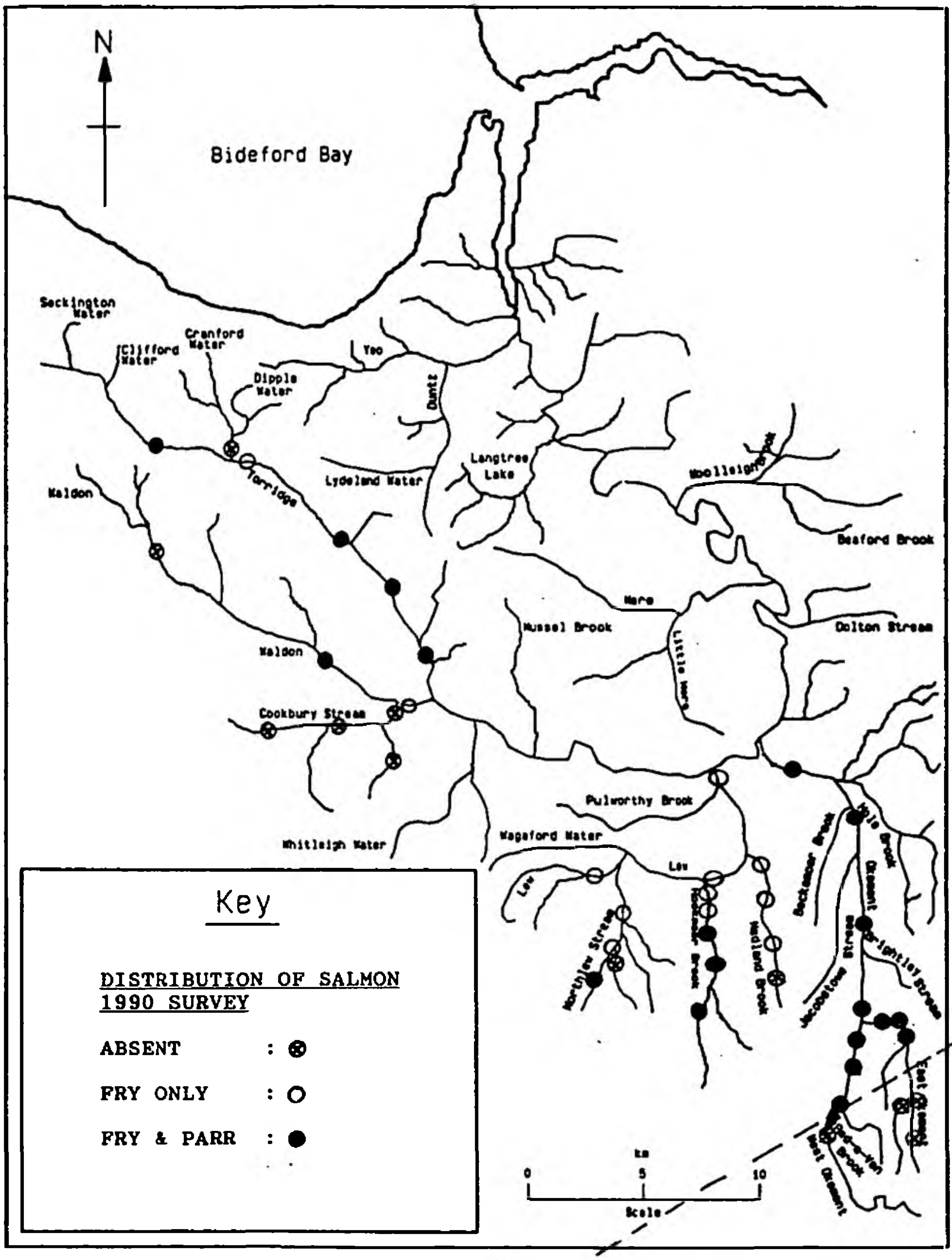
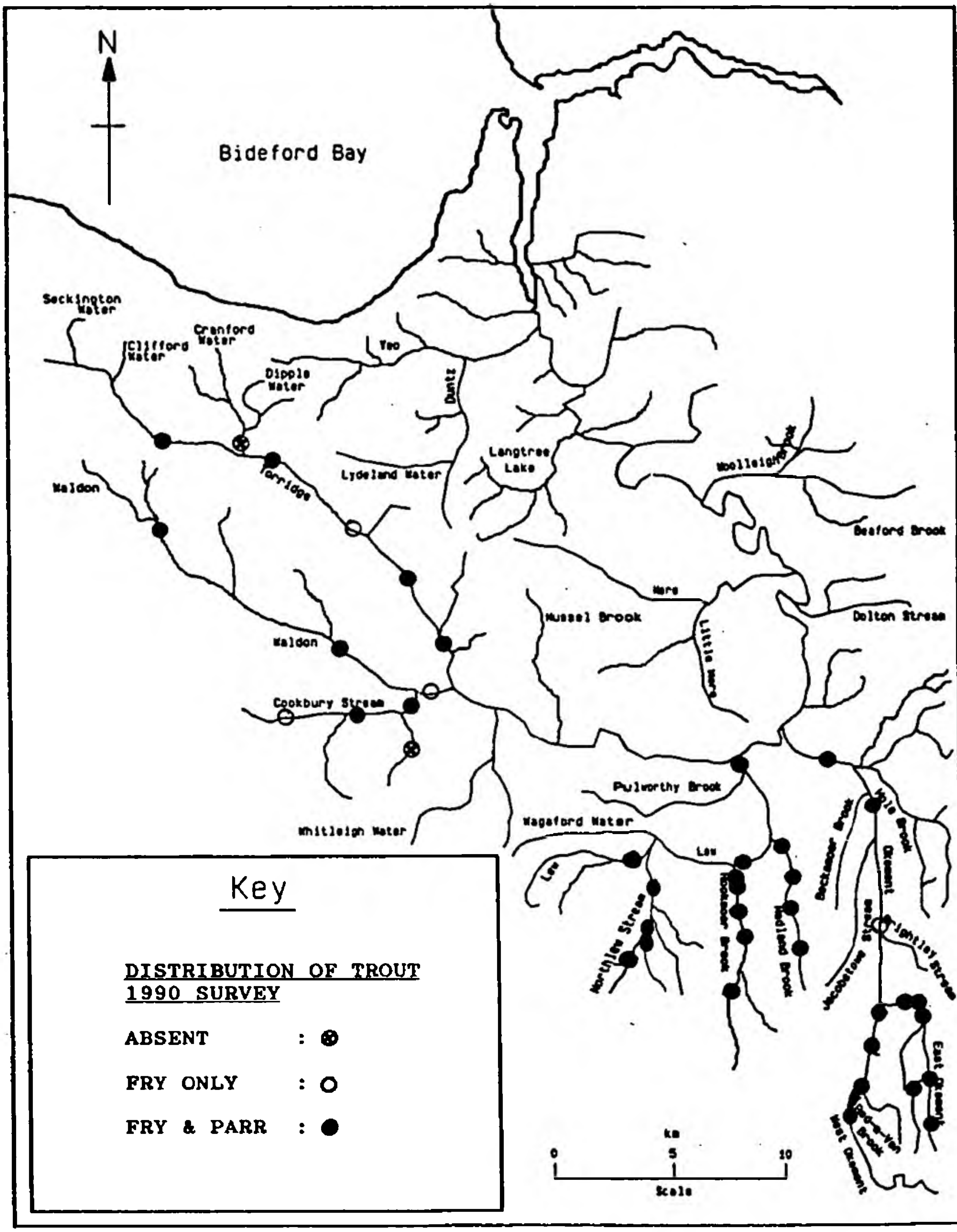


Fig.4.15 The distribution of trout fry and parr from the 1990 fisheries survey.



Trout

The distribution of trout is more widespread than that of salmon with both fry and parr present at each survey site in the R. Okement and the R. Lew and it's sub-catchments. In the Cookbury stream fry were present at three and parr at two of the four sites surveyed. The headwaters of the E. Okement, above the waterfall contain brown trout.

Population density

Salmonid population density is examined below in two ways due to the use of both quantitative (3-catch depletion) and semi-quantitative (single shock) sampling method. Absolute density (N/100 m^2) is compared between quantitatively sampled sites (26), whilst relative density, derived from the first catch, is compared for all sites (40).

1. Population density at quantitatively sampled sites, surveyed Jun-Aug 1990.

   Table 4.29 and Figure 4.16 show the densities of salmon and trout fry and parr at quantitatively sampled sites.

Salmon

The highest densities salmon fry (>34/100m^2) were encountered in the R. Okement and the lower section of the E. Okement which is accessible to migratory fish. The three Lew study catchments yielded densities of 0.0-8.4/100m^2, with one exception on the Hookmoor Brook, where 37.5/100m^2 were found. No salmon fry, or parr, were encountered in the Cookbury Stream.

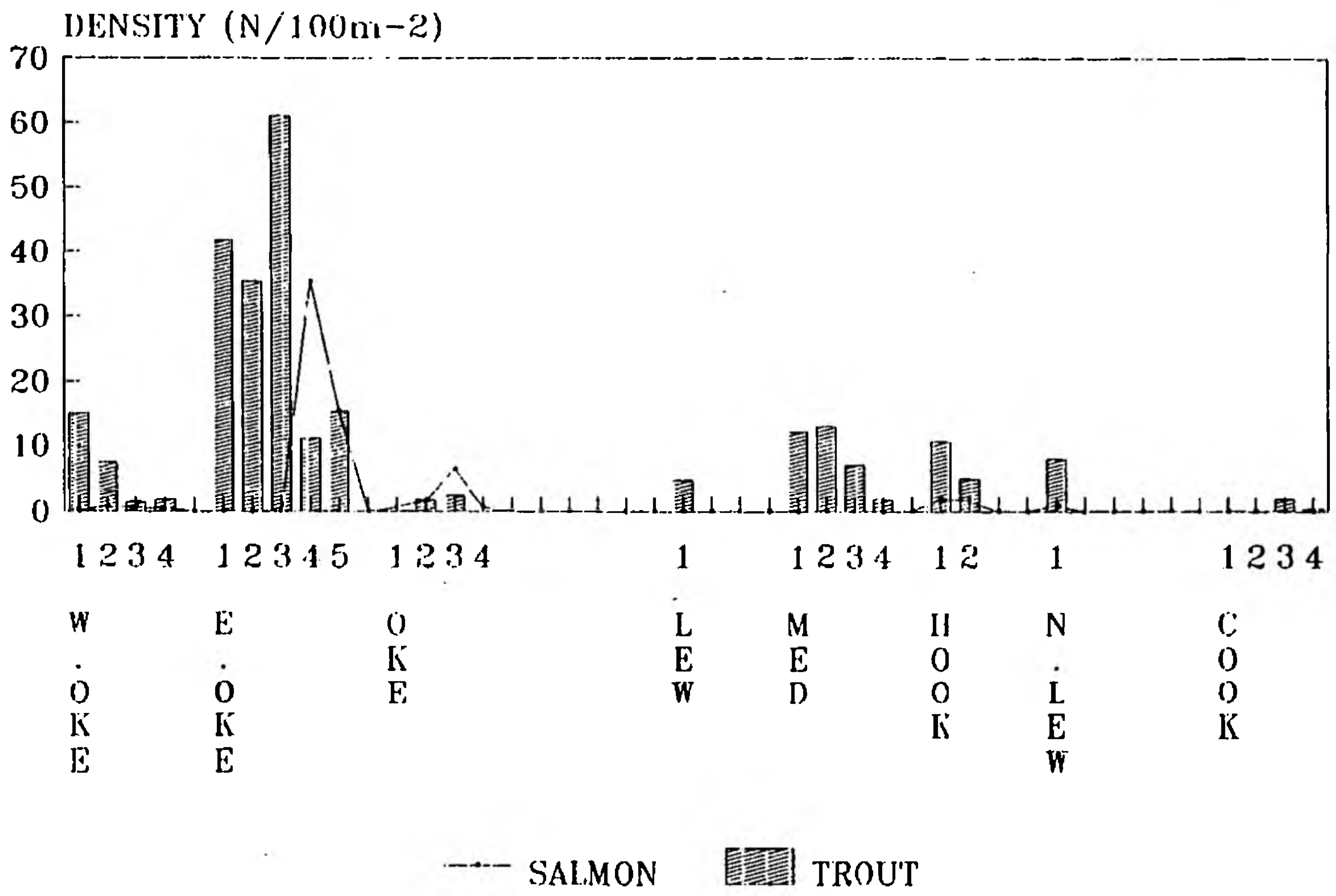
Table 4.29 - Density ($N/100m^2$) of salmon and trout fry and parr at quantitatively surveyed sites

LOCATION	SITE OF No.	SALMON 0+	SALMON >1+	TROUT 0+	TROUT >1+
R. OKEMENT	1	77.2	0.5	3.3	0.0
	2	34.2	0.7	0.5	1.5
	3	40.5	6.5	2.1	2.9
	4	93.2	0.5	0.0	6.2
E. OKEMENT	1 *	NIL	NIL	3.1	41.7
	2 *	NIL	NIL	2.1	35.5
	3 *	NIL	NIL	3.2	54.3
	4	22.6	35.4	16.2	11.1
	5	5.3	15.8	9.4	8.5
MEDLAND	1	0.0	0.0	89.6	12.1
	2	1.0	0.0	88.8	13.0
	3	8.4	0.0	26.2	7.2
	4	7.7	0.0	10.2	1.9
HOOKMOOR	1	37.4	1.8	26.2	10.7
	2	6.8	1.7	5.9	5.1
NORTHLEW	1	4.0	1.0	34.4	8.1
	4	3.3	0.0		
COOKBURY	1	0.0	0.0	2.4	0.0
	2	0.0	0.0	0.0	0.0
	3	0.0	0.0	0.4	2.0
	4	0.0	0.0	0.0	0.6

* impassable to migratory fish due to a waterfall

Fig.4.16

The densities of salmon and trout parr, estimated by three-catch depletion.



The density of salmon parr was highest in the E. Okement with 15.8 and 35.4/100m^2 at the two sites surveyed in the summer. Densities in the main R. Okement were, however, much lower (0.5-6.5/100m^2), despite the presence of large numbers of fry. This reflects, however, the effects of a major fish kill from acid runoff affecting the R. West Okement and main R. Okement in the autumn of 1989, prior to spawning. Small numbers of parr were found in the Hookmoor Brook and Northlew Stream (0.0-1.8/100m^2), but were absent in the Medland Brook.

The ageing of scales showed that all parr encountered in the Lew study catchments were age 1+ whilst 1+,2+ and 3+ were found in the East Okement.

Trout

The isolated population of brown trout in the upper reaches of the E. Okement yielded the highest densities of trout parr encountered on the Torridge (35.5-54.3/100m^2). Fry densities were however low (2.1-3.2/100m^2). This may be a function of poor capture efficiency since the moorland fry were smaller (3-4cm) than elsewhere in the Torridge (5-8cm) and conductivity was lower (approx. 60 in E. Okement and 160 elsewhere)

Below the waterfall on the E. Okement fry densities of 9.4-16.2/100m^2 and parr of 8.5-11.1 greatly exceeded those of the main R. Okement (0.0-3.3 and 0.0-5.25/100m^2), and observation which may again be related the Autumn 1989 fish kill.

High densities of fry were encountered at the upper survey sites on Medland Brook, Hookmoor Brook and Northlew Stream (89.6, 26.2 and 34.4/100m^2 respectively). In each of these watercourses parr densities were also high towards the headwaters (8.1-13/100m^2).

The density of fry (0.0-2.4/100m^2) and parr (0.0-2.0/100m^2) in the Cookbury Stream were low by comparison with the other four study catchments.

2. Semi-quantitative data

The comparison of relative density between all the 1990 survey sites (Figures 4.17 and 4.18) highlight the trend for density to decrease from the headwaters down stream in each of the three Lew study catchments. Low densities at the foot of each of these appear to be mirrored by relatively low densities in the R. Lew itself. Figure 4.17 also highlights the low incidence of salmon parr outside the E. Okement. The relative density of fry and parr in the upper Torridge and R. Waldon are lower than those of the Okement and parts of the Lew study catchments.

Autumn surveys

1. Quantitatively sampled sites

A limited exercise was undertaken to examine the practicalities of undertaking temporal surveys of density change by quantitatively sampling sites in the October/November period. The NRA SW routine surveys cease in September as river levels rise and problems are experienced with high turbidity following flow events, which limits the time available for surveys, and leaves choking stop nets.

This survey comprised the four summer survey sites on the Medland Brook and three sites on the E. Okement, two of which were surveyed in summer. The results from summer and autumn are compared in Table 4.30. These indicate substantial declines in fry numbers over this period (trout: 62-76%, salmon: 65-81%) on the Medland Brook though trout parr numbers increased at two sites and decreased at the two others. The corresponding changes in fry density on the lower Okement (Site 4) were smaller (trout:-26%, salmon:-46%) whilst in the moorland area (site 2) the numbers of fry recorded increased (+ 180%) thought this, however, included a relatively small number of fish.

Fig. 4.17

Relative densities of salmon and trout parr from single-shock electrofishing.

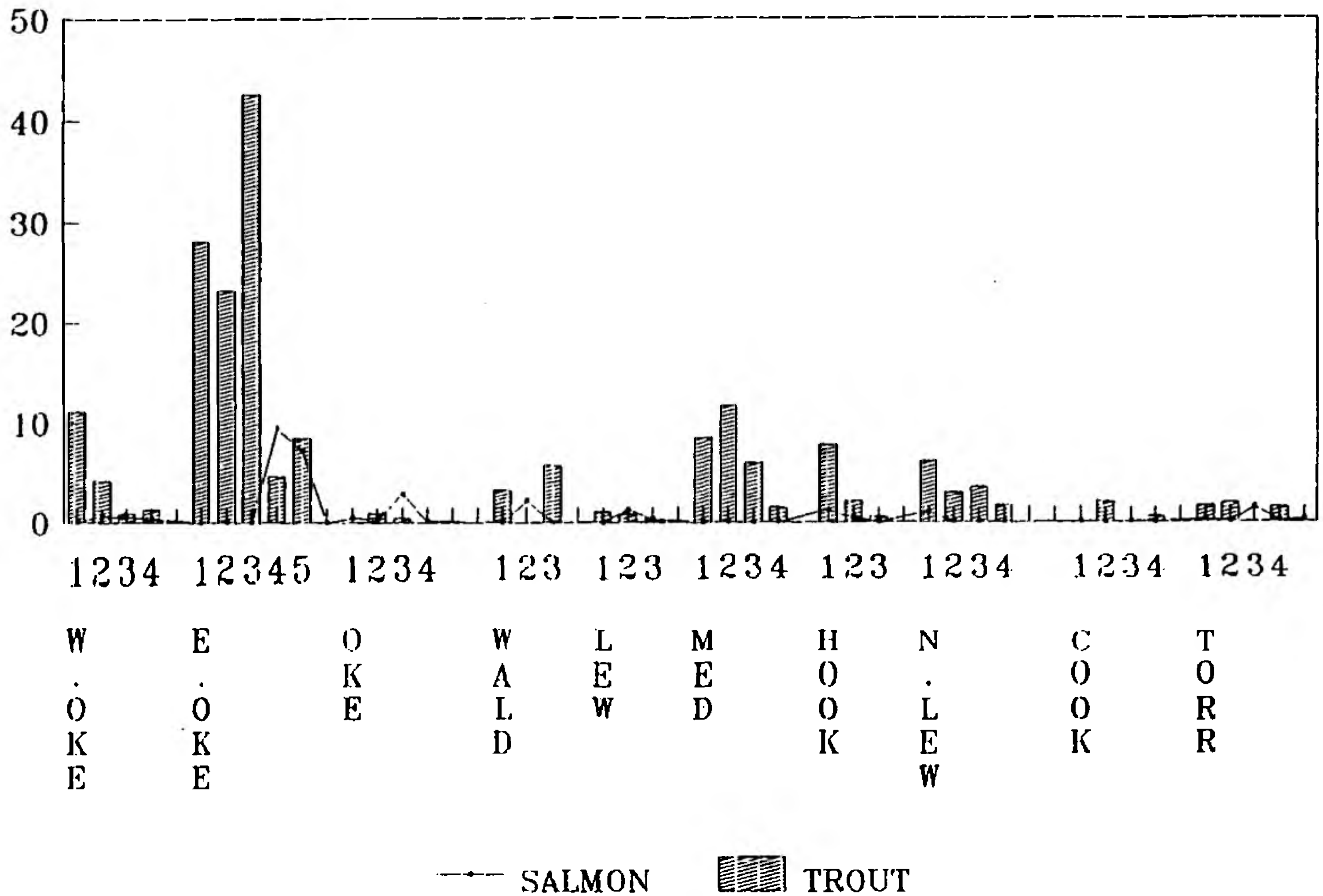


Fig.4.18

Relative densities of salmon and trout fry from single-shock electrofishing.

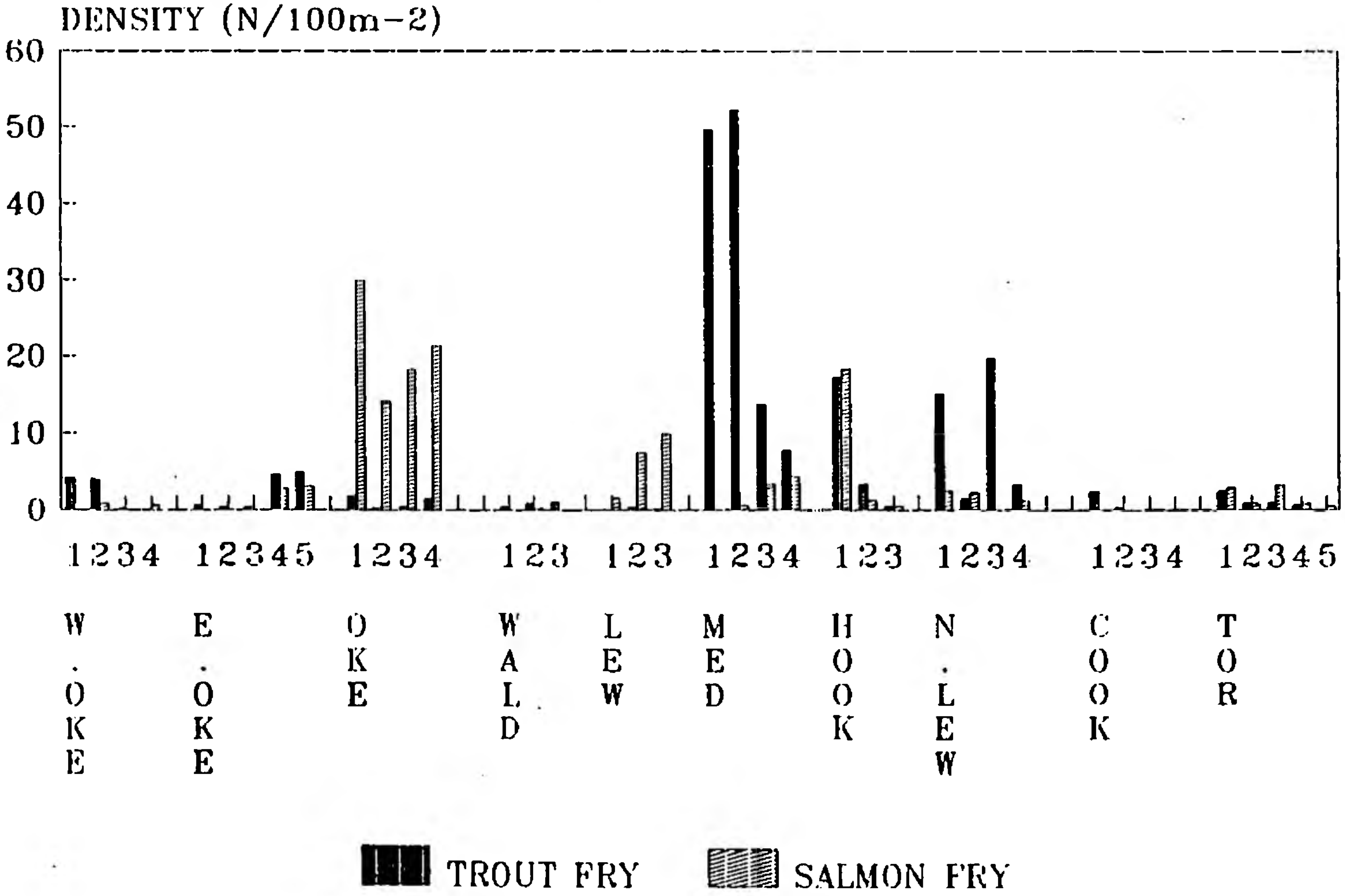


Table 4.30 - Percentage change in salmonid densities from Summer (Jun/Jul) to Autumn (Oct/Nov)

Study Catchment	Sites Nº	Salmon Fry	Trout Fry	Salmon Parr	Trout Parr
MEDLAND	1	-	- 62%	-	+ 15%
	2	-	- 70%	-	- 26%
	3	- 65%	- 64%	-	- 17%
	4	- 81%	- 76%	-	+ 50%
E. OKEMENT	2	-	+180%	-	- 6%
	4	- 46%	- 26%	*	*

* inadequate data to calculate change

2. Autumn survey of the Hookmoor Brook

A survey of the Hookmoor Brook comprising 14 single-shock sites (Figure 4.19) was undertaken in the Autumn to examine the trend for decreasing population from the headwaters to the foot of the Lew study catchments. The results are summarised in Figures 4.20 & 4.21.

The number of salmon parr encountered was small, as was found in Summer, but of particular interest is their presence and that of salmon fry at the highest site examined, indicating that spawning salmon appear to have reached this area in winter 1988/89 and 1989/90.

Trout fry were concentrated towards the headwaters and were absent from three of the bottom four sites examined. Salmon fry were present at 12 of the 14 sites.

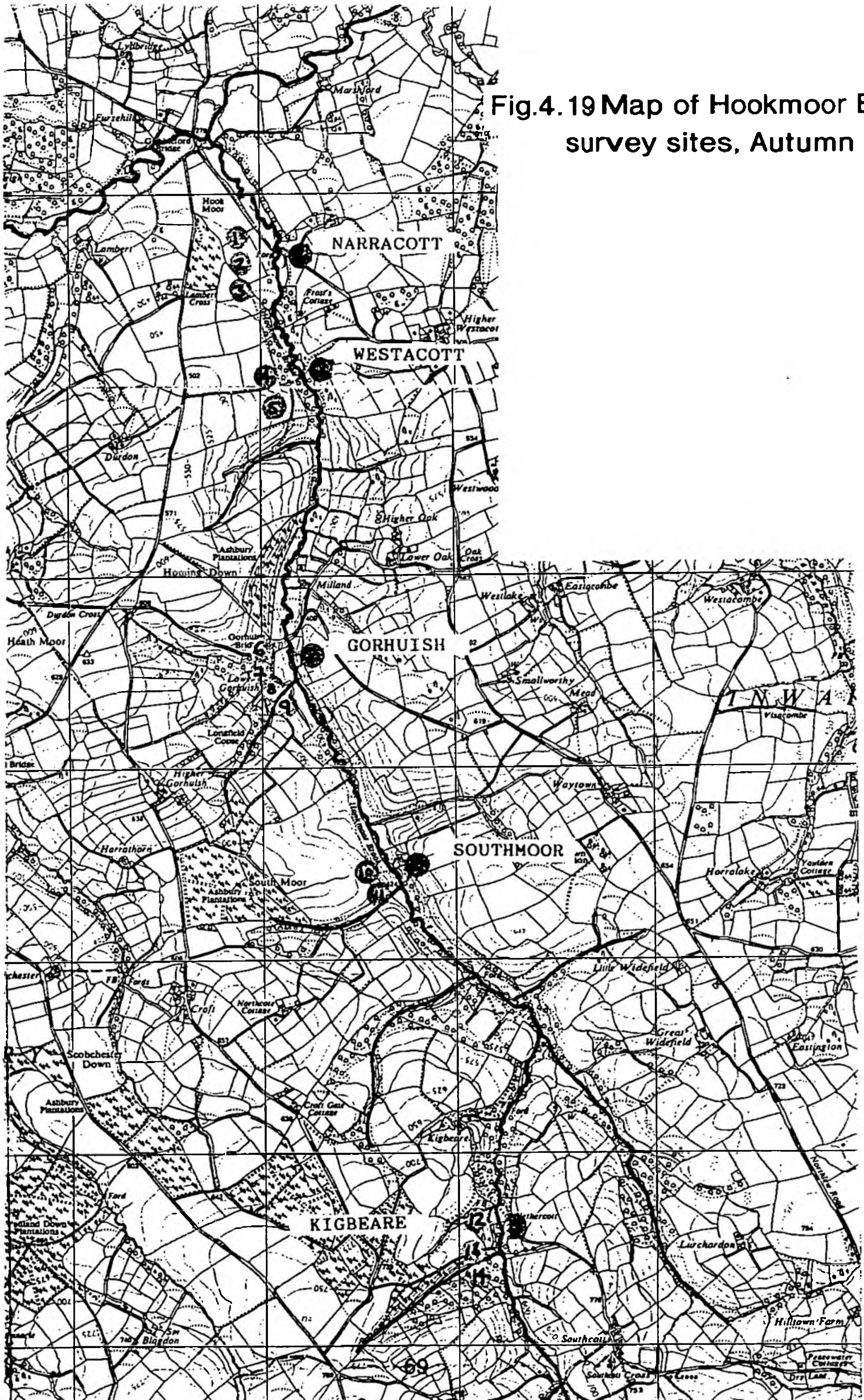


Fig.4.19 Map of Hookmoor Brook survey sites, Autumn 1990

Fig.4.20

Relative densities of salmon fry and parr from the Hookmoor Brook

Autumn 1990 survey

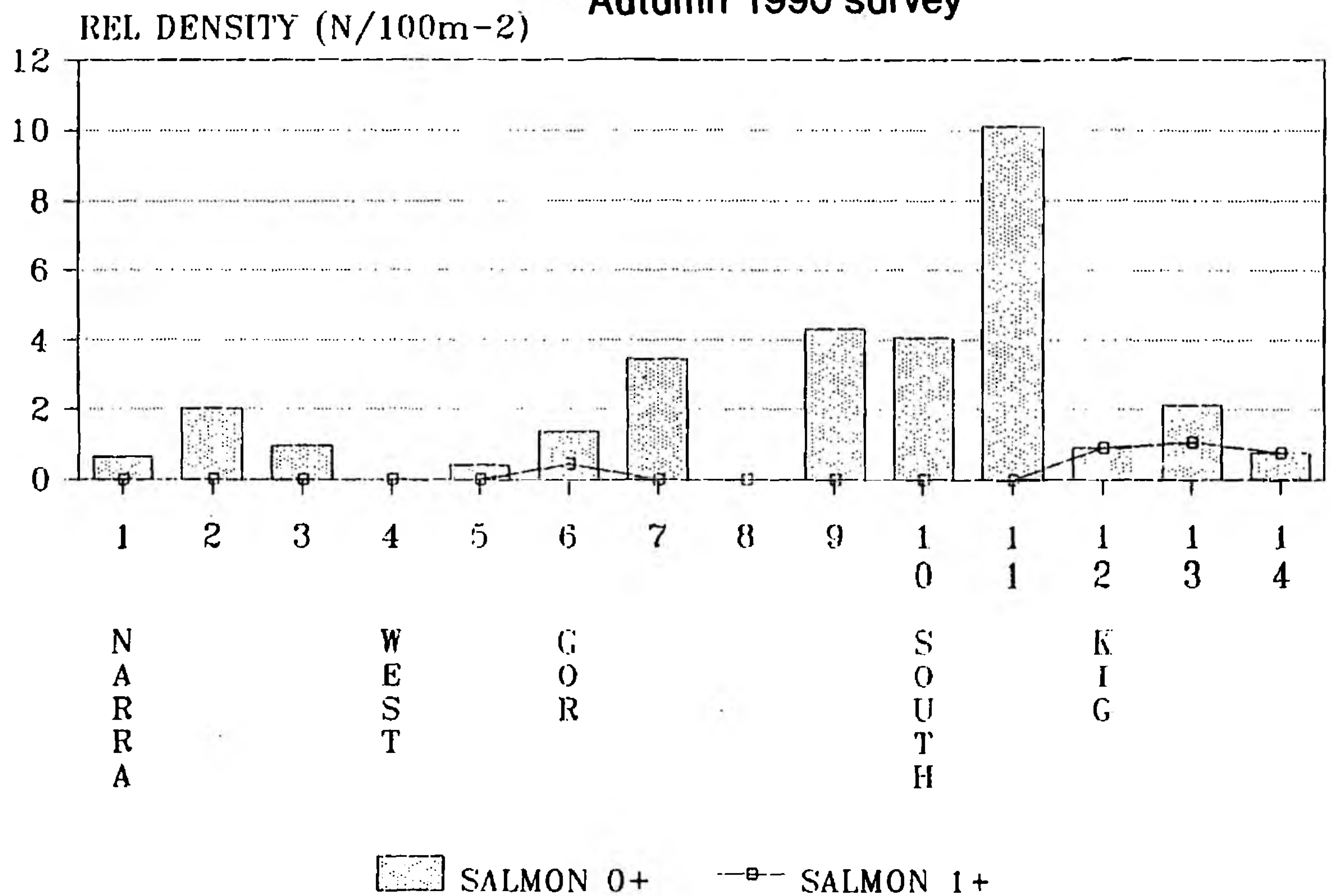
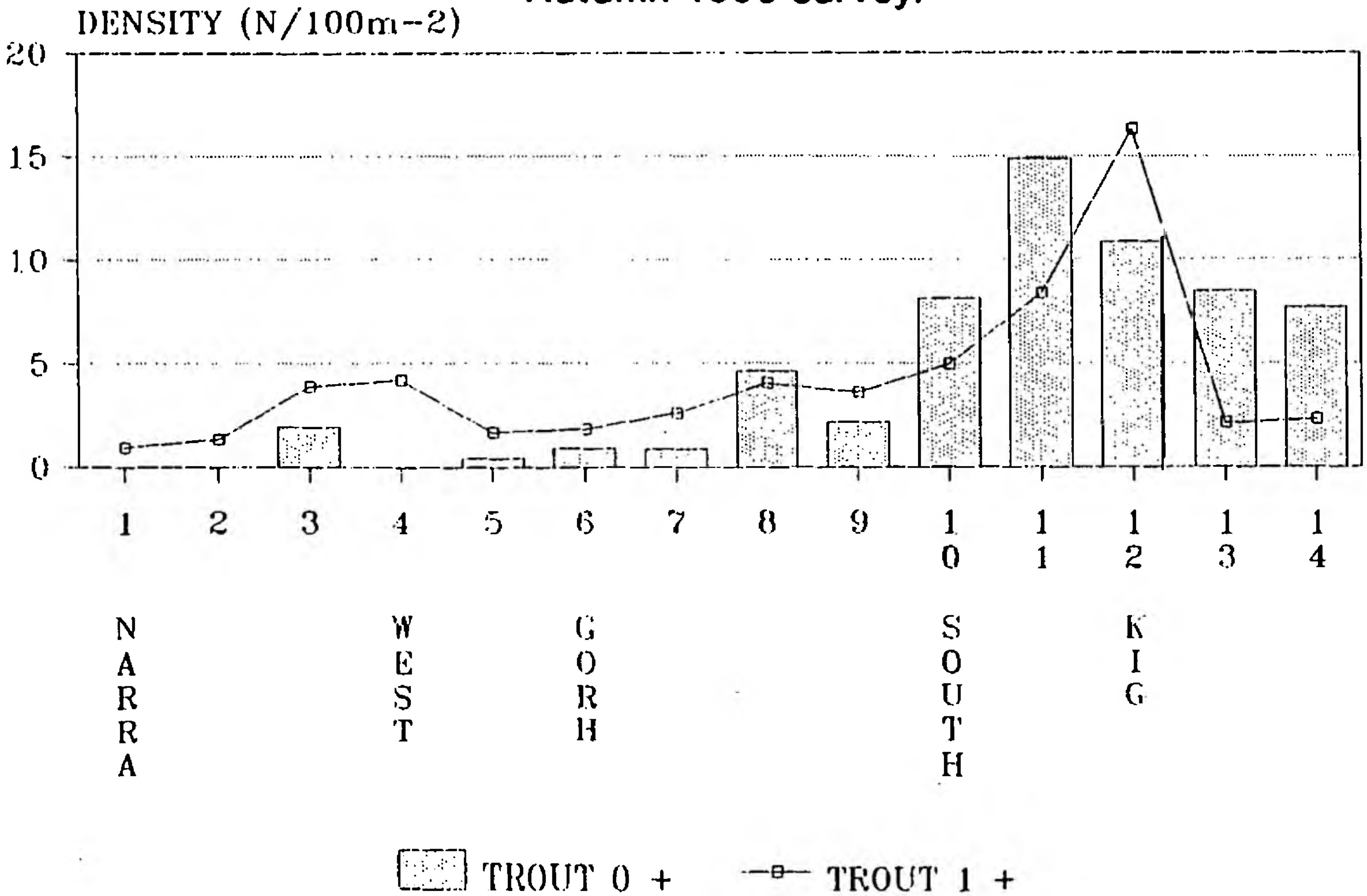


Fig. 4.21

Relative densities of trout fry and parr from the Hookmoor Brook Autumn 1990 survey.



The 'Habscore' habitat assessment system (Milner *et al* 1985), under development by the NRA, was applied to compare observed with expected populations of salmon and trout. The system has been created using data from Welsh streams and has not been applied to the South West before. Future development with data from other NRA regions will refine this programme and it will be possible to re-assess the results at a later date. The initial findings however appear to indicate that the decline in trout population density from the headwaters to the foot of the Brook is not habitat-related.

Redd density

Routine surveys to identify the distribution and number of salmon and sea trout redds are undertaken each year by NRA SW.

Table 4.31 shows the numbers of redds recorded during routine counting in November/December 1990. The use of such counts has been questioned since they can be inaccurate. However, as a relative measure of spawning the data highlights the importance of the R. Okement and a low incidence in the R. Waldon. 1990/91 appears also to have been a better year for spawning than 1989 and several previous years.

The Cookham and the three Lew study catchments were surveyed in November and again in January but are not part of the routine NRA survey.

In the E. Okement only three salmon and four sea trout redds were observed despite reports of large numbers (>40) of spawners being seen passing through Okehampton. The coarse nature of the bed substrate makes redd identification difficult however. No evidence of spawning was found on the Cookbury Stream. Figure 4.22 shows the observations in November of fish and redds on the Lew tributaries. The January survey only found evidence of two possible redds on the lower Northlew Stream, but none on any of the other study streams.

Table 4.31. Redd counts on the River Torridge 1983-90.

SALMON

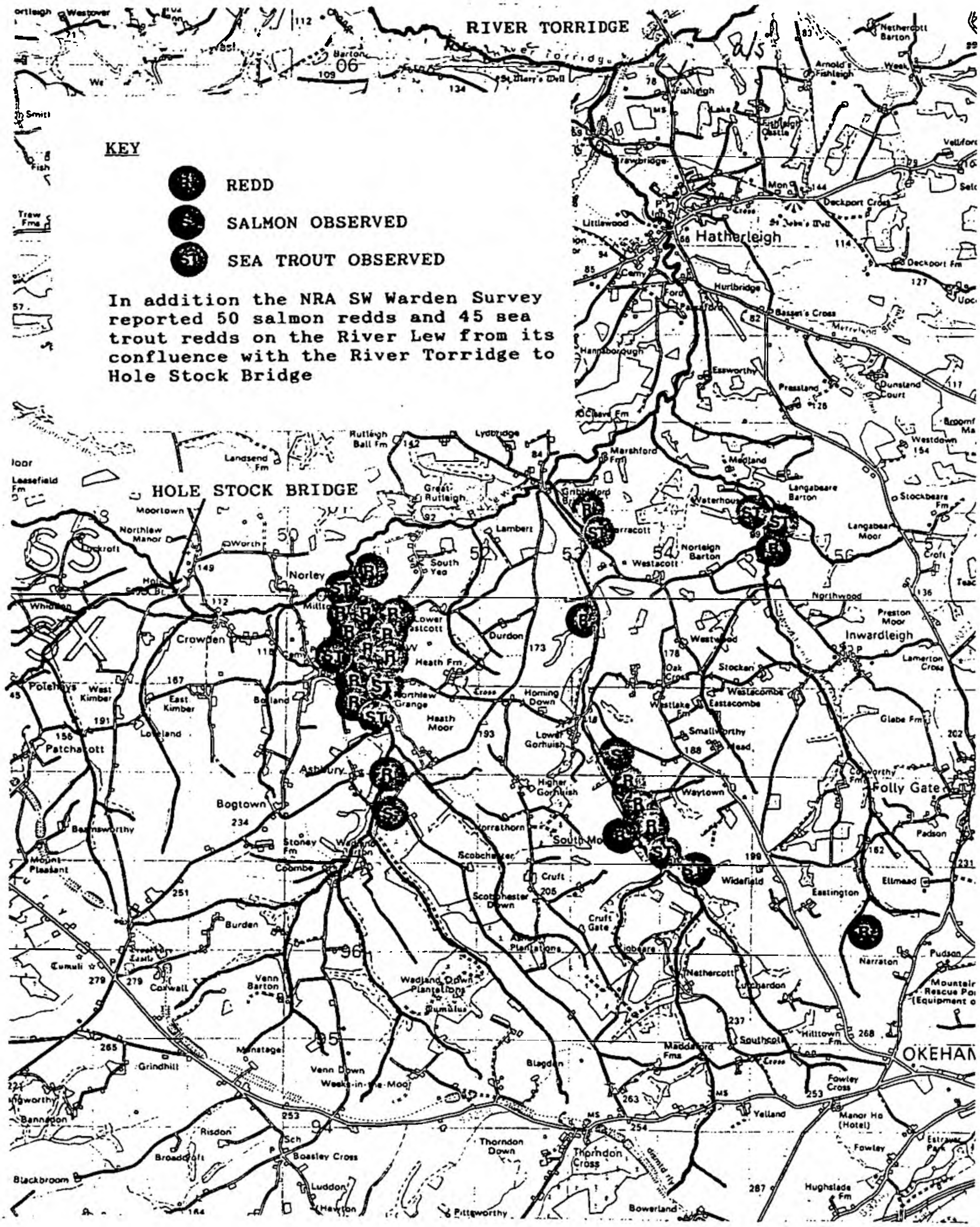
	1983*	1984	1985	1986*	1987*	1988	1989	1990
UPPER TORRIDGE	13	8	98	22	63	15	39	90
RIVER WALDON	8	2	4	-	4	3	2	6
RIVER LEW	9	10	31	3	40	11	36	50
RIVER OKEMENT	-	8	53	82	32	154	53	137
LOWER TORRIDGE	-	-	18	-	1	2	-	-
TOTAL	39	28	204	107	140	185	130	283

SEA TROUT

	1983*	1984	1985	1986*	1987*	1988	1989	1990
UPPER TORRIDGE	38	17	79	3	24	2	49	84
RIVER WALDON	22	4	14	1	11	1	5	15
RIVER LEW	16	20	98	-	15	5	29	45
RIVER OKEMENT	28	12	35	10	11	33	14	20
LOWER TORRIDGE	-	-	31	-	10	6	-	-
TOTAL	104	153	257	14	77	48	87	156

* Rivers high and coloured making observation of bed difficult.

Fig.4.22 Observations of spawning redds and adult salmon and sea trout in the Lew Catchment (Nov/Dec 1990).



Spawning salmon were observed in the middle reaches of the Hookmoor Brook and the Northlew Stream. Of particular interest is the concentration of redds observed at Southmoor on the Hookmoor Brook which coincide with the relatively high density of fry observed during electrofishing in this area (Figure 4.20).

4.5.3 Discussion

The survey results identify differences in the distribution and density of salmon and trout both within and between different parts of the Torridge Catchment.

The absence of juvenile salmon in the Cookbury Stream may be indicative of either a lack of spawning fish or high mortality in the embryo stage. Salmon are known to have spawned in the Stream in the late 1970's (pers comm. riparian owner), but a survey of 5.5 km of the main channel in November 1990 found no trace of redd cutting. The densities of trout are low by comparison with the other study tributaries suggesting either poor survival of the juvenile stages or unsuitability of habitat. It is possible however, in view of the limited number of sites surveyed that further surveys may identify isolated areas of higher trout density in the sub-catchment.

Juvenile salmon distribution in the Lew Catchment reflects a generally better recruitment of spawning fish to this river compared with the R. Waldon and other parts of the Upper Torridge. The distribution of both salmon fry and parr indicate that adult salmon penetrated the headwaters of both the Hookmoor Brook and Northlew Streams in 1988 and 1989, and the middle reaches of the Medland Brook in 1989. The numbers of parr observed were low however. The absence of salmon parr older than age 1+ may reflect early migration as older parr were also found to be absent in headwaters of the adjacent Tamar Catchment (Pers comm. K. Broad, NRA SW Fisheries Scientist).

The populations of trout fry and parr appear to be particularly strong in the headwaters of the three R. Lew study catchments, with densities of parr similar to those observed in the lower E. Okement. The overall decline in densities moving downstream may however possibly reflect increasing impaction as the drained area increases.

The impact of the 1989 acidic runoff event on the R. Okement is clearly shown in the low salmon and trout parr densities observed in the lower W. Okement and the main R. Okement and high densities in the unaffected E. Okement. It's occurrence just prior to the spawning period did not prevent migratory fish spawning but is believed to have severely affected the indigenous adult brown trout.

In the past electrofishing surveys on the Torridge (1964, 1975, 1979, 1986) were not undertaken in consecutive years and consequently historical temporal data on juvenile survival from year to year is not available. Consecutive annual surveys have however been undertaken on the River Lyd, in the adjacent Tamar Catchment, in 1988-90 as part of the Roadford Reservoir Environmental Investigation. Here eight sites yielded density changes from 0+ fry to 1+ parr the following year of -88.2% for 1988-89 and -92.06% for 1989-90. These changes in density are however considered high (pers comm NRA SW fisheries scientist) and there are concerns that this river may be suffering some kind of impaction. Corresponding data for the Girnock Burn, in Scotland (Buck and Hay, 1984) show a mean decline in juvenile salmon of -57.19% from fry to 1+ parr over the years 1968-75 (range -47.4 to 71%).

The 65-81% decline in salmon fry density on the Medland Brook relate to a shorter period than either study described above; from June/July to October/November. Such net losses of density do of course comprise a number of elements; mortality, immigration and emigration. Natural mortality is dependent on such factors as density, competition, predation and physical habitat features.

Sampling in the autumn has shown that temporal studies during the year are feasible however the number of sites that can be accommodated are fewer than in summer as both a shorter season and problems of higher flows more frequent flow events with high turbidity and problem of leaves fouling nets and collecting in trash dams.

It is recommended that summer sampling takes place in July/August as this avoids the preceding period of highest natural mortality of fry as territories are established (Broad, 1987; Elliot, 1984).

The use of Habscore has been identified as warranting further investigation. Since the system has not been used outside Wales before, predicted populations may not be directly comparable with the carrying capacity of North Devon Streams. The relative density between sites predicted by Habscore and actual densities observed in the field may be used to identify trends within a stream. Habscore will be of increasing use as it is calibrated for other UK areas during the lifetime of this project.

The overall results indicate a continued poor juvenile salmonid population in the Upper Torridge and R. Waldon. The effects of the 1989 acid runoff fish kill on the river West Okement and the Okement on salmon and trout parr have in addition reduced the numbers of one year old fish. The importance of the E. Okement as an unimpacted catchment is highlighted as it produced the highest density of salmon parr observed at any site in 1990. The Lew study catchments by comparison contain salmon fry but relatively few parr and reasonable trout stocks in their headwaters. The distribution and density of salmonids and survival of juveniles both within and between study catchments requires further investigation.

4.6 Other environmental factors and management practices affecting water quality and salmonid fish stocks

Introduction

Non-agricultural influence on the salmonid stock have been identified and are being monitored. These comprise of non-agricultural discharges to water courses, catchment management, exploitation of the stocks and predation.

4.6.1 Results

Sewage discharges

There are two small sewage treatment works within the study areas:

Northlew : Northlew Stream
Thornbury: Cookbury Stream

Some evidence of sewage fungus was discovered by project staff in February 1991 in the stream serving the Northlew facility at its confluence with the Northlew Brook (4.4.2). This is downstream of the continuous water quality monitor and has been reported to the relevant NRA SW Pollution Officer. During peak rainfall events discharges from storm overflows may occur.

Minor discharges have been found from overflowing cesspits at the foot of the Northlew and Hookmoor Brooks, both downstream of the continuous monitoring equipment, and these have been reported to NRA SW.

Industrial discharges

Industry within the Torridge Catchment is primarily associated with agriculture (dairy factories and abattoirs) and there is some quarrying, forestry, and light industry.

There are no industrial discharges on the study streams.

Quarrying and gravel abstraction

There are some small stone quarries within the study catchments, but three are mostly disused.

Farmers have an ancient right to abstract gravel from the riverbed for private use and this may have a local impact on individual spawning riffles. Evidence of abstraction has been found at one site on the Northlew.

Exploitation of adult salmonid stock

1. Angling

The Torridge rod catch of salmon for 1990 was 44, an improvement on the 19 taken in 1989, and derives mainly from a strong run of Spring Fish. 250 sea trout were taken. A voluntary rod limit imposed in 1990 is to be enacted as a by-law in 1991:

Salmon	:		2 per week	5 per season
Sea Trout	:	2 per day	3 per week	20 per season

2. Netting

No salmon or sea trout have been netted on the Taw/Torridge estuary in 1990 as the netsmen are being compensated not to fish for the next six years.

3. Poaching

The low summer flows and generally small runs of fish in the Torridge have reduced the incidence of poaching. A problem has developed at the foot of the E. Okement, where fish congregate in pools in the town of Okehampton, since the opening of Monkokehampton Weir in 1978 (4.1.3). Measures to ease the passage of fish through the town are under consideration.

Flow regime

The NRA SW Hydrometric Services are currently gauging each study tributary and flow ratings will be produced (4.3.1).

The River Torridge Management Plan

The development of the River Torridge Management Plan is being monitored with regard to its impact on the project. The Stage 1 'Statement of catchment uses and problem identification' has been released for public consultation. The

Stage 2 'Plan of Action' is being developed in conjunction with management plans for the River Taw and Taw/Torridge Estuary. The fisheries targets for the River Torridge identified in Stage 1 appear in Appendix C.

Predation

1. Birds

The Heron is found on all the study tributaries and is commonly cited by farmers as an 'alternative' cause for the decline of the Torridge salmon. Numbers do not appear to be higher than elsewhere in Devon however, and illegal killing in the Lew catchment is currently under investigation by the NRA.

Kingfishers are very infrequently encountered and the only wildfowl observed were Mallards.

2. Mammals

Devon County Council (DCC) have recently appointed an Otter Officer and the population of the Torridge is being surveyed. The Torridge appears to support a significant population and evidence of their presence has been found on the Okement, Lew and Waldon. A bitch with two grown cubs were observed making a feeding foray, three quarters of a mile up the Cookbury Stream on 1 March 1991

Numbers of mink are very low on the Torridge (pers comm NRA Warden and DCC Otter Officer) reflecting a general low incidence of the species throughout Devon (pers comm, NRA SW Conservation Officer).

3. Fish

There are no predatory fish other than salmonids in the Torridge. The population of eels, the diet of which may include fish eggs and small fish, is small.

4.6.2 Discussion

Industrial and domestic discharges do not appear to have any gross impact on the study streams.

Fishery management practices are being enacted with restrictions on rod catches and a ban on netting in an effort to improve the spawning stock. It should be stressed however that these are in response to the continuing decline in the migratory salmonid fish population and the effects are being monitored. The influence of flow regime, suspended solids and sediment deposition on spawning beds and access to spawning grounds is being considered.

It is not apparent that predation is a significant factor in the decline of the Torridge salmonid stocks from the evidence available from NRA staff and field observations by the project staff.

4.7 Invertebrate sampling

Samples of invertebrates have been collected from each of the electrofishing survey sites on the study tributaries and retained for examination.

The foot of each study stream has also been sampled by the NRA SW as part of it's 1991 biological survey. Sites on study catchments have been included in comparative work between NRA Welsh and SW Regions on a farm pollution invertebrate key being developed by WRc (Sources of farm pollution and impact on river quality, NRA Ref Nº A3.001/A3.012 (1.1.1a/2.2.1a)). The potential for using this key on the study catchments to identify areas of organic loading will be examined once this data has been analysed.

5. SUMMARY TO DATE

5.1 Study catchment selection

Five study catchments have been selected reflecting a range of land use from intensive dairy, beef and sheep farming to extensive grazing of beef and sheep. These have been characterised with respect to land use, water quality and salmonid population status during the first year's work.

5.2 Catchment characterisation

The area of unimproved grassland in study catchments outside the moorland area of the E. Okement is low (<5.7%) and there is extensive use of field drains in the improved pastures which dominate these areas. Relatively few field drains actually empty directly into the watercourses and much of the runoff is carried by ditches from fields on the higher ground, providing rapid transport into the watercourses.

Differences in gradient, flow and soil type have been identified between catchments and the influence of these on suspended solid and gravel sediment loadings requires further investigation. Erosion of banks by stock is common, especially on the Cookbury Stream. The protection of banksides is not a common management practice and there is little attempt to remove trash dams from watercourses.

The number of reported pollution incidents is relatively low, probably due to the sparsely populated nature of the catchments, and events are consequently often difficult to follow up. The full frequency and impact of historical farm pollution is therefore unclear.

Gross impacts from continuous farm discharges were not encountered during the 1990/91 field work and it appears therefore that the Farm Campaign of 1984-87 has been effective in this respect.

The Cookbury catchment has been identified as containing both fewer farms and a lower stock density than the three Lew study catchments. It was also found to contain fewer polluting farms during the Farm Campaign. This contrasts however with observations of the wild salmonid stock which is sparse in the Cookbury Stream and more abundant in the other three.

There are a number of management practices that may have an influence on water quality such as indoor overwintering of animals, waste disposal, silage production and fertilizer application. Many of these occur on a seasonal basis and further work is required to identify their relative importance between study catchments.

5.3 Water quality

Water quality has been demonstrated to be better in the E. Okement than the other four study catchments with lower BOD, ammonia and nitrite levels.

Flow events have been identified as the most important cause of poor water quality in the study catchments with rising water accompanied by peaks in unionised ammonia, suspended solids, BOD and nitrite. Elevated ammonia levels were in fact recorded throughout the Upper Torridge catchment during the exceptional spate conditions of Christmas and New Year 1990/91.

Turbidity has been identified as a specific problem on the Cookbury Stream, but rapid and sustained colouring from suspended solids is a feature of all the study streams, with the exception of the E. Okement during flow events.

These events do not appear to reach lethal levels for fish, however further measurements of the frequency, magnitude and duration are required to examine sub-lethal ecotoxicological effects. The relationship between water quality and seasonal agricultural practices also requires further investigation.

5.4 *In situ* bioassays

The use of *in situ* bioassays and the fish monitor are at an early stage but have been identified as crucial for linking any effects of the apparent frequent, but low level, pulses of poor water quality with effects on the wild fish populations. The use of caged juvenile salmon to monitor sound, growth and pathology in different study catchments is planned to continue throughout 1991/92 and the salmon egg bioassay will be repeated over the winter 1991/92.

5.5 Wild fish stocks

Within the study catchments the most significant juvenile salmonid populations were found in the E. Okement, which has a catchment mainly comprising of unimproved extensively farmed pasture. Poorer populations were found in the four intensively farmed study catchments, and salmon were absent in the Cookbury Stream.

Redd counting surveys reflect these findings in the distribution and number of spawning sites identified, being most numerous in the R. Okement catchment and least numerous in the R. Waldon. No spawning redds were observed in the Cookbury stream.

An apparent trend for density to decline from the headwaters downstream has been identified in the three study streams in the Lew catchment and it appears that the cause may not habitat related. The 'Habscore' habitat assessment system has been identified as a potentially useful tool in this respect.

Relatively low numbers of trout fry and parr were observed in the Cookbury Stream but further sampling in the headwaters may yield better densities as have been found in the Lew study catchments.

An initial investigation of temporal change in density has indicated that this method may yield useful comparisons of between study catchments. It is apparent, however, that field conditions and availability of resources in the autumn and winter require a rationalisation of any temporal electrofishing studies to ensure the maximum accuracy of population estimates and the best use of resources.

5.6 Other environmental and management factors

There are no significant industrial or domestic discharges into the study streams.

Fishery management practices involving restrictions on rod catches and a ban on netting are being enacted in an effort to improve the spawning stock. There has been an improvement between 1989 and 1990 in the numbers of redds observed.

The principle predators on the study catchments are herons and otters. The former is subject to illegal killing whilst the latter is relatively common by UK standards.

6. STRATEGY FOR FUTURE WORK

6.1 Introduction

This section sets out the proposed work programme, for the period April 1991 to April 1992.

The programme has been structured to build on the findings of the 90/91 work programme in addressing the following three major experimental areas:

(1) The influence of land use on river quality.

(2) The influence of river quality on individual salmonids.

(3) The consequences of observed ecotoxicological effects for the wild salmonid population.

```
           (1)                   (2)                   (3)
LAND USE -----> RIVER QUALITY -----> INDIVIDUAL -----> SALMONID
                                     SALMONIDS         POPULATION
```

6.2 Programme

6.2.1 The influence of land use on river quality

The specific objectives:

- To monitor specific land use practices within study catchments which are likely to influence river quality.

- To compare river quality in catchments with different land uses covering both the background and flow event situations.

o To investigate the loading of fines in the bed substrates of rivers in catchments with different land uses.

Study Catchment Selection

It is proposed that the number of study catchments is reduced from five to four, to afford the concentration of resources for a more intensive field work programme. As the three Lew Study Catchments have been shown to exhibit similar characteristics with regard to land use, water quality and fish population status, it is proposed that the Northlew Stream, whose numerous feeder streams make monitoring relatively difficult, is removed from the programme, retaining the Hookmoor and Medland Brooks.

Table 6.1 - Proposed study catchments for 1991/92 work programme

STUDY CATCHMENT	LAND USE	SALMONID POP'N
River East Okement	Extensive	Good
Hookmoor Brook	Intensive	Poor
Medland Brook	Intensive	Poor
Cookbury Stream	Intensive	V. poor

Land Use Practices

The primary land uses identified in the study catchments are dairy and livestock farming. Management practices have been identified which may have an influence on river quality, some on a seasonal basis (e.g. indoor overwintering of animals, slurry spreading and silage making).

Land use practices will be monitored using the existing NRA Farm Campaign database and direct consultation with a representative sample of farmers in each catchment. Key factors to be considered will include numbers/types of animal stocks, storage and disposal of animal wastes, cutting and storage of silage and application of pesticides.

Water Quality Monitoring

The 1990/91 monitoring has highlighted differences in water quality between the E. Okement and the more intensively farmed catchments. Specifically there is a deterioration in water quality during flow events, which whilst not apparently reaching lethal levels for salmonid fish, may have sub-lethal impacts. Further measurement of the frequency, magnitude and duration of events for different water quality parameters is therefore required in order to assess the consequences of these episodes on the fish population.

The continuous monitoring of D.O., pH, Temperature, Turbidity and Ammonia will continue using the existing stations at the foot of each study catchment.

Automatic sampling of flow events will also continue at each station. Laboratory analysis of these samples covers a wider range of parameters and provides a means of verifying the continuously monitored data. The background levels of these parameters will be monitored by a spot sampling programme comprising of one sample per monitoring station per week, collected during routine maintenance visits.

Serious pollution incidents will be investigated if identified and sources where possible. As a result of the reduction in the number of study catchments and additional purchases sets of spare equipment will be maintained and be available to alleviate the technical problems encountered during the first year.

Further analysis of the 1990/91 data will be undertaken once flow ratings for the study streams are available from NRA SW Region Hydrometric Services.

Sediment Sampling

The sediment analysis undertaken by Loughborough University identifies a relatively high concentration of fines in the gravels of all the study catchments except the E. Okement. The source appears to be land use-related and may be a result of increasing land drainage. The presence of elevated levels of fines has consequences both for general water quality (suspended solids) and the survival of eggs and alevins.

The loading of suspended solids in each study catchment will be addressed using the automatic and spot sampling programmes already described.

Further sampling of gravels will be commissioned to address within and between catchment concentration of fines (summer 1991) and the effect on egg survival (6.2.3).

6.2.2 The influence of river quality on individual salmonids

Specific objectives:

- To investigate the relationship between fish responses and river quality in catchments with differing land use.

- To examine fish survival, growth and physiological responses to water quality changes during flow events.

- To investigate the relationships between the composition and quality of river bed substrates and the survival and development of fish embryos in catchments with differing land use.

Juvenile salmon

The survival, growth and pathology of caged juvenile salmon will be examined in the Cookbury Stream, Hookmoor Brook and E. Okement. The cages are located adjacent to the water quality monitoring stations and the study will continue throughout the year, changing the fish at regular intervals. Pathological examination of samples from each catchment is being undertaken by the NRA Anglian Region Fish Laboratory.

Fish Monitor

The response of brown trout to changes in water quality during flow events is being examined using a caravan-mounted fish monitor, measuring gill ventilation rate. It has been deployed on the Hookmoor Brook for a three month trial period.

Embryo survival and development.

The 1990/91 salmon egg bioassay indicates a significantly higher survival in the E. Okement compared with the other study catchments, and further experimentation is required to confirm these observations and examine the causes.

The survival and development of salmon eggs in Harris boxes will be examined again during the 1991/1992 spawning season. The concentration of fines in the spawning gravel will be determined during development (Jan/Feb 1992). The feasibility of monitoring D.O. levels within egg baskets is being examined.

6.2.3 The consequences of observed ecotoxicological effects for the wild salmonid population

Specific objectives:

- To quantify the observed differences in juvenile salmonid populations between extensively and intensively farmed study catchments.

- To confirm and quantify the observed downstream decline in juvenile salmonid densities in the intensively farmed study catchments.

- To compare the observed reduction in density in juvenile salmonid populations between extensively and intensively farmed study catchments.

The 1990 surveys have indicated spatial and temporal differences in salmonid density both between and within study catchments, particularly the apparent downstream decline in density in the three Lew study catchments and the absence of salmon in the Cookbury Stream. Temporal declines in density have also been observed from the repeat surveys in Oct/Nov 1990.

The Technical Meeting (Jan 1991) determined that the resources available for electrofishing surveys should be concentrated on one intensively and one non-intensively farmed study catchment. The E. Okement (non-intensive) and the Hookmoor Brook, typical of the three intensively farmed Lew study catchments, have subsequently been selected. Long-term population changes in the Torridge will also continue to be monitored via the NRA SW routine fisheries survey of the Torridge in 1991, which will be a repeat of the NRA's 1990 survey.

Quantification of differences in juvenile salmonid density between the E. Okement and Hookmoor Brook and confirmation of the downstream decline in the Hookmoor Brook

Ten sites on the E. Okement (target area 1.5 km) and 30 sites on the Hookmoor Brook (target area 8 km) will be quantitatively sampled in July/Aug. The application of appropriate equations (Bohlin, 1989) to quantitative data collected in 1990 has shown that this number of sites will detect a difference in density by a factor of 1.5 with a probability of 80% (precision level two; Bohlin, 1989).

The commencement of sampling in July will ensure that salmonid fry are large enough to sample efficiently and avoids the preceding period of high natural mortality.

The length of survey sites will be 60 m, which was found in 1990 to incorporate the full habitat range of riffle/pool/glide found in study streams.

Individual length, weight and age (0+, 1+, 2+, etc.) will be recorded to enable comparison of age distribution and growth rates of juvenile salmonids between the two streams

HABSCORE surveys will be undertaken on each site at the time of electrofishing. This will enable differences in the habitat quality of the two streams to be quantified and will aid the interpretation of the differences in the salmonid densities both within and between the streams in relation to water quality.

Population differences between the streams will be interpreted in relation to the ecotoxicological experiments in both study catchments.

Confirmation of the status of the juvenile salmonid population in the Cookbury Stream

A semi-quantitative survey of eight sites on the Cookbury stream will be undertaken in June to confirm the results of the 1990 survey. This will include four sites in the headwaters, which have not been previously surveyed.

The presence of fry will be specifically examined since no spawning was observed in the main channel in 1990/91.

This survey will additionally serve as a training exercise for the new project staff members, before the quantitative summer surveys.

Comparison of temporal decline in juvenile salmonid populations between the E. Okement and Hookmoor Brook.

The E. Okement and the Hookmoor Brook will be re-surveyed in the autumn (Oct/Nov) and winter (Jan/Feb), quantitatively, using the sites surveyed in Jul/Aug.

Observed changes in density will be statistically compared between the E. Okement and Hookmoor Brook.

The spatial pattern of observed decline will be examined within the E. Okement and Hookmoor Brook.

Spatial and temporal patterns of population decline will be interpreted in relation to the results of the ecotoxicological and water quality investigations.

6.2.4 Other environmental and management factors

Specific objectives:

- o To investigate the effect of non-agricultural influences on the wild fish population.
- o The exploitation and management of the salmonid stock will be assessed from data provided by the NRA SW Region.
- o Non-agricultural discharges to the study catchments will continue to be examined when encountered and pollution reports to the NRA SW Region will be monitored.
- o The options for identifying the density of predatory species and their potential impacts on the wild fish populations will be examined.

REFERENCES

Bohlin, T. (1989) Electrofishing - Theory and practice with special emphasis on salmonids. *Hydrobiologia* **173**, 9-43.

Broad, K.J. (1987) Population dynamics of juvenile salmon of the River Wye. Unpublished PhD Thesis, UWIST, Cardiff.

Buck, R.J.G. and Hay, D.W. (1984) The relationship between stock size and progeny of Atlantic salmon, Salmo salar L., in a Scottish stream. *J. Fish. Biol.* **23**, 1-11.

CEC (COUNCIL OF THE EUROPEAN COMMUNITY) (1978) EEC Council Directive of 1978 on the quality of fresh waters needing protection or improvement in order to support fish life', 78/659.

Elliot, J.M. (1984) Numerical changes and population regulation in young migratory trout *Salmo trutta* in a Lake District stream. *J. Anim. Ecol.,* **53,** 327-350.

Harrod, T.R. (1987) Soils and Land Use in the Upper Tamar and Torridge Catchments.

Milner, N.J., Hemsworth, R.J. and Jones, B.E. (1985) Habitat evaluation as a fisheries management tool. *J. Fish Biol.* **27** (Supplement A), 85-108.

NRA (1990) Torridge Catchment Management Plan. NRA South West Region.

O'Donnell, A.R., Mance, G. and Norton, R. (1984) A Review of the Toxicity of Aluminium in Fresh Water. Technical Report TR197, WRc Medmenham.

Seager, J., Wolfe, E.W. and Cooper, V.A. (1988) Proposed Environmental Quality Standards for List II substances in water. Ammonia Technical Report TR260, WRc Medmenham.

Solbé J. (1988) Water Quality for Salmon and Trout. Atlantic Salmon Trust.

APPENDIX A

PROBABILITY OF CAPTURE AND CAPTURE EFFICIENCY FOR SUMMER FISHERIES SURVEY SITES

PROBABILITY OF CAPTURE AND CAPTURE EFFICIENCY FOR SUMMER FISHERIES SURVEY SITES

		SALMON FRY							SALMON PARR						
		RUN 1	2	3	4	POPN	PROB OF CAPTURE	CAPTURE EFFIC-IENCY	RUN 1	2	3	4	POPN	PROB OF CAPTURE	CAPTURE EFFIC-IENCY
WEST OKEMENT NRA															
WO 1	VELLAKE														
WO 2	MELDON	4	2	1		8	0.5	87.5	3	0	0		4	0.5	75
WO 3	GOLF	0	0	0		0			3	0	0		4	0.5	75
WO 4	CASTLE	4	4	1		10	0.5	90	2	0	0		3	0.4	66.7
EAST OKEMENT															
E 1	D RANGE	0	0	0		0			0	0	0		0		
E 2	HARTHILL	0	0	0		0			0	0	0		0		
E 3	CULLEVER	0	0	0		0			0	0	0		0		
E 4	FATHERFORD	7	13	5		53	0.19	47.2	22	24	10		63	0.31	57.5
E 5	SCHOOL	14	8	1		24	0.63	95.8	33	19	9		70	0.48	87.1
R.OKEMENT NRA															
O 1	WOODALL	182	119	66		472	0.39	77.7	3	0	0		4	0.5	75
O 2	IDDESLEIGH	114	61	43		275	0.41	79.3	2	0	3		13	0.14	39
O 3	ABBEY	115	61	36		253	0.45	83.8	18	11	6		41	0.46	85.4
O 4	DORNAFORD	119	124	81	44	523	0.26	70.4	1	2	0	0	4	0.37	75
MEDLAND BROOK															
M 1	TOAD	0	0	0		0			0	0	0		0		
M 2	CURWORTHY	1	0	0		2	0.25	50	0	0	0		0		
M 3	STOCKEN	8	6	3		20	0.45	85	0	0	0		0		
M 4	MED BRIDGE	9	3	3		16	0.55	93.7	0	0	0		0		
HOOKMOOR BROOK															
H 1	SOUTHMOOR	31	16	10		67	0.46	85.1	2	0	0		3	0.40	66.7
H 2	GORHUISH	3	6	2		16	0.30	68.7	1	2	0		4	0.37	75
NORTHLEW STREAM															
N 1	WIGDON	5	1	1		8	0.54	87.5	0	1	0		2	0.20	50
N 4	NORTHLEW	3	4	0		8	0.50	87.5	0	0	0		0	0.00	0
COOKBURY STREAM															
C 1	PORTLANE	0	0	0		0			0	0	0		0		
C 2	MOOR	0	0	0		0			0	0	0		0		
C 3	DUNSLANE	0	0	0		0			0	0	0		0		
C 4	BASON	0	0	0		0			0	0	0		0		

		TROUT FRY							TROUT PARR						
		RUN 1	2	3		POPN	PROB OF CAPTURE	CAPTURE EFFIC-IENCY	RUN 1	2	3		POPN	PROB OF CAPTURE	CAPTURE EFFIC-IENCY
WEST OKEMENT NRA															
WO 1	VELLAKE	21	6	3		31	0.67	96.8	55	15	4		75	0.74	98.66
WO 2	MELDON	18	7	4		31	0.58	93.5	19	6	6		34	0.53	91.2
WO 3	GOLF	1	1	0		3	0.33	66.7	5	2	0		8	0.55	87.5
WO 4	CASTLE	1	1	1		4	0.33	75	6	0	2		11	0.59	90.3
EAST OKEMENT															
E 1	D RANGE	1	0	2		5	0.23	60	45	16	3		67	0.63	95.5
E 2	HARTHILL	1	0	2		5	0.23	60	55	17	9		84	0.65	96.4
E 3	CULLEVER	1	0	0		2	0.25	50	92	22	14		132	0.67	97
E 4	FATHERFORD	11	16	2		33	0.39	78.9	11	9	3		26	0.49	88.5
E 5	SCHOOL	23	12	5		43	0.56	93	38	17	9		70	0.55	91.4
R.OKEMENT NRA															
O 1	WOODALL	11	6	4		24	0.47	87.5	0	0	0		0		
O 2	IDDESLEIGH	2	0	0		3	0.4	66.7	8	4	2		15	0.56	93.3
O 3	ABBEY	3	5	5					3	10	3		46	0.13	34.8
O 4	DORNAFORD	9	10	11	4	55	0.19	58.6	0	0	0	0	0	0	0
MEDLAND BROOK															
M 1	TOAD	53	23	12		96	0.55	91.7	9	2	1		13	0.63	92.3
M 2	CURWORTHY	104	49	14		177	0.61	94.3	23	2	0		26	0.83	96.1
M 3	STOCKEN	33	18	6		62	0.56	91.9	14	2	0		17	0.76	94.1
M 4	MED BRIDGE	16	3	1		21	0.71	95.2	3	0	0		4	0.5	75
HOCKMOOR BROOK															
H 1	SOUTHMOOR	29	11	3		44	0.68	97.7	13	4	0		18	0.71	94.4
H 2	GORHUISH	8	4	1		14	0.59	92.9	5	5	1		12	0.52	91.7
NORTHLEW STREAM															
N 1	WIGDON	30	17	10		68	0.45	83.8	12	2	1		16	0.68	93.7
N 4	NORTHLEW	8	15	6		68	0.17	42.6	4	2	5		59	0.07	18.6
COOKBURY STREAM															
C 1	PORTLANE	4	0	0		5	0.57	80	0	0	0		0		
C 2	MOOR	1	1	0		3	0.40	66.7	5	1	0		7	0.67	85.7
C 3	DUNSLANE	0	0	0		0			0	0	0		0		
C 4	BASON	0	0	0		0			1	0	0		2	0.25	50

APPENDIX B

WATER QUALITY PARAMETERS

WATER QUALITY PARAMETERS

	NRA ROUTINE SAMPLING
pH	X
CONDUCTIVITY	X
WATER TEMP	X
DO % SATURATION	X
DO mg/l 0	X
BOD, 5 DAY	X
ORGANIC CARBON	X
NITROGEN AMMONIACAL mg/l	X
NITRATE mg/l	X
NITRITE ug/l	X
AMMONIA UNIONISED mg/l	X
SUSPENDED SOLIDS @ 105 °C	X
SUSPENDED SOLIDS (ASH)	X
TOTAL HARDNESS	X
CHLORIDE mg/l	X
ORTHO-PHOSPHATE mg/l	X
SILICATE, REACTIVE mg/l	X
SULPHATE, DISSOLVED mg/l	X

NWC RIVER QUALITY CLASSIFICATION SYSTEM

River Class	Quality criteria	Remarks	Current potential uses
	Class limiting criteria (95 percentile)		
1A Good Quality	(i) Dissolved oxygen saturation greater than 80% (ii) Biochemical oxygen demand not greater than 3 mg/l (iii) Ammonia not greater than 0.4 mg/l (iv) Where the water is abstracted for drinking water, it complies with requirements for A2* water (v) Non-toxic to fish in EIFAC terms (or best estimates if EIFAC figures not available)	(i) Average BOD probably not greater than 1.5 mg/l (ii) Visible evidence of pollution should be absent	(i) Water of high quality suitable for potable supply abstractions and for all abstractions (ii) Game or other high class fisheries (iii) High amenity value
1B Good Quality	(i) DO greater than 60% saturation (ii) BOD not greater than 5 mg/l (iii) Ammonia not greater than 0.9 mg/l (iv) Where water is abstracted for drinking water, it complies with the requirements for A2* water (v) Non-toxic to fish in EIFAC terms (or best estimates if EIFAC figures not available)	(i) Average BOD probably not greater than 2 mg/l (ii) Average ammonia probably not greater than 0.5 mg/l (iii) Visible evidence of pollution should be absent (iv) Waters of high quality which cannot be placed in Class 1A because of the high proportion of high quality effluent present or because of the effect of physical factors such as canalisation, low gradient or eutrophication (v) Class 1A and Class 1B together are essentially the Class 1 of the River Pollution Survey (RPS)	Water of less high quality than Class 1A but usable for substantially the same purposes
2 Fair Quality	(i) DO greater than 40% saturation (ii) BOD not greater than 9 mg/l (iii) Where water is abstracted for drinking water it complies with the requirements for A3* water (iv) Non-toxic to fish in EIFAC terms (or best estimates if EIFAC figures not available)	(i) Average BOD probably not greater than 5 mg/l (ii) Similar to Class 2 of RPS (iii) Water not showing physical signs of pollution other than humic colouration and a little foaming below weirs	(i) Waters suitable for potable supply after advanced treatment (ii) Supporting reasonably good coarse fisheries (iii) Moderate amenity value

3 Poor Quality	(i) DO greater than 10% saturation (ii) Not likely to be anaerobic (iii) BOD not greater than 17 mg/l. This may not apply if there is a high degree of re-aeration	Similar to Class 3 of RPS	Waters which are polluted to an extent that fish are absen only sporadically present. May be used for low grade industrial abstraction purposes. Considerable potential for further use if cleaned up
4 Bad Quality	Waters which are inferior to Class 3 in terms of dissolved oxygen and likely to be anaerobic at times	Similar to Class 4 of RPS	Waters which are grossly polluted and are likely to cause nuisance
X	DO greater than 10% saturation		Insignificant watercourses and ditches not usable, wher the objective is simply to prevent nuisance developing

Notes (a) Under extreme weather conditions (eg flood, drought, freeze-up), or when dominated by plant growth, or by aquatic plant decay, rivers usually in Class 1, 2, and 3 may have BODs and dissolved oxygen levels, or ammonia content outside the stated levels for those Classes. When this occurs the cause should be stated along with analytical results.

(b) The BOD determinations refer to 5 day carbonaceous BOD (ATU). Ammonia figures are expressed as NH_4. **

(c) In most instances the chemical classification given above will be suitable. However, the basis of the classification is restricted to a finite number of chemical determinands and there may be a few cases where the presence of a chemical substance other than those used in the classification markedly reduces the quality of the water. In such cases, the quality classification of the water should be down-graded on the basis of biota actually present, and the reasons stated.

(d) EIFAC (European Inland Fisheries Advisory Commission) limits should be expressed as 95 percentile limits.

* EEC category A2 and A3 requirements are those specified in the EEC Council directive of 16 June 1975 concerning the Quality of Surfa Water intended for Abstraction of Drinking Water in the Member State.

** Ammonia Conversion Factors

(mg NH_4/l to mg N/l)

Class 1A	0.4 mg NH_4/l = 0.31 mg N/l
Class 1B	0.9 mg NH_4/l = 0.70 mg N/l
	0.5 mg NH_4/l = 0.39 mg N/l

APPENDIX C

NRA SW RIVER TORRIDGE MANAGEMENT PLAN - FISHERIES TARGETS

General

The overall objective for the Torridge fishery can be summarised as the recovery of the game fishery to a suitable level that will support the commercial and sport fishery interests and allow sufficient escapement for natural production. Appropriate targets for salmon, sea trout and brown trout populations need to be set. Parr production levels are seen as the most meaningful indicators of stock recovery.

Local Perspective

Targets will be set for fisheries in more detail in Stage 2 including:

(i) Establishing levels of parr and fry production for different parts of the catchment based on the 1964 survey levels;

(ii) Ensuring the provision of adequate spawning areas and nursery territory;

(iii) Maintaining access for migratory fish to spawning territory by the establishment and maintenance of fish passes and the removal of trash dams;

(iv) Establishing adequate enforcement measures to protect migratory fish;

(v) Proposing cropping levels for the commercial and rod fisheries;

(vi) Maintaining adequate monitoring of fish stock levels;

(vii) Ensuring flows provide sufficient dilution for effluents, particularly in spawning and nursery areas;

(viii) Ensuring barriers to the movements of migratory fish are not formed by sewage effluent outlets.

(ix) Controlling agricultural effluent disposal to protect juvenile salmonid stocks which are particularly at risk from this source of pollution.

APPENDIX D

SEDIMENTOLOGICAL INVESTIGATION OF SPAWNING GROUNDS IN THE STUDY CATCHMENTS BY LOUGHBOROUGH UNIVERSITY

SEDIMENTOLOGICAL INVESTIGATION OF FISH SPAWNING GROUNDS IN THE TORRIDGE CATCHMENT

1990

Prepared by Loughborough University of Technology
in accordance with document CS 4018
for the WRc

Project Supervised by: Professor G.E. Petts

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CONTENTS

1. Summary

The Freshwater Environments Group at Loughborough University was commissioned by the WRc to investigate the sediment characteristics of streams in the River Torridge catchment, Devon.

This report presents data on particle-size distributions and geochemistry for five selected salmon spawning grounds on the Rivers Lew, Waldon and Okement. A well established freeze-core method was employed to obtain representative samples and over 100 kg of sediment were recovered. All samples were taken in November 1990.

Particle-size analysis revealed that the spawning grounds have a structure typical of 'upland' catchments, being dominated by a coarse-gravel framework beneath an armour layer of coarse and medium gravel. The ground on the River Okement, which directly drains the moorland area, comprises very coarse sediments (49% coarser than 37.5 mm) forming a open framework structure with a poorly developed matrix (10 % finer than 2 mm). The coarse armour layer and lack of vertical granulometric zonation within the substrate profile suggest that disruptive, high magnitude events control the 'unconsolidated' sediment of this spawning area.

The grounds on the Lew and Waldon rivers are also characterised by a coarse framework (22 % by weight coarser than 37.5 mm) but contain a well developed matrix with between 16 and 20 % by weight finer than 2 mm. Fines are concentrated in the lower 15 to 30 cms of substrate: the upper 15 cm contains about 10 % sub 2 mm whereas the 15-30 cm layer contains an average of about 26 per cent.

Geochemical analyses of the sub-0.125 mm fraction demonstrate the underlying geology and show little evidence of anthropogenic contamination. Relatively high concentrations of arsenic, copper, lead, tin and zinc are found close to the moorland area (the East Okement site), reflecting natural mineralisation. However, the highest metal loadings (gm^{-3}) are found in Hookmoor Brook (River Lew) which drains the moorland area and retains significant proportions of fine-grained particles.

2. Background.

This report presents the results of a survey undertaken to investigate the nature of channel-bed sediments in the Torridge catchment, Devon. The work, undertaken on behalf of the WRc, is an integral part of a three year project the prime objective of which is to identify the factors responsible for an observed deterioration in local salmonid populations.

The majority of channel-bed sediments in south-west England are dominated by coarse gravels and typically comprise a protective 'armour layer' of cobbles on the surface (created by selective winnowing of the fine-grained sediments), underlain by a dominant framework of coarse particles (2 to 64 mm). The framework is interspersed with a finer matrix of sands, silts and clays.

The exact granulometric composition of channel-bed sediments can influence the habitat quality of fish spawning reaches. The dominant particle-size fractions within the substrate determine the compaction and permeability thus directly influencing the success of salmonid redd formation. In addition the stability of the channel substrates will directly affect rates of egg and fry survival and, through influencing the benthic invertebrate populations, may indirectly affect the development of young fish (Petts and Greenwood 1985).

Research has shown that some heavy metals associated with the finer sediment fractions may become incorporated into the channel-bed substrate (Thoms 1988, Petts et al 1989). If supply is continuous, potentially toxic concentrations of some elements may accumulate and (under the restraints of bio-availability) degrade the habitat quality.

The composition of channel-bed sediments is influenced by the dominant hydrological regime and fluctuations in catchment sediment dynamics. Both the granulometric and geochemical characteristics of the sediment supply may respond to changes in local land-use.

3. Objectives.

This report provides data on the granulometric and geochemical nature of channel-bed materials at five separate salmonid spawning riffles in the Torridge catchment. The study allows a direct comparison of the sedimentology between catchments of different hydrological and sedimentological characteristics.

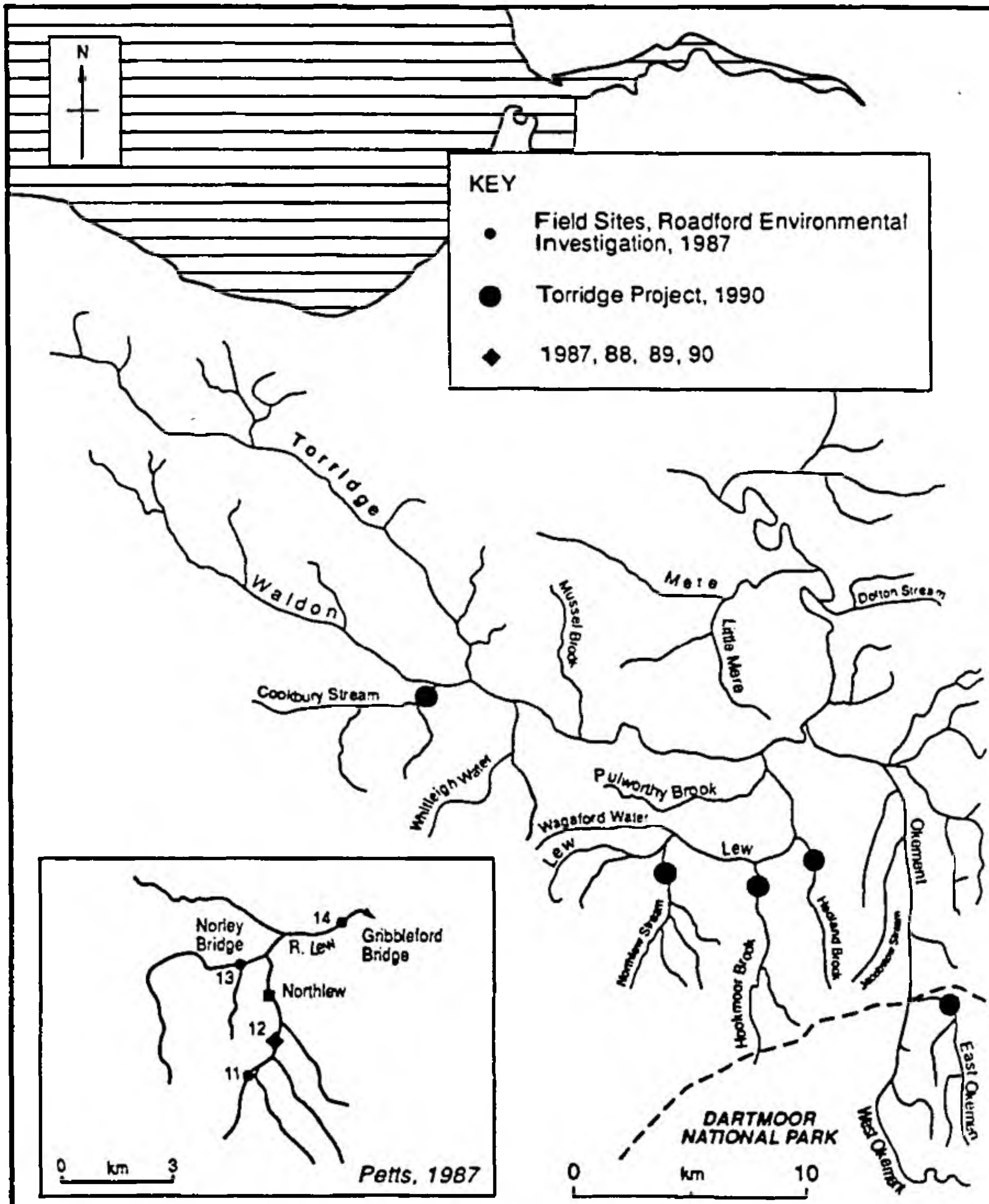
3.1 Site Location.

The River Torridge drains an upland catchment situated to the north of the Dartmoor granite batholith and underlain by impermeable, Palaeozoic strata. The study sites (shown in Figure 1) are on the rivers Lew, Waldon and the Okement.

River Lew:		
Medland Brook	(GR 548031)	These are north flowing steams, Hookmoor Shreve Number* 5, 7 and 8 respectively
Hookmoor Brook	(GR 531007)	
Northlew Stream	(GR 507990)	
River Waldon:		
Cookbury Stream	(GR412080)	A south-east north-west flowing stream, Shreve Number 17.
River Okement:		
East Okement	(GR 603948)	North flowing, Shreve Number 6 with the most southern reaches draining the extreme northern flank of Dartmoor.

* Shreve Number is determined from the blue-line network on O.S. 1:25,000 maps as the sum of first-order streams or finger-tip tributaries.

Figure 1. The Torridge Catchment



4. Methodology

4.1 The Field Survey

The five sites were sampled in November 1990. The armour layer was sampled using a Wolman Grid method. The intermediate axis length of 100 particles was recorded and used to determine the average and maximum particle-size at each site.

The substrate sediments were sampled to a depth of 30 cms using an established freeze-core sampling method (Petts et al 1989). At each site a minimum composite 'frozen' weight of 20 kg was obtained using no fewer than 5 cores. Upon extraction, each core was examined visually for distinct differences in granulometry. In the majority of cases the upper core sections (0 - 15 cms from surface) contained fewer fines, had more void spaces and were generally less compact - the core was then split accordingly into two parts, an upper- and a lower-core section. On the East Okement stream, visual differences were not apparent but to enable comparison with the other samples the core was simply divided into two sections of equal length.

4.2 Laboratory Analysis

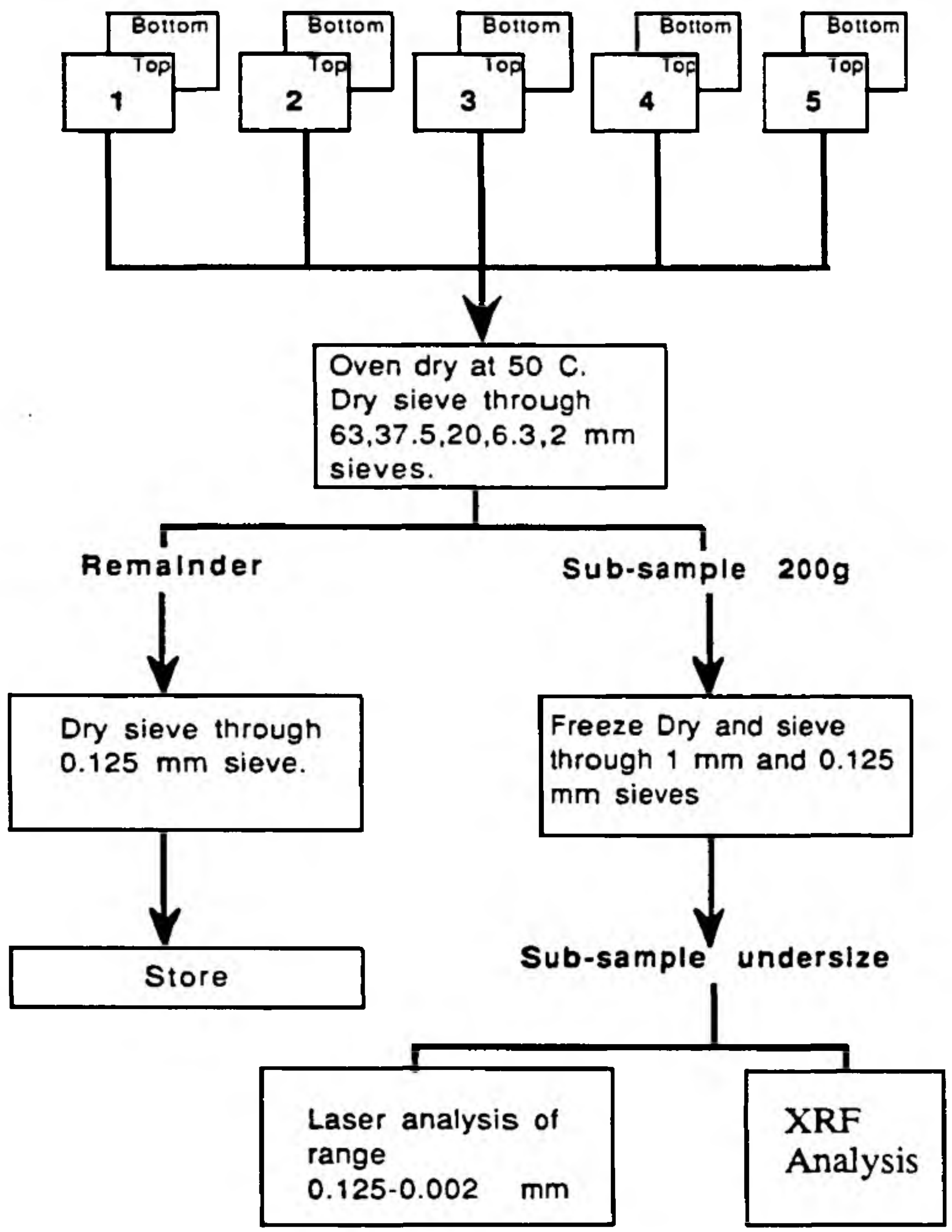
Sample preparation followed the procedure set out in Figure 2. The material was oven dried and passed through a series of nested sieves of meshes 63 mm, 37.5 mm, 20 mm, 6.3 mm, and 2 mm. A sub-sample of the material passing the 2 mm mesh (the matrix) was freeze-dried and sieved through 1.0 mm and 0.125 mm mesh sieves. The material passing the 0.125 mm sieve was analysed to 0.002 mm using a Malvern Laser Sizer; analyses were repeated three times on each sub-sample.

The sub 0.125 mm fraction was analysed for organic content by loss on ignition and a range of 28 elements using X-ray fluoresence spectrometry (Harvey and Atkin 1982) at Nottingham University. The XRF (Philips PW 1400) is calibrated against Geochemical Reference Samples including the United States Geological Survey CANMET and SARM standards. The analysis procedure was chosen to produce analyses with a detection limit of 1 ppm for all trace metals. The precision (reproducibilty) varies from +100 % at the detection limit to +5 % at 100 ppm.

4.3 Presentation of Results

Full results are given in tabular format in the Appendix section. The main body of the report contains summary data.

Figure 2. Flow chart of laboratory procedure.



5. Results

5.1 The Armour Layer

Table 1 presents a summary of the surface particle dimensions (armour layer) and size distributions for the coarse substrate framework. Overall the study sites are overlain by an armour layer with an average mean 'B' axis of 53 mm and an average maximum armour layer particle size of 161 mm. Cookbury stream has the smallest armour layer particles with a mean 'B' axis of 49 mm and a maximum of 101 mm. On the River Lew, the Hookmoor and Northlew sites have a similar armour layer composition with a mean 'B' axis of about 50 mm. The Medland Brook armour layer is coarser with a mean of 61 mm. The East Okement stream has the coarsest armour layer with a mean 'B' axis of 66 mm and the largest maximum particle size of 190 mm.

TABLE 1 Summary of River Torridge Site Based Grain Characteristics

Site	Armour B Axis (cms)		Substrate		
	Mean	Max	D50	%>37.5mm	%>6.3mm
Hookmoor Brook	4.9	14.0	20.4	29.42	70.89
Northlew	5.0	16.0	14.4	22.95	66.52
Medland Brook	6.1	18.5	16.6	24.8	66.85
East Okement	6.6	19.0	36.8	49.52	79.47
Cookbury	4.1	10.5	23.4	33.28	71.62

5.2 Substrate Characteristics

Twenty-seven cores were collected yielding a total sample weight of 117.5 kg. After drying the sample weights averaged 21.3 kg per site. Table 2 presents a summary of the sample dimensions. The average individual core weight was 4.5 kg and the average core length 31 cms. The cut-off point between the upper and the lower core sections averaged 14.9 cms.

TABLE 2 Summary of Freeze-Core Sample Data.

Site	Core Dimensions (cms)		Total Weight (kgs)	
	Average Length	(upper section)	Wet	(dry)
Hookmoor Brook	29.4	(12.8)	23.0	(21.10)
North Lew	32.7	(16.0)	22.0	(20.28)
Medland Brook	33.6	(17.0)	21.5	(17.99)
East Okement	30.1	(17.0)	25.0	(23.96)
Cookbury	29.2	(11.6)	26.0	(23.15)

5.3 The Substrate Framework

Appendix One contains the full framework size distribution, summary data are presented in Table 1. Coarse gravels dominate the substrate at all sites with over 22 % (by weight) being greater than 37.5 mm in diameter and over 66 % greater than 6.3 mm. The sites on the River Lew (Medland, Hookmoor and Northlew) and Cookbury stream contain between 22 and 34 % material coarser than 37.5 mm. There is little variation between these four sites for the proportion greater than 6.3 mm (between 66 and 72 %). The substrate at East Okement however, is distinctly coarser than the other sites with nearly 50 % coarser than 37.5 mm and nearly 80 % coarser than 6.3 mm. The D_{50} particle size on the East Okement exceeds the mean on the River Lew sites by a factor of two and is about 1.5 times that of the Cookbury stream substrate.

Referring again to the plus-37.5 mm and the plus-6.3 mm size fractions, the River Lew substrates indicate a 'coarsening upwards' in the vertical profile (Table 3). The upper-core sections (15 cms from surface) contain, on average, over 130 % more plus-37.5 mm material and 29 % more plus-6.3 mm material than the lower-core sections. Proportions of coarse-gravels (larger than 37.5 mm) are smaller in the lower-core sections of Hookmoor and Northlew streams. This 'coarsening upwards' is also present in the Cookbury substrates although slightly less distinct with over 62 % more plus-37.5 mm and over 15 % more plus-6.3 mm material being found in the upper-core sections. In the East Okement stream however, there is no significant difference in the coarse gravel content of the upper- and lower-core sections (less than 2 % and 5.5 % differences for the same two size fractions respectively).

TABLE 3 Proportion of Coarse-grained Particles in the Upper- and Lower-Core Sections

Site	% > 37.5 mm			% > 6.3 mm		
	Upper-core	Lower core	Ratio L:U	Upper-core	Lower core	Ratio L:U
Hookmoor Brook	38.03	10.00	(0.26)	75.72	60.00	(0.79)
Northlew	32.00	7.52	(0.23)	73.75	54.2	(0.73)
Medland Brook	25.49	23.62	(0.93)	72.36	57.48	(0.79)
East Okement	49.84	49.04	(0.98)	80.12	76.04	(0.95)
Cookbury	38.90	23.88	(0.61)	75.44	65.4	(0.87)

5.4 The Substrate Matrix.

The freeze-core samples yielded between 3 and 4 kg of matrix (sub-2 mm) material at each of the sites on the River Lew and Cookbury stream - the substrates containing between 16 and 20 % (by weight) matrix material. The East Okement stream however, has a very poorly developed matrix and the freeze-core samples yielded less than 2.4 kg of matrix - a proportional weight of below 11 %. Full details of the matrix sediment distributions are given in Appendix 2, but Table 4 shows weighted mean core values for the fine-grained fractions.

TABLE 4. The Size Distributions of the River Torridge Matrix Sediments.

Site	**Percentage in Size Fraction (mm)**					
	Total Matrix	2-1	1-0.125	0.125-0.01	0.01-0.002	<0.002
Hookmoor	(16.26)	5.02	5.27	3.10	2.61	0.26
Northlew	(19.53)	6.22	7.3	3.36	2.42	0.24
Medland	(17.73)	7.61	6.73	1.50	1.66	0.17
East Okement	(10.17)	4.86	5.01	0.23	0.07	0.01
Cookbury	(19.11)	6.00	8.00	2.81	2.07	0.23

The matrix sediments of the East Okement stream are particularly deficient in the sub-0.125 mm fractions, containing approximately 95 % less than the substrates on the Rivers Lew and Waldon. The East Okement also contains over 55 % less sub 1 mm material than the other sites. However, considering the matrix in isolation, the results demonstrate that on the East Okement, the matrix is dominated by the 1 > 0.125 mm fraction which comprises 49 % by weight. This compares with 42 % for Cookbury stream, 37 % for the Northlew and Medland sites and 32 % for the Hookmoor site. Differences between sites are emphasised by reference to the sub-0.01 mm fractions within the matrix: the East Okement having 0.8 %; Medland 10.3 %; Cookbury and Northlew 13.5 % and Hookmoor 17.6 %

All of the lower-core sections (15-30 cms) in the River Lew and Cookbury stream are more enriched (by between a factor of 1.6 and 1.8) in matrix material than the upper-core sections (refer to Appendix 2). There is, however, no significant vertical variation in matrix content in the East Okement stream. In fact, the East Okement core profiles show a very slight 'inverse' fine-grained sediment loading with the upper-core sections containing slightly more of the sub-2 mm fraction than the lower-core sections.

When the matrix material size distributions are examined in more detail, the difference between the upper- and lower-core sections is still evident. Table 5 summarizes the difference for the sub-1 mm and the sub-0.125 mm material. The lower 15-30 cms of substrate contain between 1.5 and 1.7 times more sub 1 mm material in the River Lew sites, whilst in Cookbury stream the lower-core sections contain nearly twice the levels found in the upper 15 cms of gravel. For the finer sub-0.125 mm fraction, similar vertical distributions are found in the River Lew sites and Cookbury stream. The upper- and lower-core sections in the East Okement however, show very little vertical difference in proportions of the sub-1 mm material. The very low quantity (less than 0.3 % by weight) of sub-125 mm material do show a graded vertical distribution.

The grain-size distributions of the matrix sediments are highly variable both between sites and with depth (Table 5). In comparison to other sites, negligible amounts of the sub-0.01 mm sediments occur in the East Okement stream. Although absolute values differ, in both the Northlew and Medland sites higher concentrations occur in the surface layer whereas on Cookbury higher concentrations occur in the 15 - 30 cms layer. Uniform levels are found throughout the profile at Hookmoor Brook.

TABLE 5 Proportion of Fine-grained Sediment in the Upper- and Lower-Core Sections

Site	% < 1.0 mm			% < 0.125 mm			% of 2 mm fraction less than 0.01 mm	
	Upper-core	Lower core	Ratio L:U	Upper-core	Lower core	Ratio L:U	Upper-core	Lower core
Hookmoor Brook	9.32	15.55	(1.67)	4.76	8.69	(1.82)	19	20
Northlew	10.64	17.88	(1.69)	4.94	7.86	(1.61)	17	13
Medland Brook	8.26	12.74	(1.53)	2.77	4.26	(1.54)	13	10
East Okement	5.52	5.01	(0.91)	0.25	0.39	(1.56)	<1	1
Cookbury	9.82	18.64	(1.87)	3.39	8.00	(2.38)	11	126

5.5 Fine Sediment Geochemistry.

The sub-0.125 mm fraction was analysed for 28 elements (Appendix 3). Levels of all elements vary widely with location according to both natural and anthropological inputs. However, some reference to typical values can be drawn from sources such as the Wolfson Geochemical Atlas of England and Wales (Webb et al 1978). Table 6 summarises concentrations of those elements that are significantly above the expected background levels.

TABLE 6 Concentrations of Selected Elements, in the River Torridge Catchment

Site	Element (ppm)								
	As	Cr	Cu	Pb	Sb	Sn	W	Zn	Zr
Hookmoor	12	120	55	30	2	135	4	470	226
Northlew	14	216	54	30	2	128	2	837	200
Medland	18	148	64	26	2	37	3	533	226
East Okement	212	200	104	133	8	952	40	1797	507
Cookbury	11	136	29	21	2	44	2	301	354
[Wolfson Atlas]	[7-30]	[1-133]	[1-79]	[2-79]	[T]	[8-100]	[T]	[45-600]	[150-300]

[T] = Trace

It is immediately clear that the East Okement substrates have a different geochemical composition to the other sites. The highest concentrations of arsenic (As), copper (Cu), lead (Pb), antimony (Sb), tin (Sn), tungsten (W), zinc (Zn) and zirconium (Zr) are all found in the East Okement. Levels of tin (probably cassiterite) and arsenic are particularly high, over 7 and 12 times the maximum found elsewhere in the study. In addition, trace proportions of tungsten are recorded in all but the East Okement where concentrations are significantly higher at 40 ppm.

Because freeze-core sampling removes undisturbed, volumetric quantities of substrate the above concentration values (in ppm) can be confidently converted into absolute weights or 'loads' (gm^{-3}). The resulting geochemical distributions reflect the sedimentological variations in substrate composition. Table 7 shows that despite the high concentrations of metals in the fine-grained fraction of River Okement, the loadings for most elements (in gm^{-3}) are significantly lower than the other sites. This is particularly apparent for copper (loads of 1.4

gm^{-3} compare to between 4 and 8 gm^{-3} found elsewhere) and zirconium (3.7 gm^{-3} compared with between 17 and 49 gm^{-3}).

Metal loadings are variable between the other sites with maximum levels of copper, lead and tin found in Hookmoor Brook and arsenic, chromium and zinc in the Northlew stream.

Metal concentrations per se do not show a significant pattern between the upper- and lower-core sections (Appendix 3). However, as the proportion of sub-0.125 mm particles is constantly higher in the lower 15 to 30 cms of the substrate profile, the lower-core sections are consequently more enriched in heavy metals than the upper-core sections. Enrichment ratios are also shown in Table 7.

In general the levels of oxides (percentage weights) show little variation between sites (Appendix 3) although Cookbury Stream contains substantially lower proportions of the clay minerals Al_2O_3 and K_2O - around 14 % and 1.9 % respectively comparing with over 16 % and 2.6 % found elsewhere. The fine-grained sediment from the East Okement contains 1.2 % CaO, significantly higher than levels recorded elsewhere (between 0.2% and 0.4 %).

According to sample-weight loss on ignition (Appendix 3), the organic content varies between sites and within the vertical core profiles. Overall the East Okement stream contained the highest organic content losing around 8.6 % on ignition. Hookmoor Stream, however, lost over 10 % from the upper-core sections but only 1.7 % from the lower 15 cms of gravel - this site showing by far the greatest vertical variation in organic content. Cookbury stream contained the lowest quantity of organic material losing around 4 % on ignition. Medland Brook and Northlew Stream lost between 5.5 and 6.2 % with little variation between the upper- and lower-core sections.

TABLE 7 Metal Loads in the Channel-bed Sediments of the River Torridge.

Site	Element (gm^{-3}) [Enrichment Ratio]*																	
	As		Cr		Cu		Pb		Sb		Sn		W		Zn		Zr	
Hookmoor	1.7	[1.3]	18.3	[2.1]	7.9	[1.4]	4.4	[1.6]	0.3	[5.4]	20.2	[2.5]	0.5	[1.4]	68.9	[1.8]	33.2	[1.9]
Northlew	2.0	[2.3]	30.6	[1.4]	6.8	[0.2]	4.2	[1.4]	0.3	[0.5]	16.8	[0.4]	0.3	[1.6]	115.2	[0.9]	28.5	[1.6]
Medland	1.4	[2.0]	12.3	[2.8]	5.0	[1.6]	1.2	[1.7]	0.4	[0.3]	2.9	[1.3]	0.2	[1.0]	41.2	[1.4]	17.7	[1.5]
E. Okement	1.5	[1.6]	0.7	[1.2]	1.4	[1.4]	1.0	[1.6]	0.1	[1.2]	7.1	[2.2]	0.3	[1.7]	12.5	[1.1]	3.7	[1.7]
Cookbury	1.5	[2.6]	19.5	[3.3]	4.1	[2.9]	2.7	[2.0]	0.2	[4.5]	6.3	[3.1]	0.3	[2.4]	40.8	[2.2]	48.4	[0.4]

***Enrichment Ratio** = the loads in the lower-core section (15 - 30 cms) divided by loads in the upper-core section (0 -15 cms).

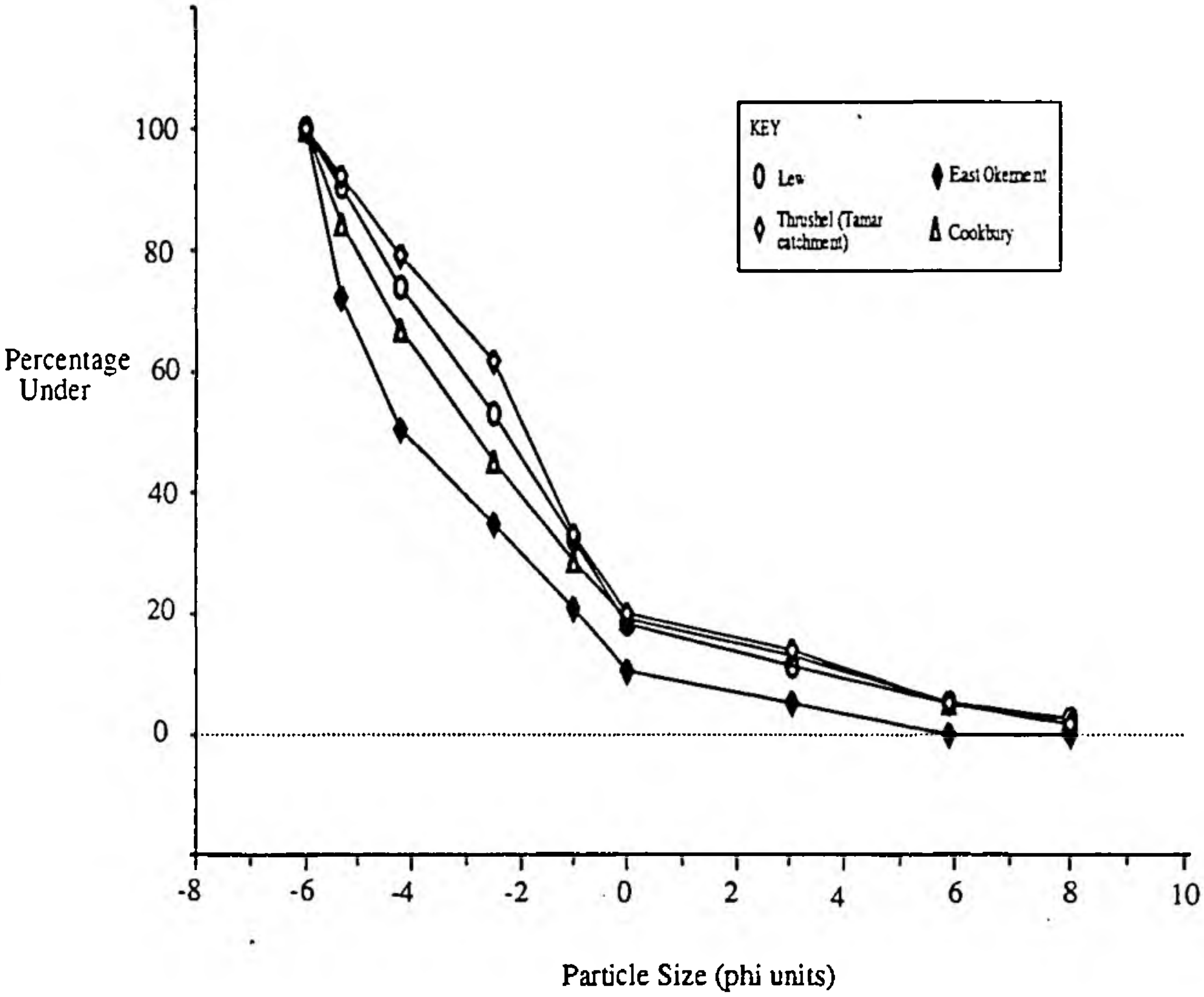
6. Discussion.

All five sites contain a high residual proportion of coarse-grained sediments typical of low order upland streams in Britain. The high range of grain sizes found in gravel-bed rivers makes it difficult to categorize size distribution patterns but within this data set a comparison between sites distinguishes the East Okement stream as having a very different substrate composition. These sediments are unusually coarse and contain exceptionally low proportions of the sub-0.125 mm material in the upper 30 cms of substrate. A summary of particle-size distributions for the three Lew sites, Cookbury and East Okement stream is presented in Figure 3. For comparison the size-distribution curve for a similar stream order spawning riffle in the adjacent Tamar catchment (River Thrushel) is included. The relative coarseness of the East Okement stream is apparent.

The composition of channel-bed sediments is in part determined by the the sediment size range made available to the the river. The coarseness of the East Okement gravels may reflect the proximity to the moorland area. The low proportion of fine-grained particles and the lack of any vertical variations in grain size distributions would suggest that the channel-bed composition is determined or controlled by very disruptive, high magnitude supply events of coarse, granitic sediment. The coarseness of the armour layer may also reflect a very 'high energy' sediment-water interface where the progressive infiltration of fine-grained material through the surface void spaces is prevented through regular and repeated washout of the fines. Without substantial fines the gravels comprise more sub-surface void spaces, have higher intra-gravel flows (more oxygenated and aerobic) and are generally less compact.

The substrate composition at the four other sites have similar characteristics (although Cookbury stream has a slightly coarser substrate framework) with all four sites having a well developed matrix proportion (between 16 and 20 % by weight) that is concentrated in the lower 15 cms of the gravel profile. Overall, the sub-0.125 mm fractions contain similar amounts of organic material - although the high loss on ignition in the upper-core sections from Hookmoor Stream may well reflect a localised occurrence of organic detritus. The finer framework and higher proportion of matrix fraction means these substrates are generally more compact. Differences in matrix content between the upper and lower 15 cms of substrate are most apparent in Cookbury stream (refer to Table 5). This possibly relates to a high supply of fine-grained sediment (in comparison to sites on the River Lew) that is able to accumulate in the lower 15 to 30 cms of gravel. The loss on ignition results suggest that the fines are relatively

FIGURE 3 Particle-Size Distributions at Fish Spawning Grounds in the Devon.



low in organic content. It is also possible that more frequent high discharge events are able to re-work and 'clean' the upper 15 cms of gravel. Cookbury also has the smallest armour layer, corroborating the suggestion of regular upper-gravel disturbance. In general, the substrates in these four sites suggest a higher catchment supply of fine-grained material that, under a less disruptive hydrological regime (bed turn-over being rarer) is able to infiltrate the gravels and eventually concentrate in the lower 15 to 30 cms of the gravel profile.

Comparison of the results from the study with data from other sites in the Torridge and neighbouring Tamar catchments emphasises the difference between the East Okement and the other streams (Table 8), particularly with reference to the sub-surface (15 - 30 cms) layers. The other streams in the survey have higher levels of fines than expected from the comparison; this Torridge survey yielded levels of fines, sub 2 mm and sub 1 mm, 5 % and 3 % higher respectively. Sites 13 and 14 from the 1987 survey are on the River Lew, close to the sites of the Torridge survey (see Figure 1), and from the data we may tentatively suggest an increase in bed sedimentation over the past three years, especially in the lower substrate.

The predominant feature revealed by geochemical analysis of the fine-grained fraction is again the differentiation between the River Okement and the other sites. High concentrations of arsenic, copper, lead, zinc and particularly tin, reflect proximity to a mineralised area commonly found in and around the granite intrusions of south-west England.

Elevated concentrations of chromium, copper, lead, nickel and zinc can often be associated with urban and industrial effluent but this study suggests very little evidence of such contamination. The Northlew site does have the maximum levels of chromium (215 ppm). This may reflect drainage from the nearby village or proximity to localised, secondary mineralisation.

When the proportion of fine-grained sediment is taken into account and absolute loadings are calculated (gm^{-3}), the high metal concentrations in the East Okement become less significant. The high levels of chromium are again evident in the Northlew stream (30.6 gm^{-3}) but it is interesting to note that maximum levels of copper, lead and zinc are found in Hookmoor Brook. The primary tributaries of Hookmoor Brook drain south off the extreme edge of the moorland area. It seems there is metal decay or dilution away from the moorland source (hence the low concentrations) but the sedimentological and hydrological regimes of Hookmoor Brook permit an overall accumulation of these relatively enriched fine-grained sediments.

Table 8. Proportions of Fine-grained Sediment in The Tamar and Torridge Catchments

Surveys for WRc.
Roadford Environmental Investigation* — **Torridge Survey**

Site N°	1987 % sub 1 mm	1990 % sub 1 mm
11	9.7	-
12	9.3	7.8
13	7.6	-
14	8.8	-

Site	1990 % sub 1 mm
Hookmoor	11.2
Northlew	13.3
Medland	10.1
E. Okement	5.3
Cookbury	13.1

Upper- and lower-Core Sections

Site N°	Section	1987 % sub 1 mm	1990 % sub 1 mm
11	U.	8.6	-
	L.	11.8	-
12	U.	7.2	5.6
	L.	15.5	23.7
13	U.	9.0	-
	L.	8.2	-
14	U.	9.0	-
	L.	8.2	-

Site	Section	1990 % sub 1 mm
Hookmoor	U.	9.3
	L.	15.5
Northlew	U.	10.6
	L.	17.9
Medland	U.	8.3
	L.	12.7
E. Okement	U.	5.5
	L.	5.0
Cookbury	U.	9.8
	L.	18.6

Site N°	1987 % sub 2 mm	1990 % sub 2mm
11	13.6	-
12	13.5	10.1
13	12.0	-
14	12.5	-

Site	1990 % sub 2 mm
Hookmoor	16.3
Northlew	19.5
Medland	17.7
E. Okement	10.2
Cookbury	19.1

Upper- and lower-Core Sections

Site N°	Section	1987 % sub 2 mm	1990 % sub 2mm
11	U.	12.5	-
	L.	16.5	-
12	U.	10.8	7.3
	L.	20.5	26.7
13	U.	14.5	-
	L.	13.0	-
14	U.	13.5	-
	L.	12.5	-

Site	Section	1990 % sub 2 mm
Hookmoor	U.	13.6
	L.	22.2
Northlew	U.	15.1
	L.	27.2
Medland	U.	13.5
	L.	24.9
E. Okement	U.	10.6
	L.	9.6
Cookbury	U.	15.7
	L.	24.9

* From to Petts, G.E., Sediment Sampling in Fish Spawning Grounds in the Upper Tamar and Torridge Catchments, Roadford Environmental Investigation Reports Phase 1 (1987) and Phase 4 (1991).

7. Conclusion.

The channel-bed sediments in the Torridge system are characterised by coarse gravels typical of upland streams. The spawning ground on the East Okement stream, draining the northern flank of Dartmoor, displays an exceptionally coarse substrate (the D50 is 36.9 mm) and a very poorly developed matrix (10% finer than 2 mm). The substrate is only weakly compacted with no vertical variation in particle-size composition. The spawning grounds on the River Lew (Medland and Hookmoor Brooks and Northlew stream) and on the river Waldon (Cookbury Stream) have coarse frameworks (D50s range from 14 to 23 mm) but also have high proportions of sub-2 mm matrix material (between 17 and 20 %). The matrix is distinctly concentrated in the more stable, lower 15 cms of the gravel profile. This vertical granulometric zonation is particularly apparent in Cookbury stream.

In terms of fines, the Okement would appear to be supply limited and the substrate may be unstable at least to a depth of 30 cm. At the other four sites, the high concentrations of fines suggests the existence of important source areas for fine sediments; the source may be land-use related; and that the substrate is relatively stable. Furthermore, in comparison to other streams in the area the proportion of fines within the spawning grounds is high and the results suggest increases in concentrations since 1987.

The concentration of fine particles in the lower 15 to 30 cms of gravel also suggests a more stable substrate.

It is clear that the granite catchments supply low quantities of metal-enriched fine-grained sediment to the Torridge system. High concentrations of arsenic, copper, lead, tin and zinc that are found in the East Okement almost certainly reflect mineralisation associated with the granite intrusion. In absolute values (gm^{-3}), highest levels of copper, lead and tin are found further downstream from the moorland source where, despite metal dilution the hydrological and sedimentological regimes permit fine sediment accumulation. High levels of chromium in the Northlew stream may reflect proximity to the small village of Northlew or very localised mineralisation that is common in the area.

8. Recommendations

By integration with water quality and biological data some assessment can be made of the ecological function performed by the different substrates. With this in mind it is recommended that the same sites are re-surveyed during the 1991 -1992 spawning season. The siltation of the substrates may be variable during the spawning season and in order to relate substrate characteristics to spawning success, the freeze-sampling programme should be integrated with hydrological data, turbidity and suspended sediment records and the egg basket experiments. Thus it is recommended that the sites be sampled once prior to the spawning and at least on one other occasion, say, in February. Ideally surveys should be undertaken in October, December, February and March to define the variations of substrate characteristics during the spawning, incubation, hatching and emergence phases. An additional use of freeze-sampling is to examine the invertebrate distributions within the substrate - and potentially also larval fish distributions using electrodes to stun the fauna before freezing commences. The latter additional studies would lead to a comprehensive analysis of the siltation problem.

9. REFERENCES.

Harvey, P. K. and Atkin, B. P., 1982, Automated X-Ray fluoresence analysis, *Institute of Mining and Metallurgy Special Publication: Sampling and Analysis for the Mineral Industry*, 17 - 26.

Petts, G. E. , Thoms, M. C., Brittan, K. and Atkin, B., 1989, A freeze-coring technique applied to pollution by fine sediments in gravel-bed rivers, *The Science of the Total Environment*, **84**, (1989) 259-272.

Petts, G. E. and Greenwood, M., 1985, Channel changes and invertebrate faunas below the Nant-y-moch Reservoir, River Rheidol, Wales, U.K., *Hydrobiologia* **122**, 65 - 80

Petts, G. E. 1987 Sediment sampling in fish spawning grounds in the upper Tamar catchment. Phases 1 (1987) and 4 (1990). *Report to the WRc.*

Thoms, M. C., 1987, Channel sedimentation within the urbanised River Tame, U.K. *Regulated Rivers: Research and Management*, Volume **1**, p 229-246.

Webb, J. S., Thornton, I., Howarth, R. J., Thompson, M. and Lowenstein, P. L., 1978, The Wolfson Geochemical Atlas of England and Wales, Oxford University Press.

APPENDIX ONE TORRIDGE DATA **FRAMEWORK PARTICLE SIZE DISTRIBUTION**

(Percentage Weights)

SITE		SIZE FRACTION (mm)						
		>63	63-37.5	37.5-20	20-6.3	6.3-2	Matrix	**Dry weight (kg)**
HOOKMOOR	U	16.46	21.57	19.75	17.94	10.65	13.63	**(14.6)**
BROOK	L	-	10.00	24.93	25.07	17.83	22.17	**(6.5)**
NORTHLEW	U	8.69	23.3	21.73	20.05	11.19	15.05	**(12.7)**
	L	-	7.52	20.13	26.55	18.62	27.17	**(7.5)**
MEDLAND	U	12.39	13.10	25.69	21.18	14.18	13.46	**(11.3)**
BROOK	L	12.05	11.58	15.2	18.75	17.49	24.94	**(6.7)**
EAST	U	28.52	21.32	16.01	14.27	9.33	10.55	**(14.5)**
OKEMENT	L	27.81	21.24	15.09	14.36	11.92	9.59	**(9.5)**
COOKBURY	U	17.86	21.03	20.54	16.00	8.91	15.65	**(14.5)**
	L	11.62	12.25	23.57	17.75	9.87	24.93	**(8.7)**

APPENDIX TWO TORRIDGE DATA

MATRIX SIZE DISTRIBUTION FROM FREEZE-DRIED SUB-SAMPLE

SITE		SIZE FRACTION (mm)				
		%2-1	%1-0.125	% 0.125 - 0.01	% 0.01 -0.002	%sub 0.002
HOOKMOOR	U	4.31	4.56	2.17	2.37	0.22
	L	6.62	6.86	4.20	4.12	0.37
NORTHLEW	U	4.41	5.70	2.38	2.37	0.19
	L	9.30	10.02	4.32	3.23	0.30
MEDLAND	U	5.20	5.49	1.09	1.54	0.14
BRIDGE	L	11.84	8.84	1.75	2.3	0.21
EAST	U	5.03	5.27	0.17	0.06	0.006
OKEMENT	L	4.59	4.62	0.29	0.09	0.007
COOKBURY	U	5.83	6.43	1.71	1.51	0.16
	L	6.29	10.64	4.06	3.6	0.34

APPENDIX THREE. GEOCHEMICAL DATA AND LOSS ON IGNITION

All oxide values are given in % weight, concentrations are in ppm and loads are in gm^{-3}.

ABBREVIATION	NAME
As	Arsenic
Ba	Barium
Bi	Bismuth
Co	Cobalt
Cr	Chromium
Cu	Copper
Ga	Gallium
La	Lanthanum
Mo	Molybdenum
Nb	Niobium
Ni	Nickel
Pb	Lead
Rb	Rhubidium
S	Sulphur
Sb	Antimony
Se	Selenium
Sn	Tin
Sr	Strontium
Ta	Tantalum
Th	Thorium
U	Uranium
V	Vanadium
W	Tungsten
Y	Yttrium
Zn	Zinc
Zr	Zirconium
OXIDES	
Al	Aluminium
Ca	Calcium
Fe	Iron
K	Potassium
Na	Sodium
Mg	Magnesium
Mn	Manganese
O	Oxygen
P	Phosphorus
Si	Silicon
Ti	Titanium

	Site Code	As	Ba	Bi	Co	CR	Cu	Ga
1	Medland Bridge Upper	15	505	2	27	107	63	18
2	Medland Bridge Lower	20	525	1	34	193	65	19
3	Hookmoor Upper	14	559	3	31	114	62	20
4	Hookmoor Lower	10	562	1	26	132	49	21
5	Northlew Upper	11	559	2	26	229	100	20
6	Northlew Lower	16	556	1	20	204	12	21
7	East Okement Upper	212	358	10	35	118	208	21
8	East Okement Lower	212	356	11	31	92	192	22
9	Cookbury Upper	10	653	2	40	110	25	11
10	Cookbury Lower	11	356	1	34	152	31	14

	La	Mo	Nb	Ni	Pb	Rb	S	Sb	Se	Sn	Sr	Te
1	41	2	14	67	25	103	1011	1	2	40	78	2
2	37	3	13	75	27	113	808	2	2	34	82	2
3	46	2	16	73	32	129	3080	1	2	112	90	2
4	42	2	15	78	28	120	4462	3	2	155	85	3
5	40	3	16	68	32	126	1601	3	2	208	86	2
6	42	3	17	67	28	129	1518	1	2	57	88	2
7	34	3	25	56	131	217	2013	9	3	778	61	2
8	49	3	24	52	135	237	1852	7	2	1113	30	2
9	26	1	11	47	23	64	882	1	2	37	78	2
10	25	1	12	45	19	62	620	2	2	49	76	2

	Th	U	V	W	Y	Zn	Zr	Site	Sio2	Al203	TiO2
1	11	4	108	3	33	564	228		62.37	18.32	1.00
2	12	4	116	2	34	499	224		59.28	18.78	1.00
3	17	4	122	4	36	476	221		60.68	20.58	1.11
4	14	3	118	3	34	466	230		60.58	19.70	1.09
5	14	3	125	2	31	1065	199		58.70	19.55	1.10
6	13	2	127	2	33	632	200		60.03	20.17	1.13
7	30	14	104	38	73	2139	491		58.81	15.74	.90
8	32	14	100	41	74	1481	522		59.13	16.14	.87
9	10	3	74	2	28	319	358		61.51	14.77	.92
10	9	2	71	2	28	291	352		62.24	14.48	.92

	Fe203	Mgo	Cao	Na2o	K2O	MnO	P205	As loads
1	8.98	.89	.36	.75	2.68	.16	.24	.935
2	10.77	.93	.30	.67	2.81	.16	.22	1.917
3	8.22	1.03	.21	.87	3.27	.08	.19	1.499
4	7.68	1.06	.20	.85	3.10	.08	.15	1.955
5	9.93	1.36	.21	.87	3.21	.15	.21	1.223
6	9.11	1.39	.17	.91	3.21	.08	.19	2.830
7	8.04	1.18	1.21	.87	3.10	.53	.33	1.192
8	7.76	1.18	1.27	.89	3.29	.47	.32	1.860
9	8.90	.70	.27	.74	1.93	.52	.29	.763
10	8.61	.76	.28	.79	1.89	.31	.25	1.980

	Cr Loads	Cu loads	Pb loads	Sb loads	Sn loads	W loads
1	6.669	3.926	1.558	.062	2.493	.187
2	18.499	6.230	2.588	.192	3.259	.192
3	12.209	6.640	3.427	.107	11.995	.428
4	25.809	9.581	5.475	.587	30.306	.587
5	25.453	11.115	3.557	.333	23.119	.222
6	36.077	2.122	4.952	.177	10.080	.354
7	.664	1.170	.737	.051	4.376	.214
8	.807	1.685	1.185	.061	9.767	.360
9	8.390	1.907	1.754	.076	2.822	.153
10	27.360	5.580	3.420	.360	8.820	.360

	Zn loads	Zr loads	% weight loss on ignition
1	35.151	14.210	6.14
2	47.829	21.470	5.86
3	50.980	23.669	10.21
4	91.115	44.971	1.73
5	118.375	22.119	5.76
6	111.769	35.370	5.53
7	12.032	2.762	7.81
8	12.996	4.581	9.46
9	24.332	27.306	4.40
10	52.380	63.360	3.67